ULTIMATE VISUAL dictionary

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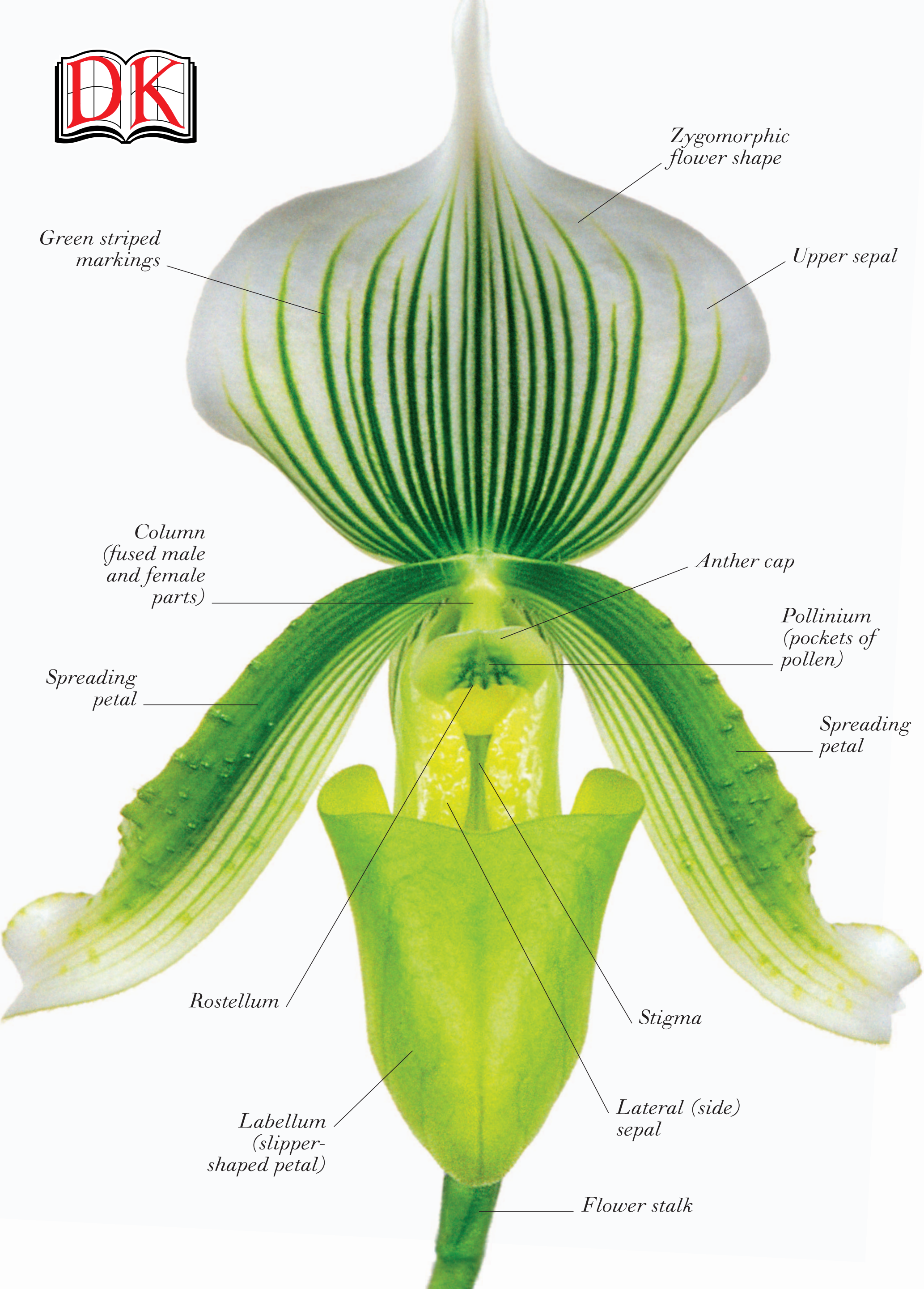
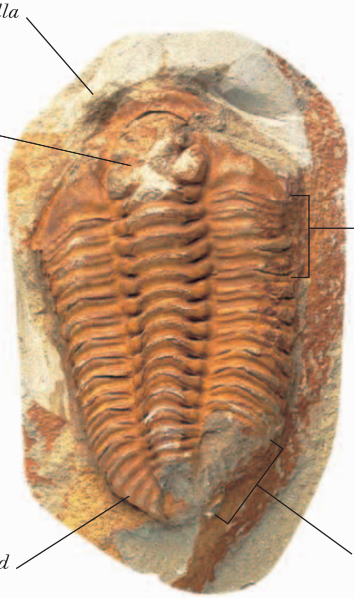


VISUAL dictionary



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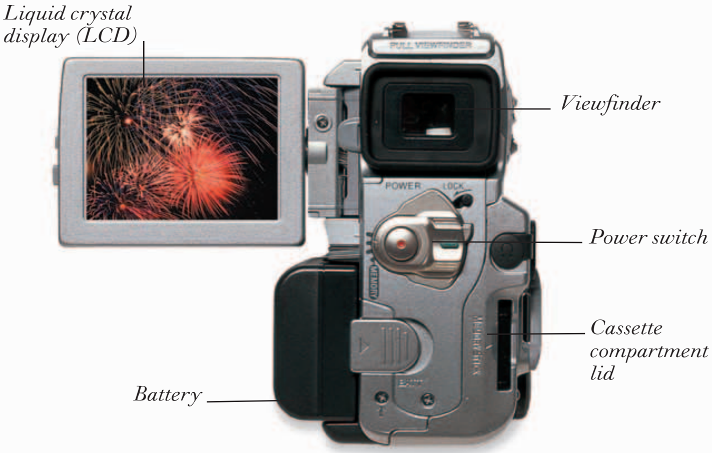
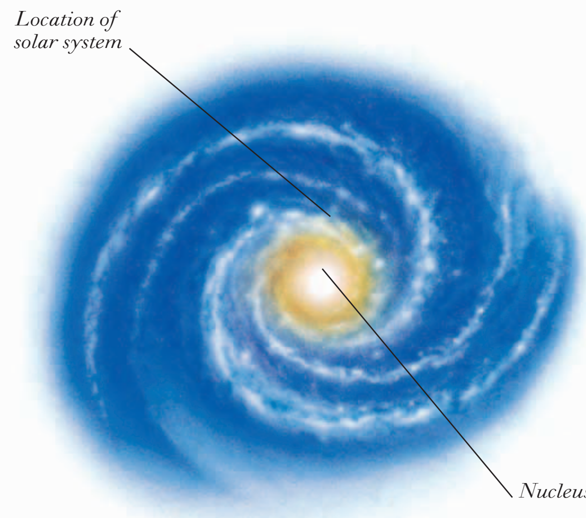
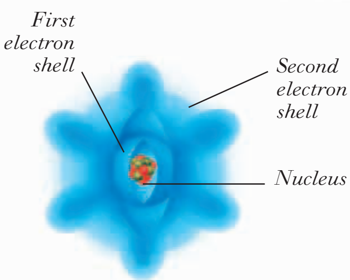


OVERHEAD VIEW OF OUR GALAXY





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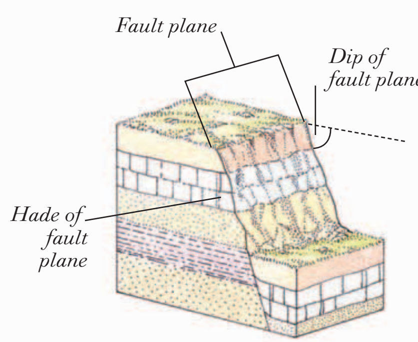

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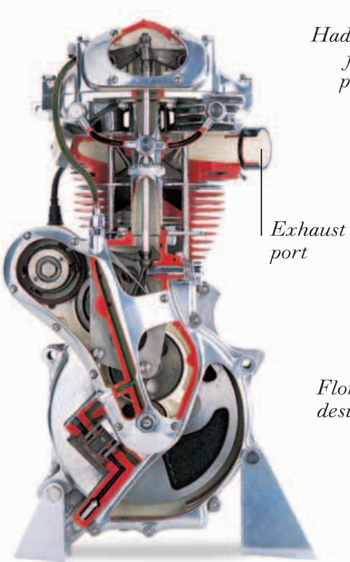

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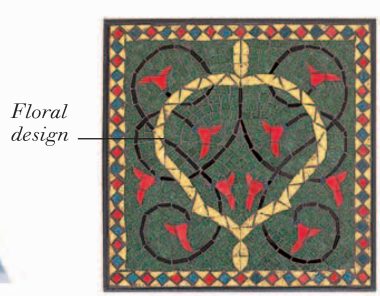

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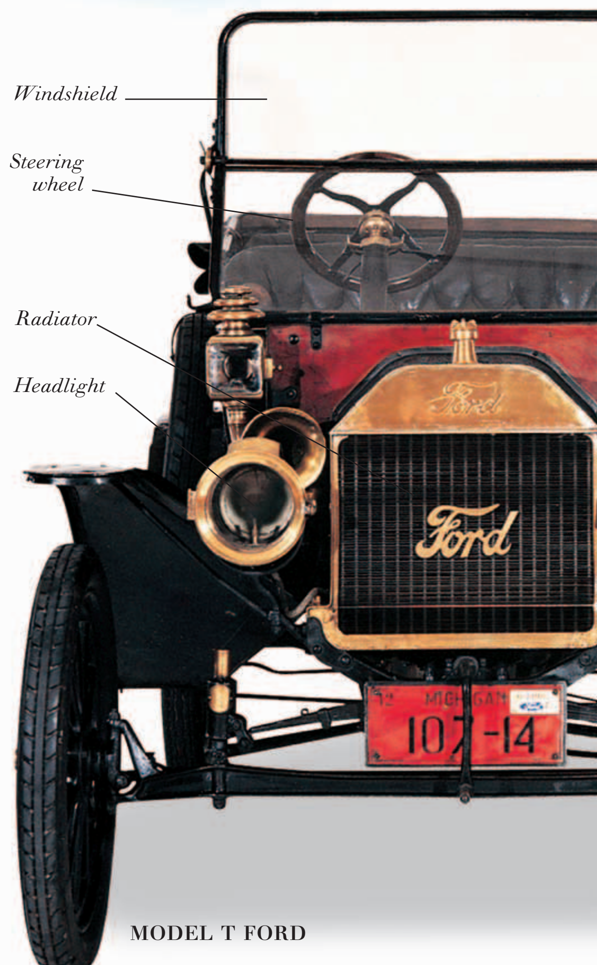

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VISUAL dictionary

STRAWBERRY

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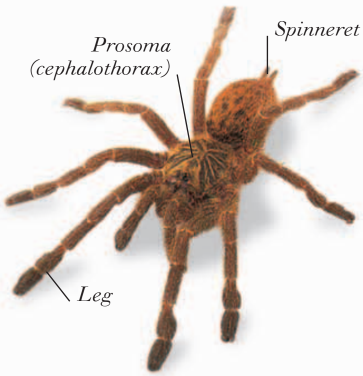
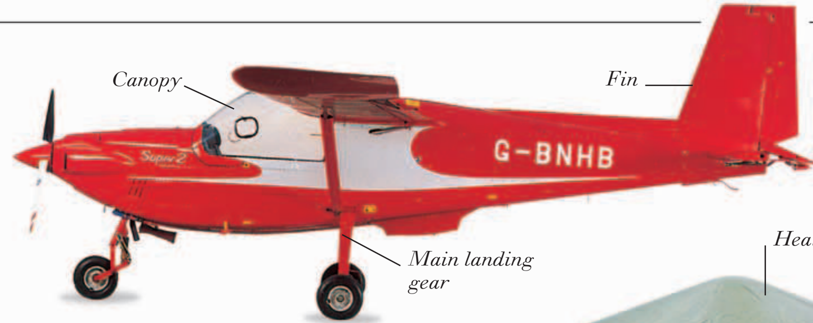


EXTERNAL FEATURES OF A SPIDER



SIDE VIEW OF ARV SUPER 2 AIRPLANE

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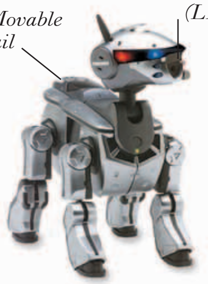

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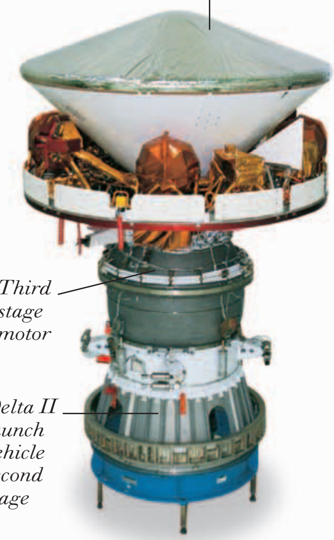
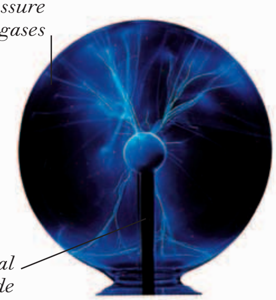


MARS PATHFINDER



BALL CONTAINING HIGH TEMPERATURE GAS (PLASMA)

FOOTBALL HELMET

Introduction

THE VISUAL DICTIONARY is a completely new kind of reference book. It provides a link between pictures and words in a way that no ordinary dictionary ever has. Most dictionaries simply tell you what a word means, but the *VISUAL DICTIONARY* shows you—through a combination of detailed annotations, explicit photographs, and illustrations. In the *VISUAL DICTIONARY*, pictures define the annotations around them. You do not read definitions of the annotated words, you see them. The highly accessible format of the *VISUAL DICTIONARY*, the thoroughness of its annotations, and the range of its subject matter make it a unique and helpful reference tool.

How to use the VISUAL DICTIONARY

You will find the *VISUAL DICTIONARY* simple to use. Instead of being organized alphabetically, it is divided by subject into 14 sections—THE UNIVERSE, PREHISTORIC EARTH, PLANTS, ANIMALS, THE HUMAN BODY, etc. Each section begins with a table of contents listing the major entries within that section. For example, The Visual Arts section has entries on *Drawing*, *Tempera*, *Fresco*, *Oils*, *Watercolor*, *Pastels*, *Acrylics*, *Calligraphy*, *Printmaking*, *Mosaic*, and *Sculpture*. Every entry has a short introduction explaining the purpose of the photographs and illustrations, and the significance of the annotations.

If you know what something looks like, but don't know its name, find the term you need by turning to the annotations surrounding the pictures; if you know a word, but don't know what it refers to, use the comprehensive index to direct you to the appropriate page.

Suppose that you want to know what the bone at the end of your little finger is called. With a standard dictionary, you wouldn't know where to begin. But with the *VISUAL DICTIONARY* you simply turn to the entry called *Hands*—within THE HUMAN BODY section—where you will find four fully annotated, color photographs showing the skin, muscles, and bones of the human hand. In this entry you will quickly find that the bone you are searching for is called the distal phalanx, and for good measure you will discover that it is attached to the middle phalanx by the distal interphalangeal joint.

Perhaps you want to know what a catalytic converter looks like. If you look up "catalytic converter" in an ordinary dictionary, you will be told what it is and possibly what it does—but you will not be able to tell what shape it is or what it is made of. However, if you look up "catalytic converter" in the index of the *VISUAL DICTIONARY*, you will be directed to the *Modern engines* entry on page 344—where the introduction gives you basic information about what a catalytic converter is—and to page 350—where there is a spectacular exploded-view photograph of the mechanics of a Renault Clio. From these pages you will find out not only what a catalytic converter looks like, but also that it is attached at one end to an exhaust pipe and at the other to a muffler.

Whatever it is that you want to find a name for, or whatever name you want to find a picture for, you will find it quickly and easily in the *VISUAL DICTIONARY*. Perhaps you need to know where the vamp on a shoe is; or how to tell obovate and lanceolate leaves apart; or what a spiral galaxy looks like; or whether birds have nostrils. With the *VISUAL DICTIONARY* at hand, the answers to each of these questions, and thousands more, are readily available.

The *VISUAL DICTIONARY* does not just tell you what the names of the different parts of an object are. The photographs, illustrations, and annotations are all specially arranged to help you understand which parts relate to one another and how objects function.

With the *VISUAL DICTIONARY* you can find in seconds the words or pictures that you are looking for; or you can simply browse through the pages of the book for your own pleasure. The *VISUAL DICTIONARY* is not intended to replace a standard dictionary or conventional encyclopedia, but is instead a stimulating and valuable companion to ordinary reference volumes. Giving you instant access to the language that is used by astronomers and architects, musicians and mechanics, scientists and sportspeople, it is the ideal reference book for specialists and generalists of all ages.

Sections of the Visual Dictionary

The 14 sections of the *Visual Dictionary* contain a total of more than 30,000 terms, encompassing a wide range of topics:

• In the first section, **The Universe**, spectacular photographs and illustrations are used to show the names of the stars and planets and to explain the structure of solar systems, galaxies, nebulae, comets, and black holes.

• **Prehistoric Earth** tells the story in annotations of how our own planet has evolved since its formation. It includes examples of prehistoric flora and fauna, and fascinating dinosaur models—some with parts of the body stripped away to show anatomical sections.

• **Plants** covers a huge range of species—from the familiar to the exotic. In addition to the color photographs of plants included in this section, there is a series of micrographic photographs illustrating plant details—such as pollen grains, spores, and cross-sections of stems and roots—in close-up.

• In the **Animals** section, skeletons, anatomical diagrams, and different parts of animals' bodies have been meticulously annotated. This section provides a comprehensive guide to the vocabulary of zoological classification and animal physiology.

• The structure of the human body, its parts, and its systems are presented in **The Human Body**. The section includes lifelike, three-dimensional models and the latest false-color images. Clear and authoritative annotations indicate the correct anatomical terms.

• **Geology, Geography, and Meteorology** describes the structure of the Earth—from the inner core to the exosphere—and the physical phenomena—such as volcanoes, rivers, glaciers, and climate—that shape its surface.

• **Physics and Chemistry** is a visual journey through the fundamental principles underlying the physical universe, and provides the essential vocabulary of these sciences.

• In **Rail and Road**, a wide range of trains, trams and buses, cars, bicycles, and motorcycles are described. Exploded-view photographs show mechanical details with striking clarity.

• **Sea and Air** gives the names for hundreds of parts of ships and airplanes. The section includes civil and fighting craft, both historical and modern.

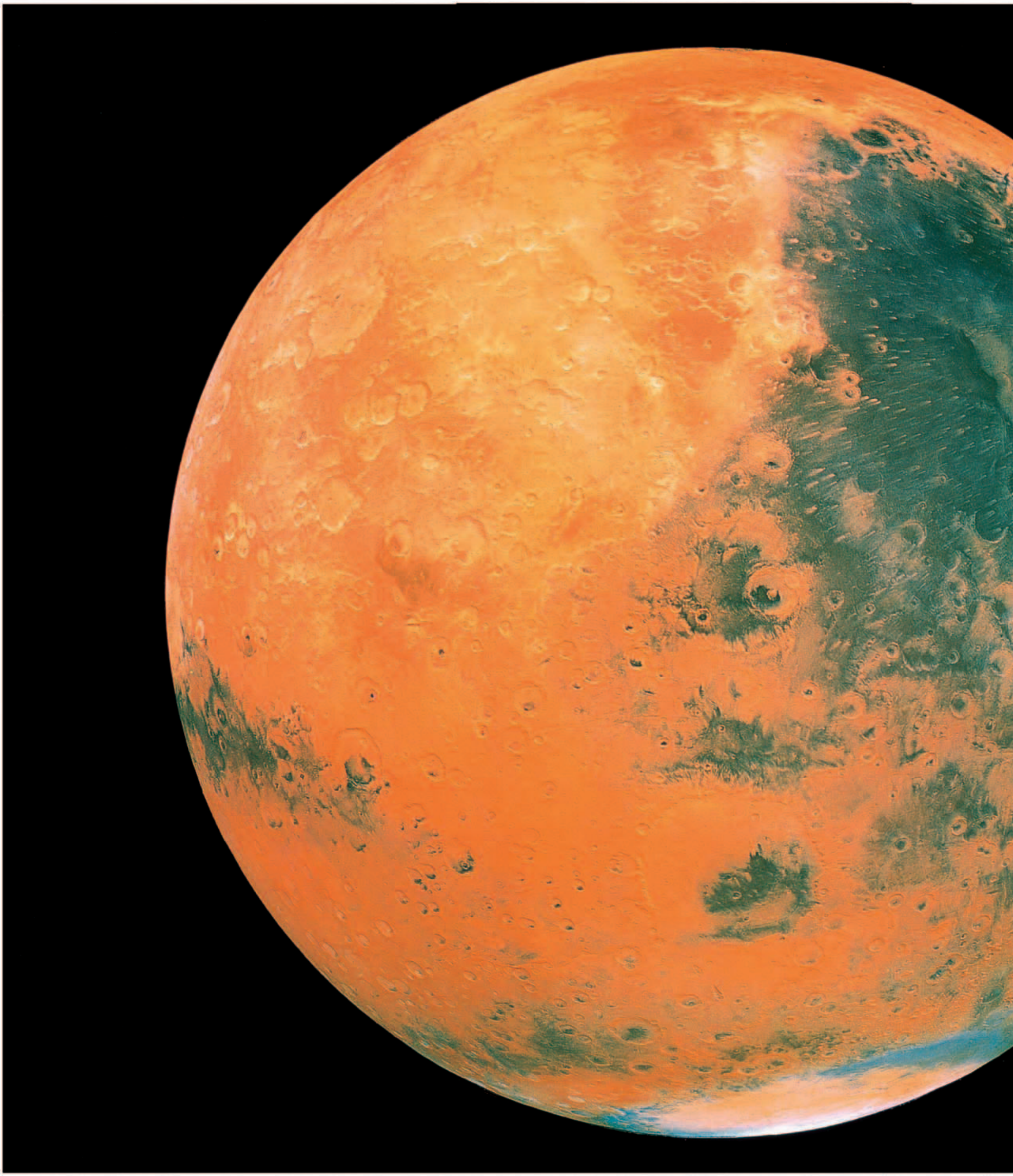
• **The Visual Arts** shows the equipment and materials used by painters, sculptors, printers, and other artists. Well-known compositions have been chosen to illustrate specific artistic techniques and effects.

• **Architecture** includes photographs of exemplary architectural models and illustrates dozens of additional features such as columns, domes, and arches.

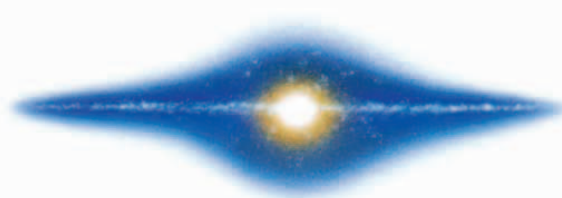
• **Music** provides a visual introduction to the special language of music and musical instruments. It includes clearly annotated photographs of each of the major groups of traditional instruments—brass, woodwind, strings, and percussion—together with modern electronic instruments.

• The **Sports** section is a guide to the playing areas, formations, equipment, and techniques needed for many of today's most popular sports.

• In **The Modern World**, items that are a familiar part of our daily lives are taken apart to reveal their inner workings and give access to the language used by their manufacturers. It also includes systems and concepts, such as the internet, that increasingly influence our 21st century world.

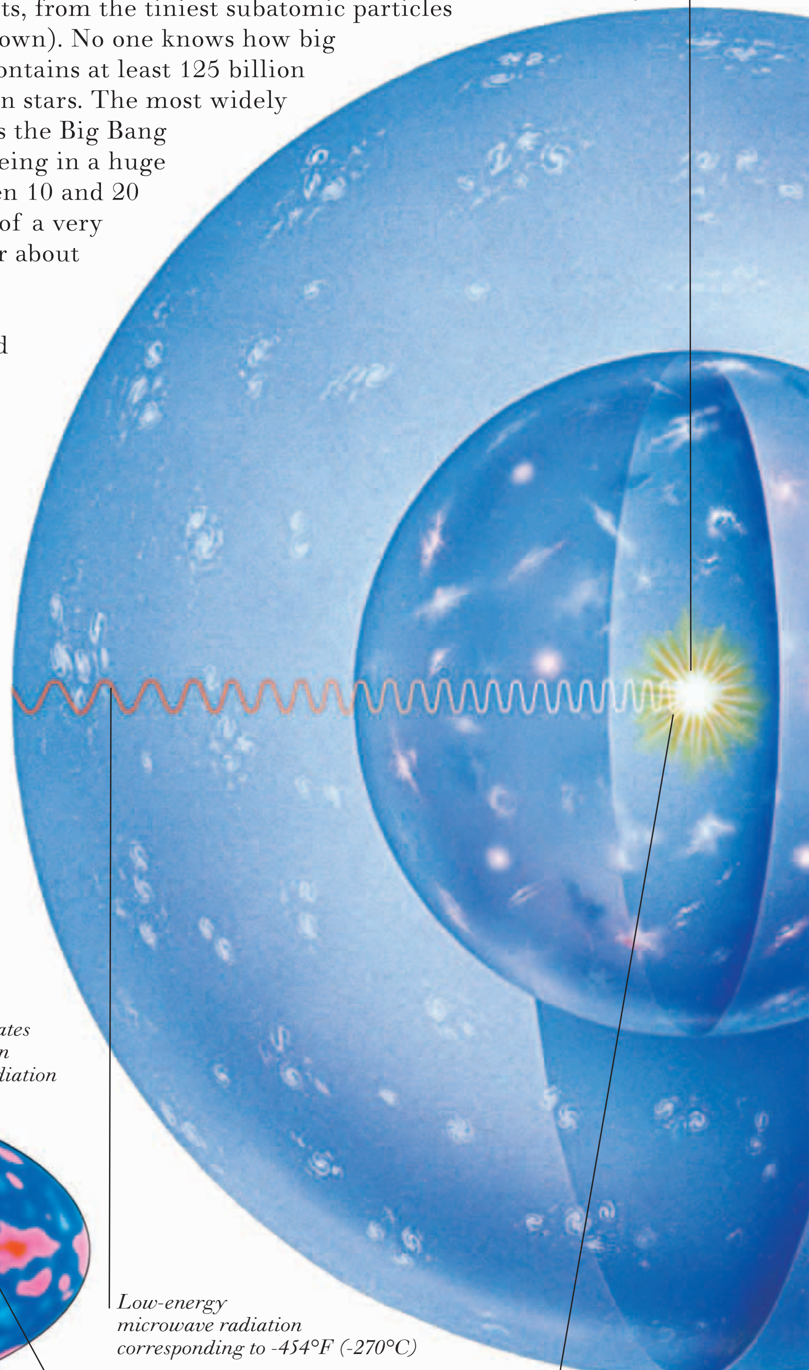


The Universe

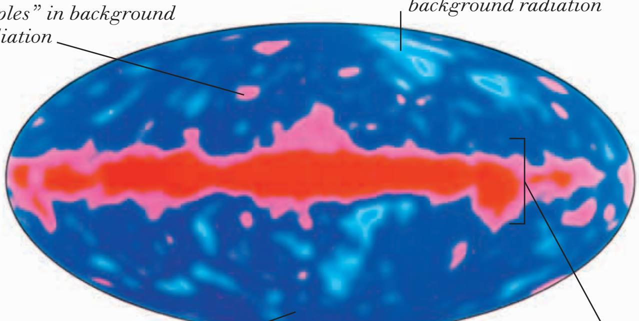


Anatomy of the universe

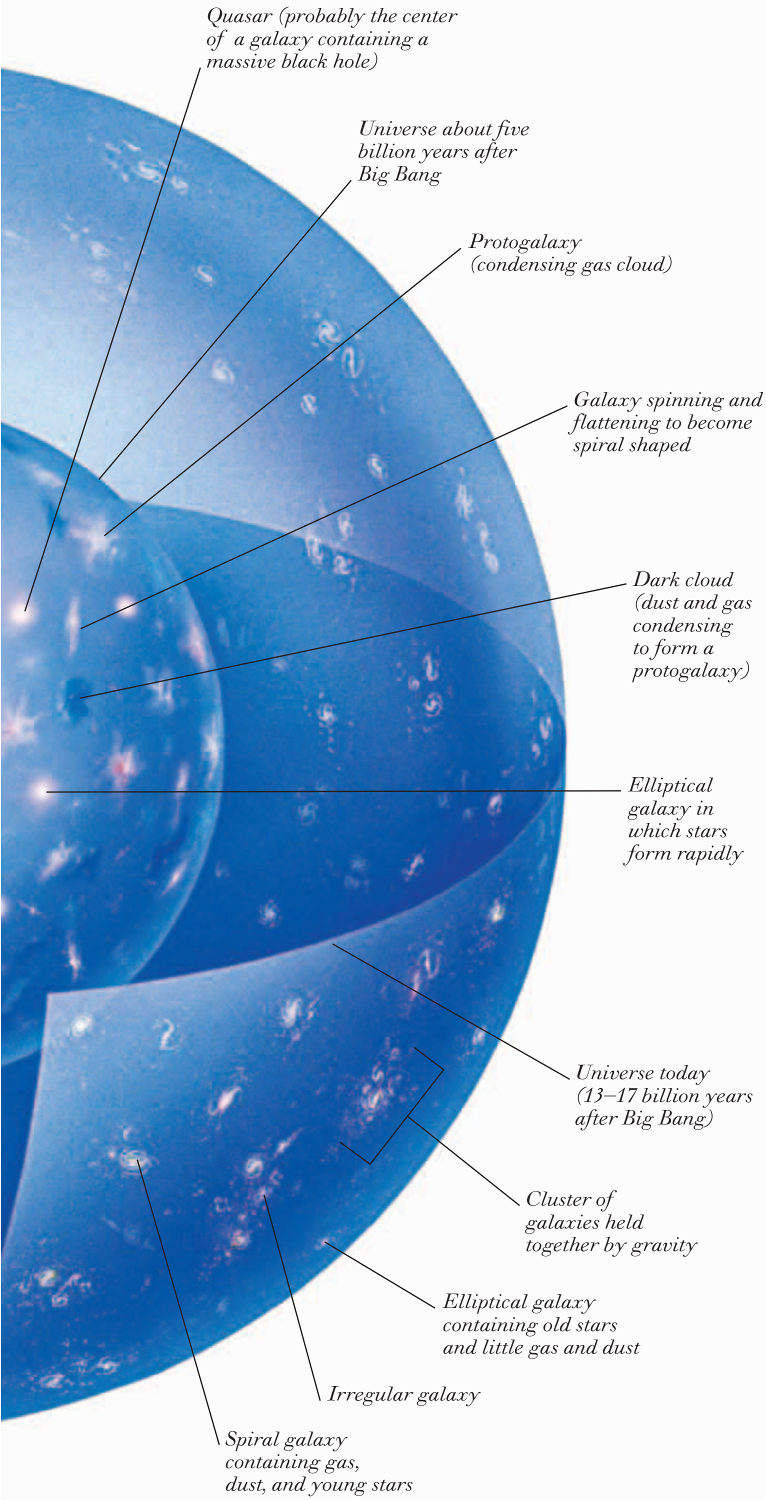
THE UNIVERSE CONTAINS EVERYTHING that exists, from the tiniest subatomic particles to galactic superclusters (the largest structures known). No one knows how big the universe is, but astronomers estimate that it contains at least 125 billion galaxies, each comprising an average of 100 billion stars. The most widely accepted theory about the origin of the universe is the Big Bang theory, which states that the universe came into being in a huge explosion—the Big Bang—that took place between 10 and 20 billion years ago. The universe initially consisted of a very hot, dense fireball of expanding, cooling gas. After about one million years, the gas began to condense into localized clumps called protogalaxies. During the next five billion years, the protogalaxies continued condensing, forming galaxies in which stars were being born. Today, billions of years later, the universe as a whole is still expanding, although there are localized areas in which objects are held together by gravity; for example, many galaxies are found in clusters. The Big Bang theory is supported by the discovery of faint, cool background radiation coming evenly from all directions. This radiation is believed to be the remnant of the radiation produced by the Big Bang. Small "ripples" in the temperature of the cosmic background radiation are thought to be evidence of slight fluctuations in the density of the early universe, which resulted in the formation of galaxies. Astronomers do not yet know if the universe is "closed," which means it will eventually stop expanding and begin to contract, or if it is "open," which means it will continue expanding forever.



FALSE-COLOR MICROWAVE MAP OF COSMIC BACKGROUND RADIATION

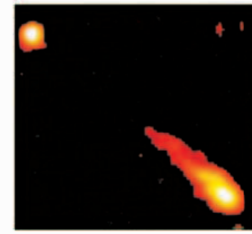


ORIGIN AND EXPANSION OF THE UNIVERSE



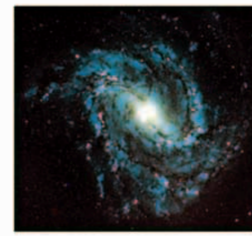
OBJECTS IN THE UNIVERSE

CLUSTER OF GALAXIES IN VIRGO

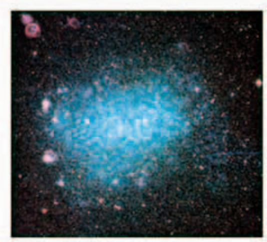


FALSE-COLOR IMAGE OF 3C273 (QUASAR)

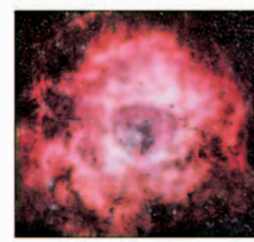
NGC 4406 (ELLIPTICAL GALAXY)



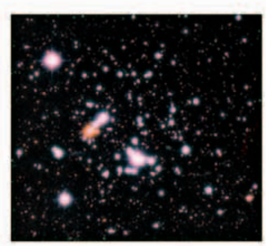
NGC 5236 (BARRED SPIRAL GALAXY)



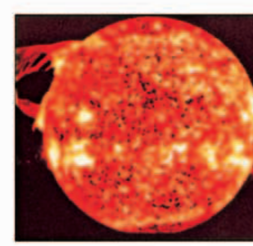
NGC 6822 (IRREGULAR GALAXY)



THE ROSETTE NEBULA (EMISSION NEBULA)



THE JEWEL BOX (STAR CLUSTER)



THE SUN (MAIN SEQUENCE STAR)

EARTH

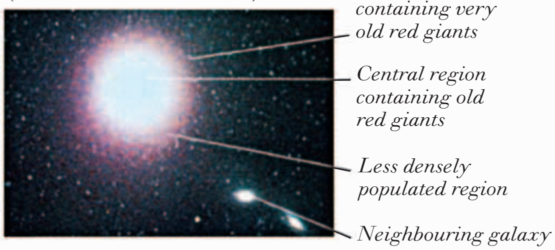
THE MOON

Galaxies

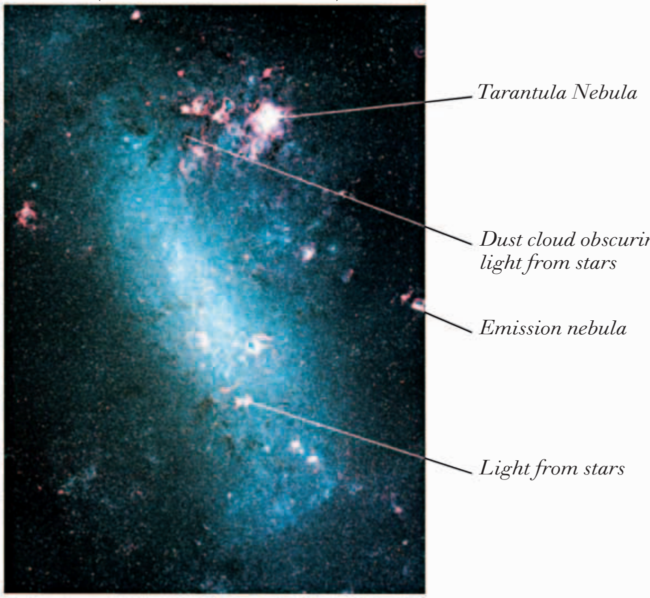
SOMBRERO, A SPIRAL GALAXY

A GALAXY IS A HUGE MASS OF STARS, nebulae, and interstellar material. The smallest galaxies contain about 100,000 stars, while the largest contain up to 3 trillion stars. There are three main types of galaxy, classified according to their shape: elliptical, which are oval shaped; spiral, which have arms spiraling outward from a central bulge (those whose arms spiral from a bar-shaped bulge are called spirals); and irregular, which have no obvious shape. Sometimes, the shape of a galaxy is distorted by a collision with another galaxy. Quasars (quasi-stellar objects) are thought to be galactic nuclei but are so far away that their exact nature is still uncertain. They are compact, highly luminous objects in the outer reaches of the known universe: while the farthest known "ordinary" galaxies are about 12 billion light-years away, the farthest known quasar is about 13 billion light-years away. Active galaxies, such as Seyfert galaxies and radio galaxies, emit intense radiation. In a Seyfert galaxy, this radiation comes from the galactic nucleus; in a radio galaxy, it also comes from huge lobes on either side of the galaxy. The radiation from active galaxies and quasars is thought to be caused by material falling into central black holes (see pp. 28-29).

OPTICAL IMAGE OF NGC 4486 (ELLIPTICAL GALAXY)



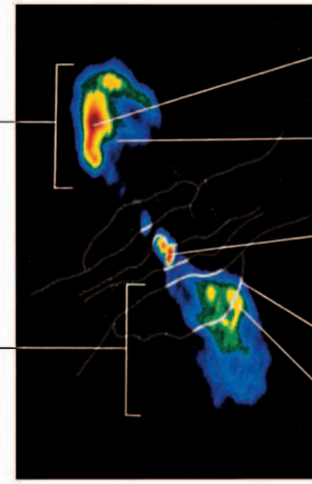
OPTICAL IMAGE OF LARGE MAGELLANIC CLOUD (IRREGULAR GALAXY)



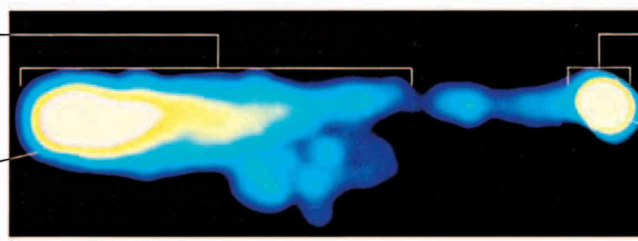
OPTICAL IMAGE OF NGC 2997 (SPIRAL GALAXY)

OPTICAL IMAGE OF CENTAURUS A (RADIO GALAXY)

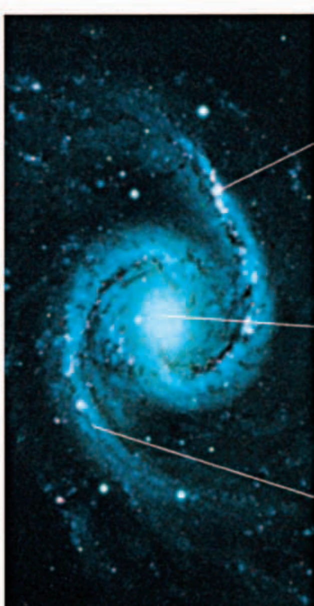
FALSE-COLOR RADIO IMAGE OF CENTAURUS A



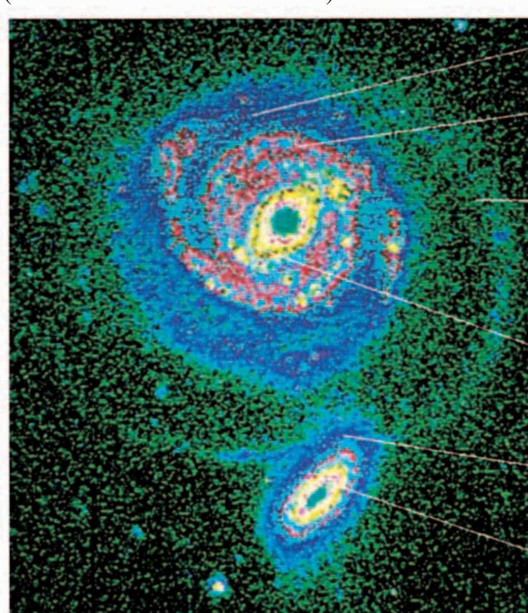
FALSE-COLOR RADIO IMAGE OF 3C 273 (QUASAR)



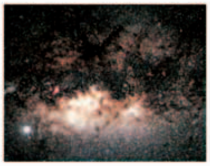
OPTICAL IMAGE OF NGC 1566 (SEYFERT GALAXY)



FALSE-COLOR OPTICAL IMAGE OF NGC 5754 (TWO COLLIDING GALAXIES)



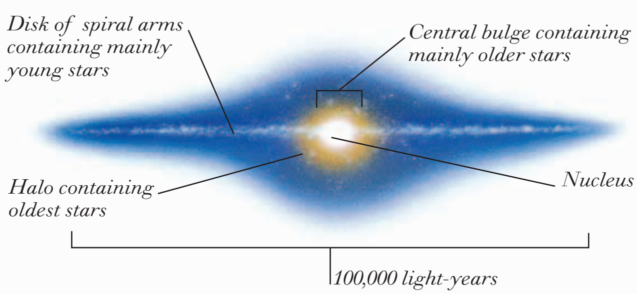
The Milky Way



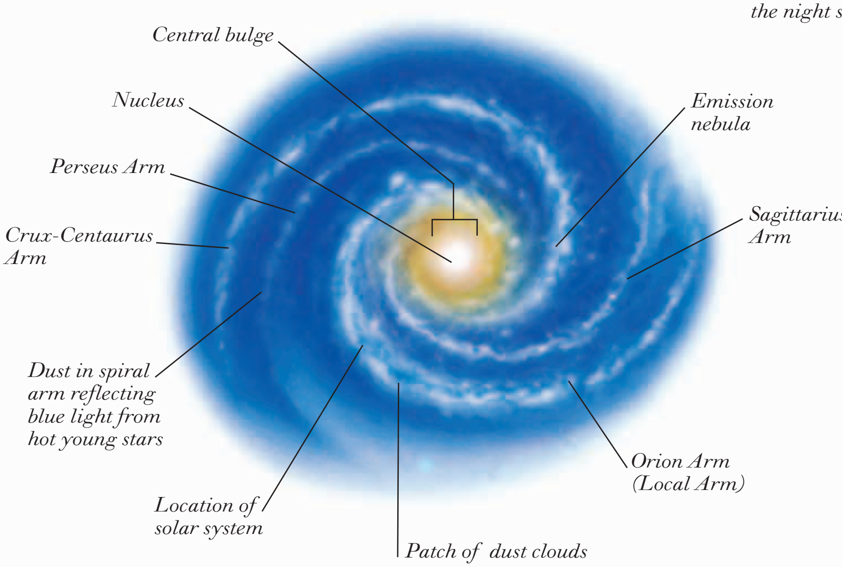
VIEW TOWARD GALACTIC CENTER

THE MILKY WAY IS THE NAME GIVEN TO THE FAINT BAND OF LIGHT that stretches across the night sky. This light comes from stars and nebulae in our galaxy, known as the Milky Way Galaxy or simply as "the Galaxy." The Galaxy is believed to be a barred spiral, with a dense central bar of stars encircled by four arms spiraling outward and surrounded by a less dense halo. We cannot see the spiral shape because the solar system is in one of the spiral arms, the Orion Arm (also called the Local Arm). From our position, the center of the Galaxy is completely obscured by dust clouds; as a result, optical maps give only a limited view of the Galaxy. However, a more complete picture can be obtained by studying radio, infrared, and other radiation. The central part of the Galaxy is relatively small and dense and contains mainly older red and yellow stars. The halo is a less dense region in which the oldest stars are situated; some of these stars are as old as the Galaxy itself (possibly 13 billion years). The spiral arms contain main sequence stars and hot, young, blue stars, as well as nebulae (clouds of dust and gas inside which stars are born). The Galaxy is vast, about 100,000 light-years across (a light-year is about 5,870 billion miles/9,460 billion km); in comparison, the solar system seems small, at about 12 light-hours across (about 8 billion miles/13 billion km). The entire Galaxy is rotating in space, although the inner stars travel faster than those farther out. The Sun, which is about two-thirds out from the center, completes one lap of the Galaxy about every 220 million years.

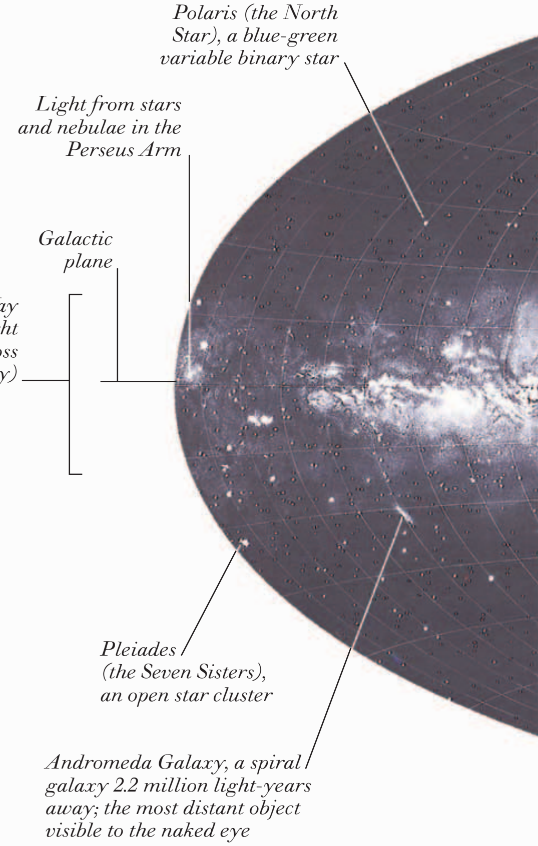
SIDE VIEW OF OUR GALAXY



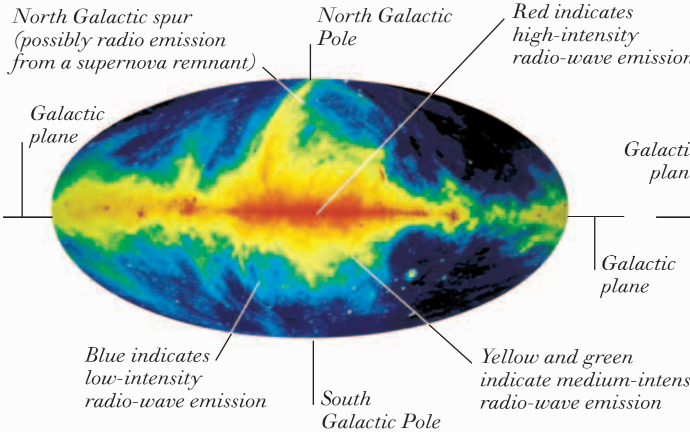
OVERHEAD VIEW OF OUR GALAXY



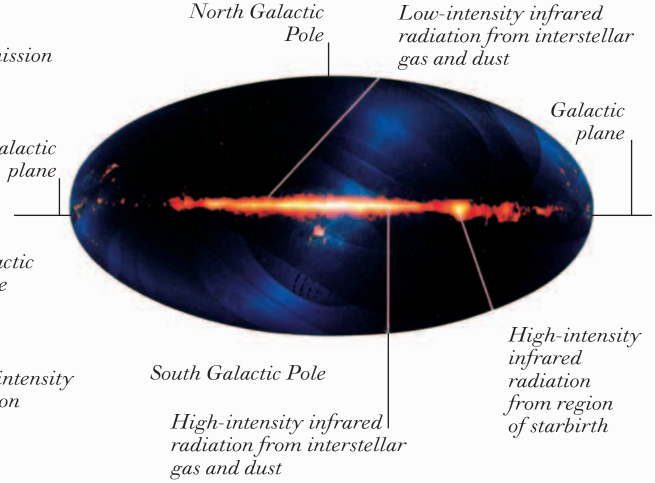
PANORAMIC OPTICAL MAP OF OUR GALAXY AND NEARBY GALAXIES

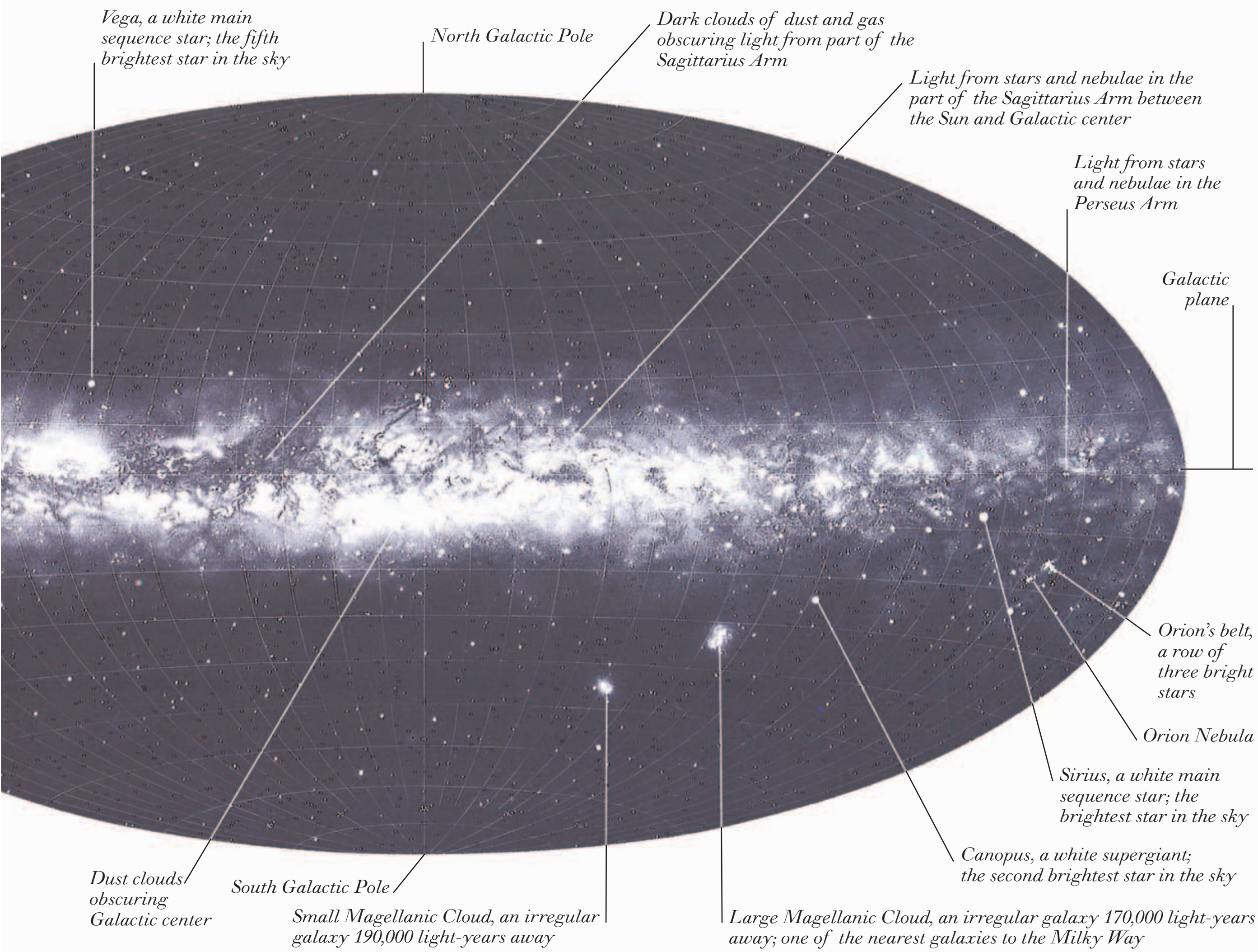


PANORAMIC RADIO MAP OF OUR GALAXY



PANORAMIC INFRARED MAP OF OUR GALAXY





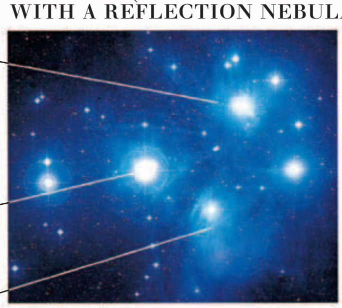
Nebulae and star clusters

HODGE 11, A GLOBULAR CLUSTER

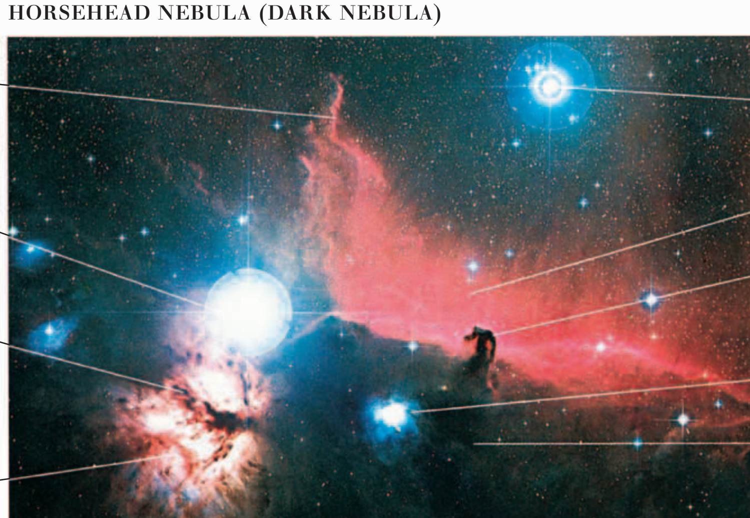
A NEBULA IS A CLOUD OF DUST AND GAS inside a galaxy. Nebulae become visible if the gas glows, or if the cloud reflects starlight or obscures light from more distant objects. Emission nebulae shine because their gas emits light when it is stimulated by radiation from hot young stars. Reflection nebulae shine because their dust reflects light from stars in or around the nebula. Dark nebulae appear as silhouettes because they block out light from shining nebulae or stars behind them. Two types of nebula are associated with dying stars: planetary nebulae and supernova remnants. Both consist of expanding shells of gas that were once the outer layers of a star. A planetary nebula is a gas shell drifting away from a dying stellar core. A supernova remnant is a gas shell moving away from a stellar core at great speed following a violent explosion called a supernova (see pp. 26-27). Stars are often found in groups known as clusters. Open clusters are loose groups of a few thousand young stars that were born from the same cloud and are drifting apart. Globular clusters are densely packed, roughly spherical groups of hundreds of thousands of older stars.

TRIFID NEBULA (EMISSION NEBULA)

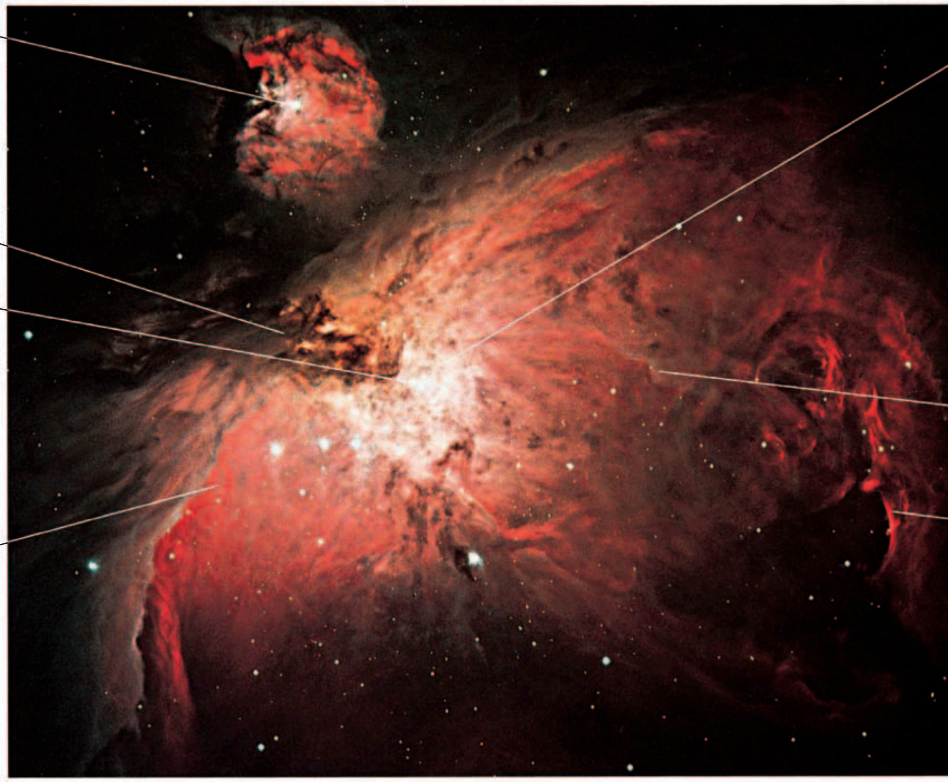
PLEIADES (OPEN STAR CLUSTER) WITH A REFLECTION NEBULA



HORSEHEAD NEBULA (DARK NEBULA)



ORION NEBULA (DIFFUSE EMISSION NEBULA)



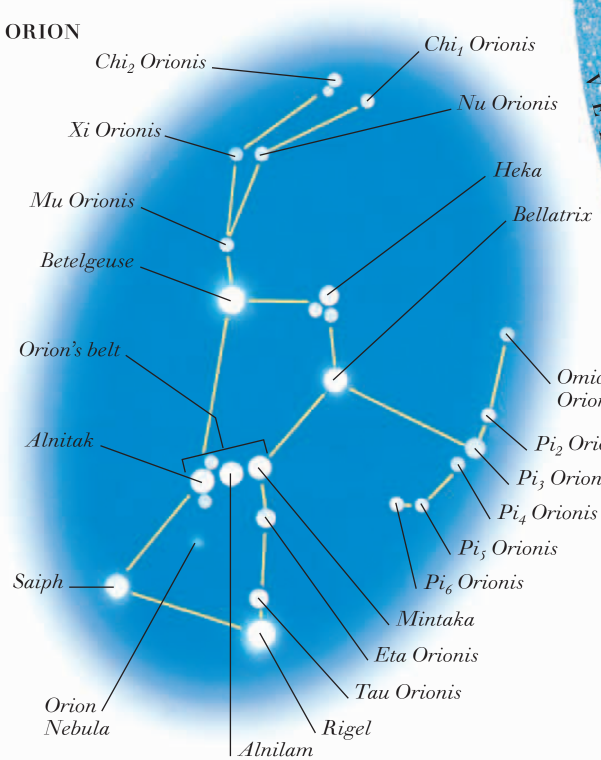
VELA SUPERNOVA REMNANT

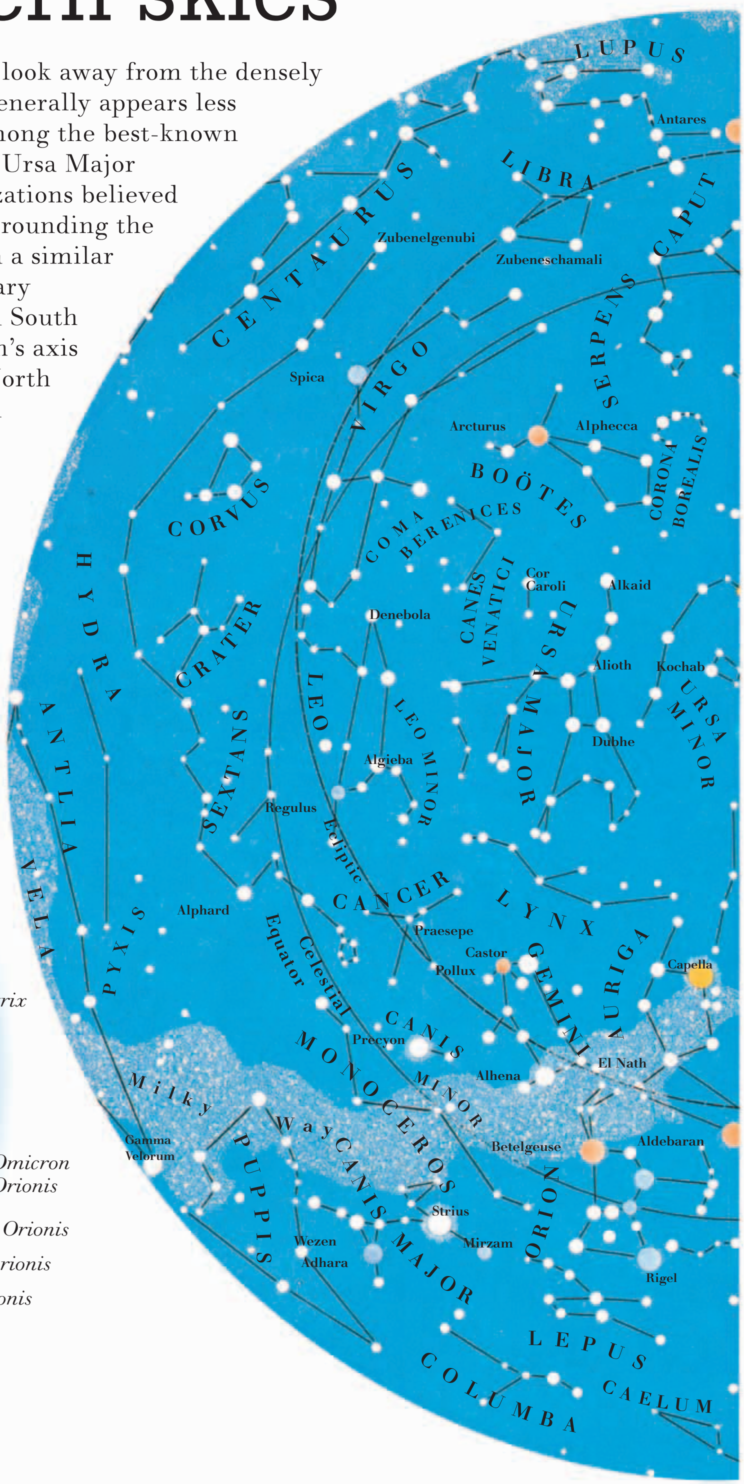
HELIX NEBULA (PLANETARY NEBULA)

Stars of northern skies

WHEN YOU LOOK AT THE NORTHERN SKY, you look away from the densely populated Galactic center, so the northern sky generally appears less bright than the southern sky (see pp. 20-21). Among the best-known sights in the northern sky are the constellations Ursa Major (the Great Bear) and Orion. Some ancient civilizations believed that the stars were fixed to a celestial sphere surrounding the Earth, and modern maps of the sky are based on a similar idea. The North and South Poles of this imaginary celestial sphere are directly above the North and South Poles of the Earth, at the points where the Earth's axis of rotation intersects the sphere. The celestial North Pole is at the center of the map shown here, and Polaris (the North Star) lies very close to it. The celestial equator marks a projection of the Earth's equator on the sphere. The ecliptic marks the path of the Sun across the sky as the Earth orbits the Sun. The Moon and planets move against the background of the stars because the stars are much more distant; the nearest star outside the solar system (Proxima Centauri) is more than 50,000 times farther away than the planet Jupiter.

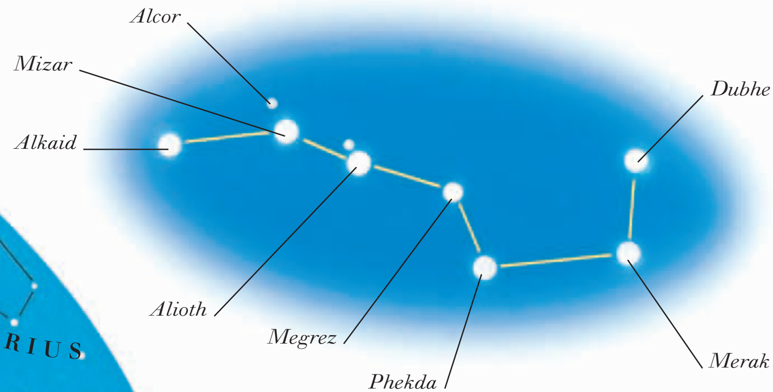
ORION





VISIBLE STARS IN THE NORTHERN SKY

THE BIG DIPPER, PART OF URSA MAJOR (THE GREAT BEAR)

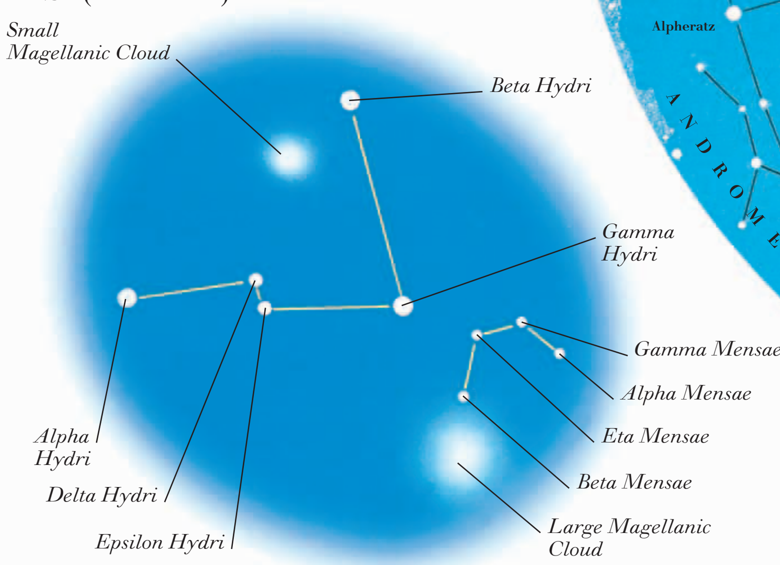


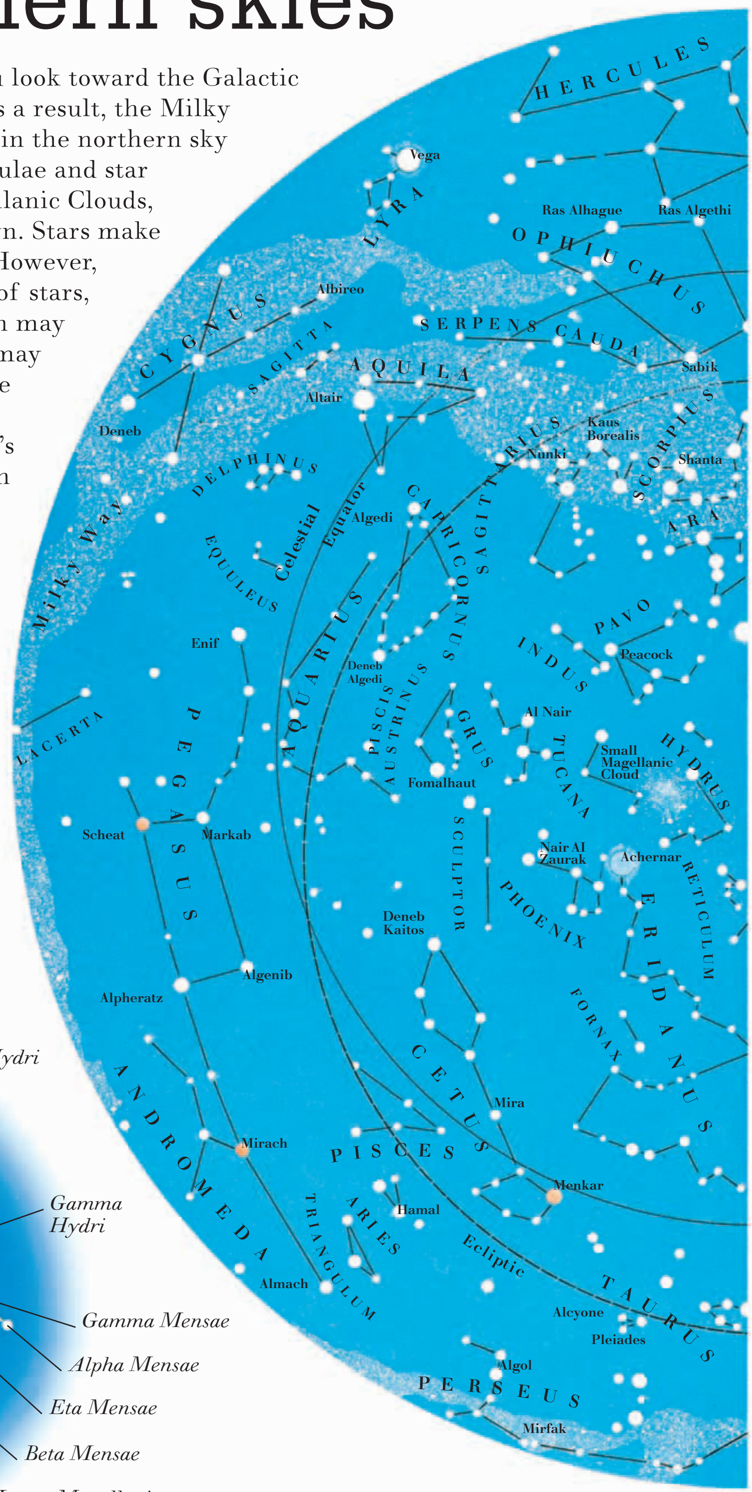
PEGASUS AND ANDROMEDA

Stars of southern skies

WHEN YOU LOOK AT THE SOUTHERN SKY, you look toward the Galactic center, which has a huge population of stars. As a result, the Milky Way appears brighter in the southern sky than in the northern sky (see pp. 18-19). The southern sky is rich in nebulae and star clusters. It contains the Large and Small Magellanic Clouds, which are two of the nearest galaxies to our own. Stars make fixed patterns in the sky called constellations. However, the constellations are only apparent groupings of stars, since the distances to the stars in a constellation may vary enormously. The shapes of constellations may change over many thousands of years due to the relative motions of stars. The movement of the constellations across the sky is due to the Earth's motion in space. The daily rotation of the Earth causes the constellations to move across the sky from east to west, and the orbit of the Earth around the Sun causes different areas of sky to be visible in different seasons. The visibility of areas of sky also depends on the location of the observer. For instance, stars near the celestial equator may be seen from either hemisphere at some time during the year, whereas stars close to the celestial poles (the celestial South Pole is at the center of the map shown here) can never be seen from the opposite hemisphere.

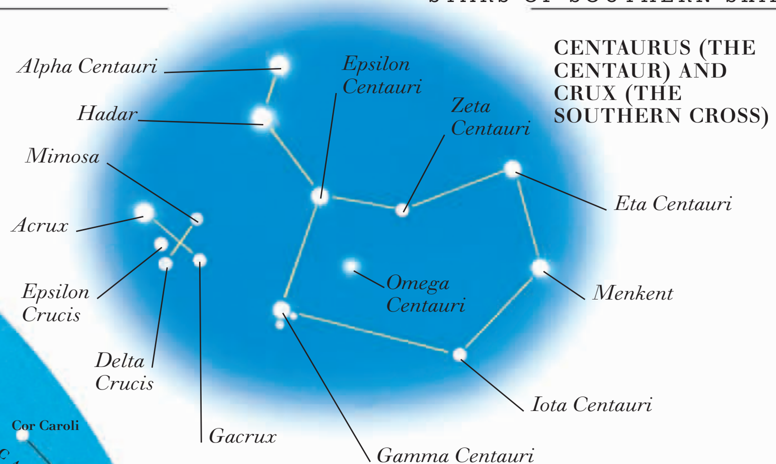
HYDRUS (THE WATER SNAKE) AND MENSA (THE TABLE)



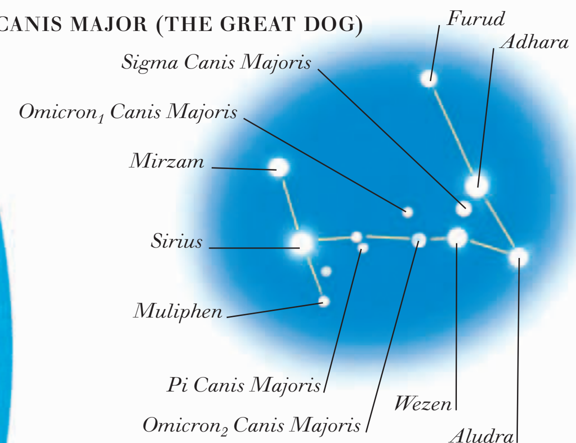


VISIBLE STARS IN THE SOUTHERN SKY

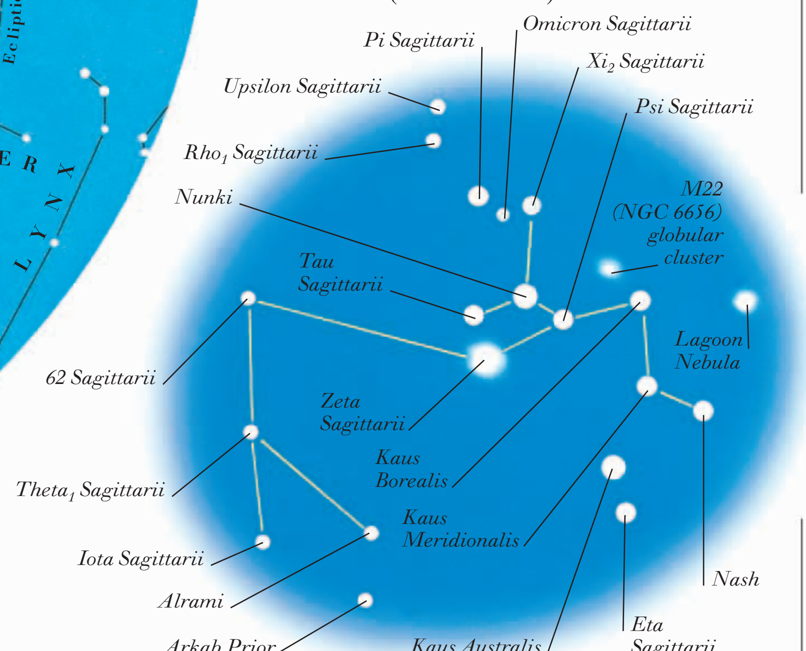
CENTAURUS (THE CENTAUR) AND CRUX (THE SOUTHERN CROSS)



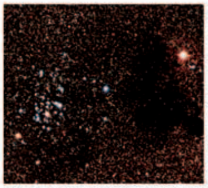
CANIS MAJOR (THE GREAT DOG)



SAGITTARIUS (THE ARCHER)

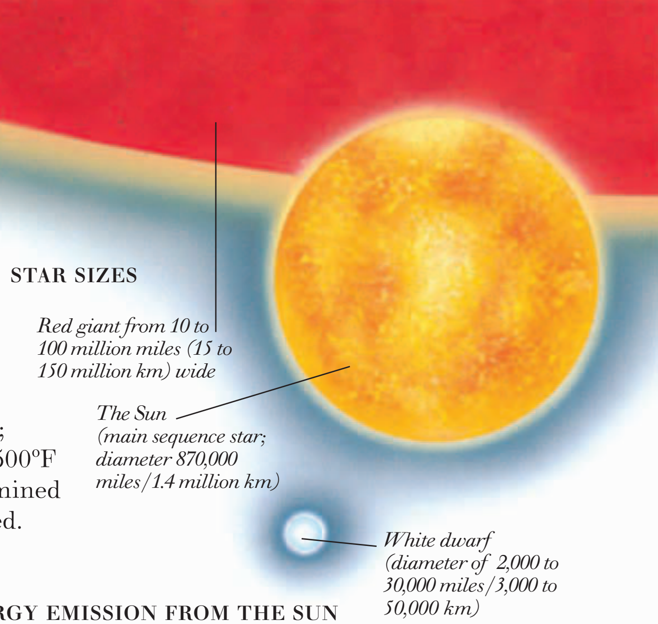


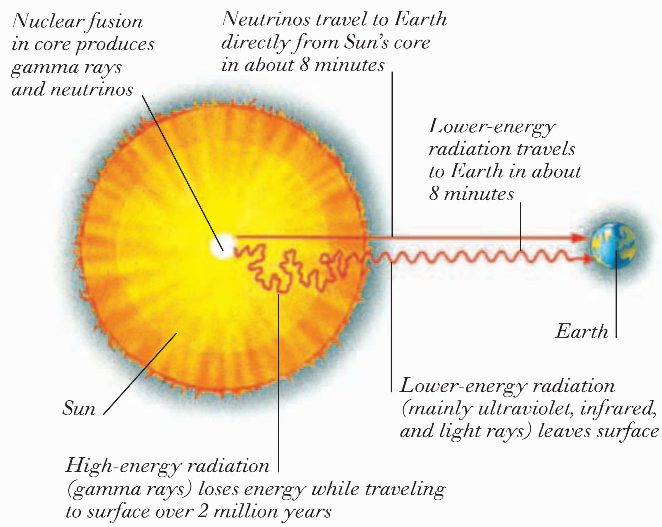
Stars

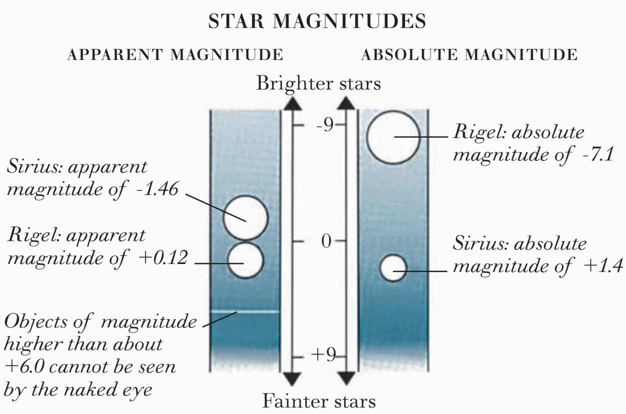


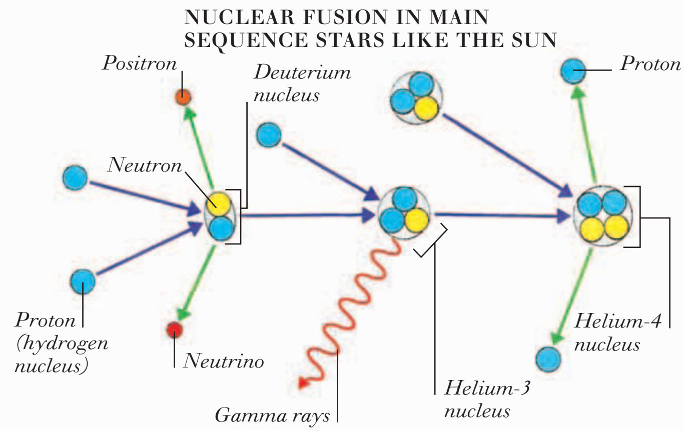
OPEN STAR CLUSTER AND DUST CLOUD

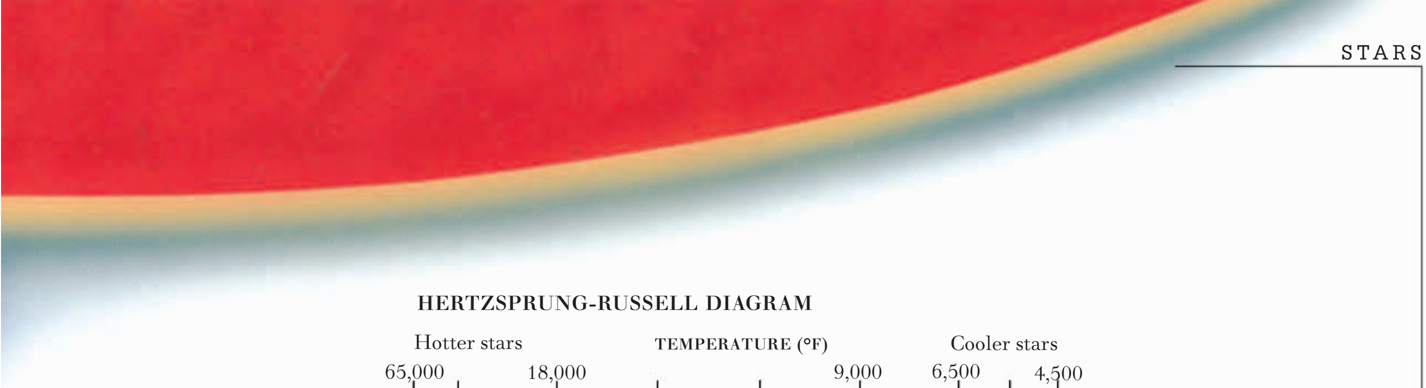
STARS ARE BODIES of hot, glowing gas that are born in nebulae (see pp. 24-27). They vary enormously in size, mass, and temperature: diameters range from about 450 times smaller to over 1,000 times bigger than that of the Sun; masses range from about a twentieth to over 50 solar masses; and surface temperatures range from about 5,500°F (3,000°C) to over 90,000°F (50,000°C). The color of a star is determined by its temperature: the hottest stars are blue and the coolest are red. The Sun, with a surface temperature of 10,000°F (5,500°C), is between these extremes and appears yellow. The energy emitted by a shining star is usually produced by nuclear fusion in the star's core. The brightness of a star is measured in magnitudes—the brighter the star, the lower its magnitude. There are two types of magnitude: apparent magnitude, which is the brightness seen from Earth, and absolute magnitude, which is the brightness that would be seen from a standard distance of 10 parsecs (32.6 light-years). The light emitted by a star may be split to form a spectrum containing a series of dark lines (absorption lines). The patterns of lines indicate the presence of particular chemical elements, enabling astronomers to deduce the composition of the star's atmosphere. The magnitude and spectral type (color) of stars may be plotted on a graph called a Hertzsprung-Russell diagram, which shows that stars tend to fall into several well-defined groups. The principal groups are main sequence stars (those which are fusing hydrogen to form helium), giants, supergiants, and white dwarfs.



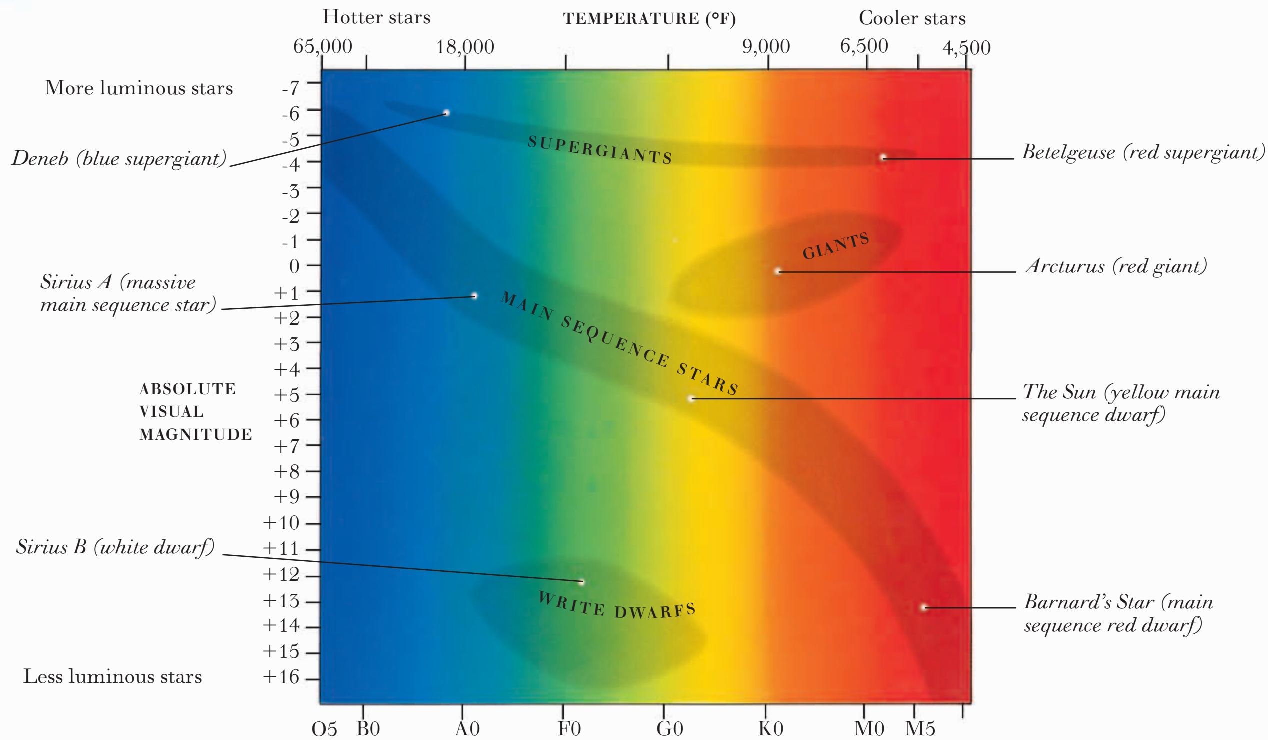




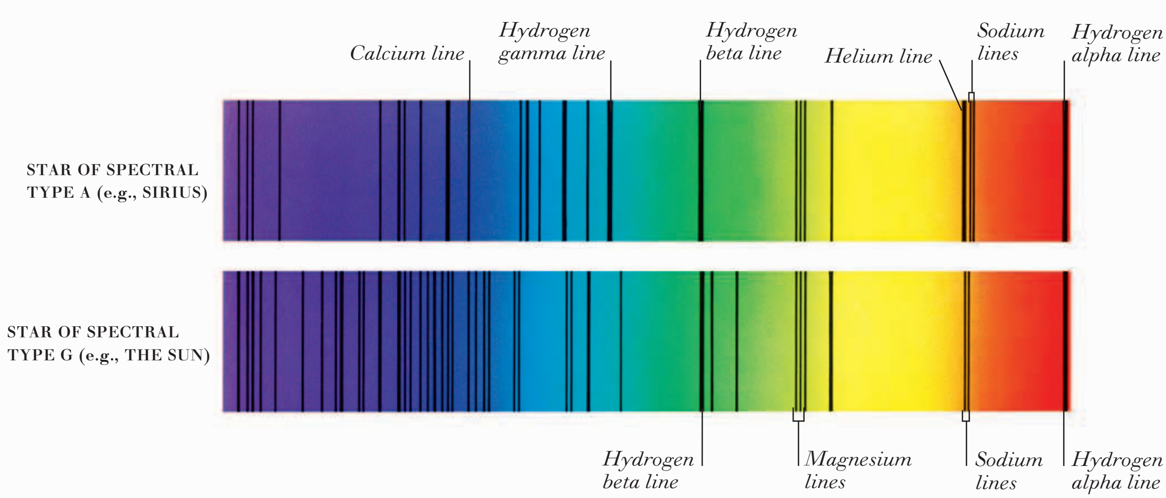




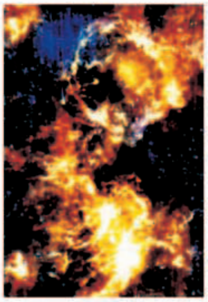
HERTZSPRUNG-RUSSELL DIAGRAM



STELLAR SPECTRAL ABSORPTION LINES



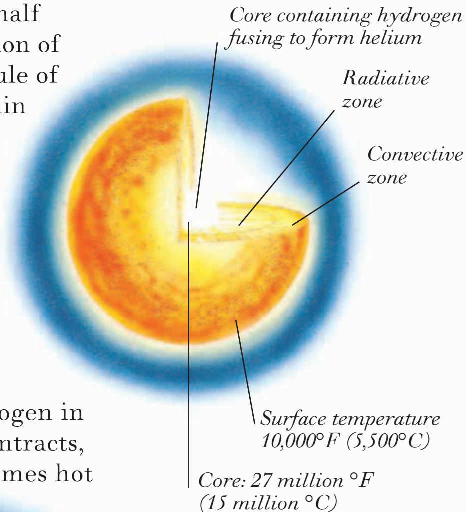
Small stars



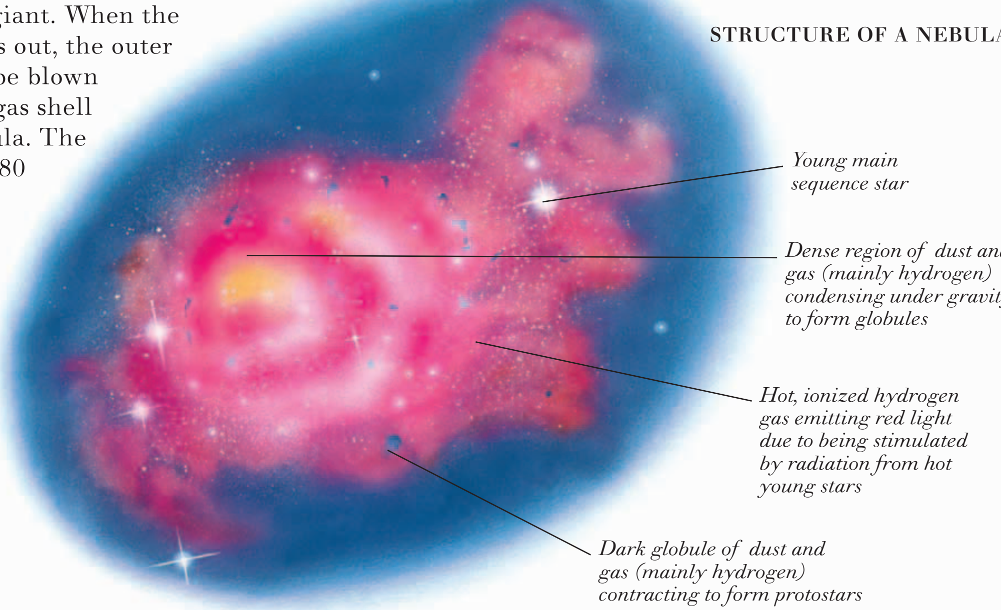
REGION OF STAR FORMATION IN ORION

SMALL STARS HAVE A MASS of up to about one and a half times that of the Sun. They begin to form when a region of higher density in a nebula condenses into a huge globule of gas and dust that contracts under its own gravity. Within a globule, regions of condensing matter heat up and begin to glow, forming protostars. If a protostar contains enough matter, the central temperature reaches about 27 million °F (8 million °C). At this temperature, nuclear reactions in which hydrogen fuses to form helium can start. This process releases energy, which prevents the star from contracting more and also causes it to shine; it is now a main sequence star. A star of about one solar mass remains on the main sequence for about 10 billion years, until much of the hydrogen in the star's core has been converted into helium. The helium core then contracts, and nuclear reactions continue in a shell around the core. The core becomes hot enough for helium to fuse to form carbon, while the outer layers of the star expand and cool. The expanding star is known as a red giant. When the helium in the core runs out, the outer layers of the star may be blown away as an expanding gas shell called a planetary nebula. The remaining core (about 80 percent of the original star) is now in its final stages. It becomes a white dwarf star that gradually cools and dims. When it finally stops shining altogether, the dead star will become a black dwarf.

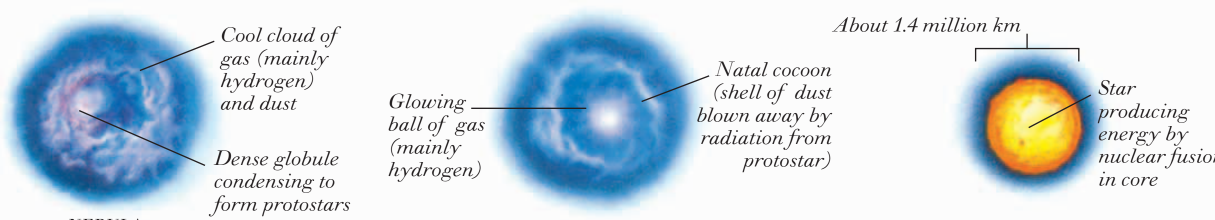
STRUCTURE OF A MAIN SEQUENCE STAR



STRUCTURE OF A NEBULA



LIFE OF A SMALL STAR OF ABOUT ONE SOLAR MASS

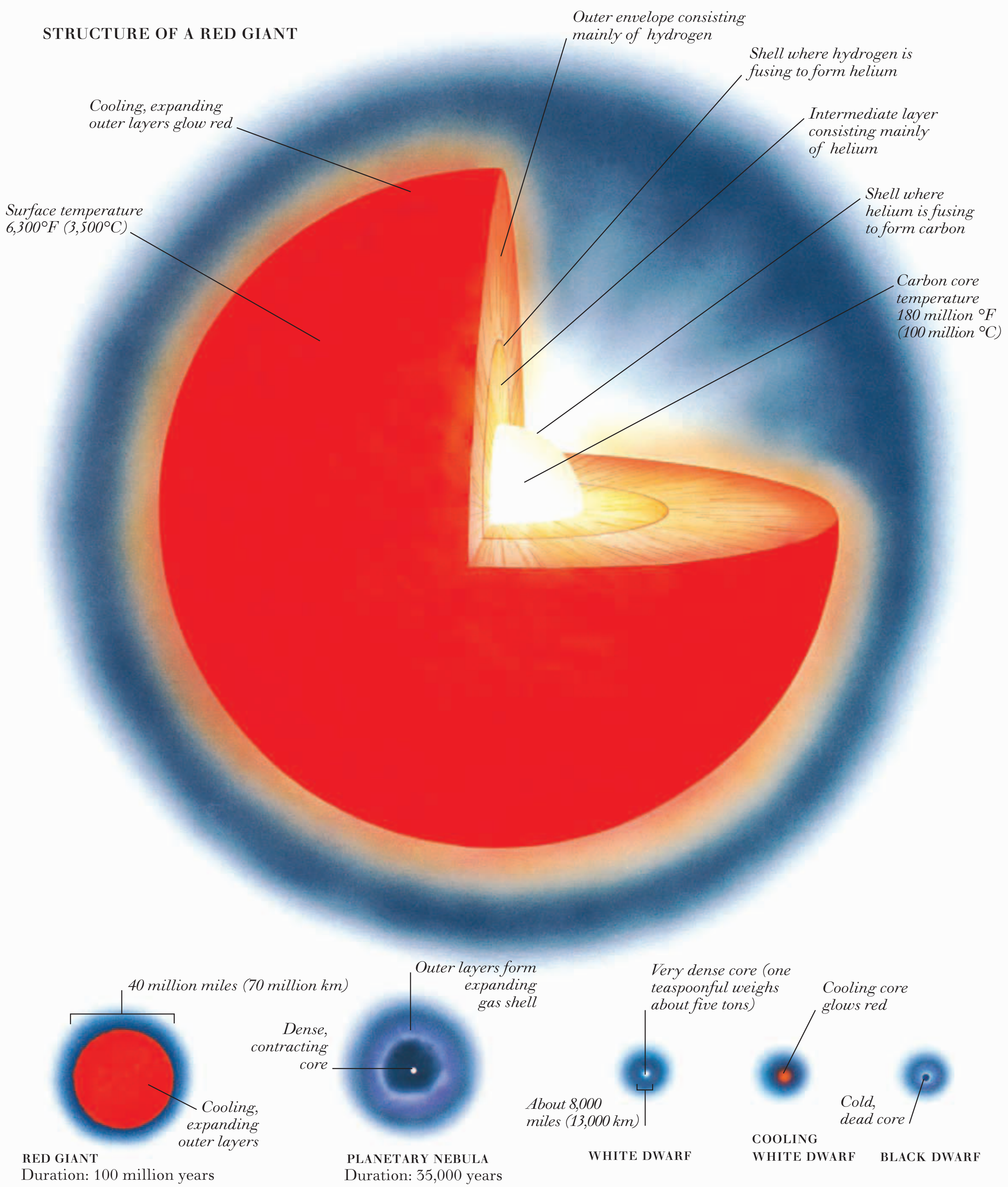


NEBULA

PROTOSTAR
Duration: 50 million years

MAIN SEQUENCE STAR
Duration: 10 billion years

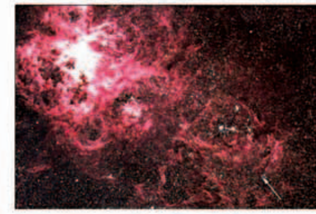
STRUCTURE OF A RED GIANT



Massive stars

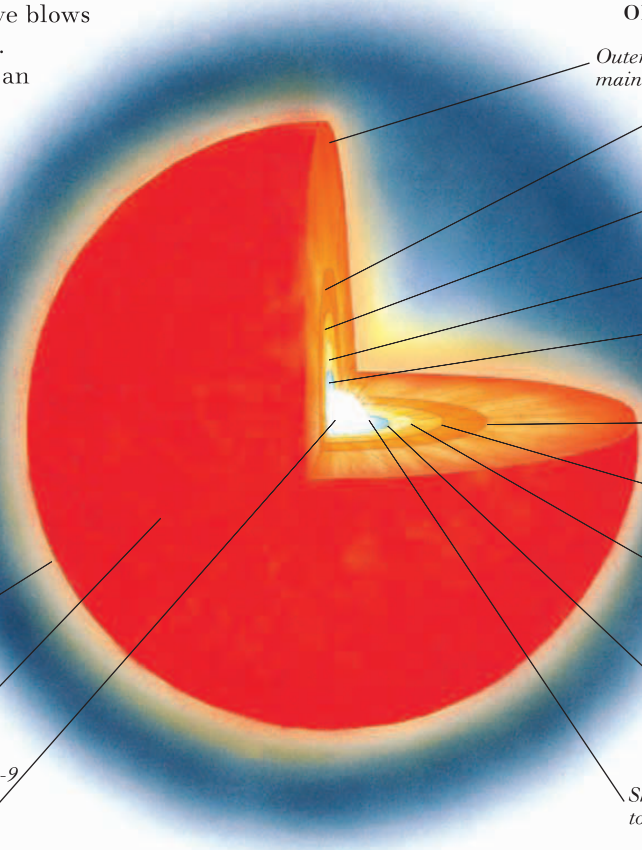
MASSIVE STARS HAVE A MASS AT LEAST THREE TIMES that of the Sun, and some stars are as massive as about 50 Suns. A massive star evolves in a similar way to a small star until it reaches the main sequence stage (see pp. 24-25). During its life as a main sequence star, it shines steadily until the hydrogen in its core has fused to form helium. This process takes billions of years in a small star, but only millions of years in a massive star. A massive star then becomes a red supergiant, which initially consists of a helium core surrounded by outer layers of cooling, expanding gas. Over the next few million years, a series of nuclear reactions form different elements in shells around an iron core. The core eventually collapses in less than a second, causing a massive explosion called a supernova, in which a shock wave blows away the outer layers of the star. Supernovae shine brighter than an entire galaxy for a short time. Sometimes, the core survives the supernova explosion. If the surviving core is between about one and a half and three solar masses, it contracts to become a tiny, dense neutron star. If the core is greater than three solar masses, it contracts to become a black hole (see pp. 28-29).

SUPERNOVA

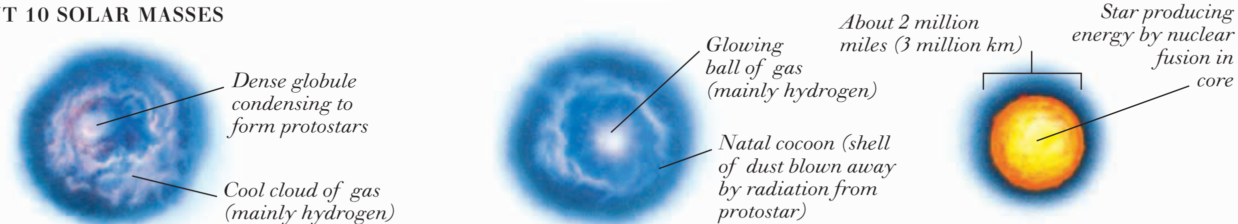


TARANTULA NEBULA BEFORE SUPERNOVA

STRUCTURE OF A RED SUPERGIANT



LIFE OF A MASSIVE STAR OF ABOUT 10 SOLAR MASSES

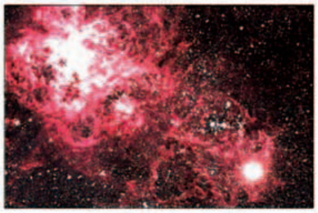


NEBULA

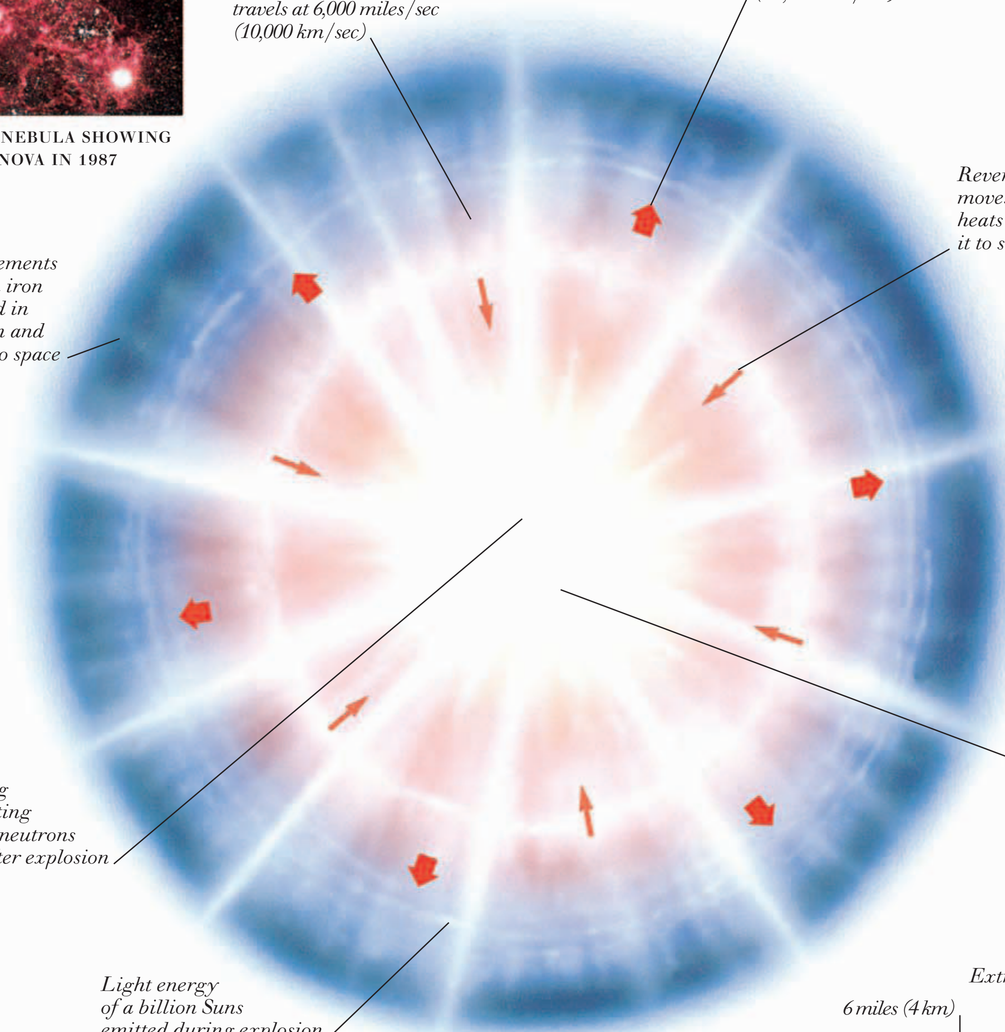
PROTOSTAR
Duration: a few hundred thousand years

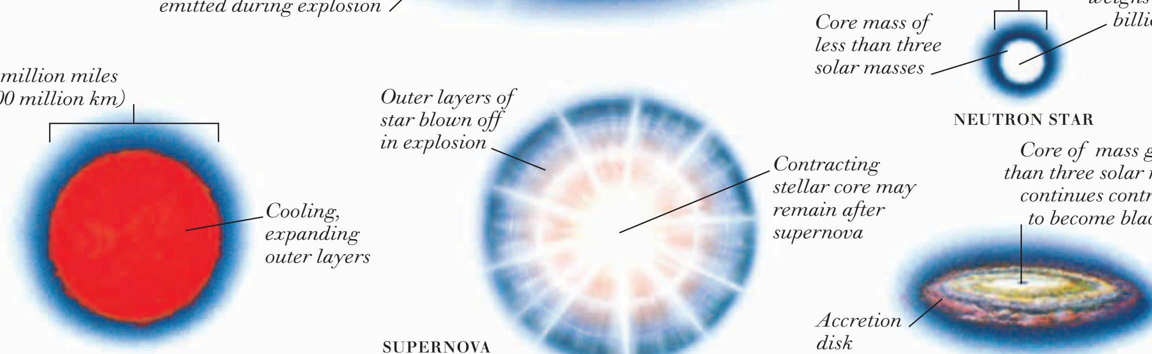
MAIN SEQUENCE STAR
Duration: 10 million years

FEATURES OF A SUPERNOVA



TARANTULA NEBULA SHOWING SUPERNOVA IN 1987





RED SUPERGIANT
Duration: 4 million years

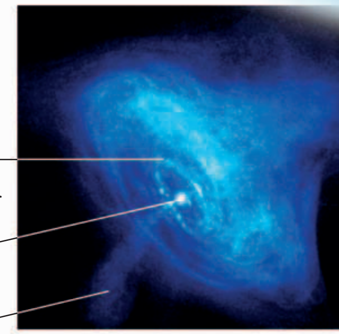
SUPERNOVA
Duration of visibility: 1–2 years

NEUTRON STAR

BLACK HOLE

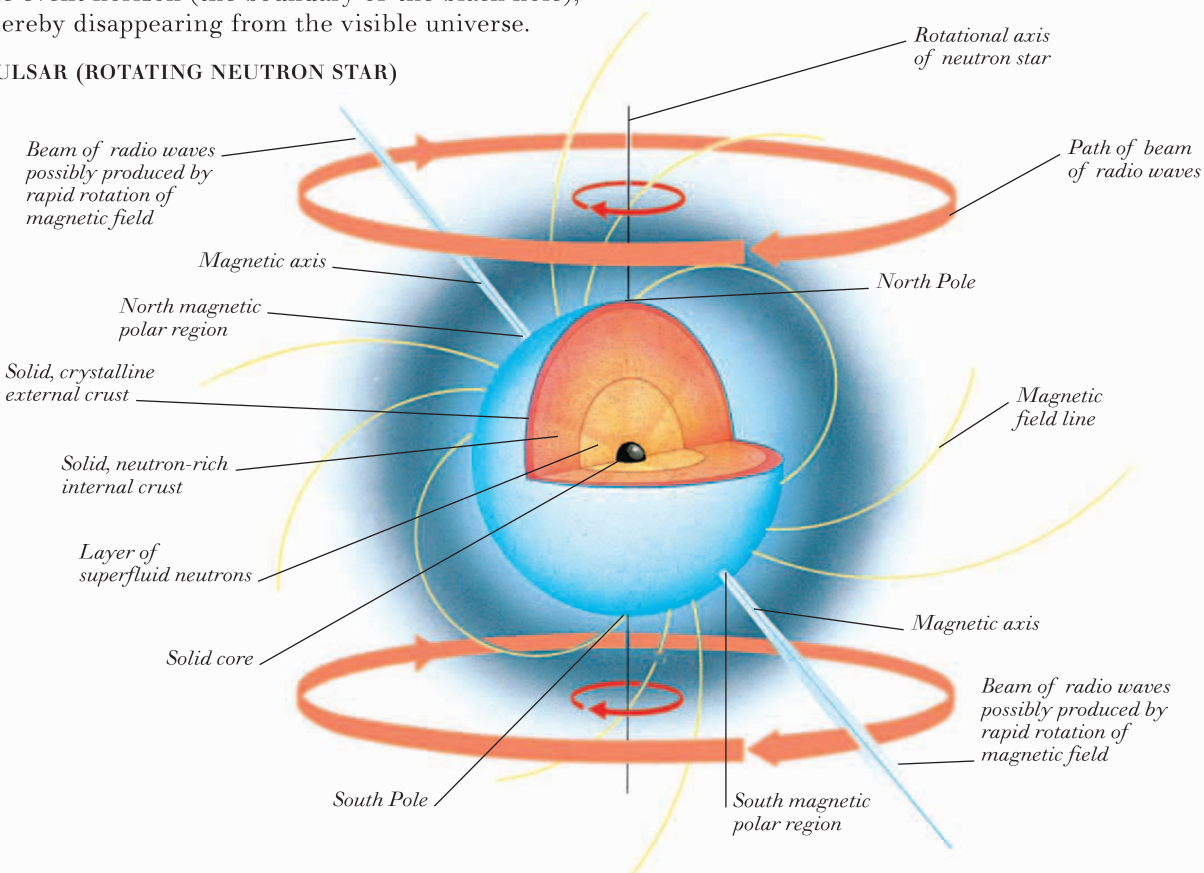
Neutron stars and black holes

NEUTRON STARS AND BLACK HOLES form from the stellar cores that remain after stars have exploded as supernovae (see pp. 26-27). If the remaining core is between about one and a half and three solar masses, it contracts to form a neutron star. If the remaining core is greater than about three solar masses, it contracts to form a black hole. Neutron stars are typically only about 6 miles (10 km) in diameter and consist almost entirely of subatomic particles called neutrons. Such stars are so dense that a teaspoonful would weigh about a billion tons. Neutron stars are observed as pulsars, so-called because they rotate rapidly and emit two beams of radio waves, which sweep across the sky and are detected as short pulses. Black holes are characterized by their extremely strong gravity, which is so powerful that not even light can escape; as a result, black holes are invisible. However, they can be detected if they have a close companion star. The gravity of the black hole pulls gas from the other star, forming an accretion disk that spirals around the black hole at high speed, heating up and emitting radiation. Eventually, the matter spirals in to cross the event horizon (the boundary of the black hole), thereby disappearing from the visible universe.

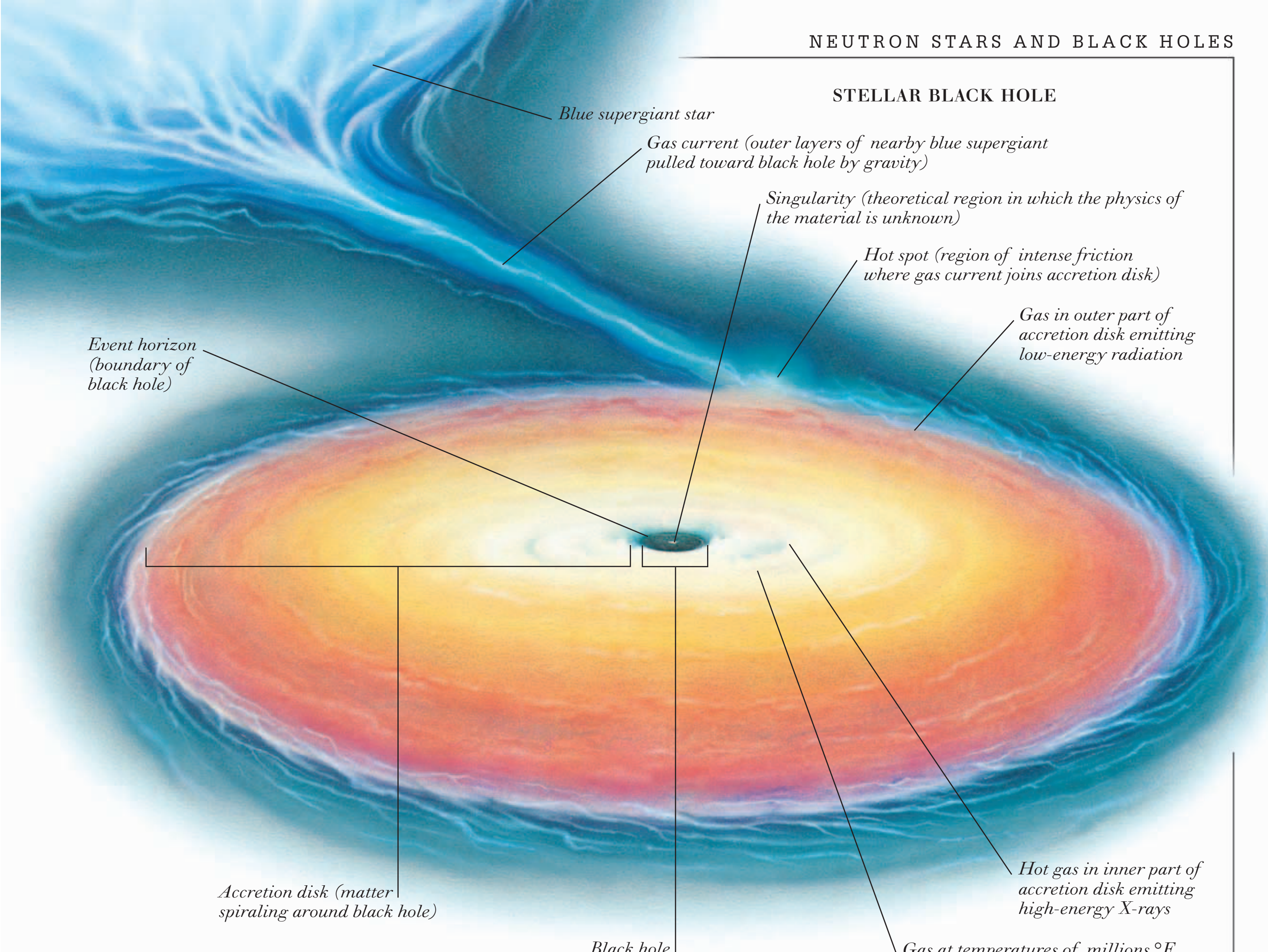


X-RAY IMAGE OF PULSAR AND CENTRAL REGION OF CRAB NEBULA (SUPERNOVA REMNANT)

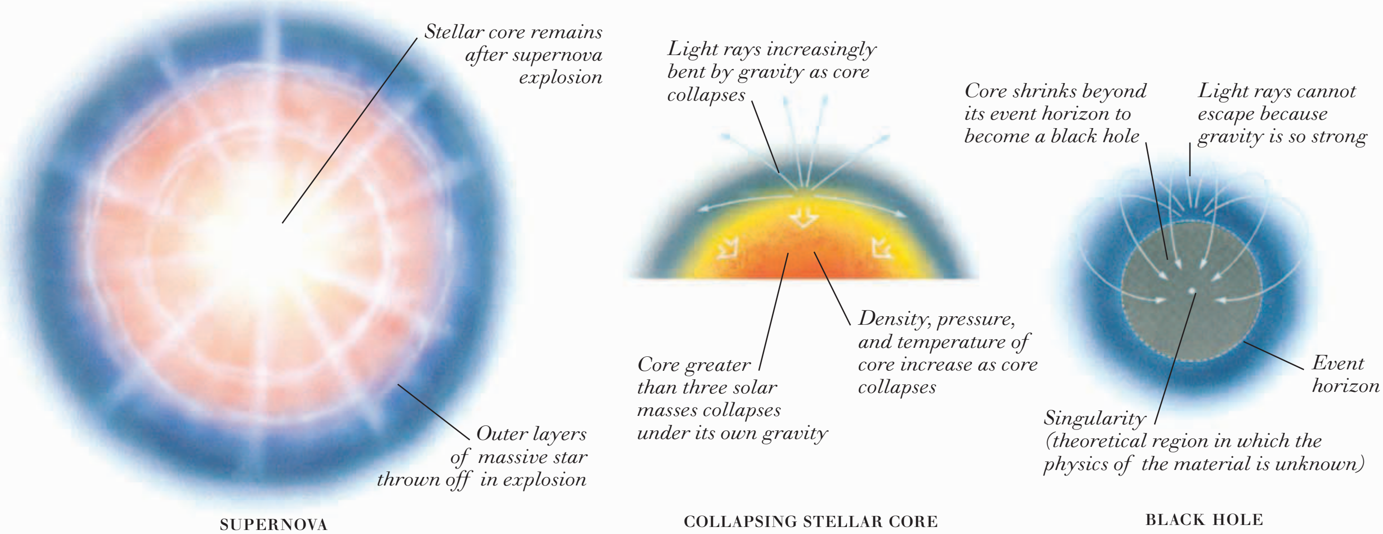
PULSAR (ROTATING NEUTRON STAR)



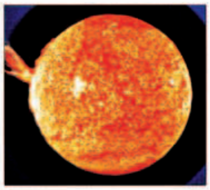
STELLAR BLACK HOLE



FORMATION OF A BLACK HOLE

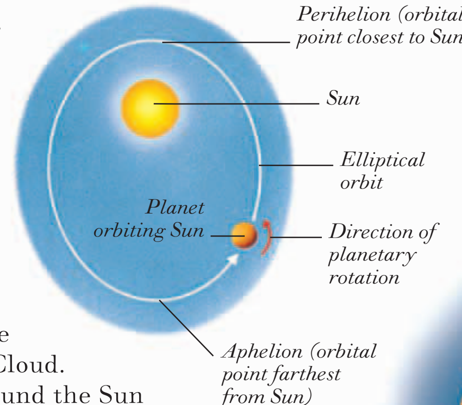


The solar system

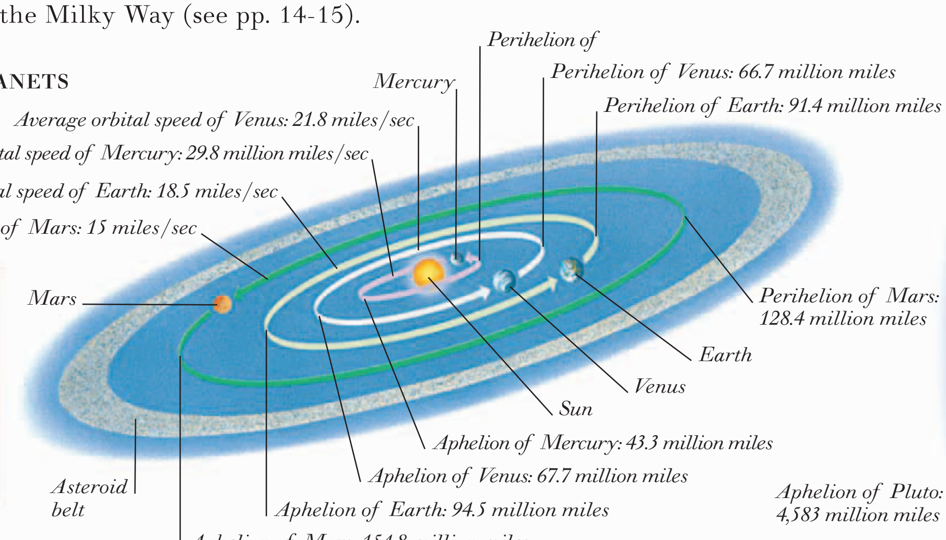


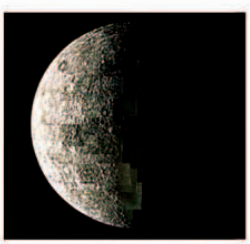
THE SOLAR SYSTEM consists of a central star (the Sun) and the bodies that orbit it. These bodies include eight planets and their more than 160 known moons; dwarf planets; Kuiper Belt objects; asteroids; comets; and meteoroids. The solar system also contains interplanetary gas and dust. The planets fall into two groups: four small rocky planets near the Sun (Mercury, Venus, Earth, and Mars); and four planets farther out, the giants (Jupiter, Saturn, Uranus, and Neptune). Between the rocky planets and giants is the asteroid belt, which contains thousands of chunks of rock orbiting the Sun. Beyond Neptune is the Kuiper Belt and, more distant, the Oort Cloud. Most of the bodies in the planetary part of the solar system move around the Sun in elliptical orbits located in a thin disk around the Sun's equator. All the planets orbit the Sun in the same direction (counterclockwise when viewed from above) and all but Venus and Uranus also spin about their axes in this direction. Moons also spin as they, in turn, orbit their planets. The entire solar system orbits the center of our galaxy, the Milky Way (see pp. 14-15).

PLANETARY ORBIT (EXAGGERATED)

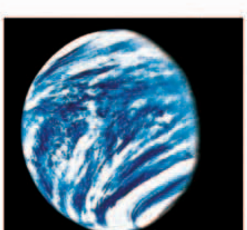


ORBITS OF INNER PLANETS





MERCURY
Year: 87.97 Earth days
Mass: 0.06 Earth masses
Diameter: 3,031 miles



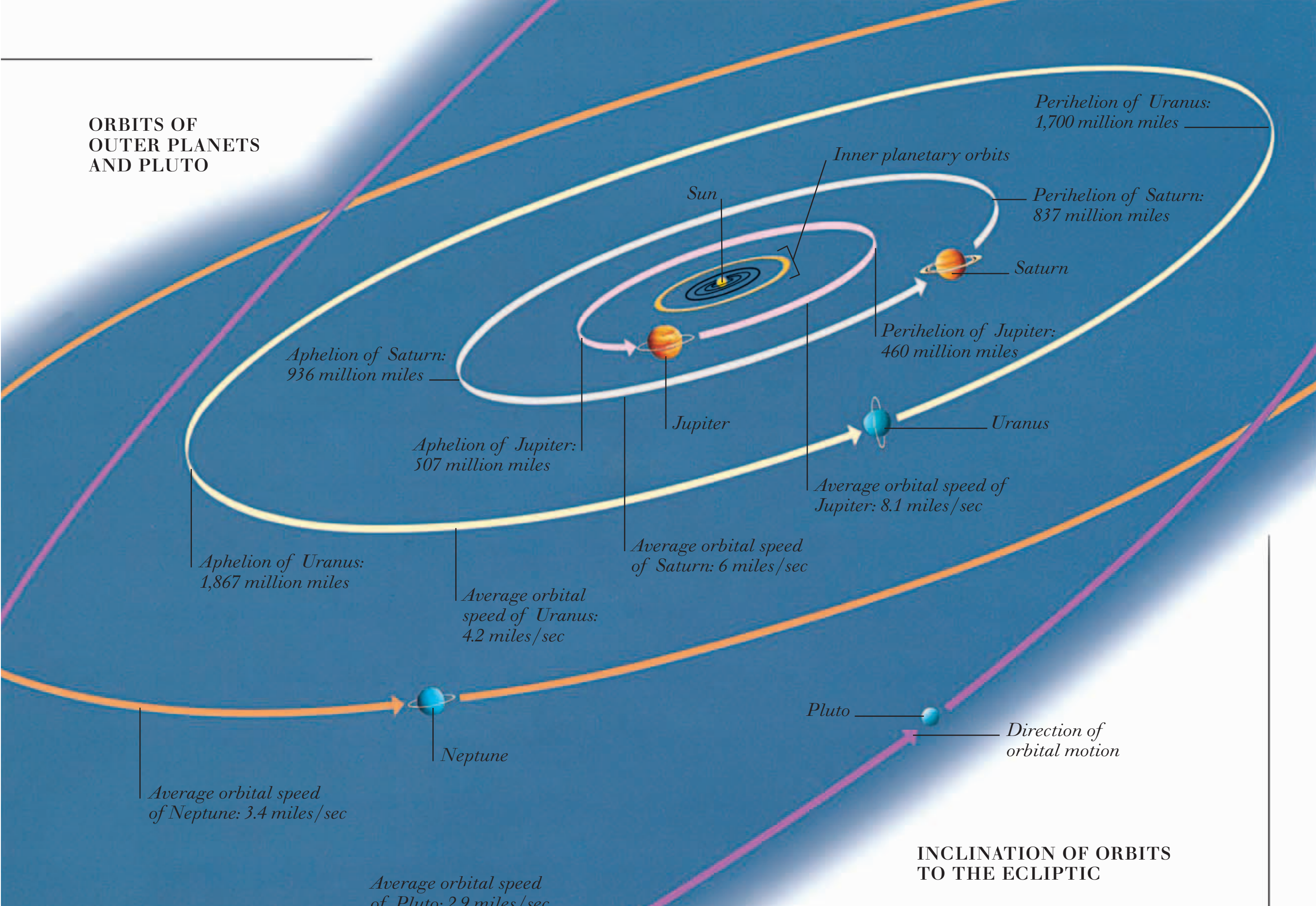
VENUS
Year: 224.7 Earth days
Mass: 0.81 Earth masses
Diameter: 7,521 miles

EARTH
Year: 365.26 days
Mass: 1 Earth mass
Diameter: 7,926 miles

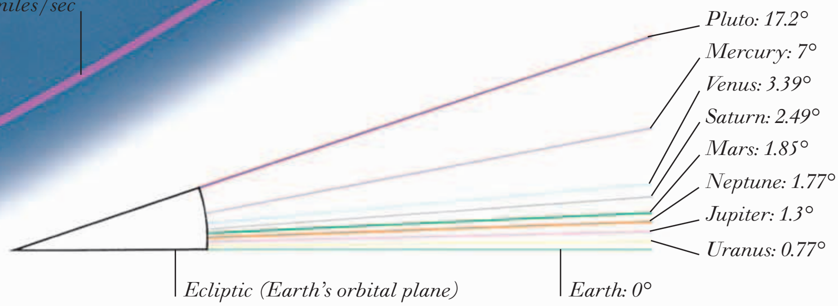
MARS
Year: 1.88 Earth years
Mass: 0.11 Earth masses
Diameter: 4,217 miles

JUPITER
Year: 11.87 Earth years
Mass: 317.83 Earth masses
Diameter: 88,850 miles

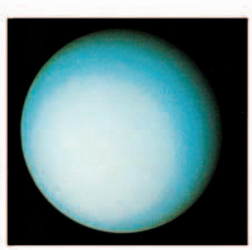
ORBITS OF OUTER PLANETS AND PLUTO



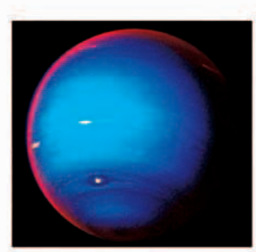
INCLINATION OF ORBITS TO THE ECLIPTIC



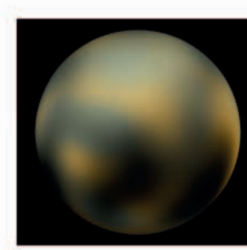
SATURN
Year: 29.66 Earth years
Mass: 95.16 Earth masses
Diameter: 74,901 miles



URANUS
Year: 84.13 Earth years
Mass: 14.54 Earth masses
Diameter: 31,765 miles

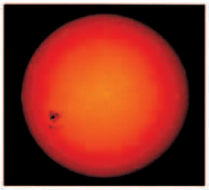


NEPTUNE
Year: 164.70 Earth years
Mass: 17.14 Earth masses
Diameter: 30,777 miles



PLUTO
Year: 248.09 Earth years
Mass: 0.0022 Earth masses
Diameter: 1,429 miles

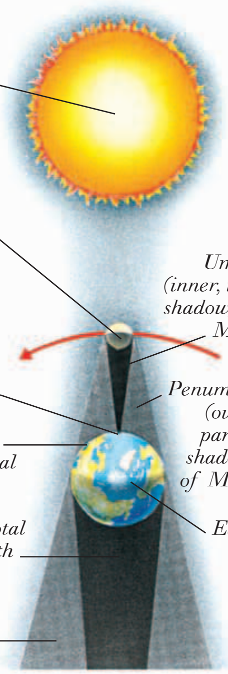
The Sun



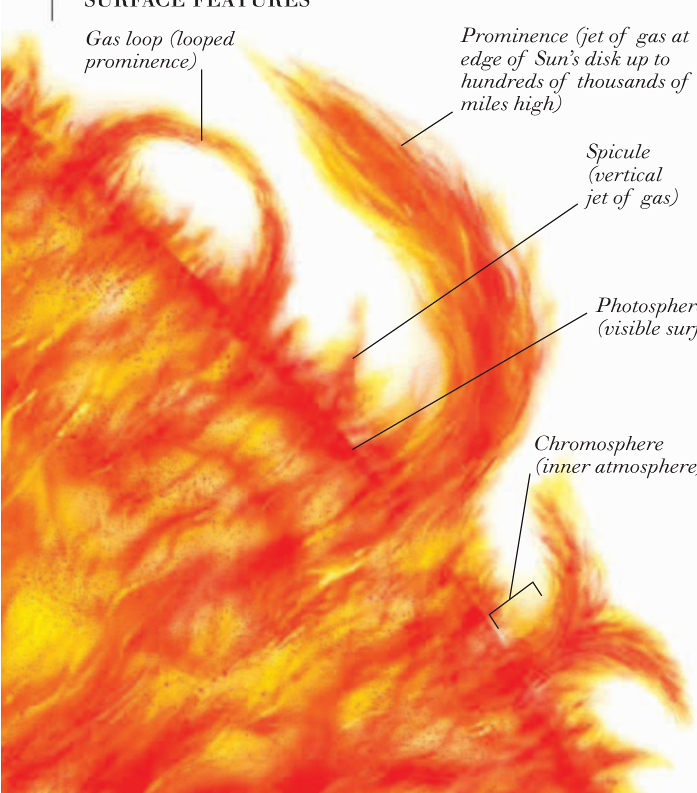
SOLAR PHOTOSPHERE

THE SUN IS THE STAR AT THE CENTER of the solar system. It is about five billion years old and will continue to shine as it does now for about another five billion years. The Sun is a yellow main sequence star (see pp. 22-23) about 870,000 miles (1.4 million km) in diameter. It consists almost entirely of hydrogen and helium. In the Sun's core, hydrogen is converted to helium by nuclear fusion, releasing energy in the process. The energy travels from the core, through the radiative and convective zones, to the photosphere (visible surface), where it leaves the Sun in the form of heat and light. On the photosphere there are often dark, relatively cool areas called sunspots, which usually appear in pairs or groups and are caused by the cooling effect of the magnetic field. Other types of solar activity are flares, which are usually associated with sunspots, and prominences. Flares are sudden discharges of high-energy radiation and atomic particles. Prominences are huge loops or filaments of gas extending into the solar atmosphere; some last for hours, others for months. Beyond the photosphere is the chromosphere (inner atmosphere) and the extremely rarified corona (outer atmosphere), which extends millions of miles into space. Tiny particles that escape from the corona give rise to the solar wind, which streams through space at hundreds of miles per second. The chromosphere and corona can be seen from Earth when the Sun is totally eclipsed by the Moon.

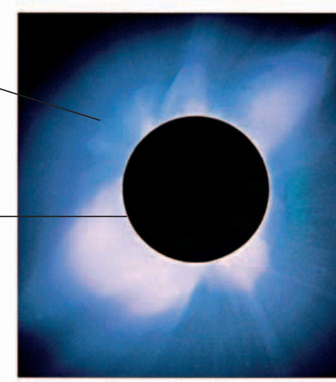
HOW A SOLAR ECLIPSE OCCURS



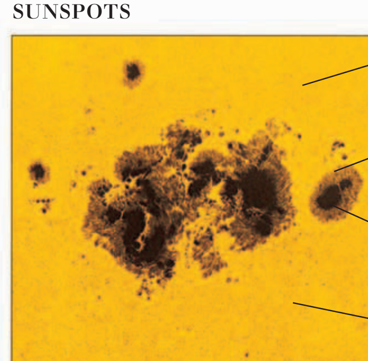
SURFACE FEATURES



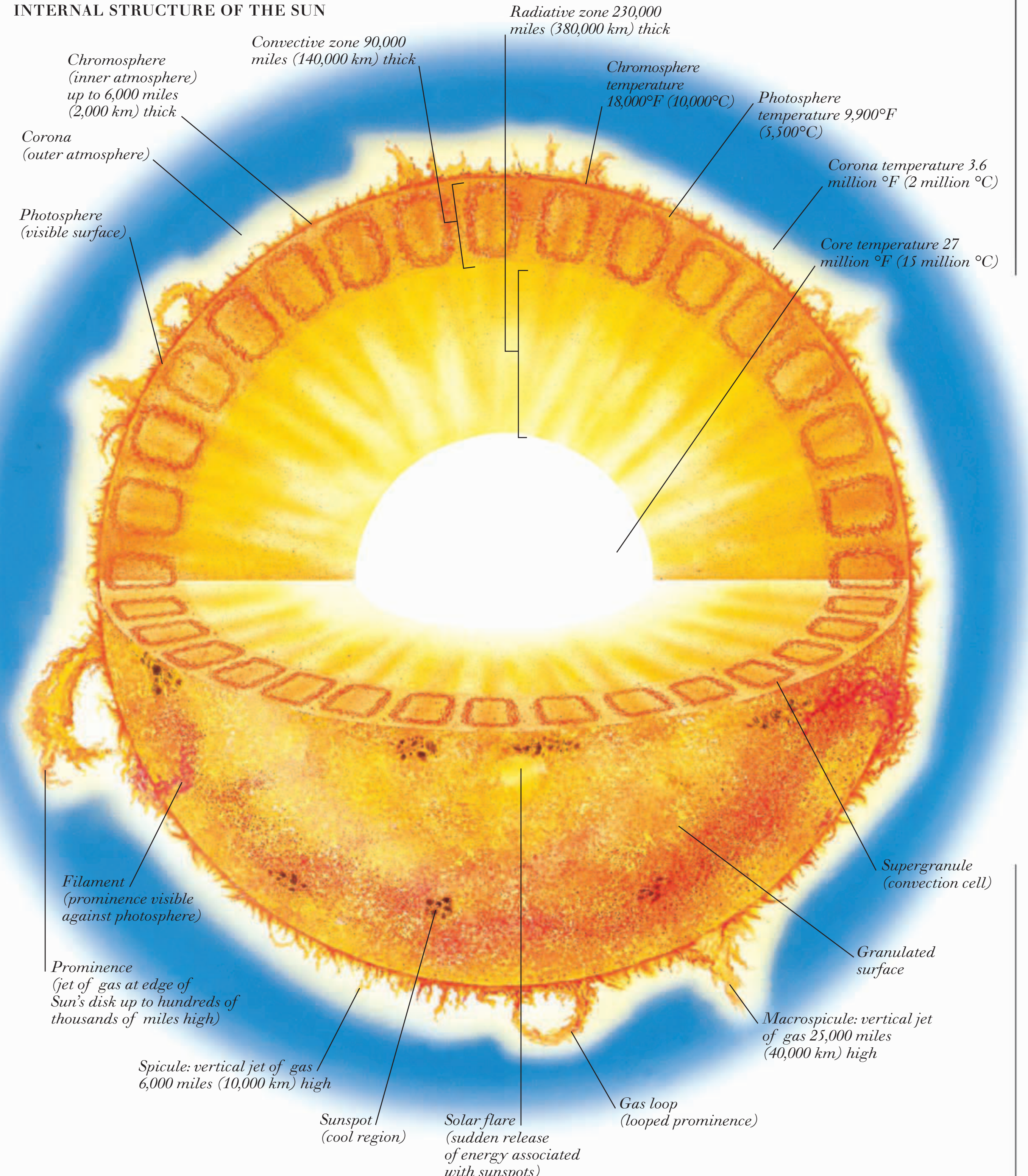
TOTAL SOLAR ECLIPSE



SUNSPOTS



EXTERNAL FEATURES AND INTERNAL STRUCTURE OF THE SUN

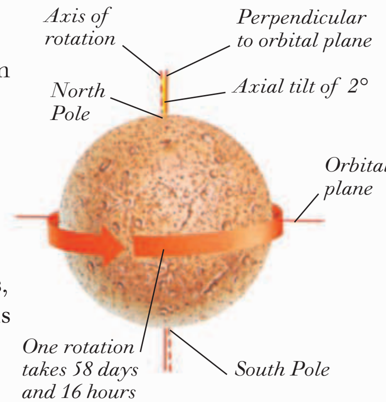


Mercury

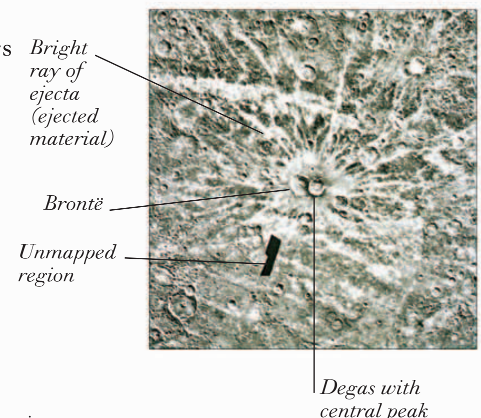
MERCURY

MERCURY IS THE NEAREST PLANET to the Sun, orbiting at an average distance of about 36 million miles (58 million km). Because Mercury is the closest planet to the Sun, it moves faster than any other planet, travelling at an average speed of nearly 30 miles (48 km) per second and completing an orbit in just under 88 days. Mercury is very small (only 40 percent bigger than the Moon) and rocky. Most of the surface has been heavily cratered by the impact of meteorites, although there are also smooth, sparsely cratered lava-covered plains. The Caloris Basin is the largest crater, measuring about 800 miles (1,300 km) across. It is thought to have been formed when a 38-mile- (60-km-) diameter asteroid hit the planet, and is surrounded by concentric rings of mountains thrown up by the impact. The surface also has many clifflike ridges (called rupes) that are thought to have been formed when the hot core of the young planet cooled and shrank about four billion years ago, buckling the planet's surface in the process. The planet rotates about its axis very slowly, taking nearly 59 Earth days to complete one rotation. As a result, a solar day (sunrise to sunrise) on Mercury is about 176 Earth days—twice as long as the 88-day Mercurian year. Mercury has extreme surface temperatures, ranging from a maximum of 800°F (430°C) on the sunlit side to -270°F (-170°C) on the dark side. At nightfall, the temperature drops very quickly because the planet's atmosphere is almost nonexistent. It consists only of minute amounts of helium and hydrogen captured from the solar wind, plus traces of other gases.

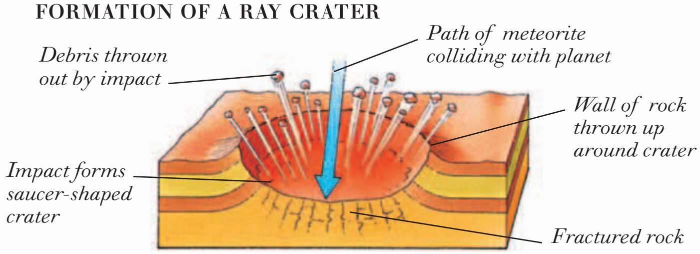
TILT AND ROTATION OF MERCURY



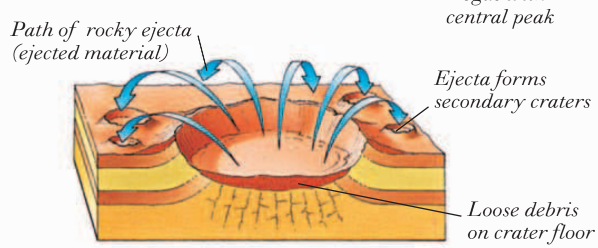
DEGAS AND BRONTË (RAY CRATERS)



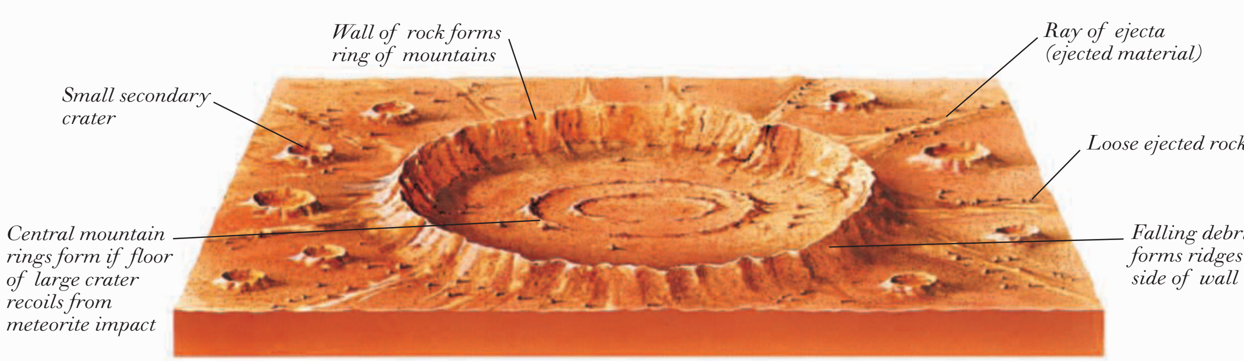
FORMATION OF A RAY CRATER



METEORITE IMPACT

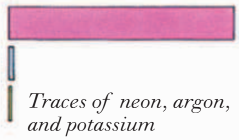


SECONDARY CRATERING

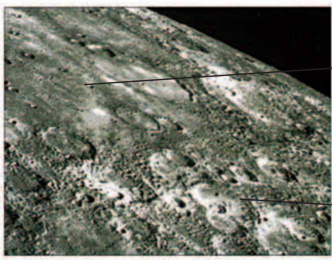


RAY CRATER

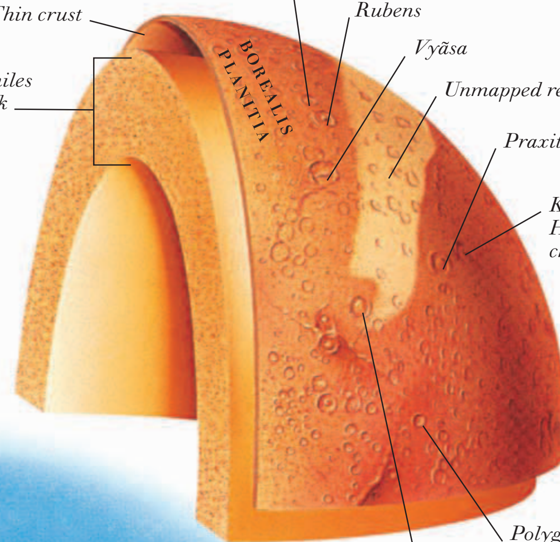
COMPOSITION OF ATMOSPHERE

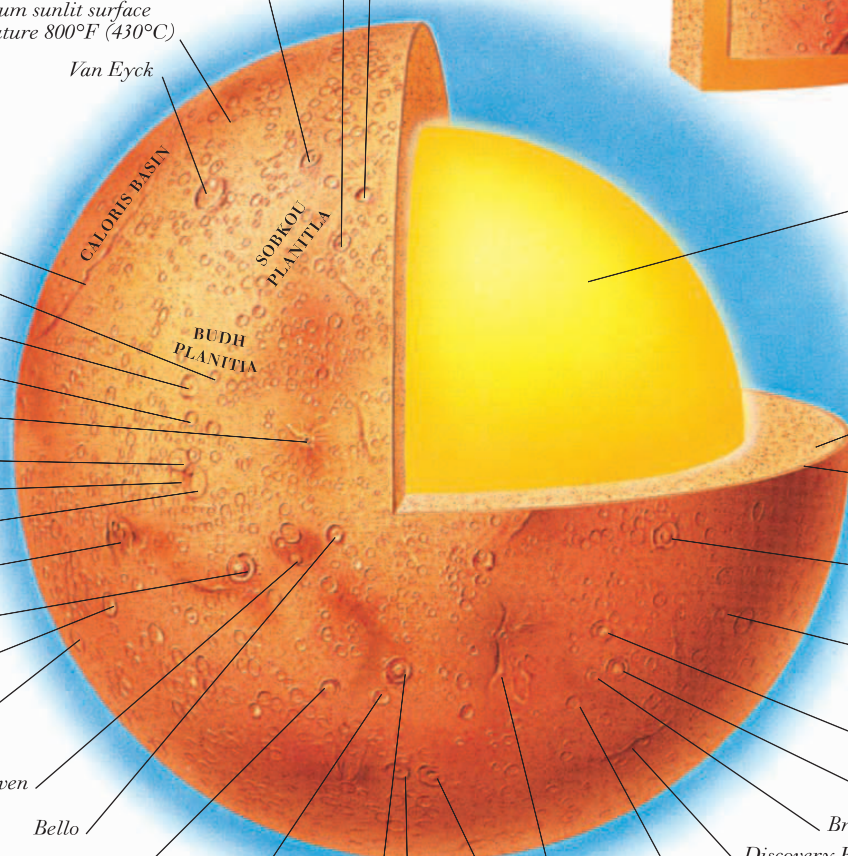


CRATERS AND PLAINS NEAR MERCURY'S NORTH POLE

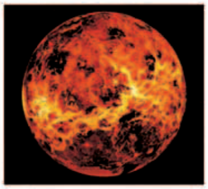


EXTERNAL FEATURES AND INTERNAL STRUCTURE OF MERCURY





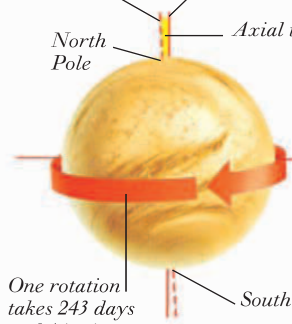
Venus



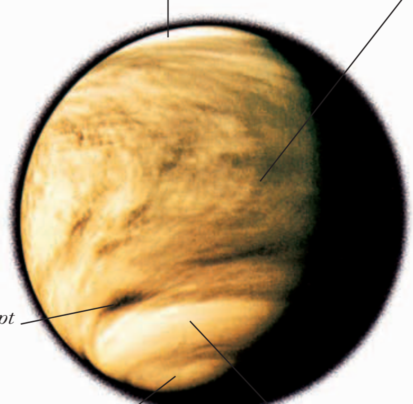
RADAR IMAGE OF VENUS

VENUS IS A ROCKY PLANET and the second planet from the Sun. Venus spins slowly backwards as it orbits the Sun, causing its rotational period to be the longest in the solar system, at about 243 Earth days. It is slightly smaller than Earth and probably has a similar internal structure, consisting of a semisolid metal core, surrounded by a rocky mantle and crust. Venus is the brightest object in the sky after the Sun and Moon because its clouds reflect sunlight strongly. The main component of the atmosphere is carbon dioxide, which traps heat in a greenhouse effect far stronger than that on Earth. As a result, Venus is the hottest planet, with a maximum surface temperature of about 900°F (480°C). The thick cloud layers contain droplets of sulfuric acid and are driven around the planet by winds at speeds of up to 220 miles (360 km) per hour. Although the planet takes 243 Earth days to rotate once, the high-speed winds cause the clouds to circle the planet in only four Earth days. The high temperature, acidic clouds, and enormous atmospheric pressure (about 90 times greater at the surface than that on Earth) make the environment extremely hostile. However, space probes have managed to land on Venus and photograph its dry, dusty surface. The Venusian surface has also been mapped by probes with radar equipment that can "see" through the cloud layers. Such radar maps reveal a terrain with craters, mountains, volcanoes, and areas where craters have been covered by plains of solidified volcanic lava. There are two large highland regions called Aphrodite Terra and Ishtar Terra.

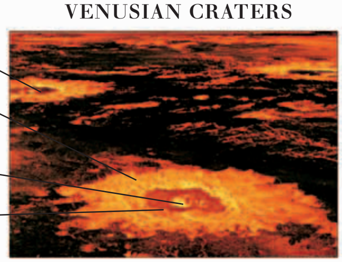
TILT AND ROTATION OF VENUS



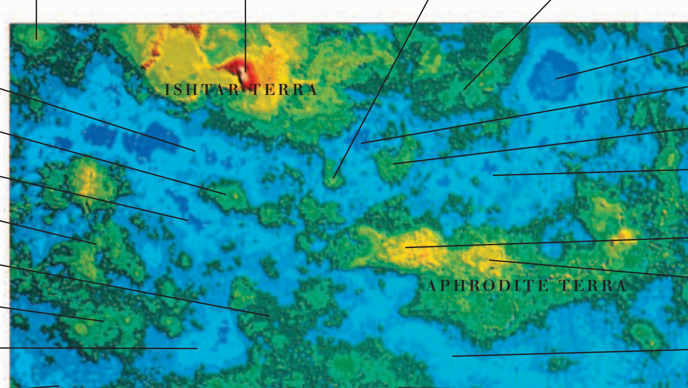
CLOUD FEATURES



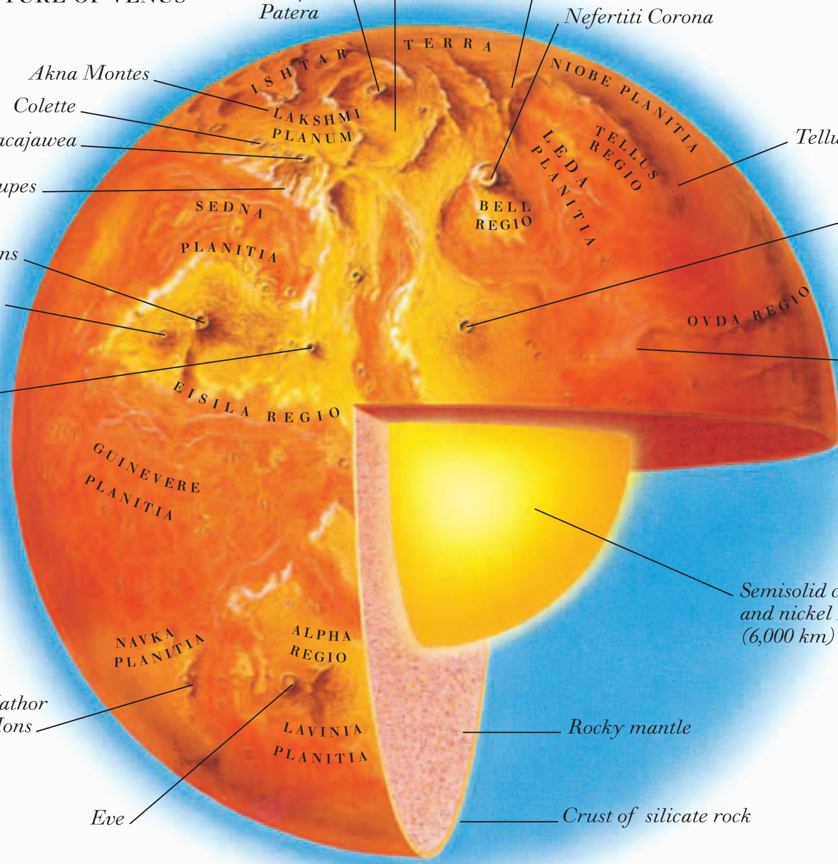
VENUSIAN CRATERS



FALSE-COLOR RADAR MAP OF THE SURFACE OF VENUS

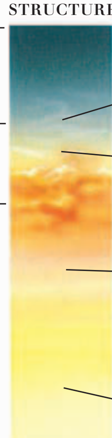


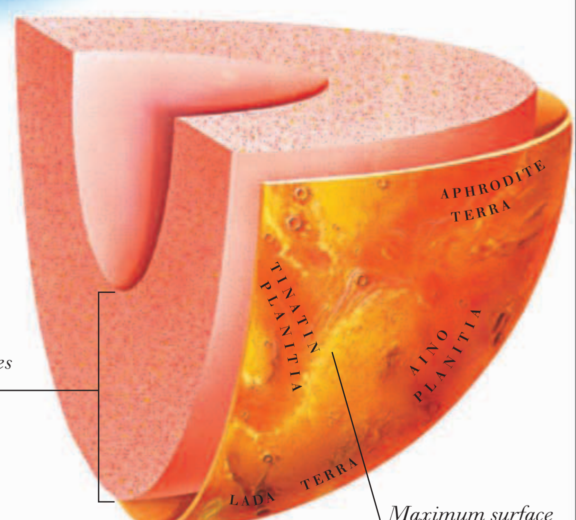
EXTERNAL FEATURES AND INTERNAL STRUCTURE OF VENUS



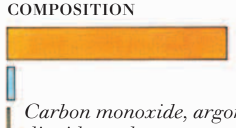
ATMOSPHERE

STRUCTURE

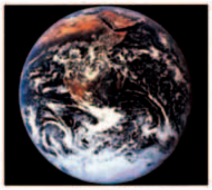




COMPOSITION



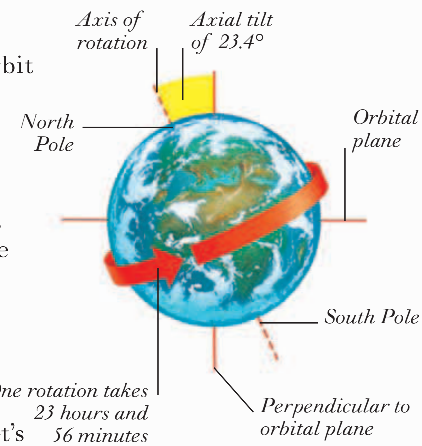
The Earth



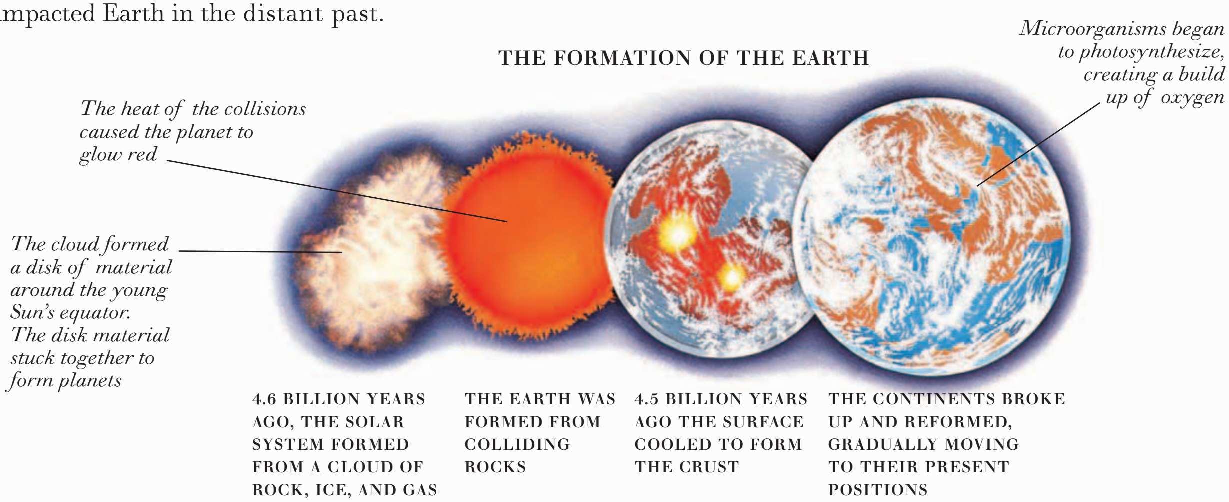
THE EARTH

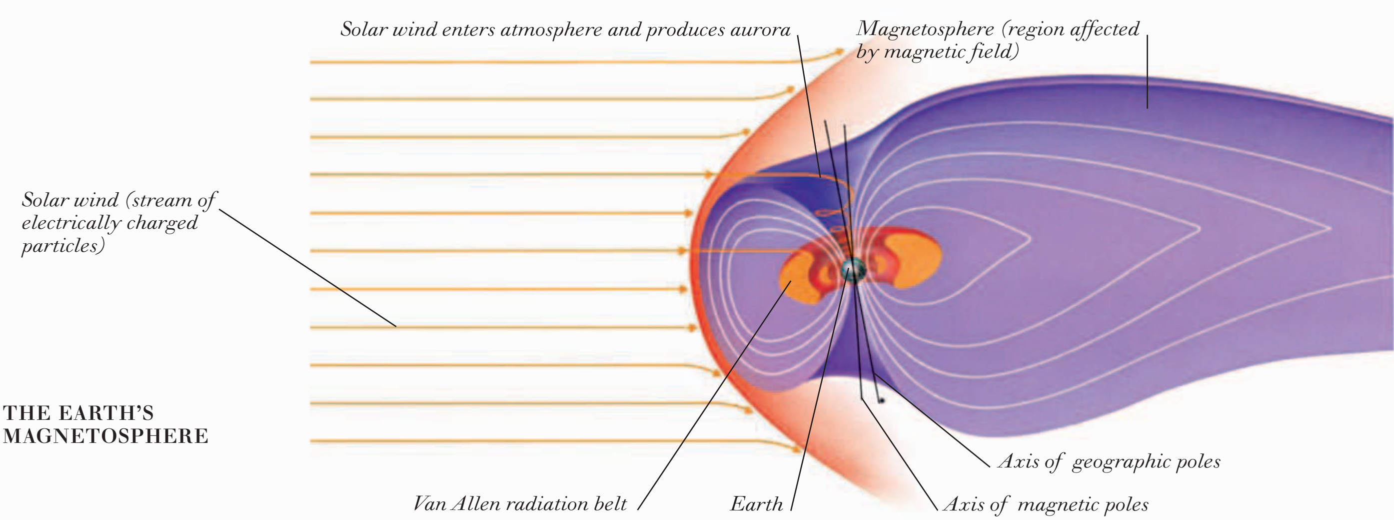
THE EARTH IS THE THIRD of the eight planets that orbit the Sun. It is the largest and densest rocky planet, and the only one known to support life. About 70 percent of the Earth's surface is covered by water, which is not found in liquid form on the surface of any other planet. There are four main layers: the inner core, the outer core, the mantle, and the crust. At the heart of the planet the solid inner core has a temperature of about 11,900°F (6,600°C). The heat from this inner core causes material in the molten outer core and mantle to circulate in convection currents. It is thought that these convection currents generate the Earth's magnetic field, which extends into space as the magnetosphere. The Earth's atmosphere helps screen out some of the harmful radiation from the Sun, stops most meteoroids from reaching the planet's surface, and traps enough heat to prevent extremes of cold. The Earth has one natural satellite, the Moon, which is thought to have formed when a huge asteroid impacted Earth in the distant past.

TILT AND ROTATION OF THE EARTH



THE FORMATION OF THE EARTH

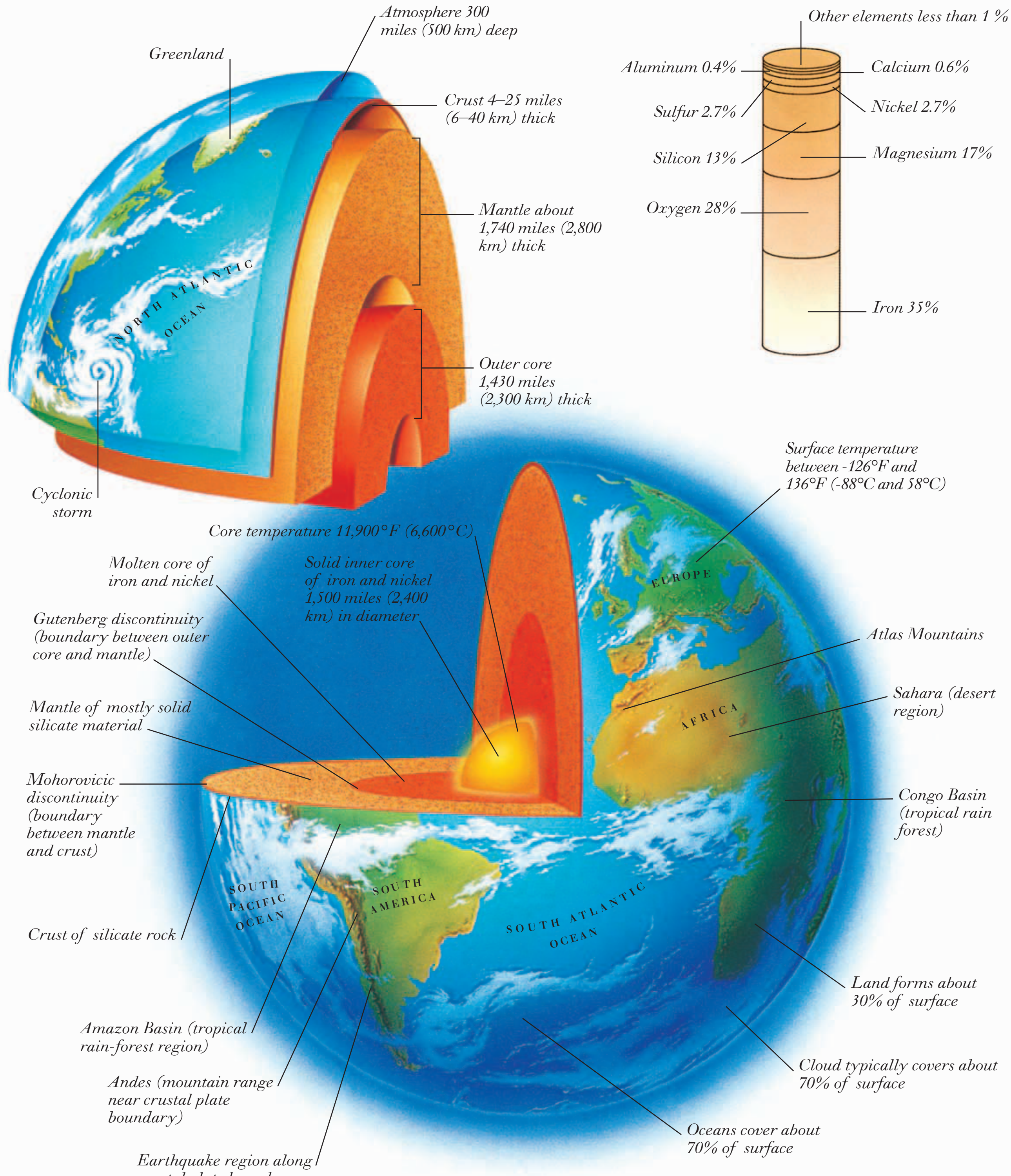




THE EARTH'S MAGNETOSPHERE

EXTERNAL FEATURES AND INTERNAL STRUCTURE OF THE EARTH

COMPOSITION OF THE EARTH

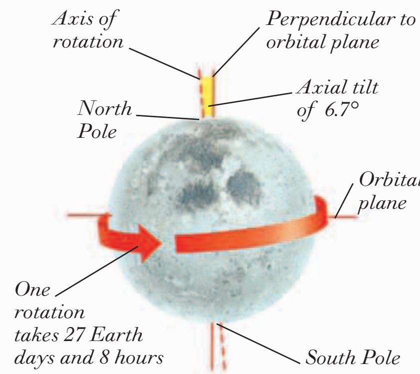


The Moon

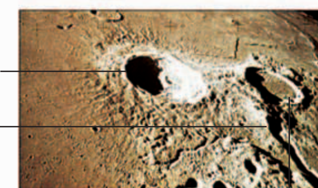
THE MOON FROM EARTH

THE MOON IS THE EARTH'S only natural satellite. It is relatively large for a moon, with a diameter of about 2,155 miles (3,470 km)—just over a quarter that of the Earth. The Moon takes the same time to rotate on its axis as it takes to orbit the Earth (27.3 days), and so the same side (the near side) always faces us. However, the amount of the surface we can see—the phase of the Moon—depends on how much of the near side is in sunlight. The Moon is dry and barren, with negligible atmosphere and water. It consists mainly of solid rock, although its core may contain molten rock or iron. The surface is dusty, with highlands covered in craters caused by meteorite impacts, and lowlands in which large craters have been filled by solidified lava to form dark areas called maria or "seas." Maria occur mainly on the near side, which has a thinner crust than the far side. Many of the craters are rimmed by mountain ranges that form the crater walls and can be thousands of feet high.

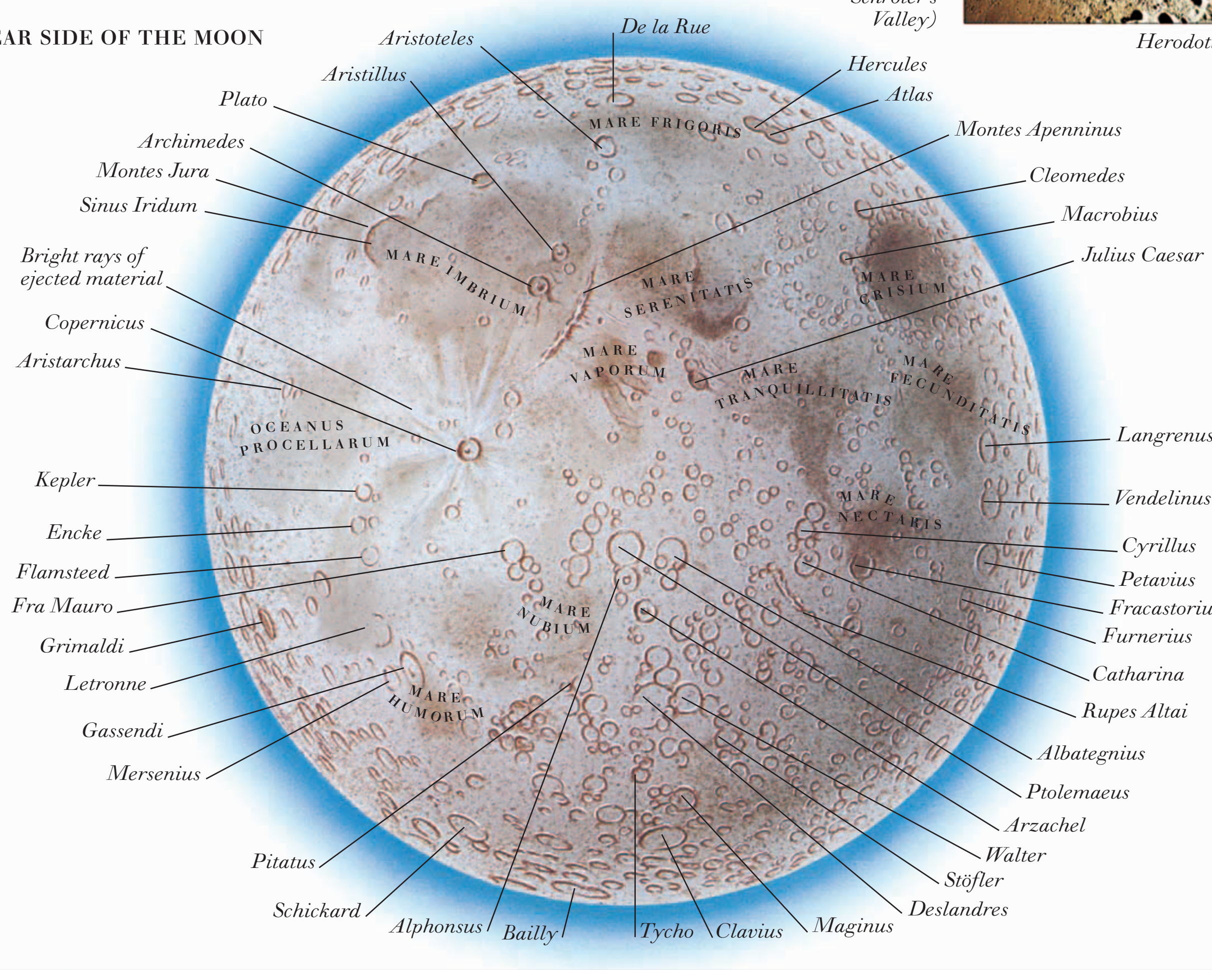
TILT AND ROTATION OF THE MOON



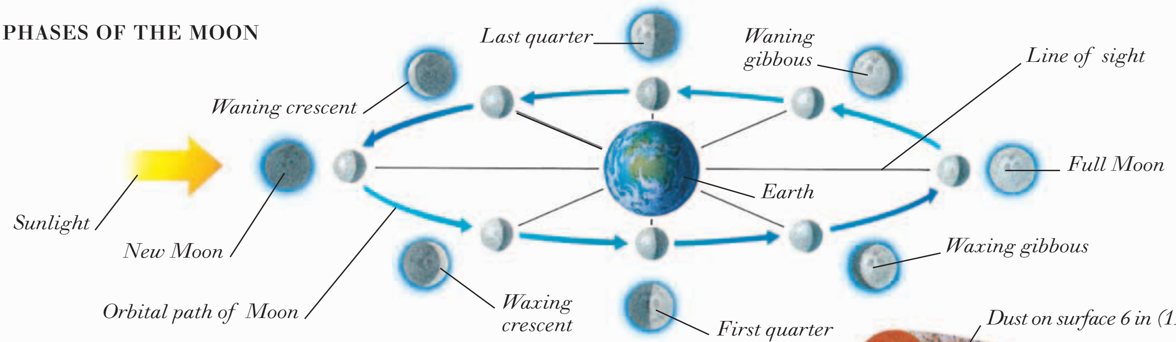
CRATERS ON OCEANUS PROCELLARUM



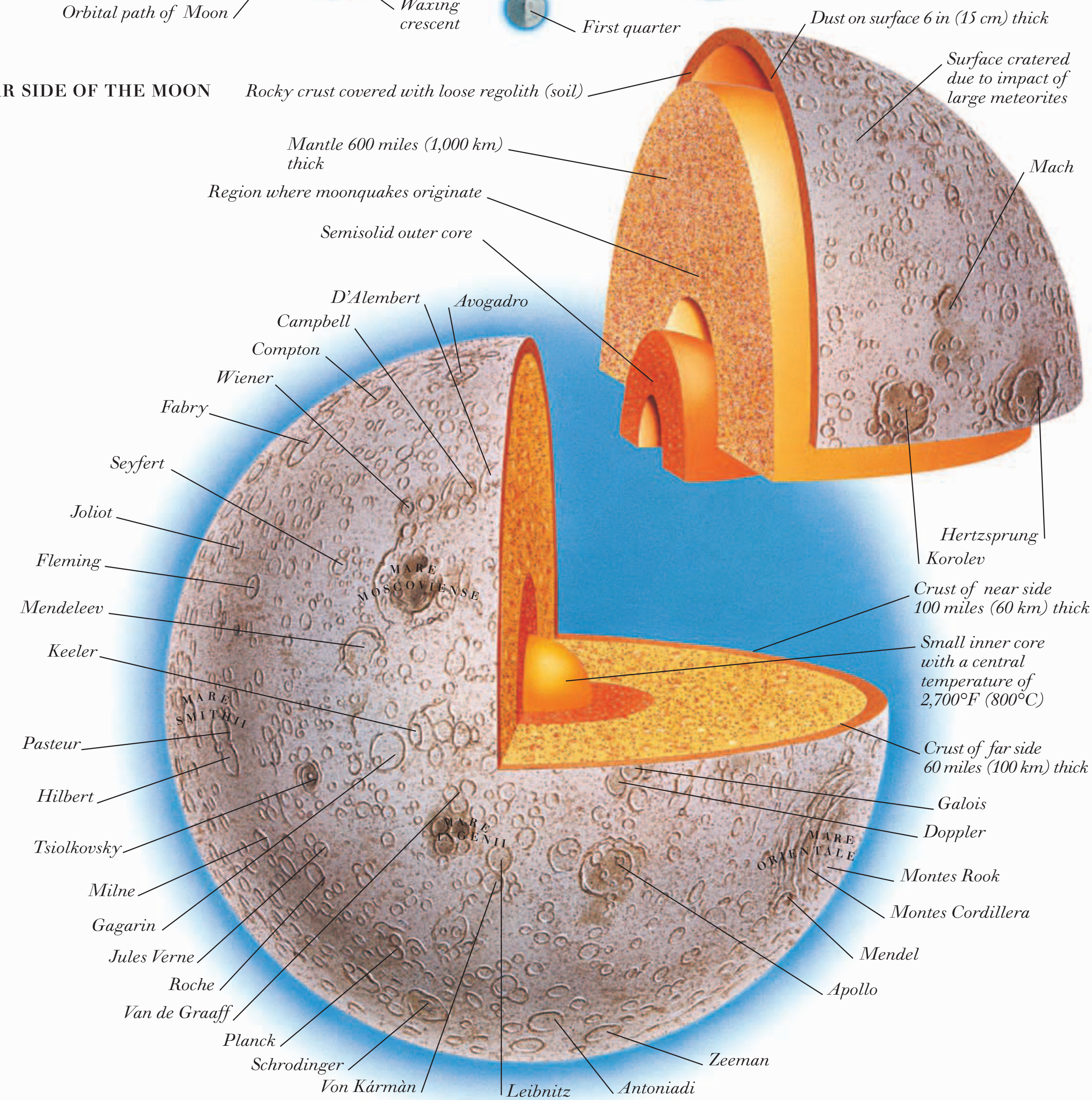
NEAR SIDE OF THE MOON



PHASES OF THE MOON



FAR SIDE OF THE MOON

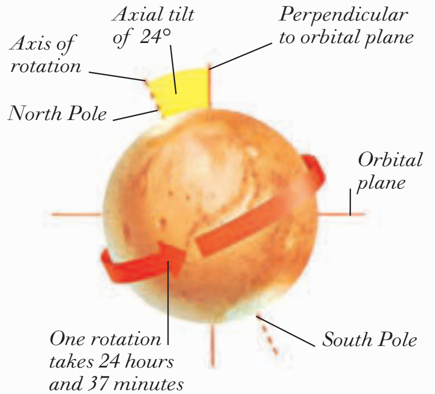


Mars

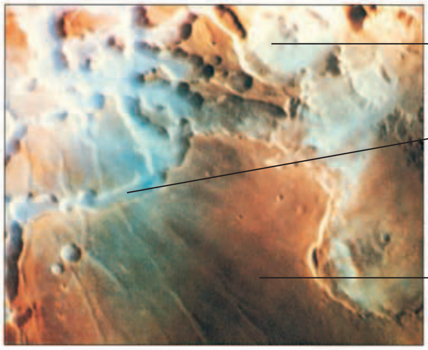
MARS

MARS, KNOWN AS THE RED PLANET, is the fourth planet from the Sun and the outermost rocky planet. In the 19th century, astronomers first observed what were thought to be signs of life on Mars. These signs included apparent canal-like lines on the surface, and dark patches that were thought to be vegetation. It is now known that the "canals" are an optical illusion, and the dark patches are areas where the red dust that covers most of the planet has been blown away. The fine dust particles are often whipped up by winds into dust storms that occasionally obscure almost all the surface. Residual fine dust in the atmosphere gives the Martian sky a pinkish hue. The northern hemisphere of Mars has many large plains formed of solidified volcanic lava, whereas the southern hemisphere has many craters and large impact basins. There are also several huge, extinct volcanoes, including Olympus Mons, which, at 370 miles (600 km) across and 15 miles (25 km) high, is the largest known volcano in the solar system. The surface also has many canyons and branching channels. The canyons were formed by movements of the surface crust, but the channels are thought to have been formed by flowing water that has now dried up. The Martian atmosphere is much thinner than Earth's, with only a few clouds and morning mists. Mars has two tiny, irregularly shaped moons called Phobos and Deimos. Their small size indicates that they may be asteroids that have been captured by the gravity of Mars.

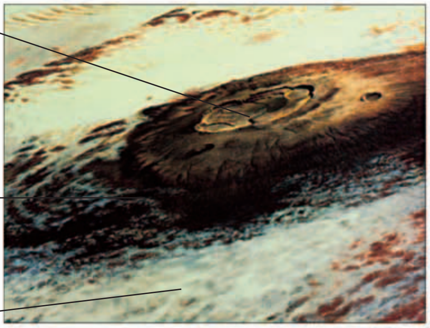
TILT AND ROTATION OF MARS



SURFACE FEATURES OF MARS

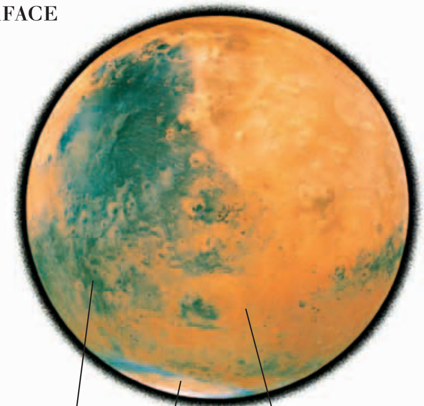


NOCTIS LABYRINTHUS (CANYON SYSTEM)



OLYMPUS MONS (EXTINCT SHIELD VOLCANO)

THE SURFACE OF MARS

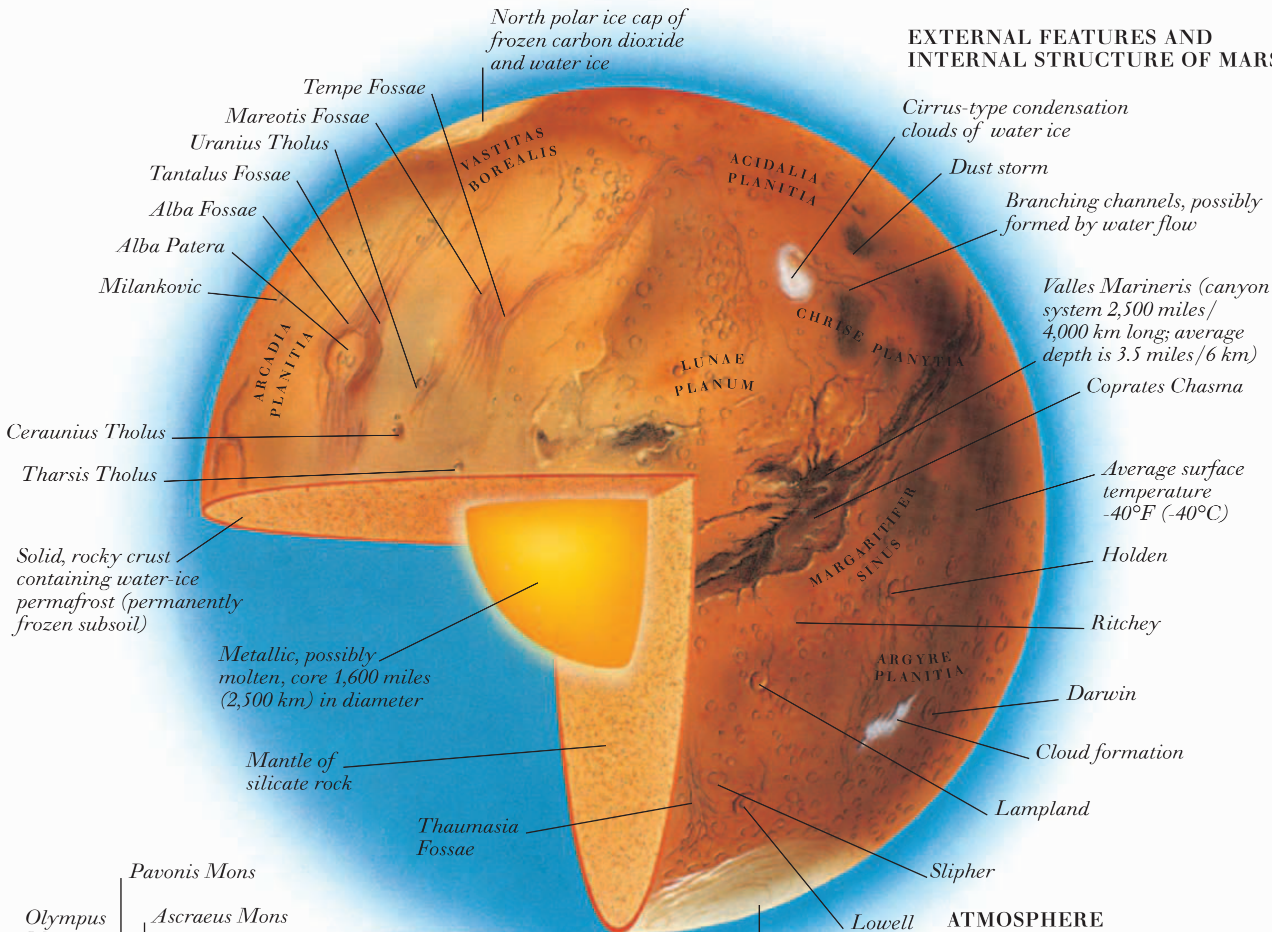


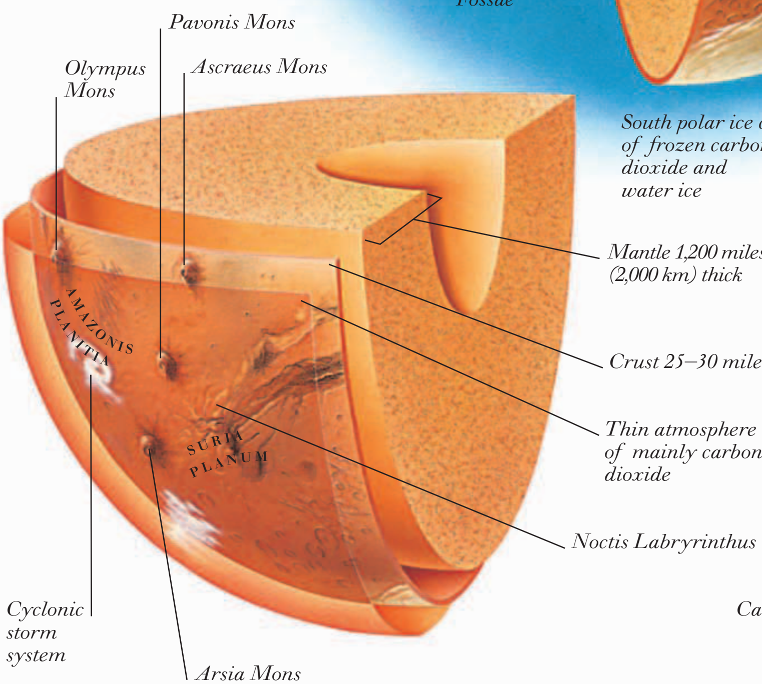
MOONS OF MARS

PHOBOS
Average diameter: 14 miles
Average distance from planet: 5,800 miles

DEIMOS
Average diameter: 8 miles
Average distance from planet: 14,600 miles

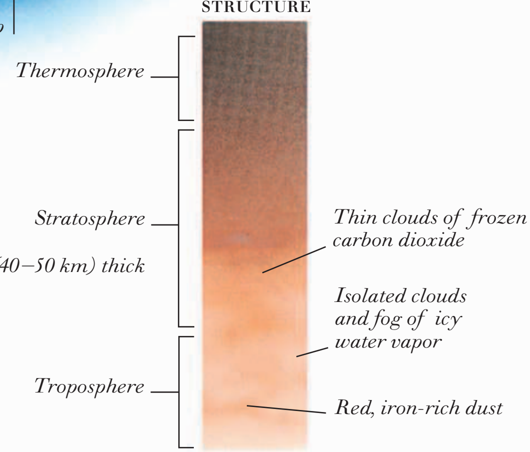
EXTERNAL FEATURES AND INTERNAL STRUCTURE OF MARS



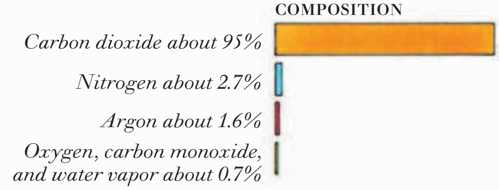


ATMOSPHERE

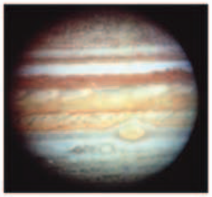
STRUCTURE



COMPOSITION



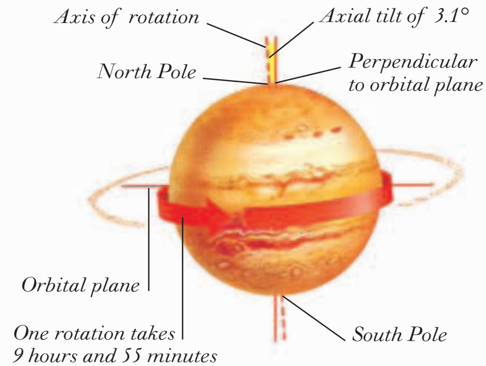
Jupiter



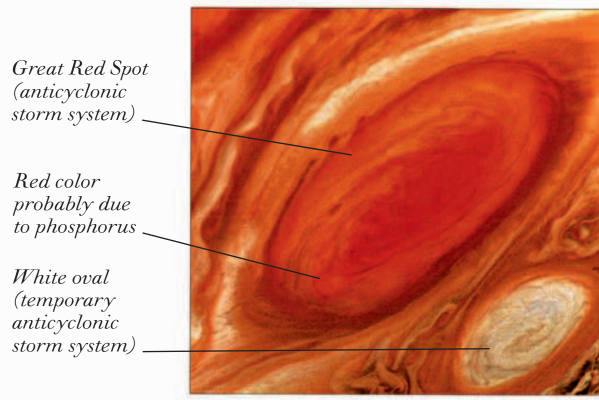
JUPITER

JUPITER IS THE FIFTH PLANET from the Sun and the innermost of the four giant planets. It is the largest and the most massive planet, with a diameter about 11 times that of the Earth and a mass about 2.5 times the combined mass of the seven other planets. Jupiter is thought to have a small rocky core surrounded by an inner mantle of metallic hydrogen (liquid hydrogen that acts like a metal). Outside the inner mantle is an outer mantle of liquid hydrogen and helium that merges into the gaseous atmosphere. Jupiter's rapid rate of rotation causes the clouds in its atmosphere to form belts and zones that encircle the planet parallel to the equator. Belts are dark, low-lying, relatively warm cloud layers, and zones are bright, high-altitude, cooler cloud layers. Within the belts and zones, turbulence causes the formation of cloud features such as white ovals and red spots, both of which are huge storm systems. The most prominent cloud feature is a storm called the Great Red Spot, which consists of a spiraling column of clouds three times wider than the Earth that rises about five miles (8 km) above the upper cloud layer. Jupiter has a thin, faint, main ring, inside which is a tenuous halo ring of tiny particles. Beyond the main ring's outer edge is a broad and faint two-part gossamer ring. There are 63 known Jovian moons. The four largest moons (called the Galileans) are Ganymede, Callisto, Io, and Europa. Ganymede and Callisto are cratered and icy. Europa is smooth and icy and is thought to have a subsurface water ocean. Io is covered in bright red, orange, and yellow splotches. This coloring is caused by sulfurous material from active volcanoes that shoot plumes of lava hundreds of miles above the surface.

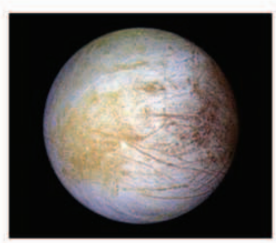
TILT AND ROTATION OF JUPITER



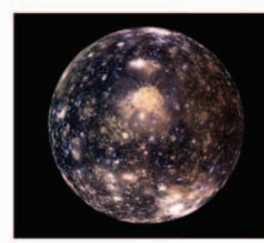
GREAT RED SPOT AND WHITE OVAL



GALILEAN MOONS OF JUPITER

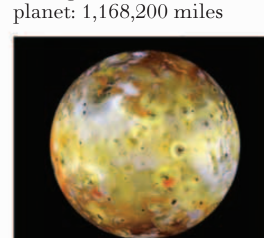


EUROPA
Diameter: 1,950 miles
Average distance from planet: 416,900 miles



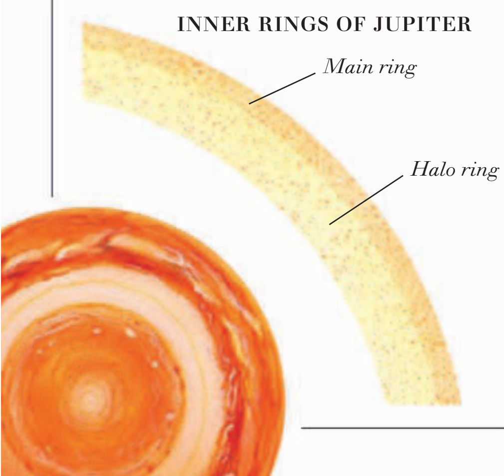
CALLISTO
Diameter: 2,983 miles
Average distance from planet: 1,168,200 miles

GANYMEDE
Diameter: 3,270 miles
Average distance from planet: 664,900 miles

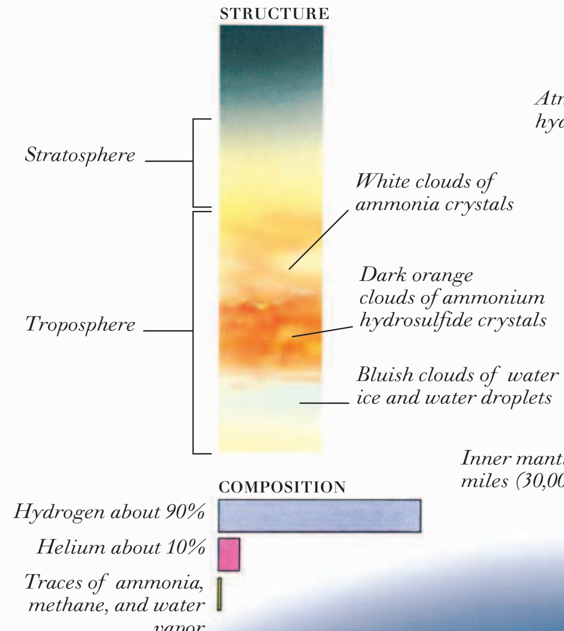


IO
Diameter: 2,263 miles
Average distance from planet: 262,100 miles

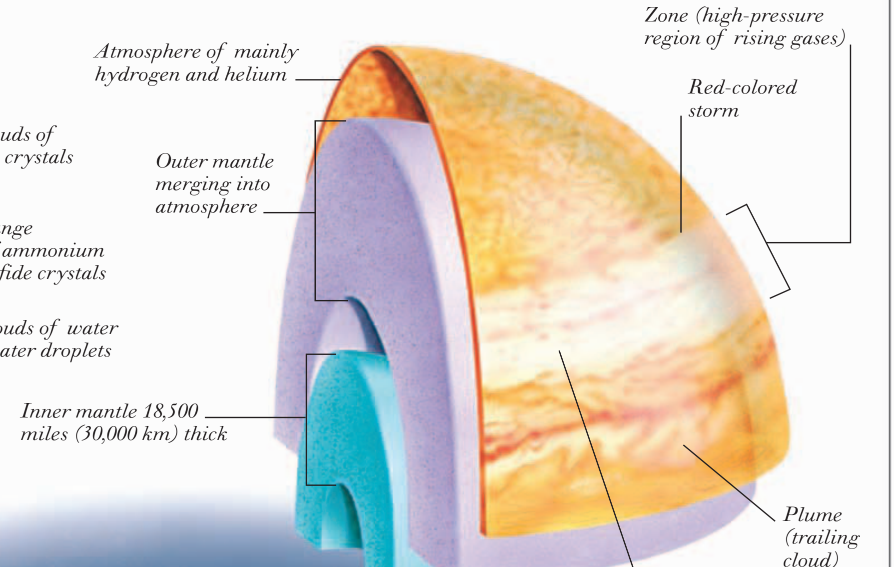
INNER RINGS OF JUPITER

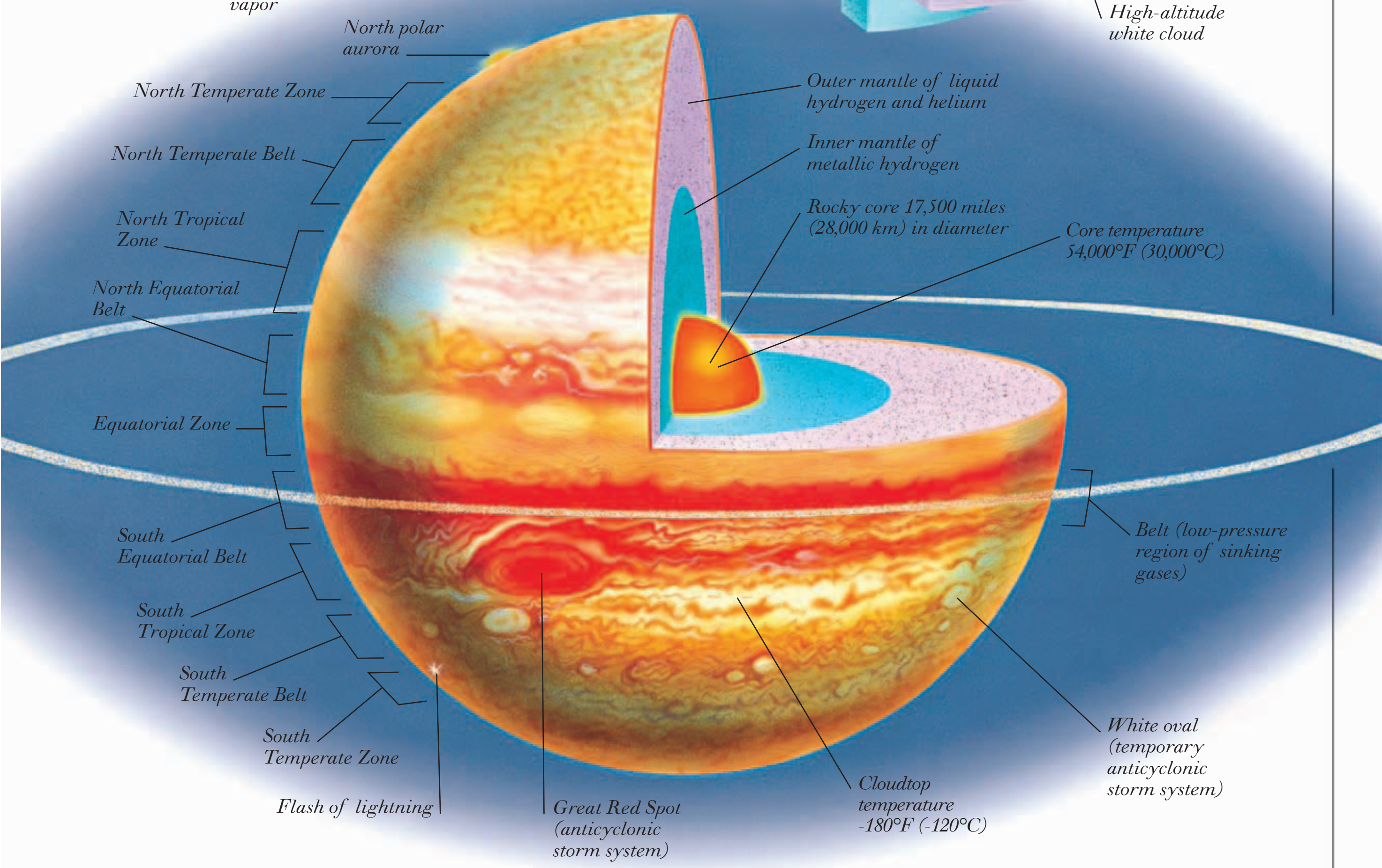


ATMOSPHERE



EXTERNAL FEATURES AND INTERNAL STRUCTURE OF JUPITER



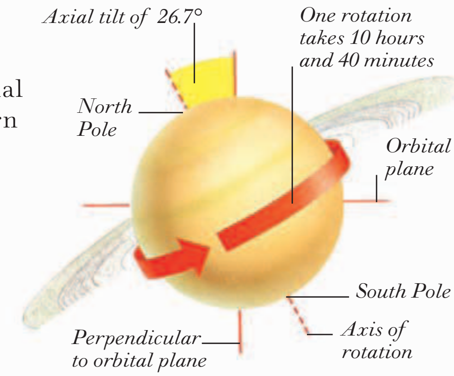


Saturn

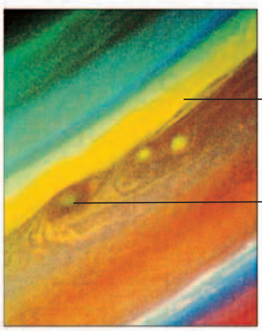
FALSE-COLOR IMAGE OF SATURN

SATURN IS THE SIXTH PLANET from the Sun. It is a gas giant almost as big as Jupiter, with an equatorial diameter of about 75,000 miles (120,500 km). Saturn is thought to consist of a small core of rock and ice surrounded by an inner mantle of metallic hydrogen (liquid hydrogen that acts like a metal). Outside the inner mantle is an outer mantle of liquid hydrogen that merges into a gaseous atmosphere. Saturn's clouds form belts and zones similar to those on Jupiter, but obscured by overlying haze. Storms and eddies, seen as red or white ovals, occur in the clouds. Saturn has an extremely thin but wide system of rings that is about half a mile (1 km) thick but extends outward to about 260,000 miles (420,000 km) from the planet's surface. The main rings comprise thousands of narrow ringlets, each made of icy rock lumps that range in size from tiny particles to chunks several yards across. The D, E, and G rings are very faint, the F ring is brighter, and the A, B, and C rings are bright enough to be seen from Earth with binoculars. In 2009, a huge dust ring was discovered 4 million miles (6 million km) beyond the main system. Saturn has more than 60 known moons, some of which orbit inside the rings and are thought to exert a gravitational influence on the shapes of the rings. Unusually, seven of the moons are co-orbital—they share an orbit with another moon. Astronomers believe that such co-orbital moons may have originated from a single satellite that broke up.

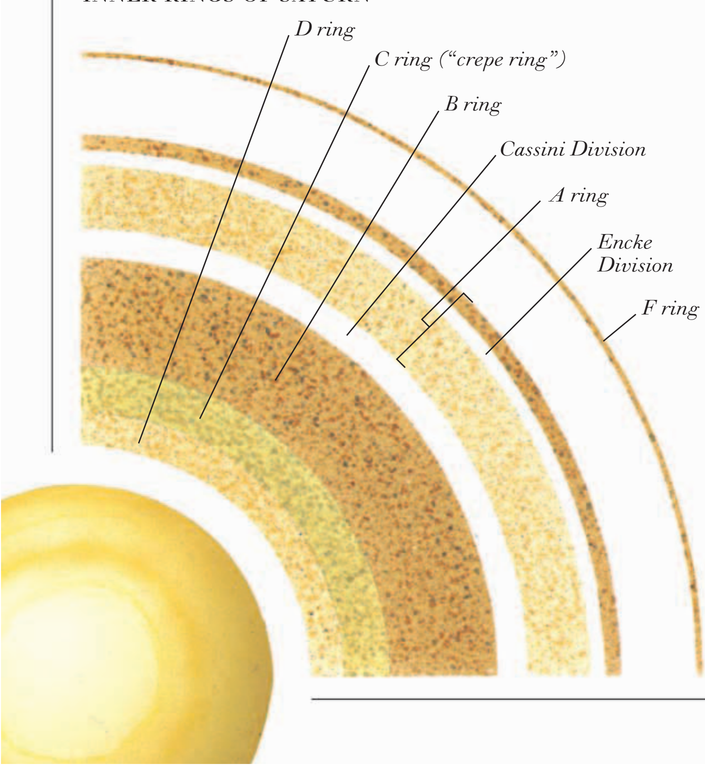
TILT AND ROTATION OF SATURN



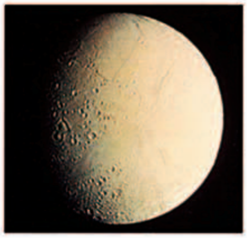
FALSE-COLOR IMAGE OF SATURN'S CLOUD FEATURES



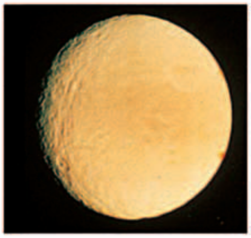
INNER RINGS OF SATURN



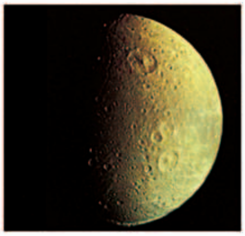
MOONS OF SATURN



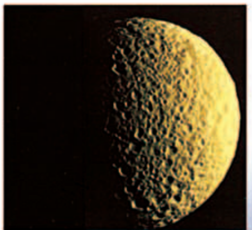
ENCELADUS
Diameter: 509 miles
Average distance from planet: 148,000 miles



TETHYS
Diameter: 652 miles
Average distance from planet: 183,000 miles

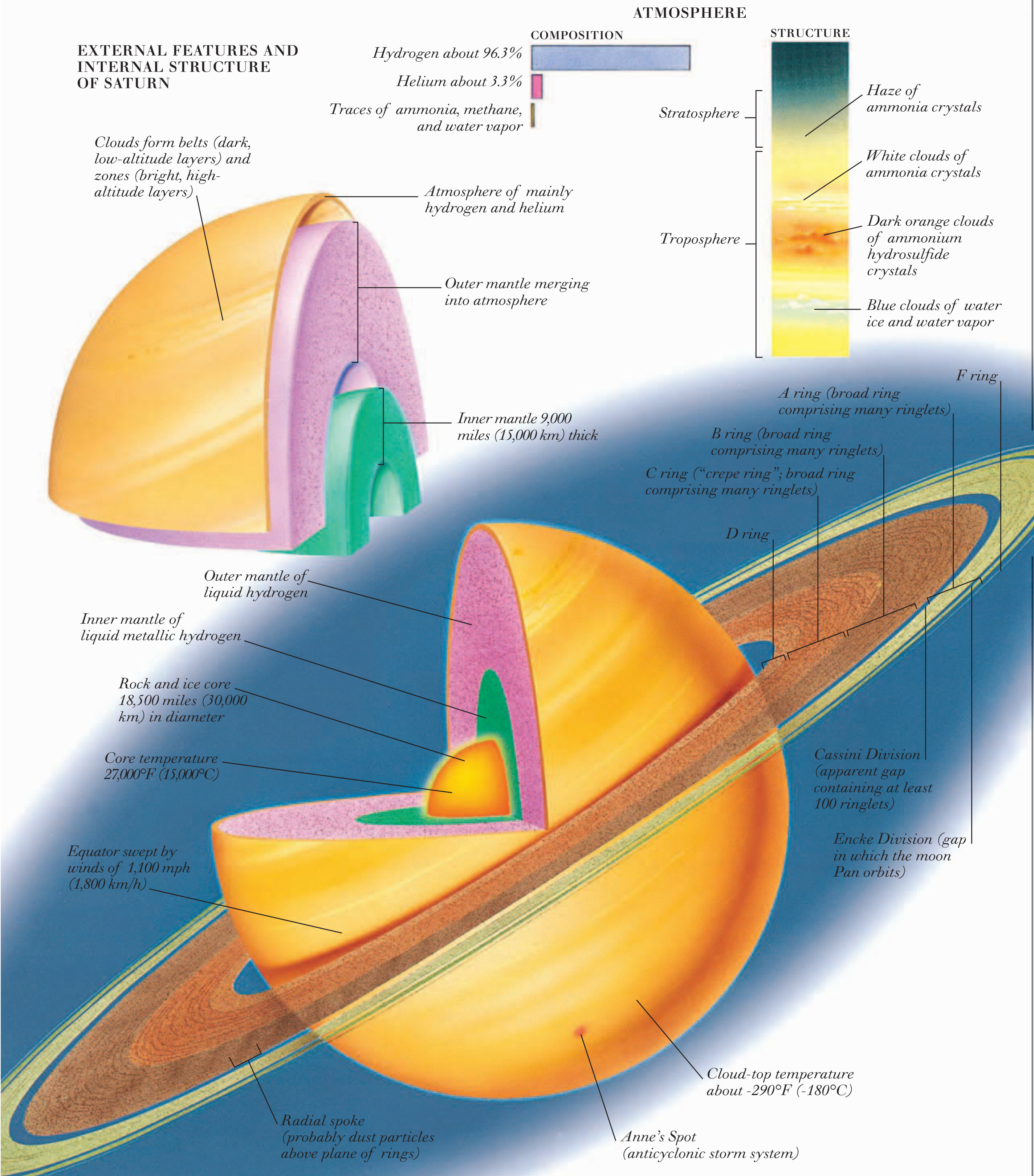


DIONE
Diameter: 695 miles
Average distance from planet: 254,000 miles

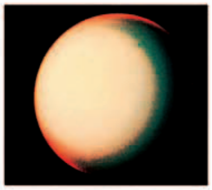


MIMAS
Diameter: 247 miles
Average distance from planet: 115,600 miles

EXTERNAL FEATURES AND INTERNAL STRUCTURE OF SATURN



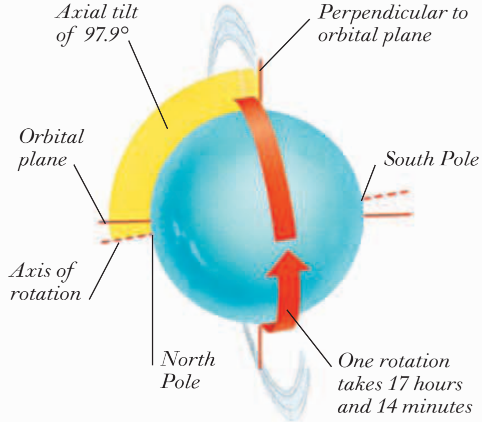
Uranus



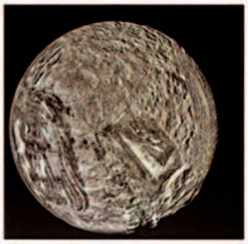
FALSE-COLOR IMAGE OF URANUS

URANUS IS THE SEVENTH PLANET from the Sun and the third largest, with a diameter of about 32,000 miles (51,000 km). It is thought to consist of a dense mixture of different types of ice and gas around a solid core. Its atmosphere contains traces of methane, giving the planet a blue-green hue, and the temperature at the cloud tops is about -350°F (-210°C). Uranus is the most featureless planet to have been closely observed: only a few icy clouds of methane have been seen so far. Uranus is unique among the planets in that its axis of rotation lies close to its orbital plane. As a result of its strongly tilted rotational axis, Uranus rolls on its side along its orbital path around the Sun, whereas other planets spin more or less upright. Uranus is encircled by main rings that consist of rocks interspersed with dust lanes and two distant outer rings made of dust. The rings contain some of the darkest matter in the solar system and are extremely narrow, making them difficult to detect: most of them are less than 6 miles (10 km) wide, whereas most of Saturn's rings are thousands of miles in width. There are 27 known Uranian moons, all of which are icy and most of which are farther out than the rings. The 13 inner moons are small and dark, with diameters of less than 100 miles (160 km), and the five major moons are between about 290 and 1,000 miles (470 and 1,600 km) in diameter. The major moons have a wide variety of surface features. Miranda has the most varied surface, with cratered areas broken up by huge ridges and cliffs 12 miles (20 km) high. Beyond these are nine much more distant moons with diameters less than 90 miles (150 km).

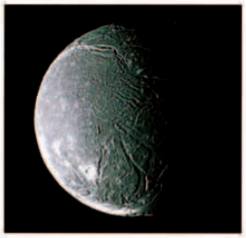
TILT AND ROTATION OF URANUS



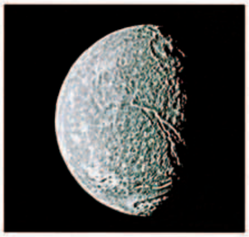
MAJOR MOONS



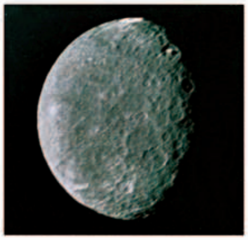
MIRANDA
Diameter: 295 miles
Average distance from planet: 80,700 miles



ARIEL
Diameter: 720 miles
Average distance from planet: 118,800 miles



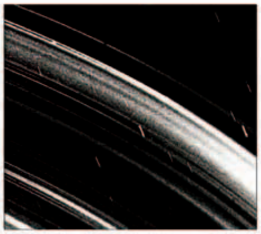
TITANIA
Diameter: 981 miles
Average distance from planet: 270,900 miles



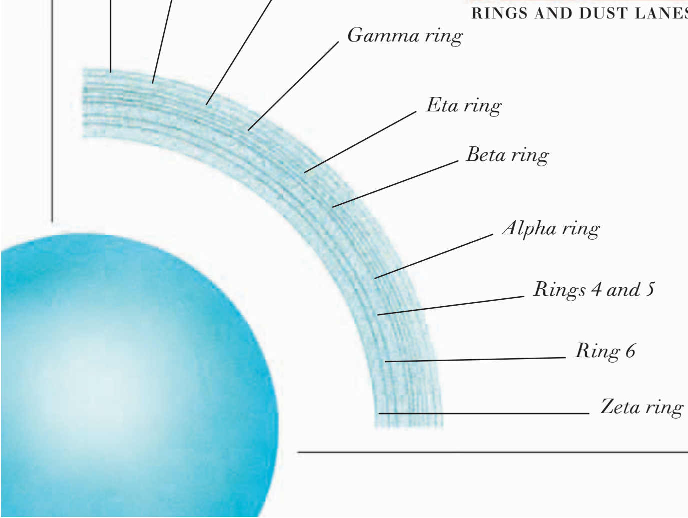
UMBRIEL
Diameter: 726 miles
Average distance from planet: 165,500 miles

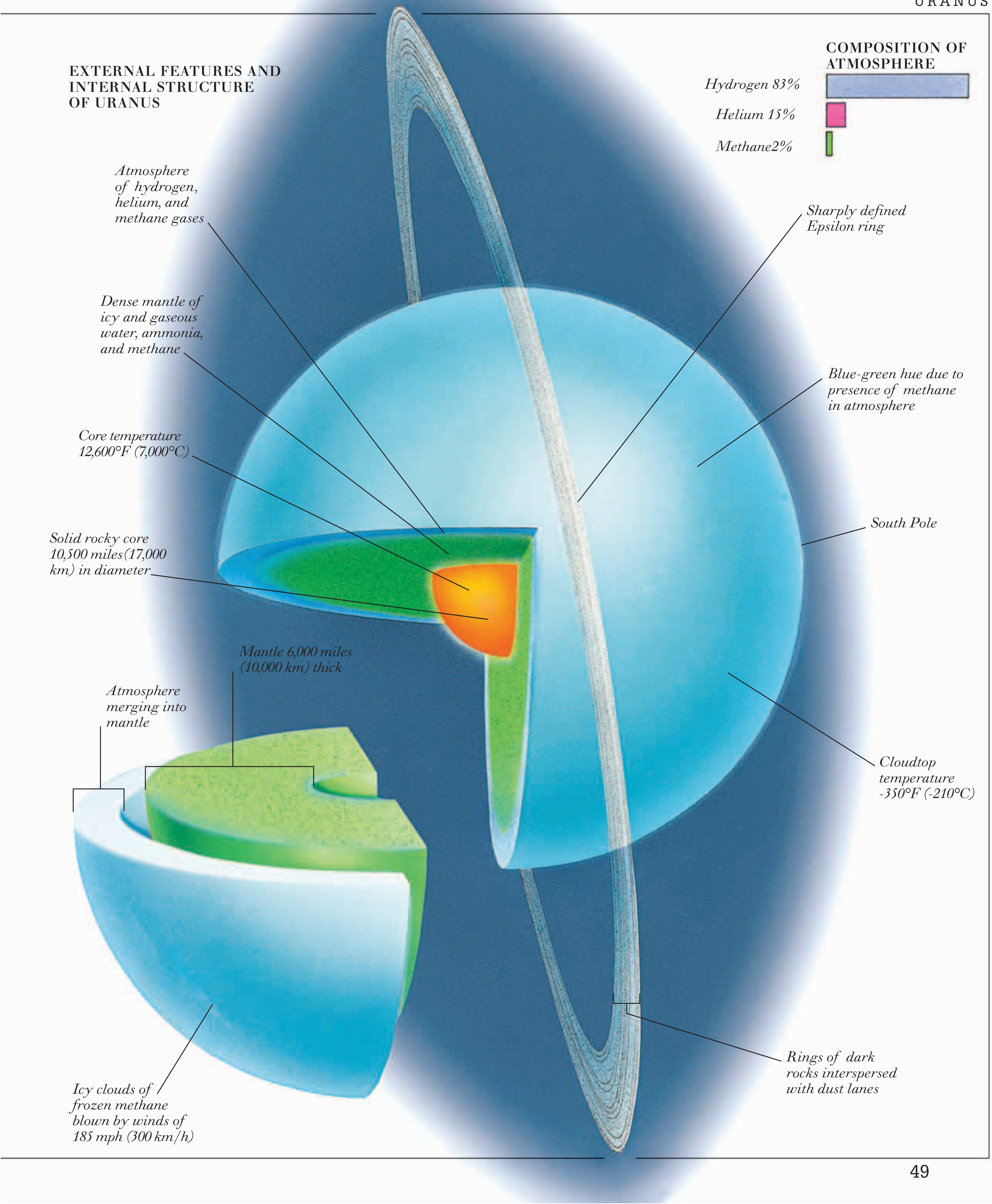
OBERON
Diameter: 946 miles
Average distance from planet: 362,000 miles

RINGS OF URANUS

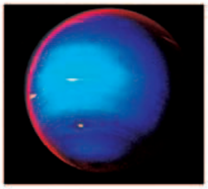


RINGS AND DUST LANES




EXTERNAL FEATURES AND INTERNAL STRUCTURE OF URANUS
COMPOSITION OF ATMOSPHERE
Hydrogen 83%
Helium 15%
Methane2%
Atmosphere of hydrogen, helium, and methane gases
Dense mantle of icy and gaseous water, ammonia, and methane
Core temperature 12,600°F (7,000°C)
Solid rocky core 10,500 miles(17,000 km) in diameter
Mantle 6,000 miles (10,000 km) thick
Atmosphere merging into mantle
Icy clouds of frozen methane blown by winds of 185 mph (300 km/h)
Sharply defined Epsilon ring
Blue-green hue due to presence of methane in atmosphere
South Pole
Cloudtop temperature -350°F (-210°C)
Rings of dark rocks interspersed with dust lanes

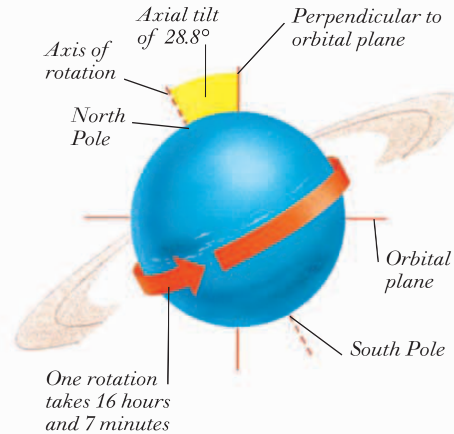
Neptune and Pluto



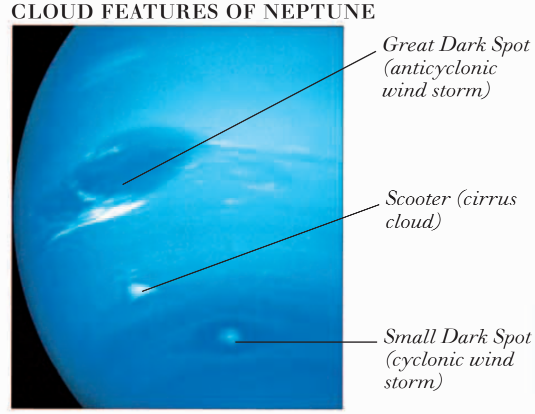
FALSE-COLOR IMAGE OF NEPTUNE

NEPTUNE IS the farthest planet from the Sun, at an average distance of about 2.8 billion miles (4.5 billion km). Neptune is the smallest of the giant planets and is thought to consist of a small rocky core surrounded by a mixture of liquids and gases. Several transient cloud features have been observed in its atmosphere. The largest of these were the Great Dark Spot, which was as wide as the Earth, the Small Dark Spot, and the Scooter. The Great and Small Dark Spots were huge storms that were swept around the planet by winds of about 1,200 miles (2,000 km) per hour. The Scooter was a large area of cirrus cloud. Neptune has six tenuous rings and 13 known moons. Triton is the largest Neptunian moon and the coldest object in the solar system, with a temperature of -390°F (-240°C). Unlike most moons in the solar system, Triton orbits its mother planet in the opposite direction of the planet's rotation. The region extending out from Neptune's orbit is populated by Kuiper Belt objects and dwarf planets. They make a doughnut-shaped belt called the Kuiper Belt. The Kuiper Belt objects are a mix of rock and ice, irregular in shape, and less than 600 miles (1,000 km) across. The larger dwarf planets, which include Pluto, are almost round bodies. Pluto was the first object discovered beyond Neptune and was considered a planet until the dwarf planet category was introduced in 2006. It is made of rock and ice and is 1,365 miles (2,274 km) across. It has three known moons. The largest, Charon, is about half Pluto's size and the two probably had a common origin.

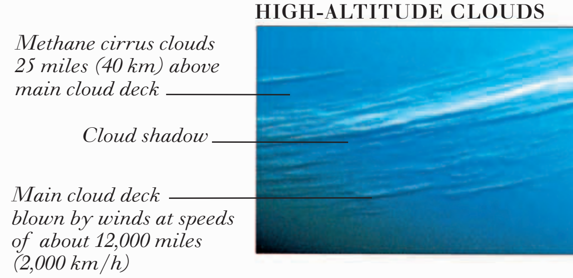
TILT AND ROTATION OF NEPTUNE



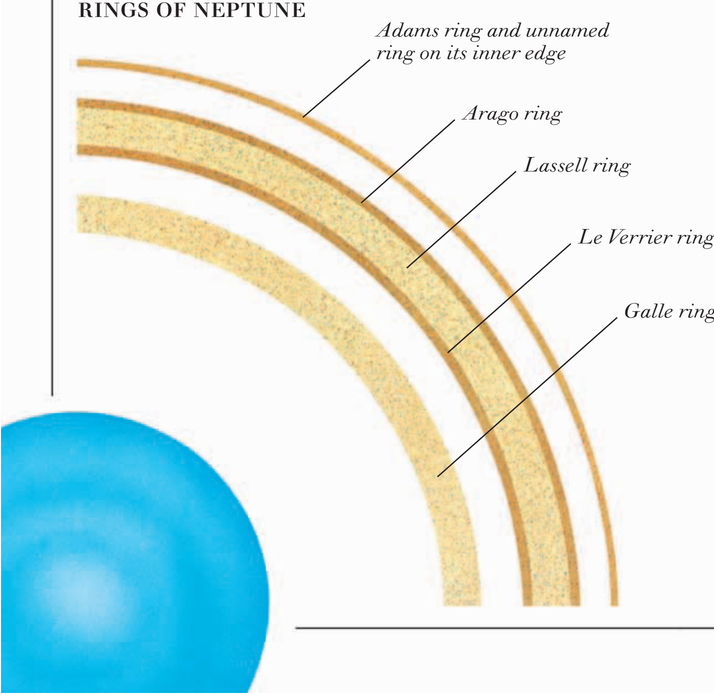
CLOUD FEATURES OF NEPTUNE



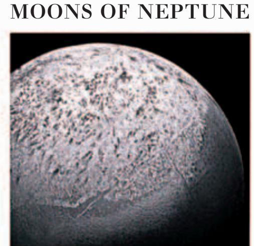
HIGH-ALTITUDE CLOUDS



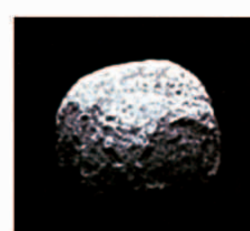
RINGS OF NEPTUNE



MOONS OF NEPTUNE



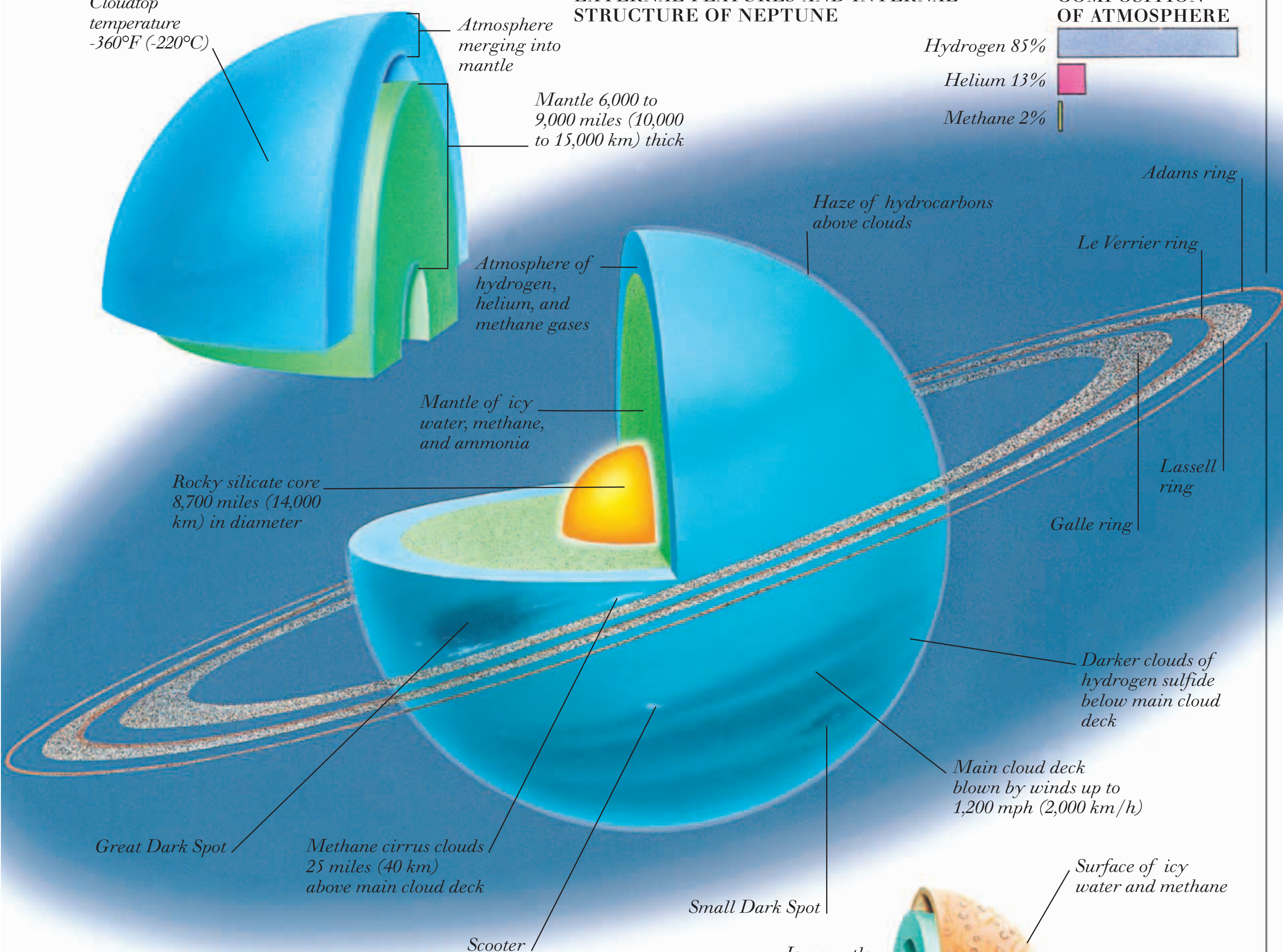
TRITON
Diameter: 1,681 miles
Average distance from planet: 220,500 miles



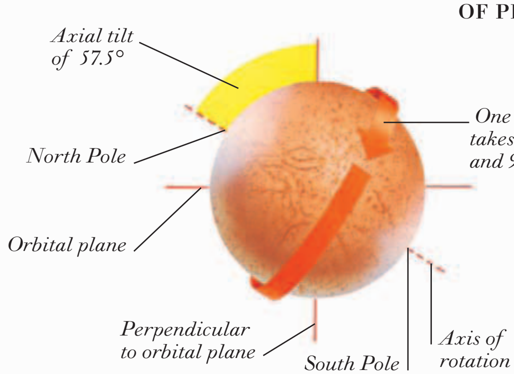
PROTEUS
Diameter: 259 miles
Average distance from planet: 73,100 miles

EXTERNAL FEATURES AND INTERNAL STRUCTURE OF NEPTUNE

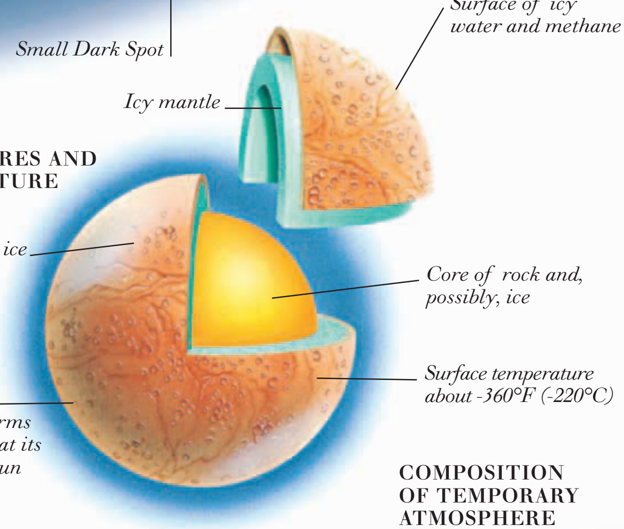
COMPOSITION OF ATMOSPHERE



TILT AND ROTATION OF PLUTO

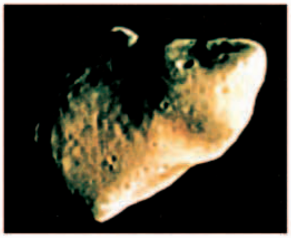


EXTERNAL FEATURES AND INTERNAL STRUCTURE OF PLUTO



COMPOSITION OF TEMPORARY ATMOSPHERE

Asteroids, comets, and meteoroids

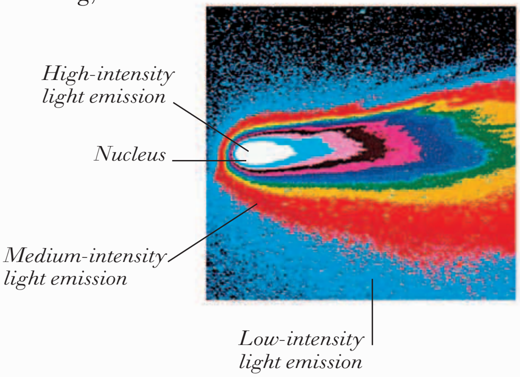


ASTEROID 951 GASPRA

ASTEROIDS, COMETS, AND METEOROIDS are all debris remaining from the nebula from which the solar system formed 4.6 billion years ago. Asteroids are rocky bodies up to about 600 miles (1,000 km) in diameter, although most are much smaller. Most of them orbit the Sun in the asteroid belt, which lies between the orbits of Mars and Jupiter. Cometary nuclei exist in a huge cloud (called the Oort Cloud) that surrounds the planetary part of the solar system. They are made of frozen water and dust and are a few miles in diameter. Occasionally, a comet is deflected from the Oort Cloud on to a long, elliptical path that brings it much closer to the Sun. As the comet approaches the Sun, the cometary nucleus starts to vaporize in the heat, producing both a brightly shining coma (a huge sphere of gas and dust around the nucleus), and a gas tail, and a dust tail. Meteoroids are small chunks of stone or stone and iron, which are fragments of asteroids or comets. Meteoroids range in size from tiny dust particles to objects tens of meters across. If a meteoroid enters the Earth's atmosphere, it is heated by friction and appears as a glowing streak of light called a meteor (also known as a shooting star). Meteor showers occur when the Earth passes through the trail of dust particles left by a comet. Most meteoroids burn up in the atmosphere. The remnants of the few that are large enough to reach the Earth's surface are termed meteorites.

OPTICAL IMAGE OF HALLEY'S COMET

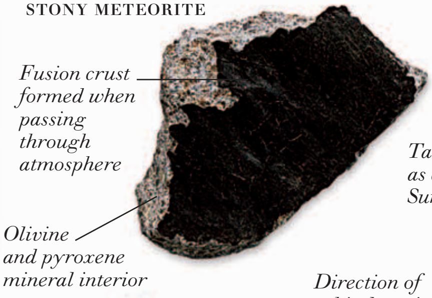
FALSE-COLOR IMAGE OF HALLEY'S COMET



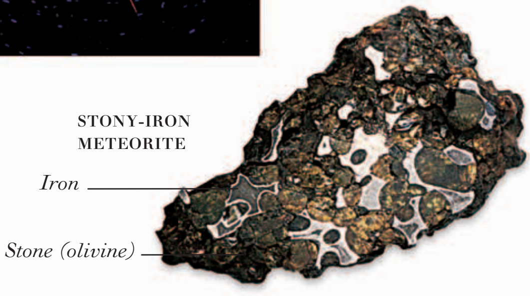
FALSE-COLOR IMAGE OF A LEONID METEOR SHOWER

METEORITES

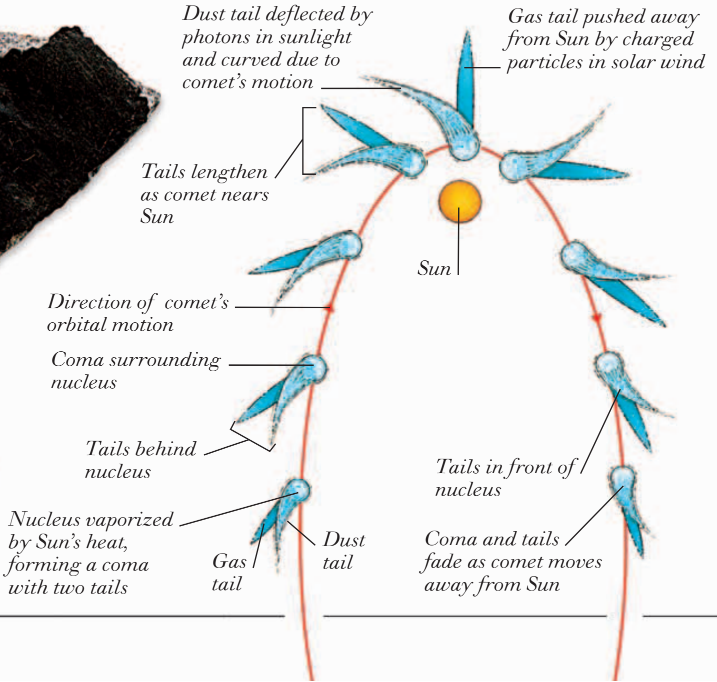
STONY METEORITE



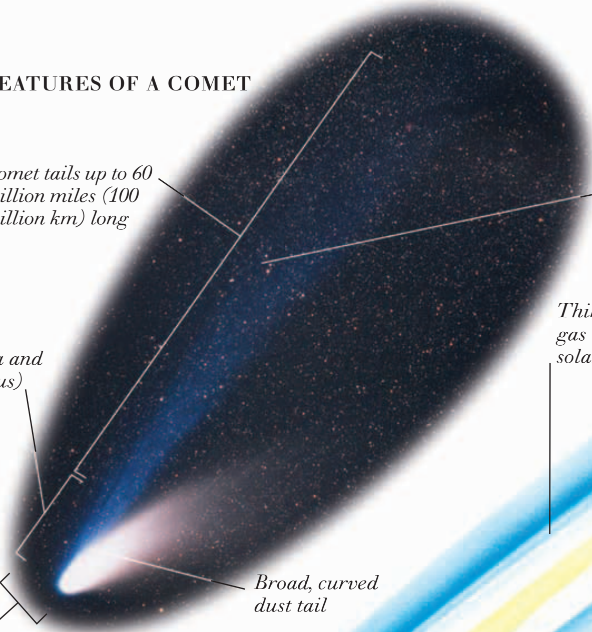
STONY-IRON METEORITE



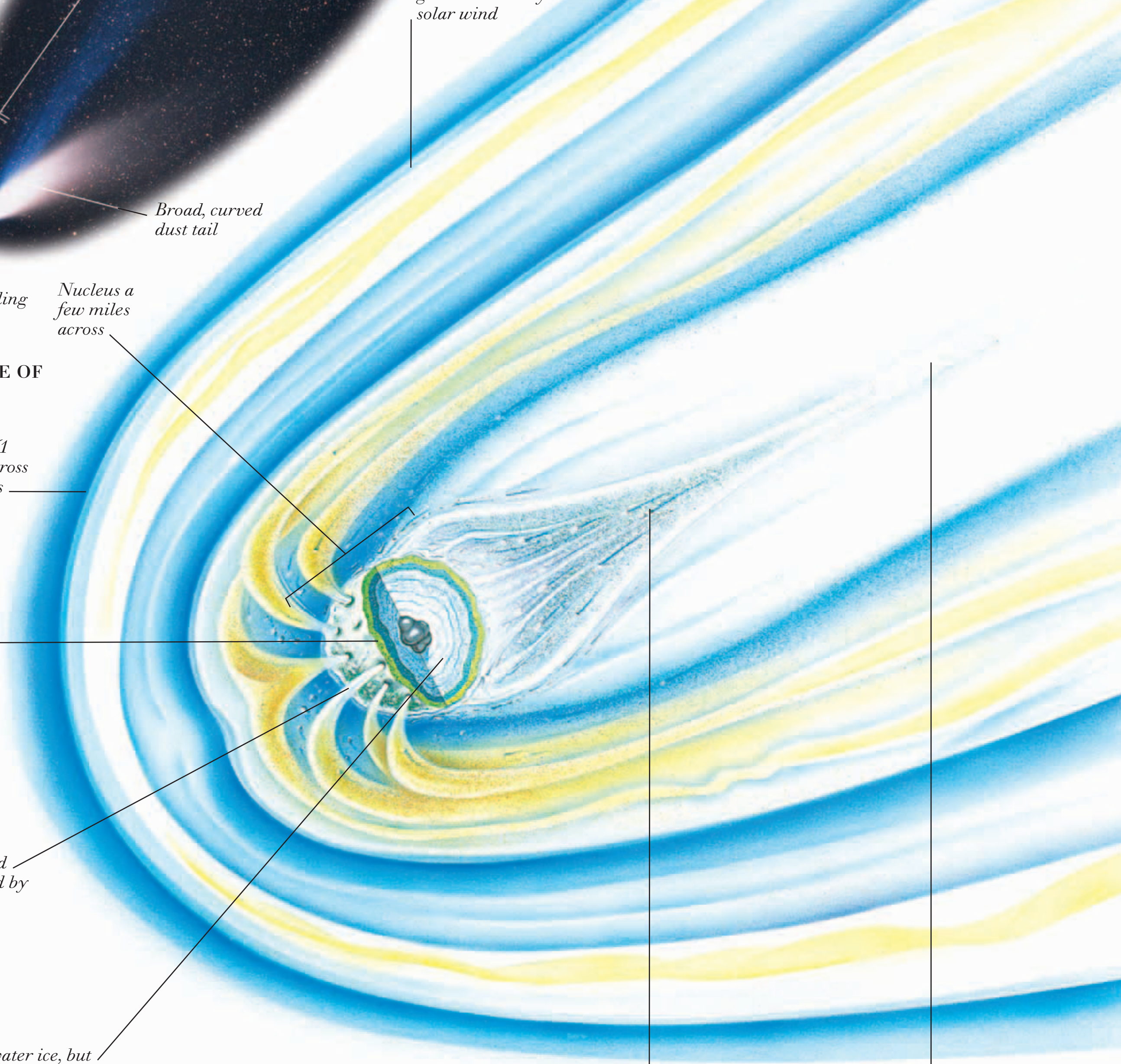
DEVELOPMENT OF COMET TAILS



FEATURES OF A COMET



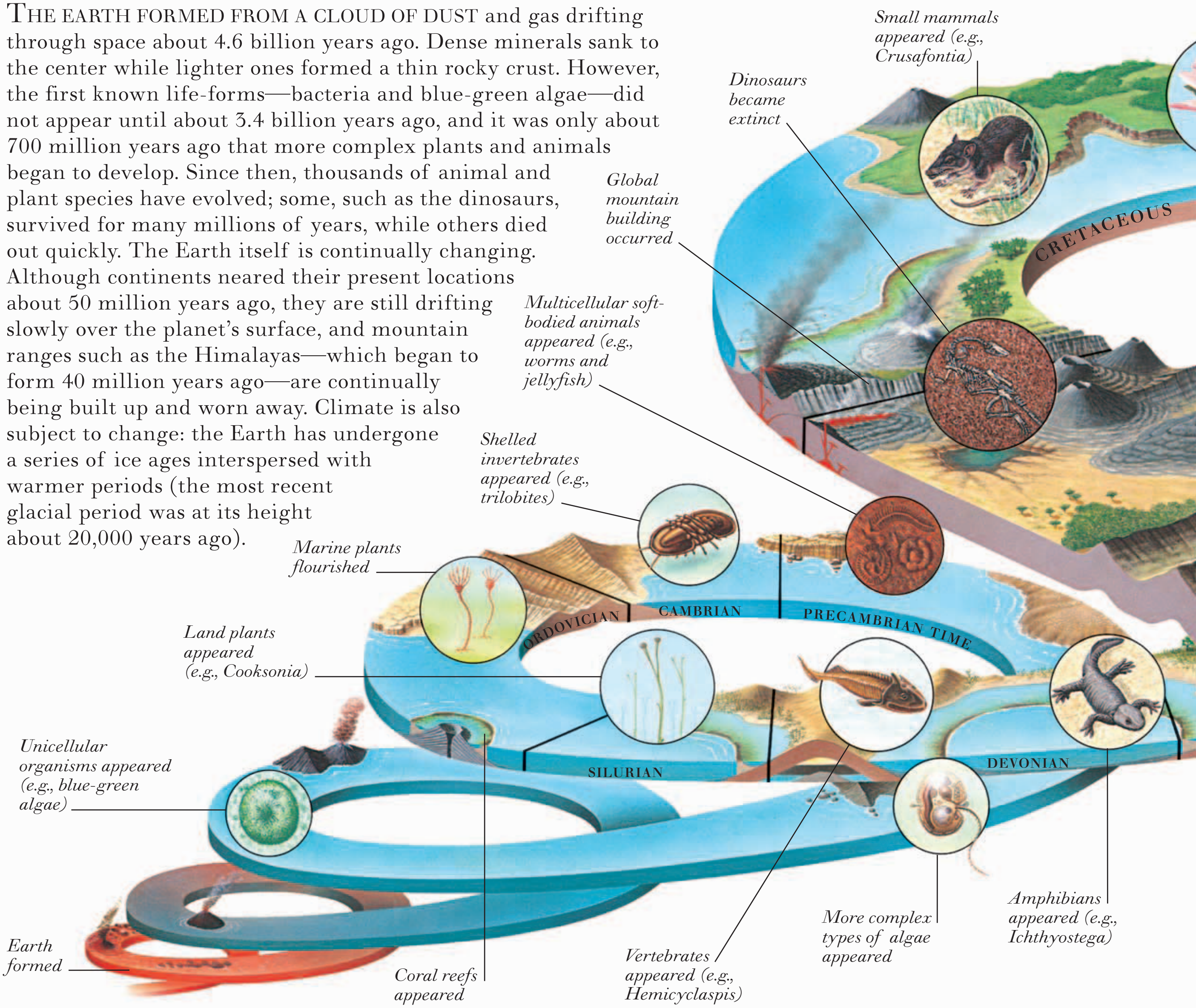
STRUCTURE OF A COMET



Prehistoric Earth

The changing Earth

THE EARTH FORMED FROM A CLOUD OF DUST and gas drifting through space about 4.6 billion years ago. Dense minerals sank to the center while lighter ones formed a thin rocky crust. However, the first known life-forms—bacteria and blue-green algae—did not appear until about 3.4 billion years ago, and it was only about 700 million years ago that more complex plants and animals began to develop. Since then, thousands of animal and plant species have evolved; some, such as the dinosaurs, survived for many millions of years, while others died out quickly. The Earth itself is continually changing. Although continents neared their present locations about 50 million years ago, they are still drifting slowly over the planet's surface, and mountain ranges such as the Himalayas—which began to form 40 million years ago—are continually being built up and worn away. Climate is also subject to change: the Earth has undergone a series of ice ages interspersed with warmer periods (the most recent glacial period was at its height about 20,000 years ago).

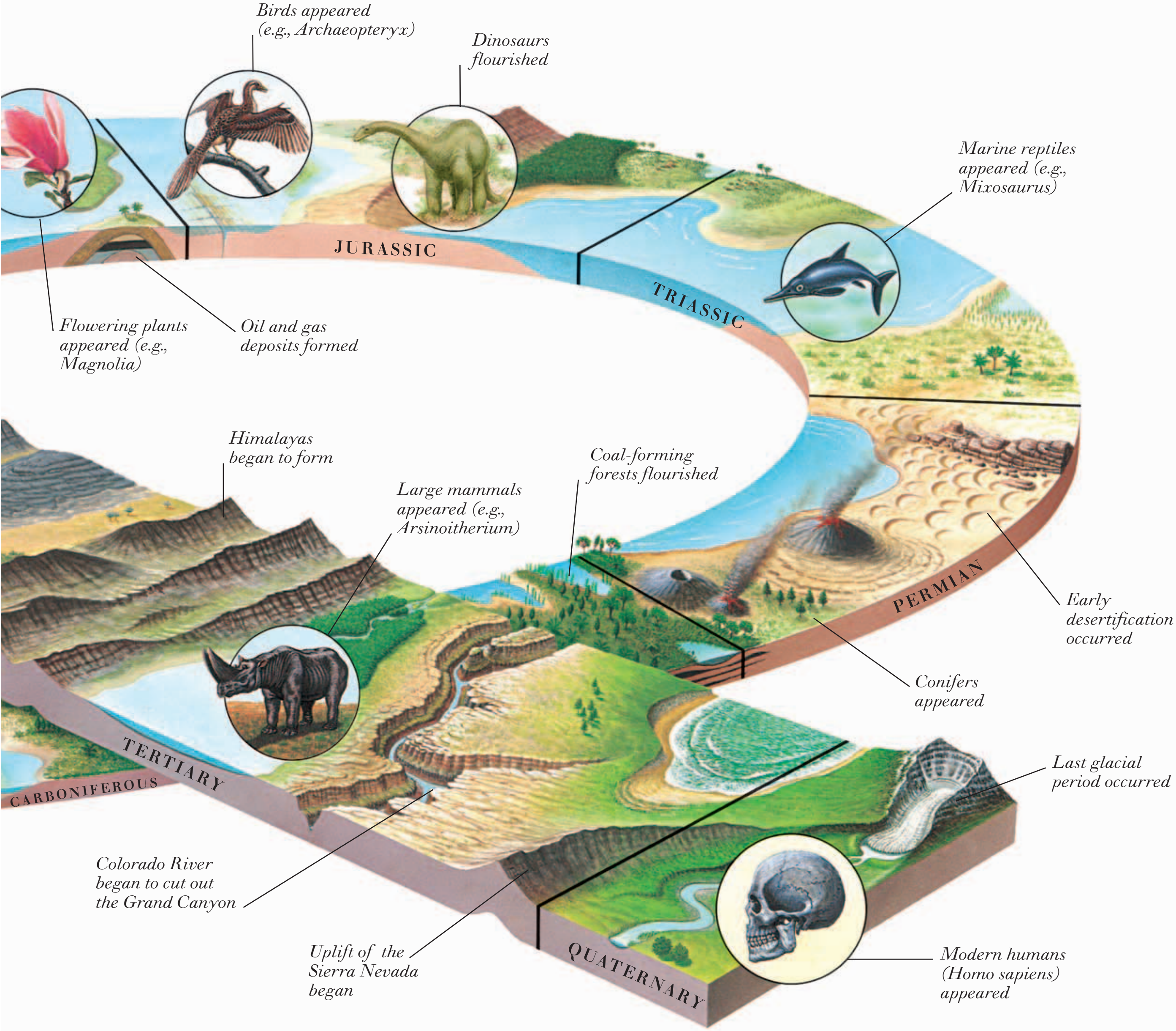


GEOLOGICAL TIMESCALE

MILLIONS OF YEARS AGO (MYA)

4,600–570	570–510	510–439	439–409	409–363	363–323	323–290
					MISSISSIPPIAN (NORTH AMERICA)	PENNSYLVANIAN (NORTH AMERICA)
	CAMBRIAN	ORDOVICIAN	SILURIAN	DEVONIAN	CARBONIFEROUS	
PRECAMBRIAN TIME	PALEOZOIC					

EVOLUTION OF THE EARTH

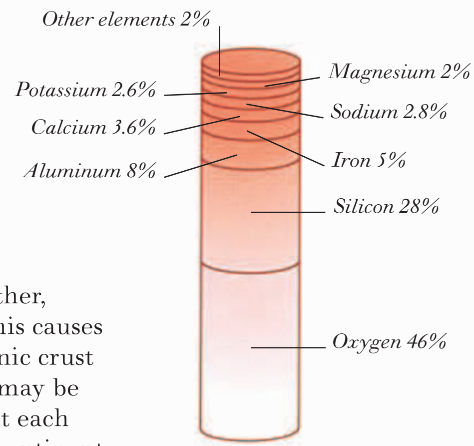


MYA	290–250	250–200	200–145	145–65	65–56.5	56.5–35.5	35.5–23.5	23.5–5.2	5.2–1.64	1.64–0.01	0.01–0
EPOCH					PALEOCENE	EOCENE	OLIGOCENE	MIOCENE	PLIOCENE	PLEISTOCENE	HOLOCENE
PERIOD	PERMIAN	TRIASSIC	JURASSIC	CRETACEOUS	TERTIARY					QUATERNARY	
ERA		MESOZOIC			CENOZOIC						

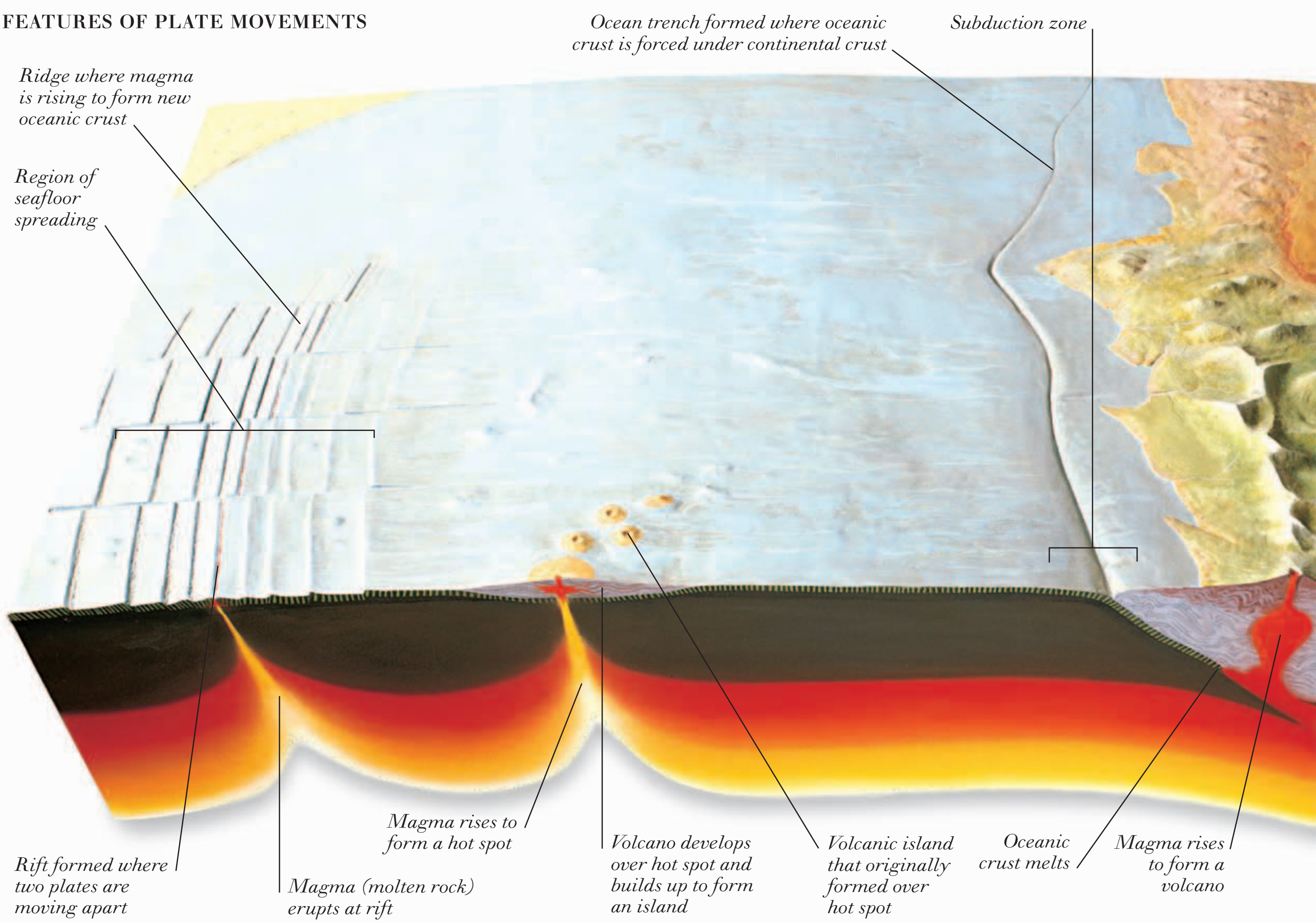
The Earth's crust

THE EARTH'S CRUST IS THE SOLID outer shell of the Earth. It includes continental crust (about 25 miles/40 km thick) and oceanic crust (about four miles/6 km thick). The crust and the topmost layer of the mantle form the lithosphere. The lithosphere consists of semirigid plates that move relative to each other on the underlying asthenosphere (a partly molten layer of the mantle). This process is known as plate tectonics and helps explain continental drift. Where two plates move apart, there are rifts in the crust. In mid-ocean, this movement results in seafloor spreading and the formation of ocean ridges; on continents, crustal spreading can form rift valleys. When plates move toward each other, one may be subducted beneath (forced under) the other. In mid-ocean, this causes ocean trenches, seismic activity, and arcs of volcanic islands. Where oceanic crust is subducted beneath continental crust or where continents collide, land may be uplifted and mountains formed (see pp. 62–65). Plates may also slide past each other—along the San Andreas fault, for example. Crustal movement on continents may result in earthquakes, while movement under the seabed can lead to tidal waves.

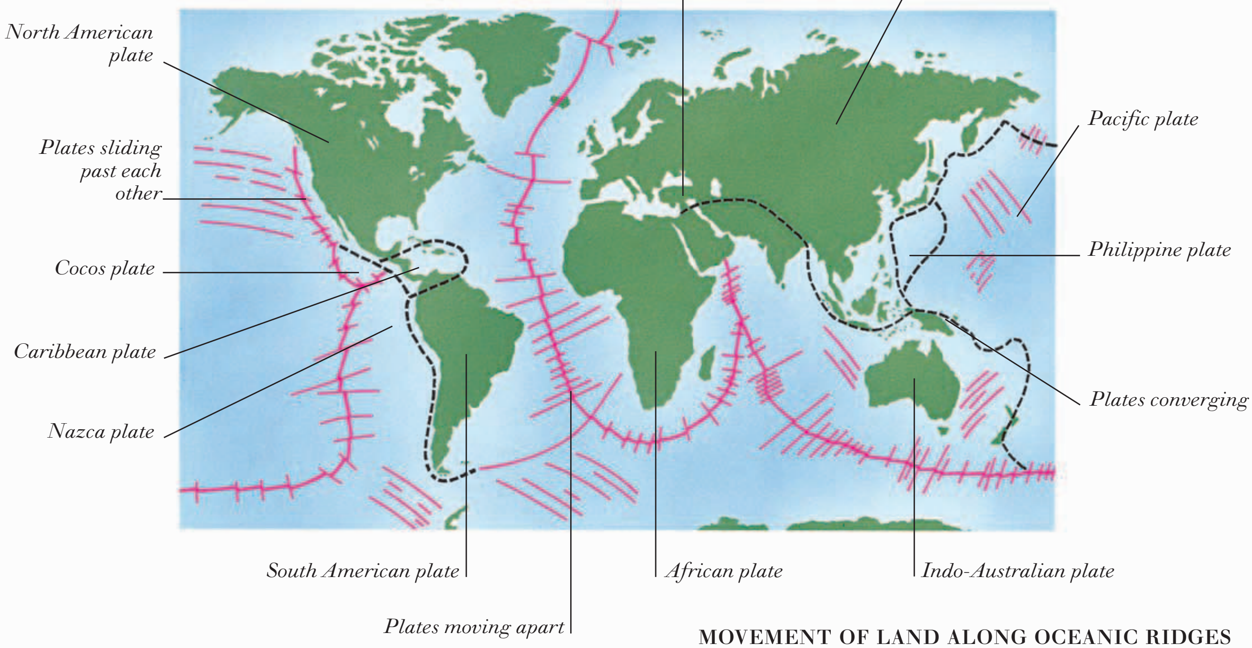
ELEMENTS IN THE EARTH'S CRUST

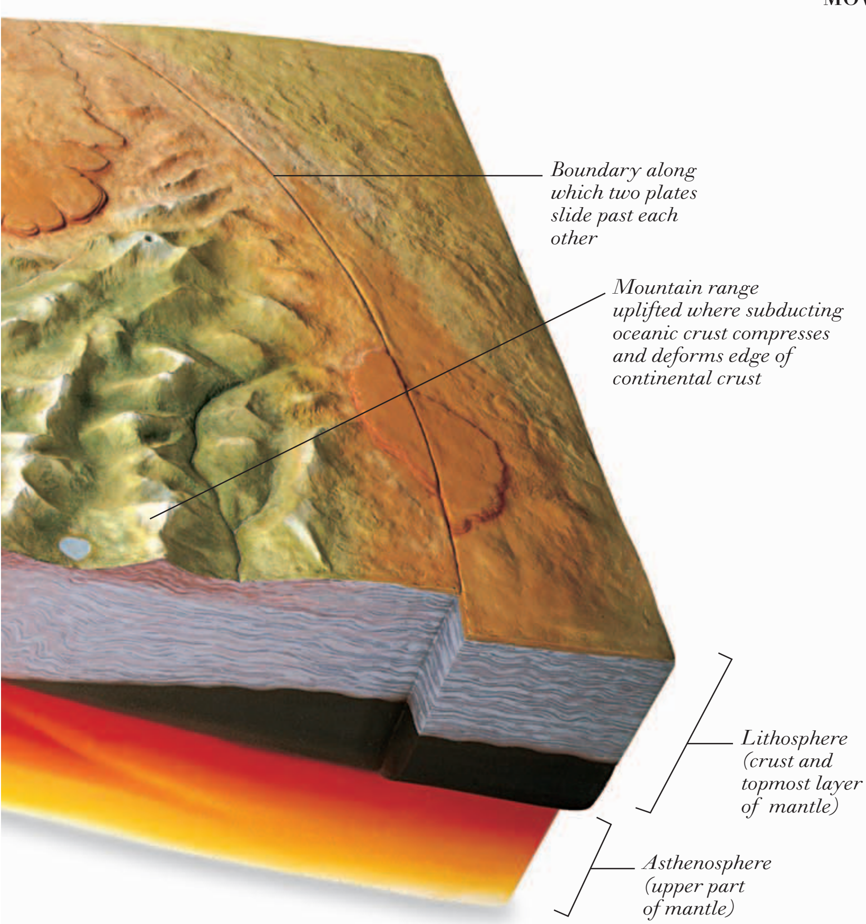


FEATURES OF PLATE MOVEMENTS

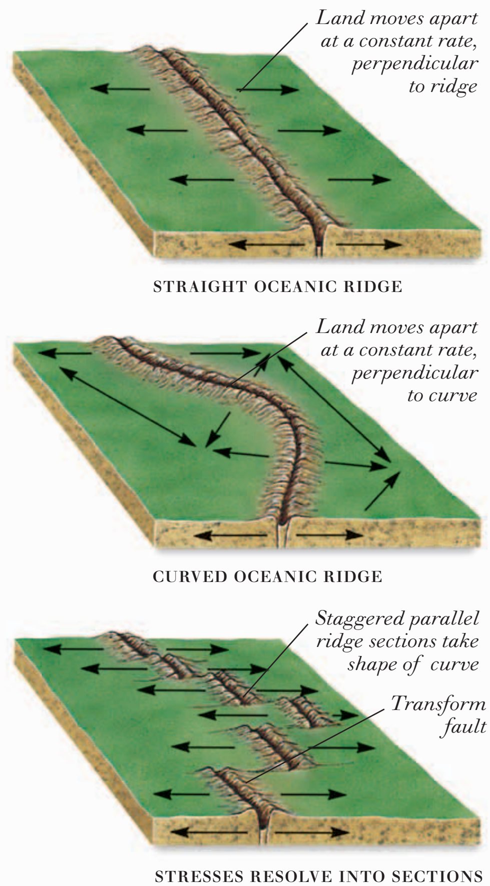


MAJOR PLATES OF THE EARTH'S CRUST





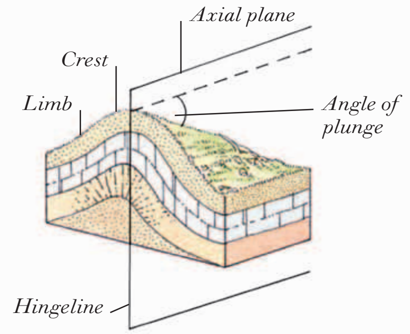
MOVEMENT OF LAND ALONG OCEANIC RIDGES



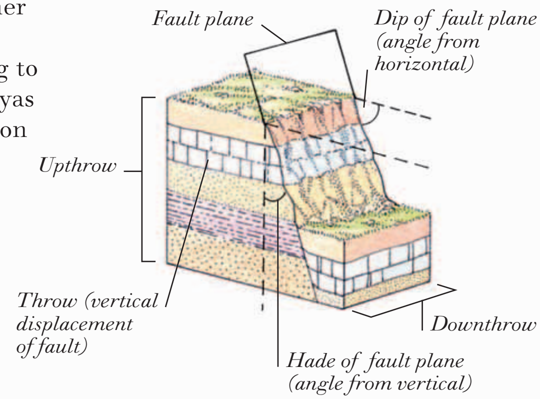
Faults and folds

THE CONTINUOUS MOVEMENT of the Earth's crustal plates (see pp. 58–59) can squeeze, stretch, or break rock strata, deforming them and producing faults and folds. A fault is a fracture in a rock along which there is movement of one side relative to the other. The movement can be vertical, horizontal, or oblique (vertical and horizontal). Faults develop when rocks are subjected to compression or tension. They tend to occur in hard, rigid rocks, which are more likely to break than bend. The smallest faults occur in single mineral crystals and are microscopically small, whereas the largest—the Great Rift Valley in Africa, which formed between 5 million and 100,000 years ago—is more than 6,000 miles (9,000 km) long. A fold is a bend in a rock layer caused by compression. Folds occur in elastic rocks, which tend to bend rather than break. The two main types of fold are anticlines (upfolds) and synclines (downfolds). Folds vary in size from a few millimeters long to folded mountain ranges hundreds of miles long, such as the Himalayas (see pp. 62–63) and the Alps, which are repeatedly folding. In addition to faults and folds, other features associated with rock deformations include boudins, mullions, and *en échelon* fractures.

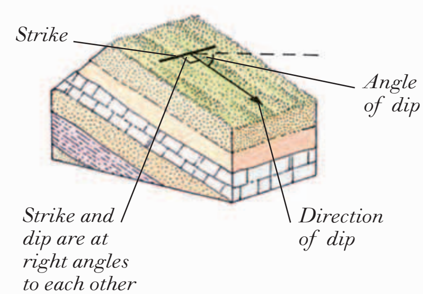
STRUCTURE OF A FOLD



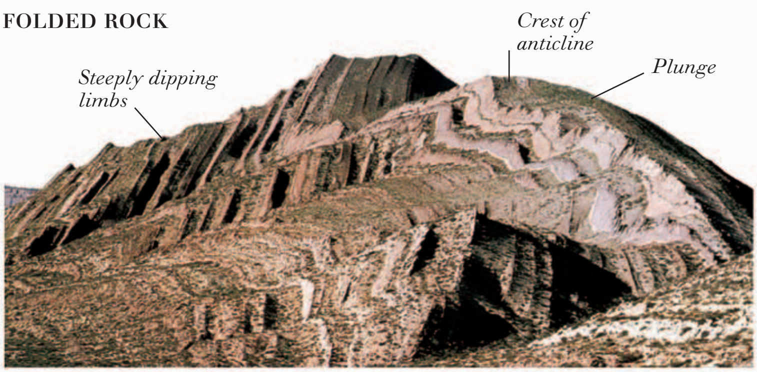
STRUCTURE OF A FAULT



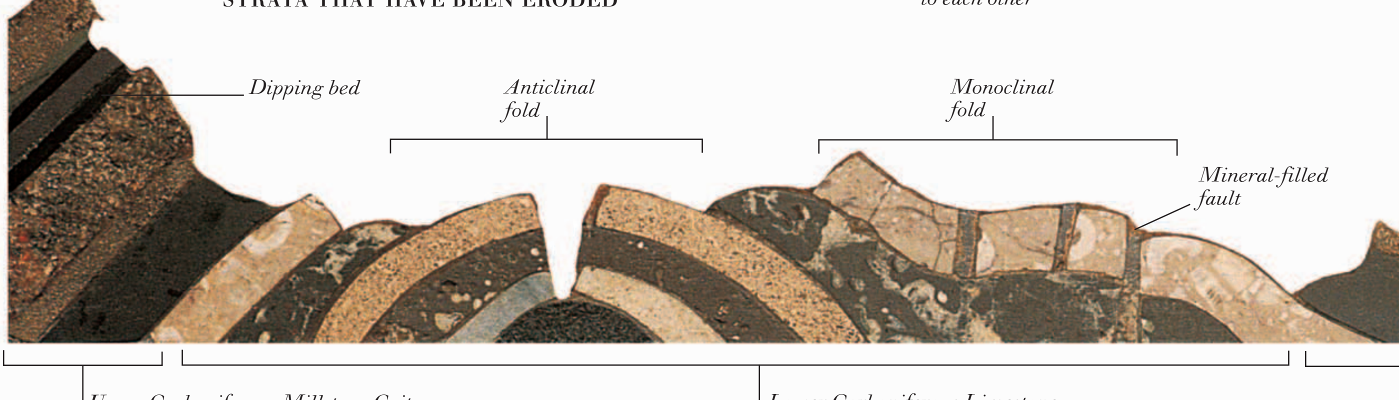
STRUCTURE OF A SLOPE



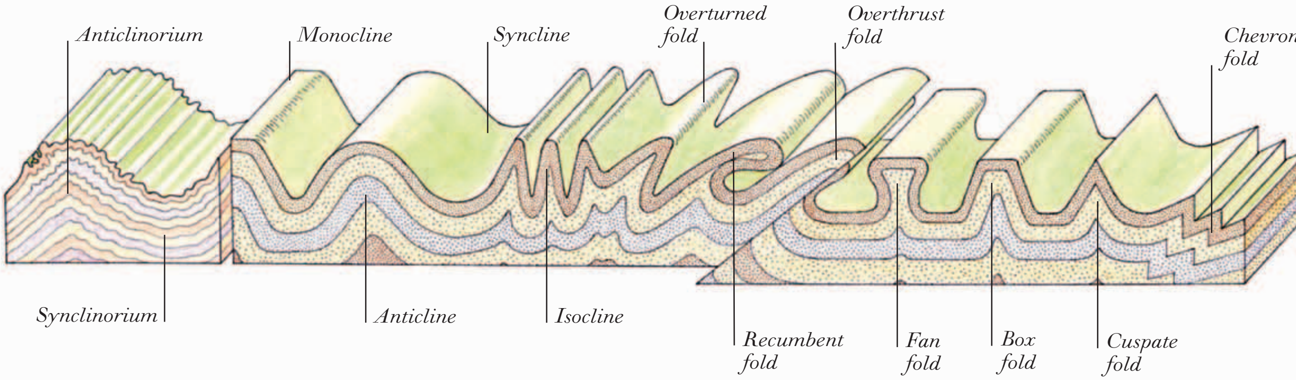
FOLDED ROCK



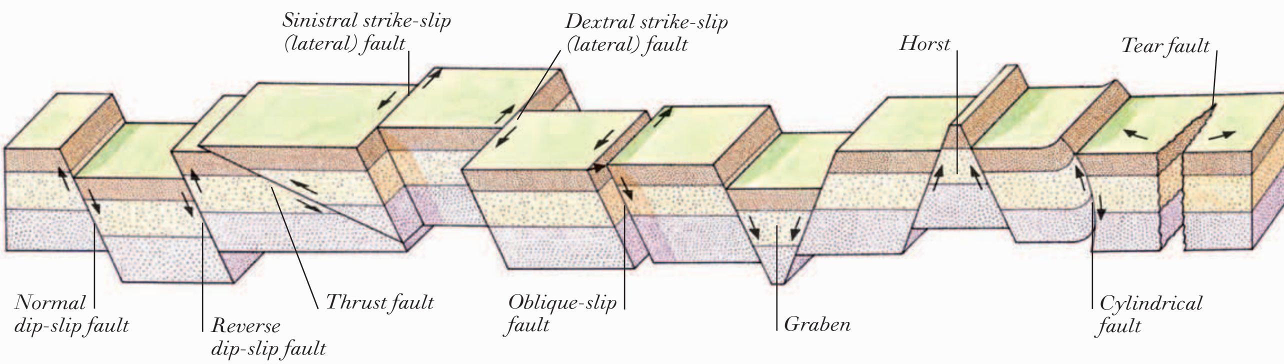
SECTION THROUGH FOLDED ROCK STRATA THAT HAVE BEEN ERODED



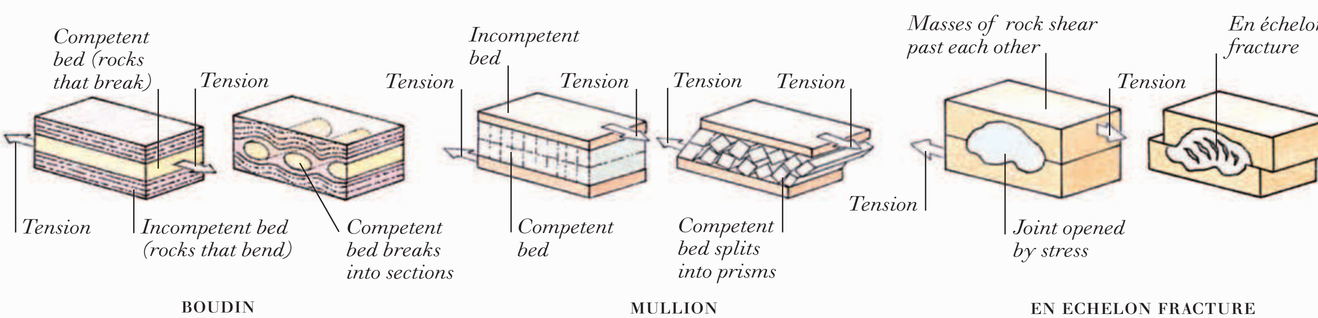
EXAMPLES OF FOLDS



EXAMPLES OF FAULTS



SMALL-SCALE ROCK DEFORMATIONS

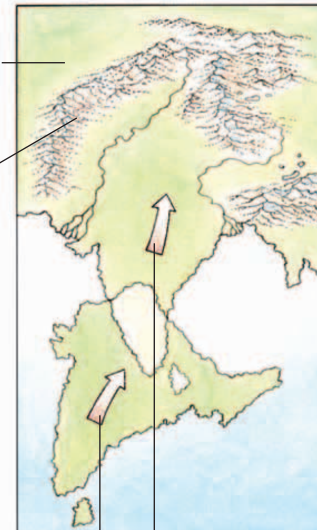


Mountain building

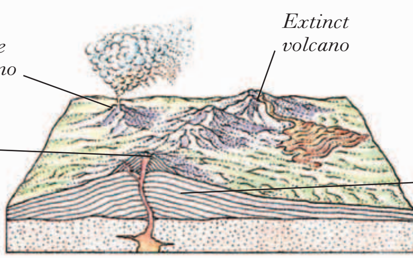
THE PROCESSES INVOLVED in mountain building—termed orogenesis—occur as a result of the movement of the Earth's crustal plates (see pp. 58–59). There are three main types of mountains: volcanic mountains, fold mountains, and block mountains. Most volcanic mountains have been formed along plate boundaries where plates have come together or moved apart and lava and other debris have been ejected onto the Earth's surface. The lava and debris may have built up to form a dome around the vent of a volcano. Fold mountains are formed where plates push together and cause the rock to buckle upward. Where oceanic crust meets less dense continental crust, the oceanic crust is forced under the continental crust. The continental crust is buckled by the impact. This is how folded mountain ranges, such as the Appalachian Mountains in North America, were formed. Fold mountains are also formed where two areas of continental crust meet. The Himalayas, for example, began to form when India collided with Asia, buckling the sediments and parts of the oceanic crust between them. Block mountains are formed when a block of land is uplifted between two faults as a result of compression or tension in the Earth's crust (see pp. 60–61). Often, the movement along faults has taken place gradually over millions of years. However, two plates may cause an earthquake by suddenly sliding past each other along a faultline.

BHAGIRATHI PARBAT, HIMALAYAS

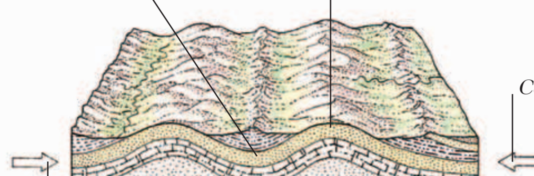
FORMATION OF THE HIMALAYAS



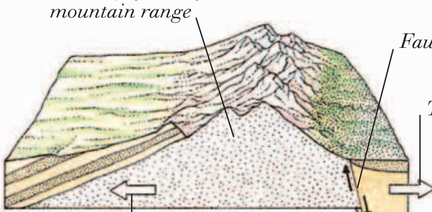
EXAMPLES OF MOUNTAINS



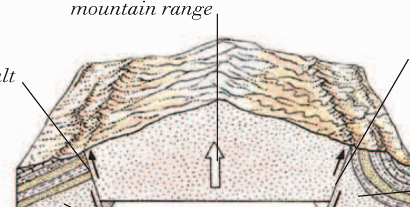
VOLCANIC MOUNTAIN



FOLD MOUNTAIN

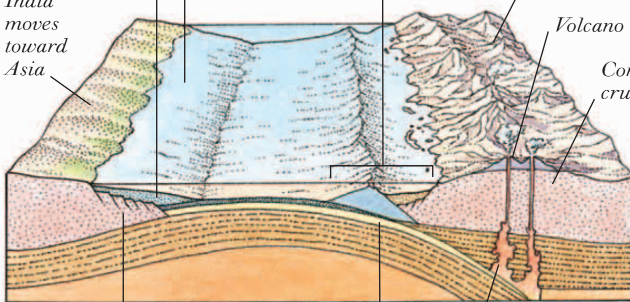


BLOCK-FAULT MOUNTAIN

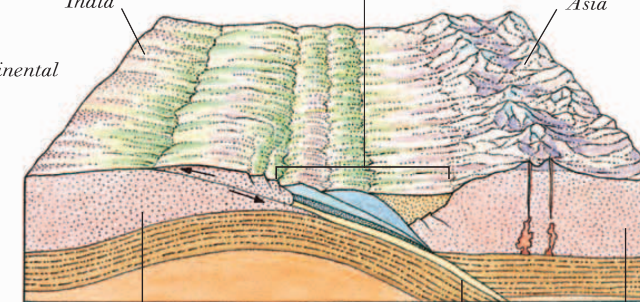


UPLIFTED BLOCK-FAULT MOUNTAIN

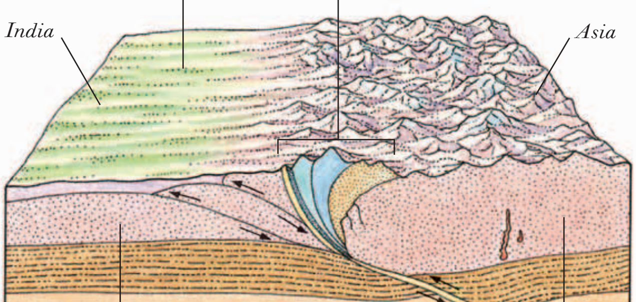
STAGES IN THE FORMATION OF THE HIMALAYAS



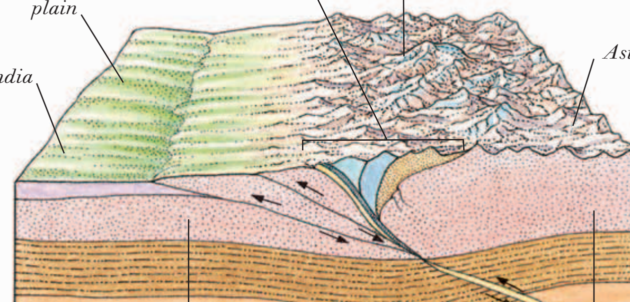
60 MILLION YEARS AGO



40 MILLION YEARS AGO

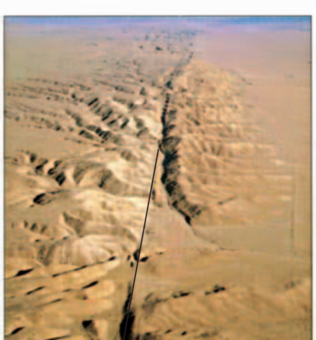


20 MILLION YEARS AGO

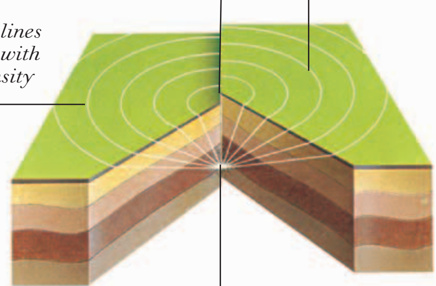


TODAY

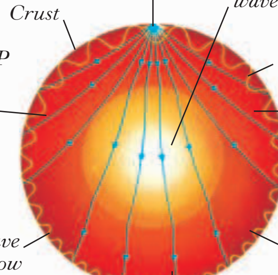
SAN ANDREAS FAULT



EARTHQUAKES



ANATOMY OF AN EARTHQUAKE

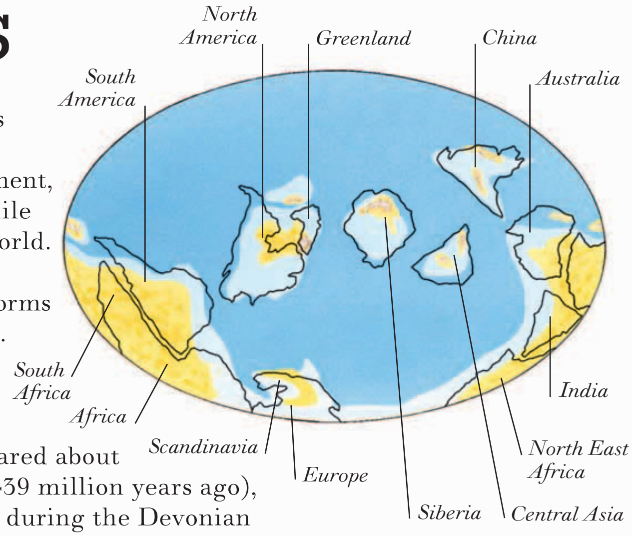


PATH OF SHOCK WAVES THROUGH THE EARTH

Precambrian to Devonian periods

WHEN THE EARTH FORMED about 4.6 billion years ago, its atmosphere consisted of volcanic gases with little oxygen, making it hostile to most forms of life. One large supercontinent, Gondwana, was situated over the southern polar region, while other smaller continents were spread over the rest of the world. Constant movement of the Earth's crustal plates carried continents across the earth's surface. The first primitive life-forms emerged around 3.4 billion years ago in shallow, warm seas. The build up of oxygen began to form a shield of ozone around the Earth, protecting living organisms from the Sun's harmful rays and helping to establish an atmosphere in which life could sustain itself. The first vertebrates appeared about 470 million years ago, during the Ordovician period (510–439 million years ago), the first land plants appeared around 400 million years ago during the Devonian period (409–363 million years ago), and the first land animals about 30 million years later.

MIDDLE ORDOVICIAN POSITIONS OF PRESENT-DAY LANDMASSES



EXAMPLES OF PRECAMBRIAN TO DEVONIAN PLANT GROUPS

A PRESENT-DAY CLUBMOSS
(Lycopodium sp.)

A PRESENT-DAY LAND PLANT
(Asparagus setaceous)

FOSSIL OF AN EXTINCT LAND PLANT
(Cooksonia hemisphaerica)

FOSSIL OF AN EXTINCT SWAMP PLANT
(Zosterophyllum llanoveranum)

EXAMPLES OF PRECAMBRIAN TO DEVONIAN TRILOBITES

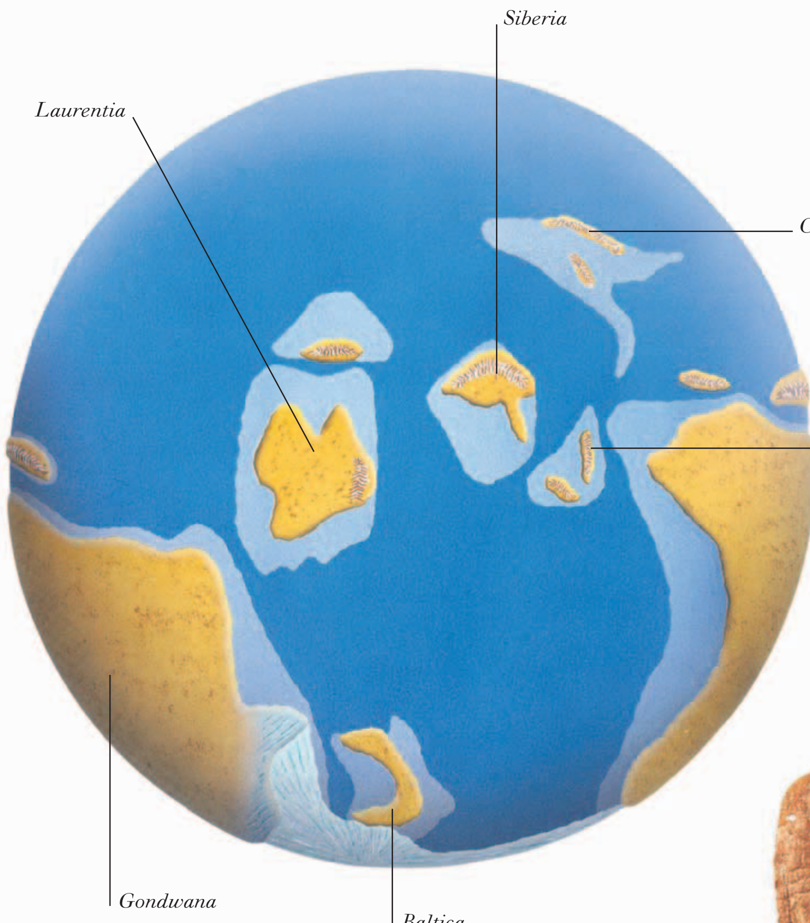
ACADAGNOSTUS
Group: Agnostidae
Length: ⅓ in (8 mm)

PHACOPS
Group: Phacopidae
Length: 1¾ in (4.5 cm)

OLENELLUS
Group: Olenellidae
Length: 2½ in (6 cm)

ELRATHIA
Group: Ptychopariidae
Length: ¾ in (2 cm)

THE EARTH DURING THE MIDDLE ORDOVICIAN PERIOD



EXAMPLES OF EARLY MARINE INVERTEBRATES

FOSSIL NAUTILOID
(Estonioceras perforatum)

FOSSIL BRACHIOPOD
(Dicoelosia bilobata)

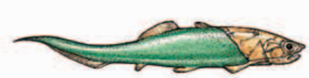
TRACE FOSSIL
(Mawsonites spriggi)

FOSSIL GRAPTOLITE
(Monograptus convolutus)

EXAMPLES OF DEVONIAN FISH

RHAMPHODOPSIS
Group: Ptyctodontidae
Length: 6 in (15 cm)

PTERASPIS
Group: Pteraspidae
Length: 10 in (25 cm)



COCCOSTEUS
Group: Coccosteidae
Length: 14 in (35 cm)

BOTHRIOLEPIS
Group: Bothriolepididae
Length: 16 in (40 cm)

CHEIRACANTHUS
Group: Acanthodidae
Length: 12 in (30 cm)

PTERICHTHYODES
Group: Asterolepididae
Length: 6 in (15 cm)

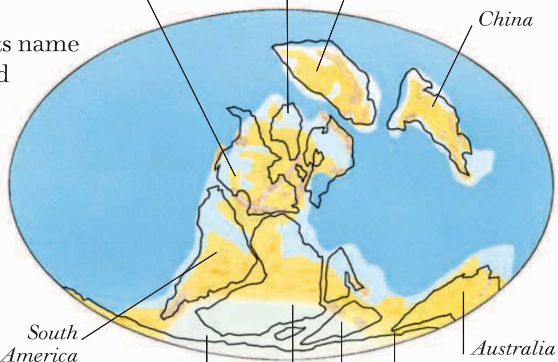
CHEIROLEPIS
Group: Cheirolepidae
Length: 6¾ in (17 cm)

CEPHALASPIS
Group: Cephalaspidae
Length: 8¾ in (22 cm)

Carboniferous to Permian periods

THE CARBONIFEROUS PERIOD (363–290 million years ago) takes its name from the thick, carbon-rich layers—now coal—that were produced during this period as swampy tropical forests were repeatedly drowned by shallow seas. The humid climate across northern and equatorial continents throughout Carboniferous times produced the first dense plant cover on Earth. During the early part of this period, the first reptiles appeared. Their development of a waterproof egg with a protective internal structure ended animal life's dependence on an aquatic environment. Toward the end of Carboniferous times, the earth's continents Laurasia and Gondwana collided, resulting in the huge landmass of Pangaea. Glaciers smothered much of the southern hemisphere during the Permian period (290–245 million years ago), covering Antarctica, parts of Australia, and much of South America, Africa, and India. Ice locked up much of the world's water and large areas of the northern hemisphere experienced a drop in sea level. Away from the poles, deserts and a hot dry climate predominated. As a result of these conditions, the Permian period ended with the greatest mass extinction of life on Earth ever.

LATE CARBONIFEROUS POSITIONS OF PRESENT-DAY LANDMASSES



EXAMPLES OF CARBONIFEROUS AND PERMIAN PLANT GROUPS

A PRESENT-DAY FIR
(Abies concolor)

FOSSIL OF AN EXTINCT FERN
(Zeilleria frenzlii)

FOSSIL OF AN EXTINCT HORSETAIL
(Equisetites sp.)

FOSSIL OF AN EXTINCT CLUBMOSS
(Lepidodendron sp.)

EXAMPLES OF CARBONIFEROUS AND PERMIAN TREES

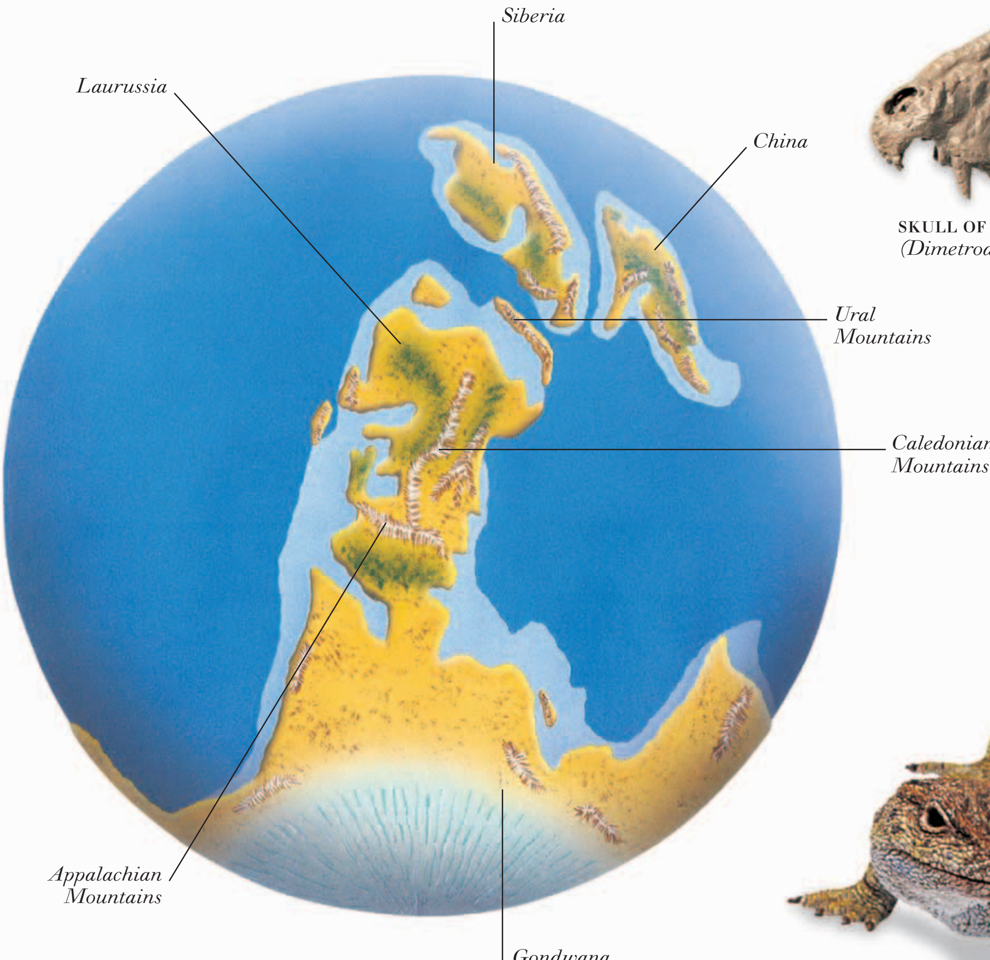
PECOPTERIS
Group: Marattiaceae
Height: 13 ft (4 m)

PARIPTERIS
Group: Medullosaceae
Height: 16 ft 6 in (5 m)

MARIOPTERIS
Group: Lyginopteridales
Height: 16 ft 6 in (5 m)

MEDULLOSA
Group: Medullosaceae
Height: 16 ft 6 in (5 m)

THE EARTH DURING THE LATE CARBONIFEROUS PERIOD



EXAMPLES OF CARBONIFEROUS AND PERMIAN ANIMALS

SKULL OF AN EXTINCT SYNAPSID
(Dimetrodon loomisi)

FOSSIL TEETH OF AN EXTINCT SHARK
(Helicoprion bessonowi)

MODEL OF AN EXTINCT EARLY REPTILELIKE ANIMAL
(Westlothiana lizziae)

LEPIDODENDRON
Group: Lepidodendraceae
Height: 100 ft (30 m)

CORDAITES
Group: Cordaitacea
Height: 33 ft (10 m)

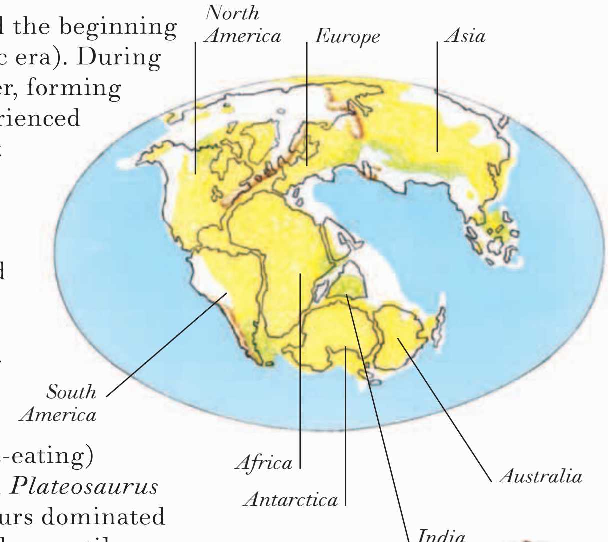
GLOSSOPTERIS
Group: Glossopteridaceae
Height: 26 ft (8 m)

ALETHOPTERIS
Group: Medullosaceae
Height: 16 ft 6 in (5 m)

Triassic period

THE TRIASSIC PERIOD (250–200 million years ago) marked the beginning of what is known as the Age of the Dinosaurs (the Mesozoic era). During this period, the present-day continents were massed together, forming one huge continent known as Pangaea. This landmass experienced extremes of climate, with lush green areas around the coast or by lakes and rivers, and arid deserts in the interior. The only forms of plant life were nonflowering plants, such as conifers, ferns, cycads, and ginkgos; flowering plants had not yet evolved. The principal forms of animal life included diverse, often gigantic, amphibians, rhynchosaurs ("beaked lizards"), and primitive crocodilians. Dinosaurs first appeared about 230 million years ago, at the beginning of the Late Triassic period. Among the earliest dinosaurs were the carnivorous (flesh-eating) herrerasaurids, such as *Herrerasaurus* and *Staurikosaurus*. Early herbivorous (plant-eating) dinosaurs first appeared in Late Triassic times and included *Plateosaurus* and *Technosaurus*. By the end of the Triassic period, dinosaurs dominated Pangaea, possibly contributing to the extinction of many other reptiles.

TRIASSIC POSITIONS OF PRESENT-DAY LANDMASSES



EXAMPLES OF TRIASSIC PLANT GROUPS

A PRESENT-DAY CYCAD
(Cycas revoluta)

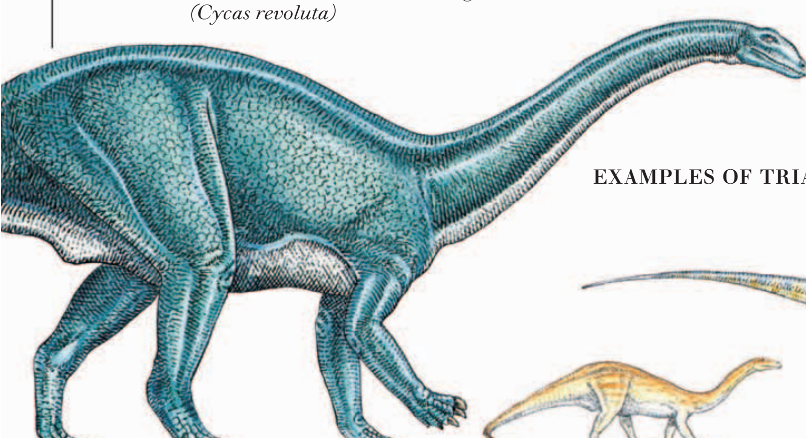
A PRESENT-DAY GINKGO
(Ginkgo biloba)

A PRESENT-DAY CONIFER
(Araucaria araucana)

FOSSIL OF AN EXTINCT FERN
(Pachypteris sp.)

FOSSIL LEAF OF AN EXTINCT CYCAD
(Cycas sp.)

EXAMPLES OF TRIASSIC DINOSAURS



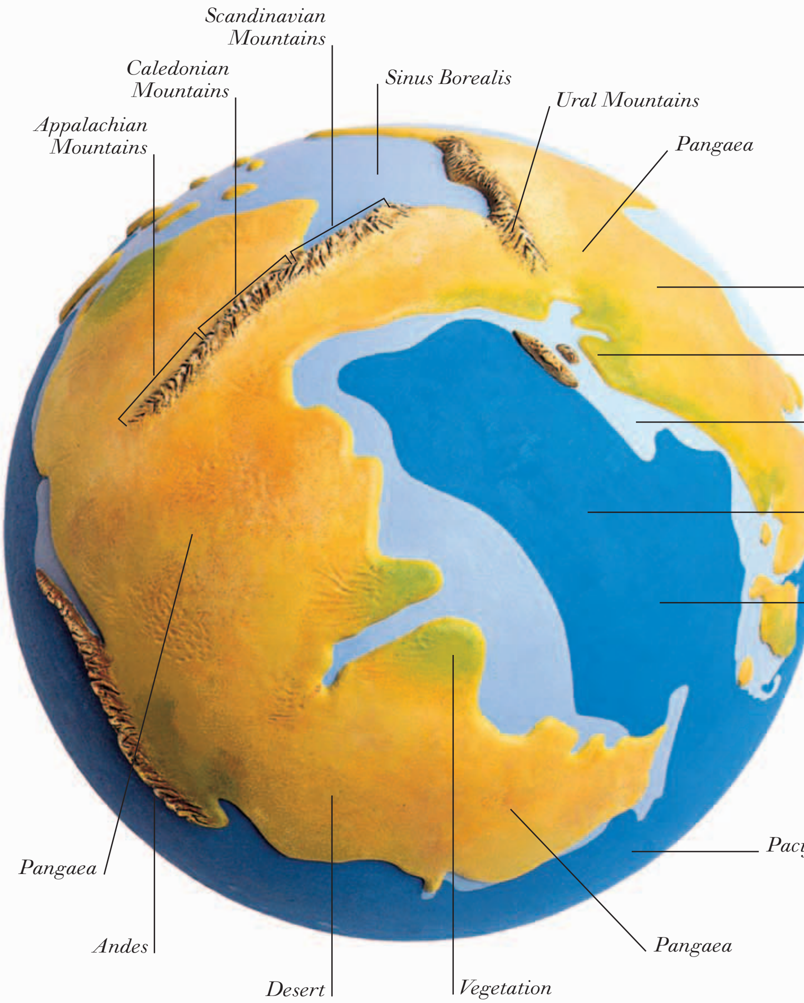
MELANOROSAURUS
Group: Melanorosauridae
Length: 40 ft (12.2 m)

MUSSAURUS
Group: Sauropodomorpha
Length: 6 ft 6 in–10 ft (2–3 m)

HERRERASAURUS
Group: Herrerasauridae
Length: 10 ft (3 m)

PISANOSAURUS
Group: Ornithischia
Length: 3 ft (90 cm)

THE EARTH DURING THE TRIASSIC PERIOD



EXAMPLES OF TRIASSIC ANIMALS

AN EXTINCT AMPHIBIAN

A NAUTILOID MOLLUSK
(Nautilus sp.)

AN EXTINCT CHONDROSTEAN FISH
(Cleithrolepis granulatus)

AN EXTINCT SEA-GOING REPTILE
(Pachypleurosaurus sp.)

AN EXTINCT RHYNCHOSAURIAN REPTILE
(Scaphonyx fischeri)

PLATEOSAURUS
Group: Plateosauridae
Length: 26 ft (7.9 m)

TECHNOSAURUS
Group: Ornithischia
Length: 3 ft 3 in (1 m)

COELOPHYSIS
Group: Coelophysidae
Length: 10 ft (3 m)

STAURIKOSAURUS
Group: Herrerasauridae
Length: 6 ft 6 in (2 m)

Jurassic period

THE JURASSIC PERIOD, the middle part of the Mesozoic era, lasted from 199 to 145 million years ago. During Jurassic times, the landmass of Pangaea broke up into the continents of Gondwana and Laurasia, and sea levels rose, flooding areas of lower land. The Jurassic climate was warm and moist. Plants such as ginkgos, horsetails, and conifers thrived, and giant redwood trees appeared, as did the first flowering plants. The abundance of plant food coincided with the proliferation of herbivorous (plant-eating) dinosaurs, such as the large sauropods (e.g., *Diplodocus*) and stegosaurs (e.g., *Stegosaurus*). Carnivorous (flesheating) dinosaurs, such as *Compsognathus* and *Allosaurus*, also flourished by hunting the many animals that existed—among them other dinosaurs. Further Jurassic animals included shrewlike mammals, and pterosaurs (flying reptiles), as well as plesiosaurs and ichthyosaurs (both marine reptiles).

JURASSIC POSITIONS OF PRESENT-DAY LANDMASSES

EXAMPLES OF JURASSIC PLANT GROUPS

A PRESENT-DAY FERN
(Dicksonia antarctica)

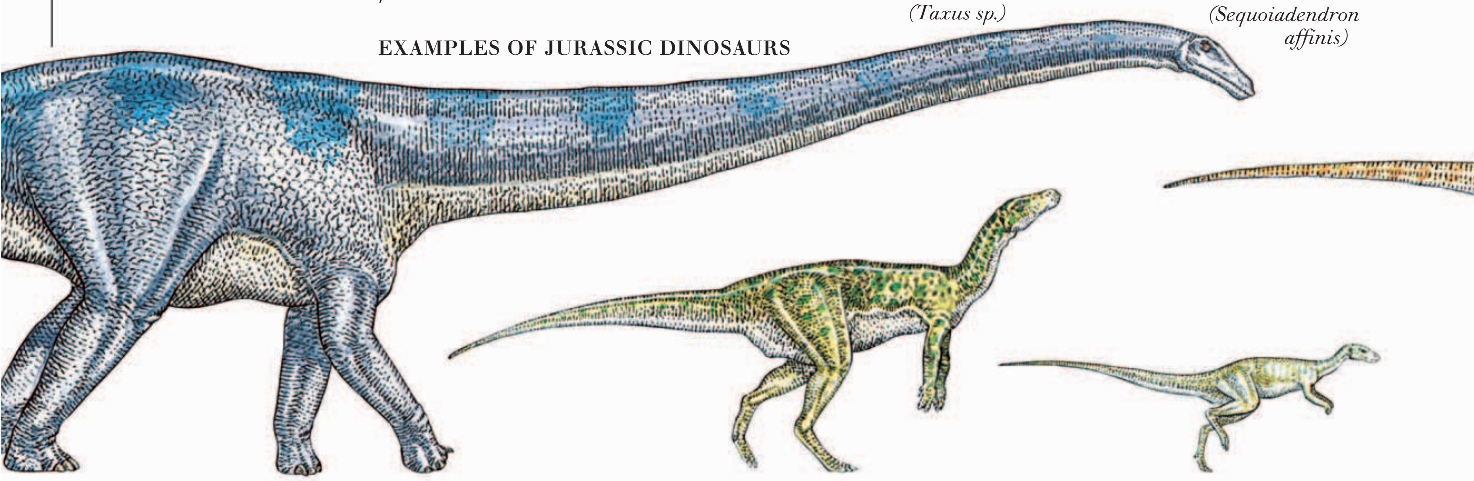
A PRESENT-DAY HORSETAIL
(Equisetum arvense)

A PRESENT-DAY CONIFER
(Taxus baccata)

FOSSIL LEAF OF AN EXTINCT CONIFER
(Taxus sp.)

FOSSIL LEAF OF AN EXTINCT REDWOOD
(Sequoiadendron affinis)

EXAMPLES OF JURASSIC DINOSAURS

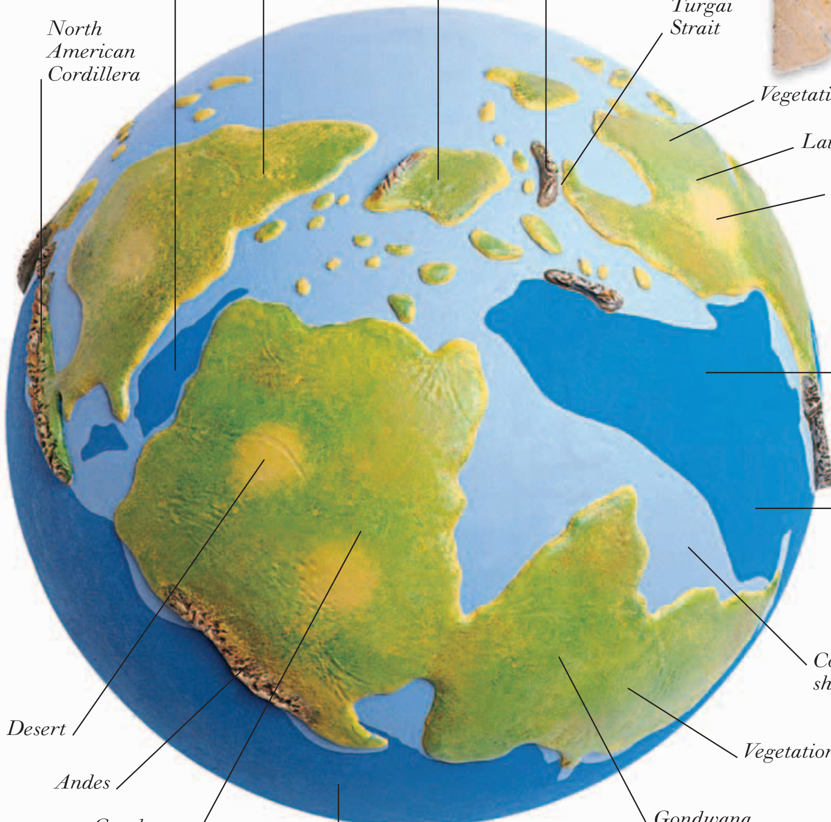


DIPLODOCUS
Group: Diplodocidae
Length: 88 ft (26.8 m)

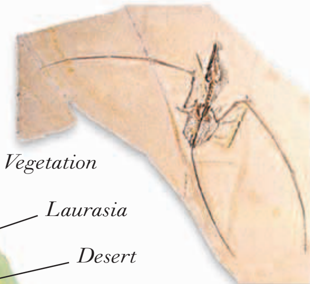
CAMPTOSAURUS
Group: Iguanodontia
Length: 16–23 ft (4.9–7 m)

DRYOSAURUS
Group: Dryosauridae
Length: 10–13 ft (3–4 m)

THE EARTH DURING THE JURASSIC PERIOD



EXAMPLES OF JURASSIC ANIMALS



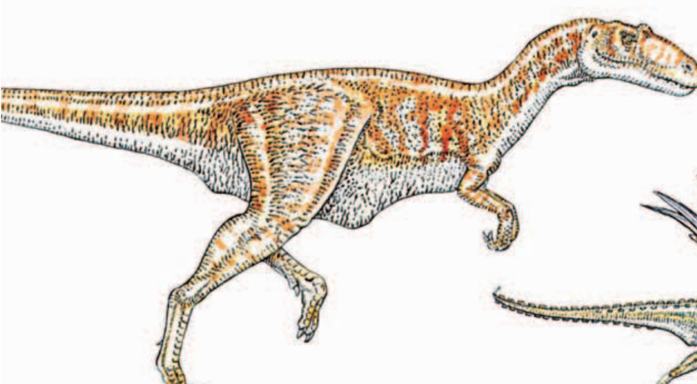
AN EXTINCT PTEROSAUR
(Rhamphorhynchus sp.)

AN EXTINCT BELEMNITE MOLLUSK
(Belemnoteuthis sp.)

AN EXTINCT RHYNCHOSAURIAN REPTILE
(Homeosaurus pulchellus)

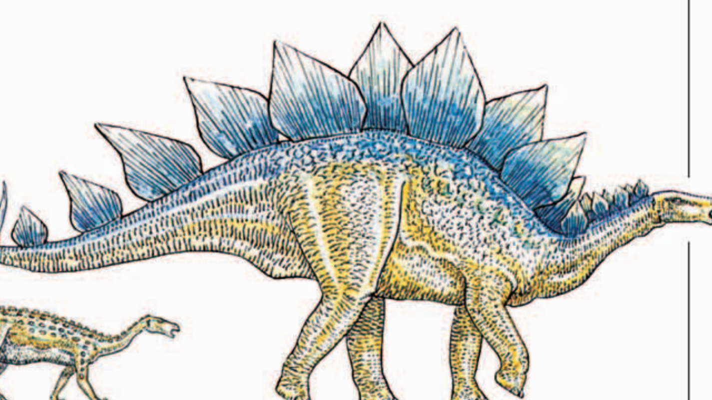
AN EXTINCT PLESIOSAUR
(Peloneustes philarcus)

AN EXTINCT ICHTHYOSAUR
(Stenopterygius megacephalus)



ALLOSAURUS
Group: Allosauroidea
Length: 36 ft (11 m)

SCELIDOSAURUS
Group: Thyreophora
Length: 13 ft (4m)

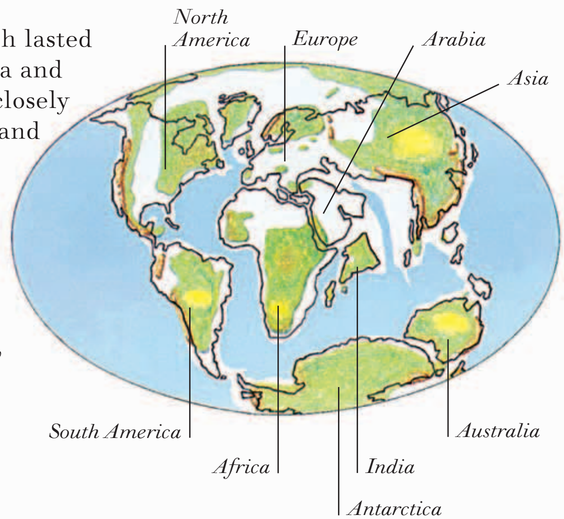


STEGOSAURUS
Group: Stegosauridae
Length: 30 ft (9.1 m)

Cretaceous period

THE MESOZOIC ERA ENDED WITH the Cretaceous period, which lasted from 146 to 65 million years ago. During this period, Gondwana and Laurasia were breaking up into smaller landmasses that more closely resembled the modern continents. The climate remained mild and moist but the seasons became more marked. Flowering plants, including deciduous trees, replaced many cycads, seed ferns, and conifers. Animal species became more varied, with the evolution of new mammals, insects, fish, crustaceans, and turtles. Dinosaurs evolved into a wide variety of species during Cretaceous times; more than half of all known dinosaurs—including *Iguanodon*, *Deinonychus*, *Tyrannosaurus*, and *Hypsilophodon*—lived during this period. At the end of the Cretaceous period, however, most dinosaurs became extinct. The reason for this mass extinction is unknown but it is thought to have been caused by climatic changes due to either a catastrophic meteor impact with the Earth or extensive volcanic eruptions.

CRETACEOUS POSITIONS OF PRESENT-DAY LANDMASSES



EXAMPLES OF CRETACEOUS PLANT GROUPS

A PRESENT-DAY CONIFER
(Pinus muricata)

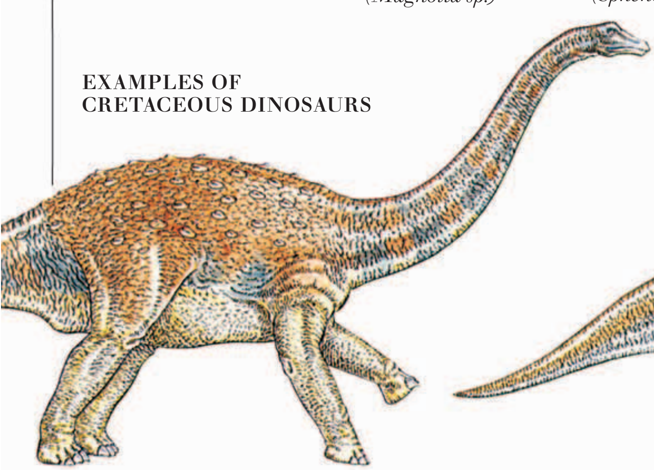
A PRESENT-DAY DECIDUOUS TREE
(Magnolia sp.)

FOSSIL OF AN EXTINCT FERN
(Sphenopteris latiloba)

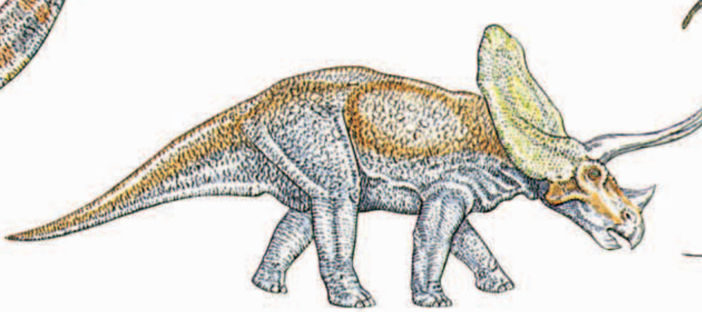
FOSSIL OF AN EXTINCT GINKGO
(Ginkgo pluripartita)

FOSSIL LEAVES OF AN EXTINCT DECIDUOUS TREE
(Cercidyphyllum sp.)

EXAMPLES OF CRETACEOUS DINOSAURS



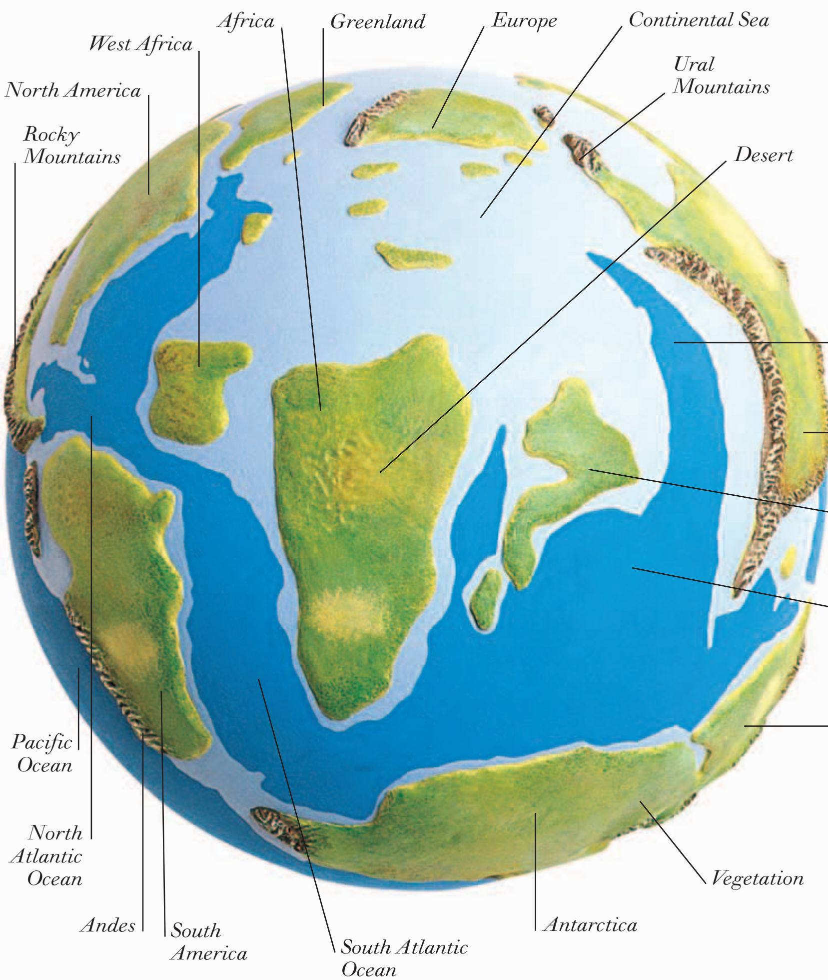
SALTASAURUS
Group: Saltasauridae
Length: 40 ft (12.2 m)



TOROSAURUS
Group: Ceratopsidae
Length: 25 ft (7.6 m)

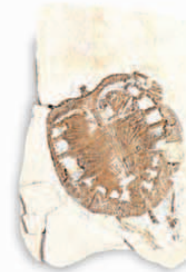
HYPSILOPHODON
Group: Ornithopoda
Length: 4 ft 6 in–7 ft 6 in (1.4–2.3 m)

THE EARTH DURING THE CRETACEOUS PERIOD



EXAMPLES OF CRETACEOUS ANIMALS

AN EXTINCT INSECT
(Libellulium longialatum)

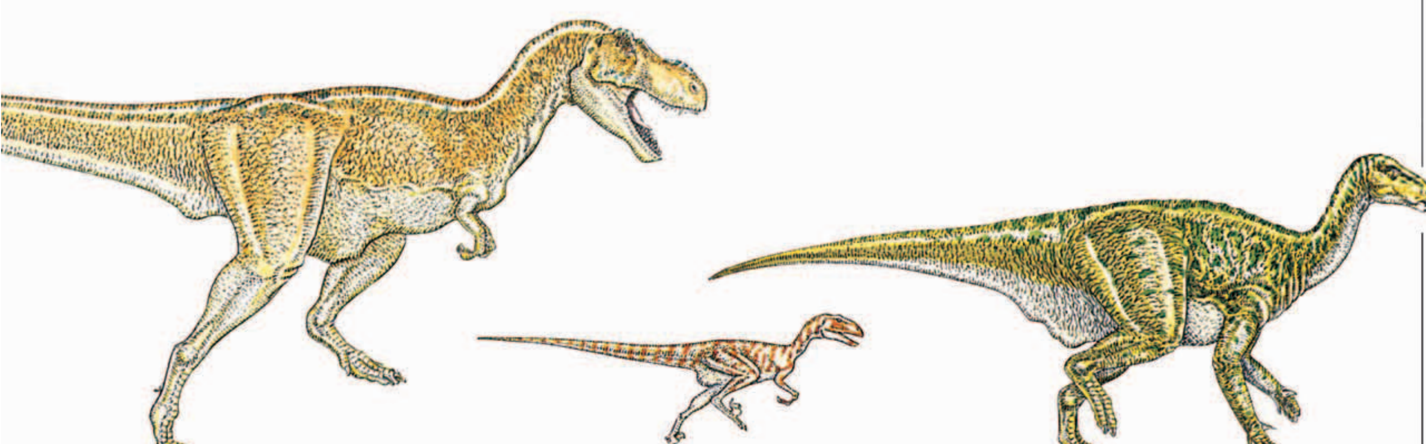


AN EXTINCT MARINE TURTLE
(Plesiochelys latiscutata)

AN EXTINCT CRUSTACEAN
(Homarus sp.)

AN EXTINCT CROCODILIAN

AN EXTINCT HOLOSTEAN FISH
(Lepidotes maximus)



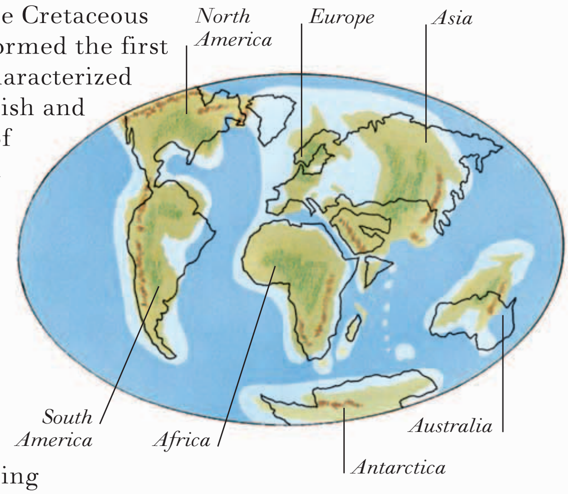
TYRANNOSAURUS
Group: Tyrannosauridae
Length: 40 ft (12.2 m)

DEINONYCHUS
Group: Dromaeosauridae
Length: 8–11 ft (2.4–3.4 m)

IGUANODON
Group: Iguanodontia
Length: 30 ft (9.1 m)

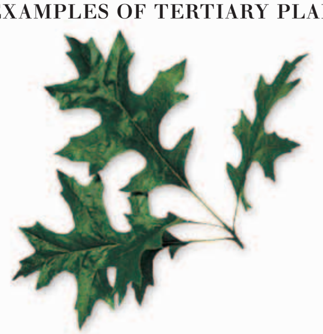
Tertiary period

TERTIARY POSITIONS OF PRESENT-DAY LANDMASSES



FOLLOWING THE DEMISE OF THE DINOSAURS at the end of the Cretaceous period, the Tertiary period (65–1.6 million years ago), which formed the first part of the Cenozoic era (65 million years ago–present), was characterized by a huge expansion of mammal life. Placental mammals nourish and maintain the young in the mother's uterus; only a few groups of placental mammals existed during Cretaceous times, compared with a few dozen during the Tertiary period. One of these included the first hominid (see pp.108–109), *Ardipithecus*, which appeared in Africa. By the beginning of the Tertiary period, the continents had almost reached their present position. The Tethys Sea, which had separated the northern continents from Africa and India, began to close up, forming the Mediterranean Sea and allowing the migration of terrestrial animals between Africa and western Europe. India's collision with Asia led to the formation of the Himalayas. During the middle part of the Tertiary period, the forest-dwelling and browsing mammals were replaced by mammals such as the horses, better suited to grazing the open savannahs that began to dominate. Repeated cool periods throughout the Tertiary period established the Antarctic as an icy island continent.

EXAMPLES OF TERTIARY PLANT GROUPS



A PRESENT-DAY OAK
(Quercus palustris)

A PRESENT-DAY BIRCH
(Betula grossa)

FOSSIL LEAF OF AN EXTINCT BIRCH
(Betulites sp.)

FOSSILIZED STEM OF AN EXTINCT PALM
(Palmoxylon sp.)

EXAMPLES OF TERTIARY ANIMAL GROUPS

HYAENODON
Group: Hyaenodontidae
Length: 6 ft 6 in (2 m)

TITANOHYRAX
Group: Pliohyracidae
Length: 6 ft 6 in (2 m)

PHORUSRHACOS
Group: Phorusrhacidae
Length: 5 ft (1.5 m)

SAMOTHERIUM
Group: Giraffidae
Length: 10 ft (3 m)

THE EARTH DURING THE TERTIARY PERIOD

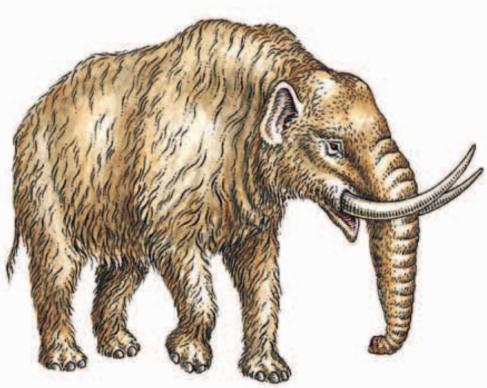
EXAMPLES OF TERTIARY ANIMALS

AN EXTINCT MAMMAL
(Arsinoitherium)

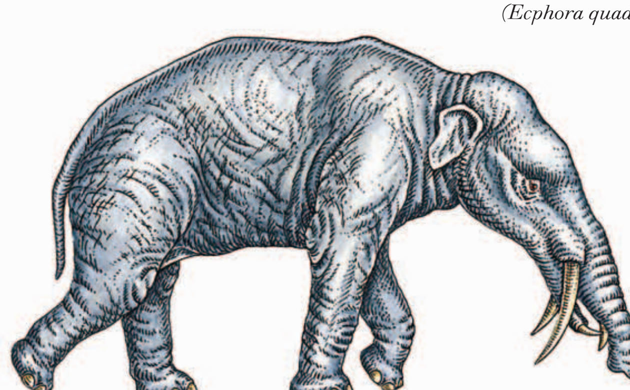
AN EXTINCT MAMMAL
(Merycoidodon culbertsonii)

AN EXTINCT PRIMATE
(Aegyptopithecus sp.)

AN EXTINCT GASTROPOD MOLLUSK
(Ecphora quadricostata)



MAMMUT
Group: Mammutidae
Length: 8 ft (2.5 m)

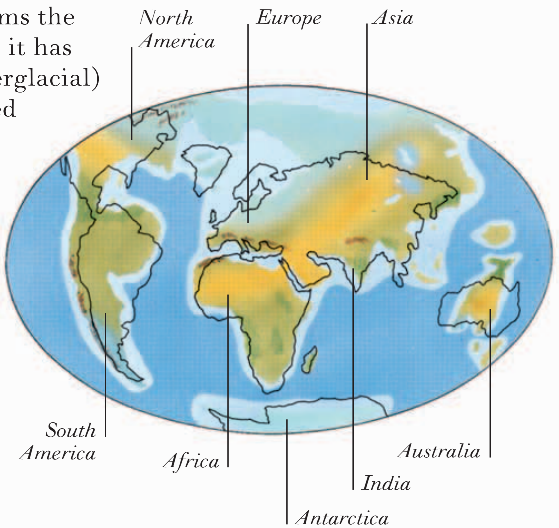


TETRALOPHODON
Group: Gomphotheriidae
Length: 8 ft (2.5 m)

Quaternary period

THE QUATERNARY PERIOD (1.6 million years ago–present) forms the second part of the Cenozoic era (65 million years ago–present): it has been characterized by alternating cold (glacial) and warm (interglacial) periods. During cold periods, ice sheets and glaciers have formed repeatedly on northern and southern continents. The cold environments in North America and Eurasia, and to a lesser extent in southern South America and parts of Australia, have caused the migration of many life-forms toward the Equator. Only the specialized ice age mammals such as *Mammuthus* and *Coelodonta*, with their thick wool and fat insulation, were suited to life in very cold climates. Humans developed throughout the Pleistocene period (1.6 million–10,000 years ago) in Africa and migrated northward into Europe and Asia. Modern humans, *Homo sapiens*, lived on the cold European continent 30,000 years ago and hunted other mammals. The end of the last ice age and the climatic changes that occurred about 10,000 years ago brought extinction to many Pleistocene mammals, but enabled humans to flourish.

QUATERNARY POSITIONS OF PRESENT-DAY LANDMASSES



EXAMPLES OF QUATERNARY PLANT GROUPS

A PRESENT-DAY BIRCH
(Betula lenta)

A PRESENT-DAY SWEEETGUM
(Liquidambar styraciflua)

FOSSIL LEAF OF A SWEETGUM
(Liquidambar europeanum)

FOSSIL LEAF OF A BIRCH
(Betula sp.)

EXAMPLES OF QUATERNARY ANIMAL GROUPS

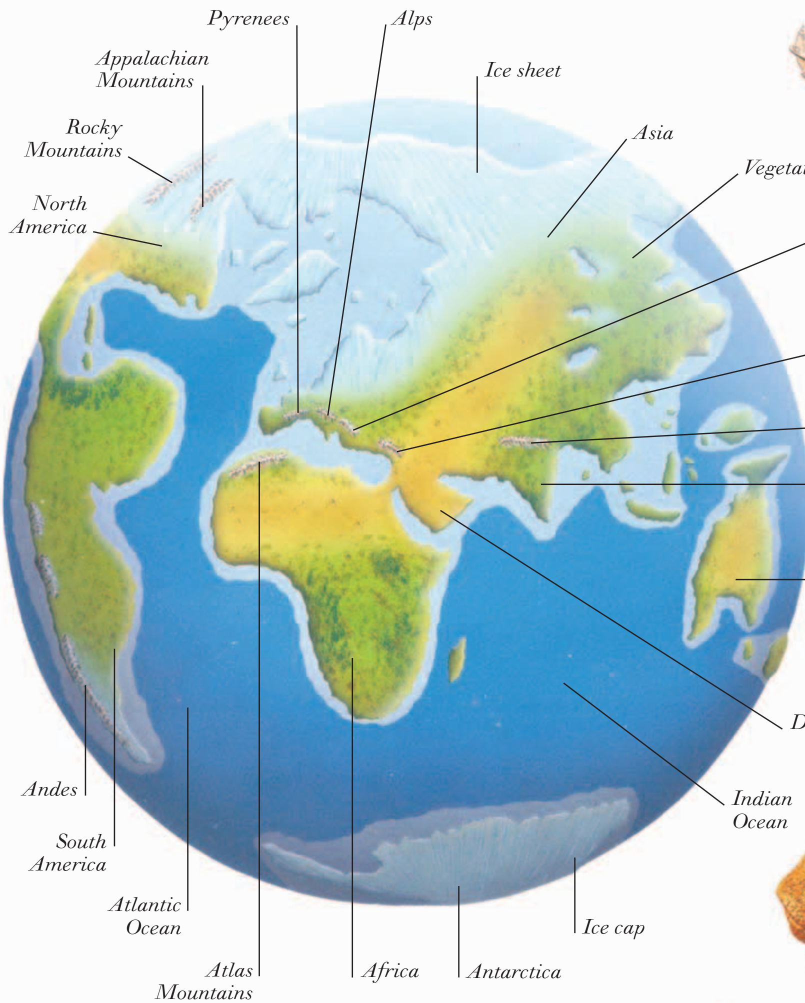
PROCOPTODON
Group: Macropodidae
Length: 10 ft (3 m)

DIPROTODON
Group: Diprotodontidae
Length: 10 ft (3 m)

TOXODON
Group: Toxodontidae
Length: 10 ft (3 m)

MAMMUTHUS
Group: Elephantidae
Length: 10 ft (3 m)

THE EARTH DURING THE QUATERNARY PERIOD



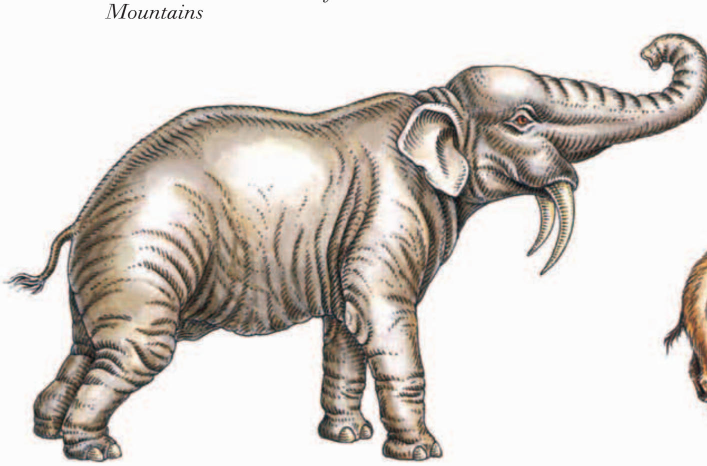
EXAMPLES OF QUATERNARY ANIMALS

A MAMMAL SKELETON
(Hippopotamus amphibius)

SKULL OF AN EXTINCT CAVE BEAR
(Ursus spelaeus)

SKULL OF AN EXTINCT TORTOISE
(Meiolania platyceps)

A MAMMOTH TOOTH
(Mammuthus primigenius)



DEINOTHERIUM
Group: Deinotheriidae
Length: 13 ft (4 m)

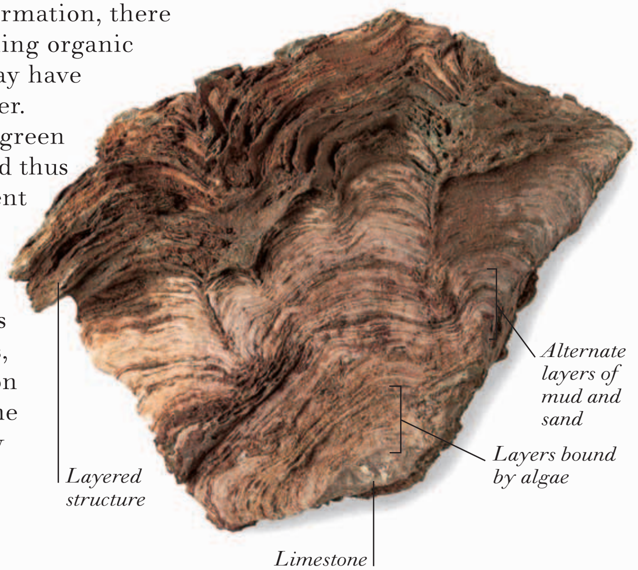
COELODONTA
Group: Rhinocerotidae
Length: 13 ft (4 m)

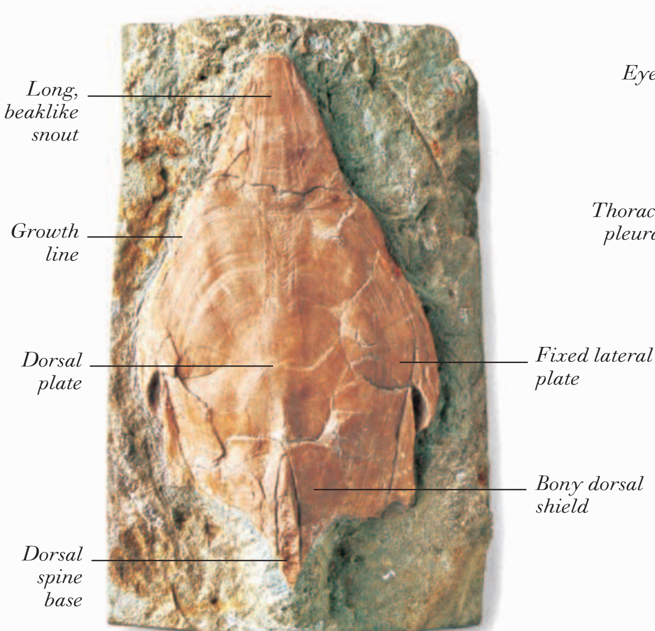
AUSTRALOPITHECUS
Group: Hominidae
Length: 4 ft (1.2 m)

Early signs of life

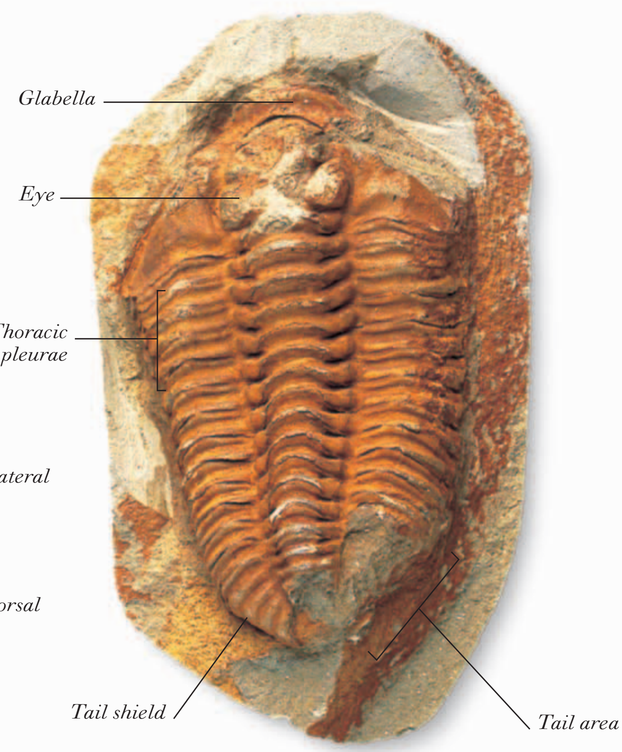
FOR ALMOST A THOUSAND MILLION YEARS after its formation, there was no known life on Earth. The first simple, sea-dwelling organic structures appeared about 3.5 billion years ago; they may have formed when certain chemical molecules joined together. Prokaryotes, single-celled microorganisms such as blue-green algae, were able to photosynthesize (see pp. 138–139), and thus produce oxygen. A thousand million years later, sufficient oxygen had built up in the Earth's atmosphere to allow multicellular organisms to proliferate in the Precambrian seas (before 570 million years ago). Soft-bodied jellyfish, corals, and seaworms flourished about 700 million years ago. Trilobites, the first animals with hard body frames, developed during the Cambrian period (570–510 million years ago). However, it was not until the beginning of the Devonian period (409–363 million years ago) that early land plants, such as *Asteroxylon*, formed a water-retaining cuticle, which ended their dependence on an aquatic environment. About 360 million years ago, the first amphibians (see pp. 80–81) crawled onto the land, although they probably still returned to the water to lay their soft eggs. By the time the first reptiles and synapsids appeared late in the Carboniferous, animals with backbones had become fully independent of water.

STROMATOLITIC LIMESTONE





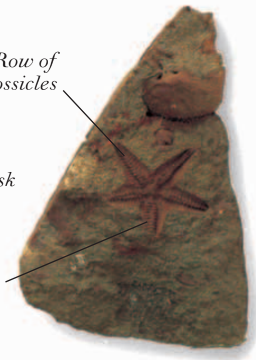
FOSSILIZED JAWLESS FISH



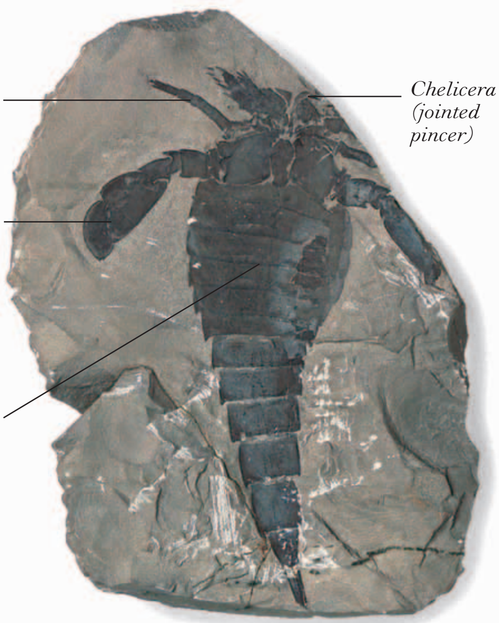
FOSSILIZED TRILOBITE

FOSSILIZED STARFISH

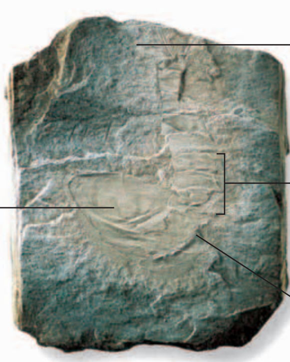
UPPER SURFACE OF FOSSILIZED STARFISH



LOWER SURFACE OF FOSSILIZED STARFISH



UNDERSIDE OF FOSSILIZED EURYPTERID



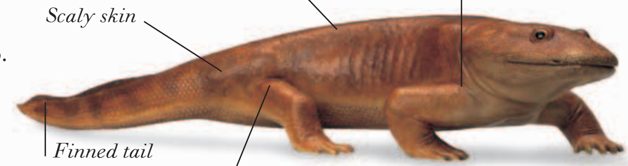
FOSSIL OF AN EXTINCT SHRIMP

RECONSTRUCTION OF ASTEROXYLON

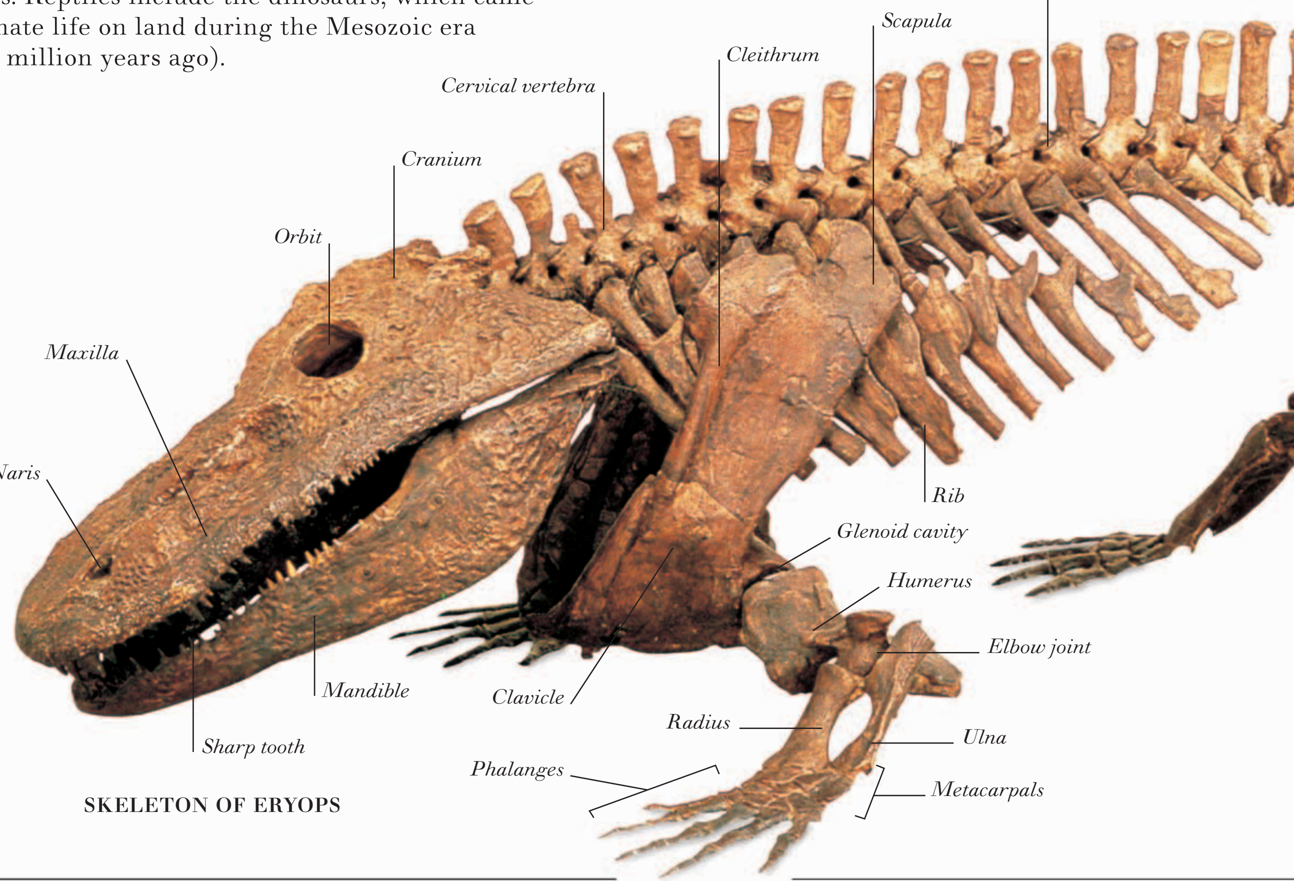
Amphibians and reptiles

THE EARLIEST KNOWN AMPHIBIANS, such as *Acanthostega* and *Ichthyostega*, lived about 363 million years ago at the end of the Devonian period (409–363 million years ago). Their limbs may have evolved from the muscular fins of lungfishlike creatures. These fish can use their fins to push themselves along the bottom of lakes and some can breathe at the water's surface. While amphibians (see pp. 182–183) can exist on land, they are dependent on a wet environment because their skin does not retain moisture and most species must return to the water to lay their eggs. Evolving from amphibians, reptiles (see pp. 184–187) first appeared during the Carboniferous period (363–290 million years ago): *Westlothiana*, a possible early reptile, lived on land 338 million years ago. The development of the amniotic egg, with an embryo enclosed in its own wet environment (the amnion) and protected by a waterproof shell, freed reptiles from the amphibian's dependence on a wet habitat. A scaly skin protected the reptile from desiccation on land and enabled it to exploit ways of life closed to its amphibian ancestors. Reptiles include the dinosaurs, which came to dominate life on land during the Mesozoic era (245–65 million years ago).

FOSSIL SKULL OF ACANTHOSTEGA

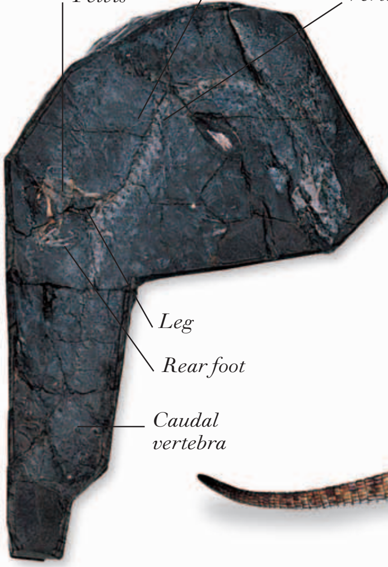


MODEL OF ICHTHYOSTEGA

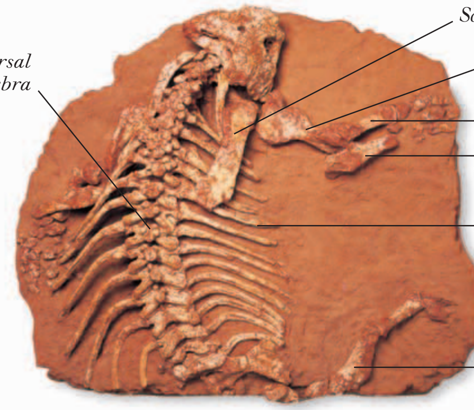


SKELETON OF ERYOPS

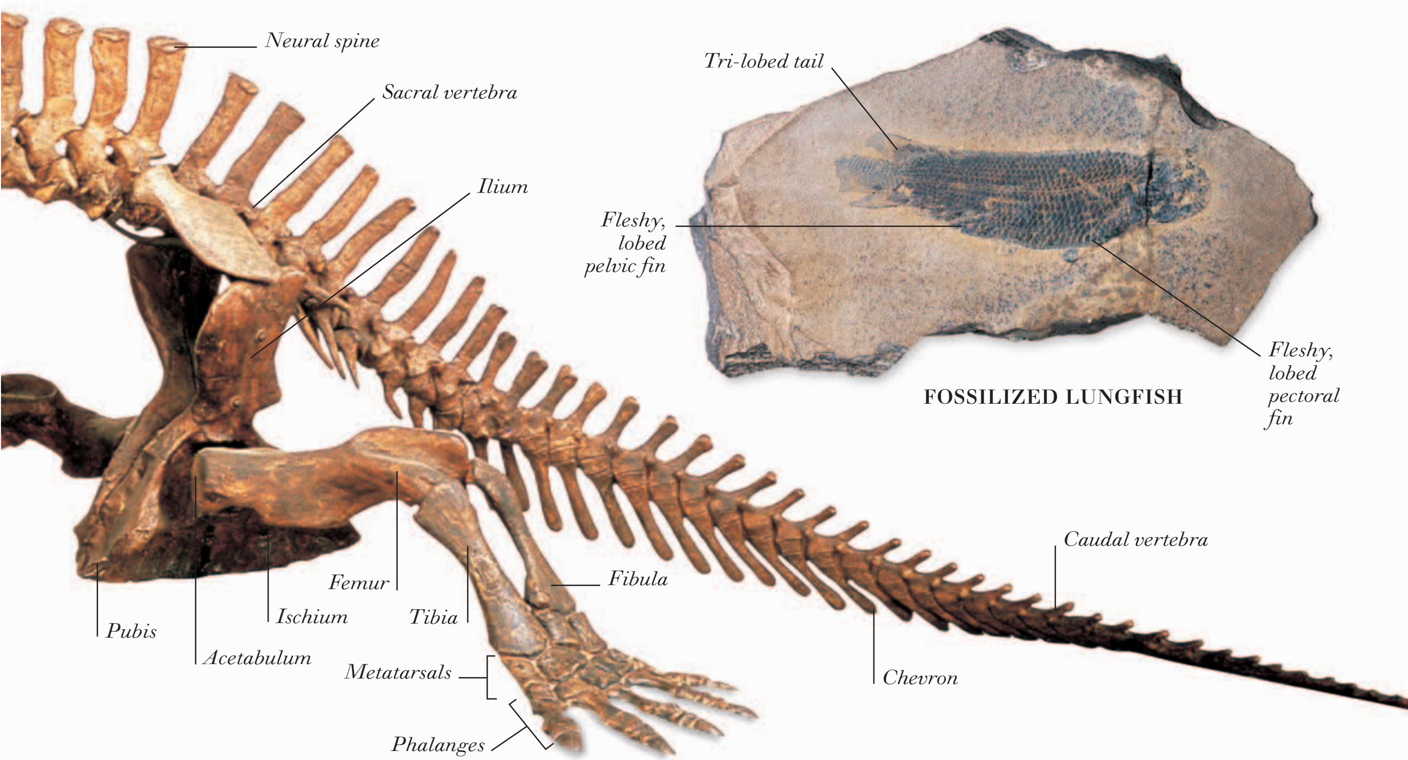
FOSSIL SKELETON OF WESTLOTHIANA



FOSSIL SKELETON OF A PAREIASAUR



MODEL OF WESTLOTHIANA

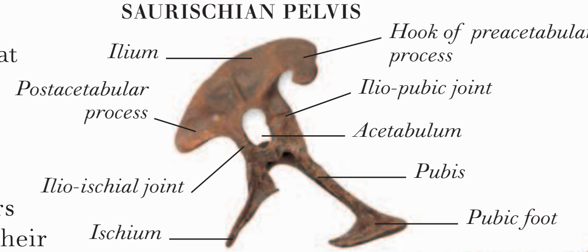


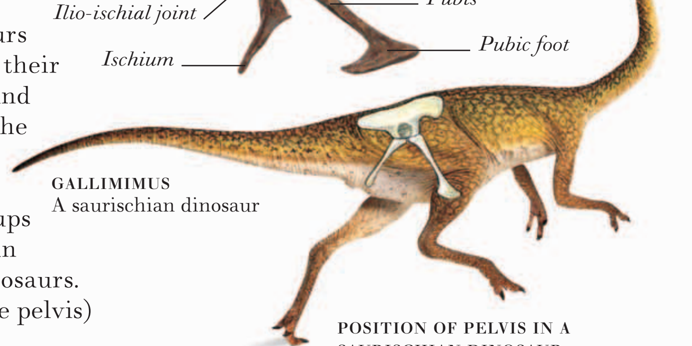
FOSSILIZED LUNGFISH

The dinosaurs

THE DINOSAURS WERE A LARGE GROUP of reptiles that were the dominant land vertebrates (animals with backbones) for most of the Mesozoic era (245–65 million years ago). They appeared some 230 million years ago and were distinguished from other scaly, egg-laying reptiles by an important feature: dinosaurs had an erect limb stance. This enabled them to keep their bodies well above the ground, unlike the sprawling and semisprawling stance of other reptiles. The head of the dinosaur's femur (thighbone) fit into a socket in its pelvis (hip-bone), producing efficient and mobile locomotion. Dinosaurs are categorized into two groups according to the structure of their pelvis: saurischian (lizard-hipped) and ornithischian (bird-hipped) dinosaurs. In the case of most saurischians, the pubis (part of the pelvis) jutted forward, while in ornithischians it slanted back, parallel to the ischium (another part of the pelvis). Dinosaurs ranged in size from smaller than a domestic cat to the biggest land animals ever known. The Dinosauria were the most successful land vertebrates ever, and survived for 165 million years, until most became extinct 65 million years ago.

STRUCTURE OF SAURISCHIAN PELVIS

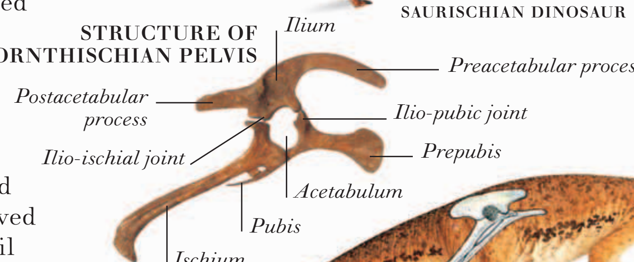


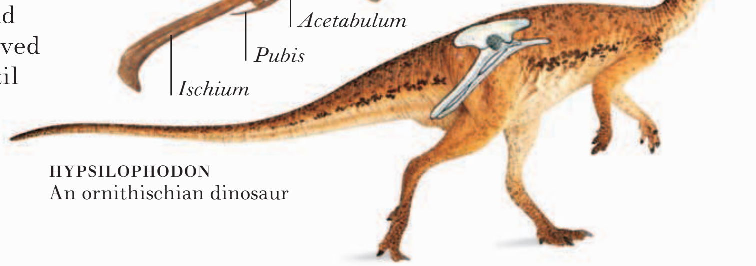


GALLIMIMUS
A saurischian dinosaur

POSITION OF PELVIS IN A SAURISCHIAN DINOSAUR

STRUCTURE OF ORNTHISCHIAN PELVIS



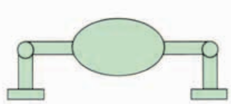


HYPSILOPHODON
An ornithischian dinosaur

POSITION OF PELVIS IN AN ORNITHISCHIAN DINOSAUR

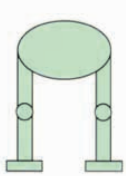
BAROSAURUS
A saurischian dinosaur

COMPARISON OF ANIMAL STANCES

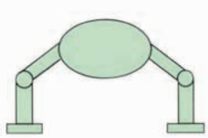


SPRAWLING STANCE
The thighs and upper arms project straight out from the body so that the knees and elbows are bent at right angles.

COMMON IGUANA
(Iguana iguana)
A present-day reptile



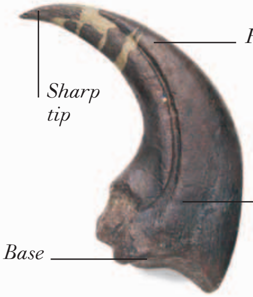
ERECT STANCE
The thighs and upper arms project straight down from the body so that the knees and elbows are straight.



SEMISPRAWLING STANCE
The thighs and upper arms project downwards and outwards so that the knees and elbows are slightly bent.

DWARF CROCODILE
(Osteolaemus tetraspis)
A present-day reptile

EXAMPLES OF DINOSAUR CLAWS



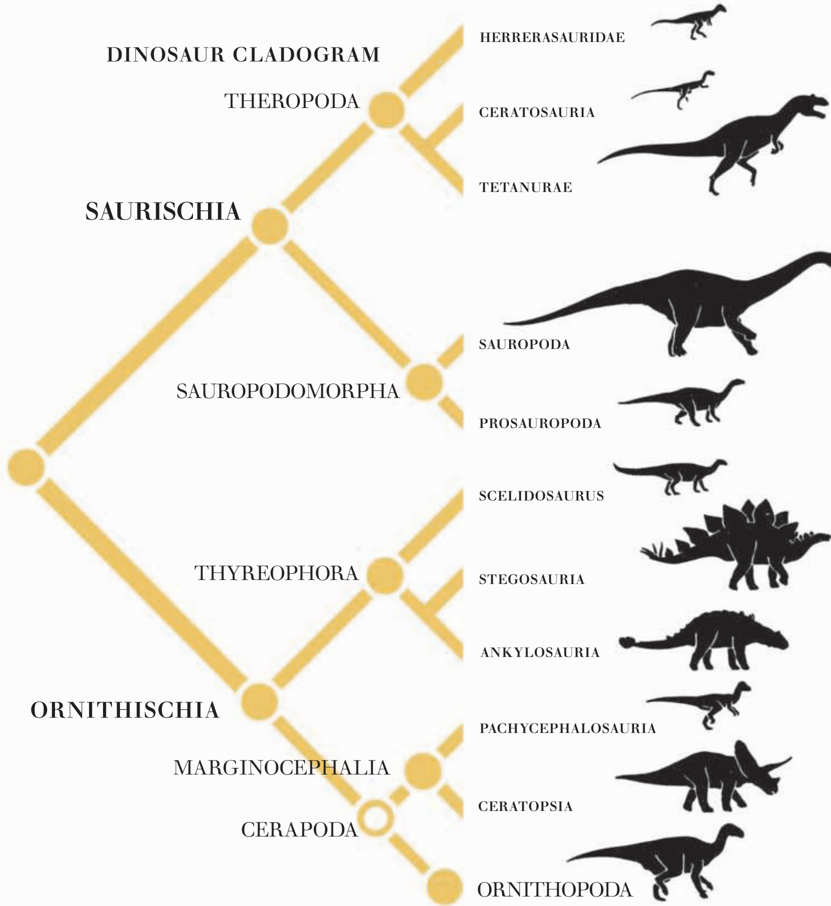
BARYONYX THUMB-CLAW

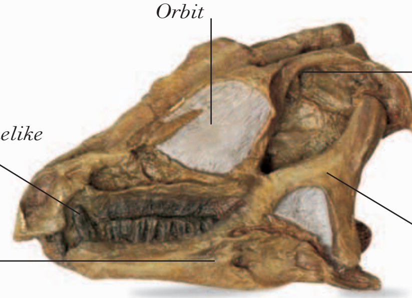
MASSOSPONDYLUS THUMB-CLAW

APATOSAURUS THUMB-CLAW

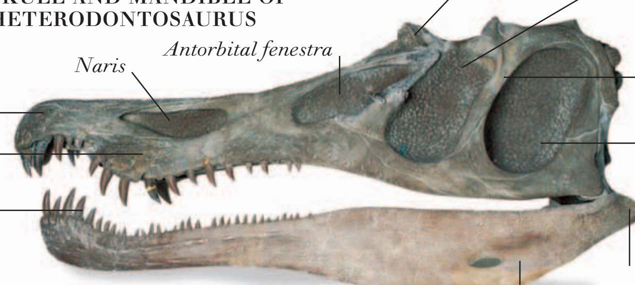
ORNITHOMIMUS FINGER-CLAW

DINOSAUR CLADOGRAM





SKULL AND MANDIBLE OF HETERODONTOSAURUS

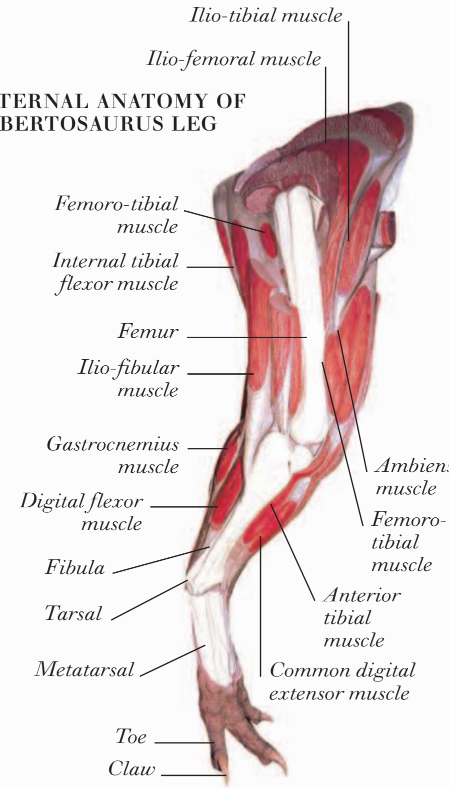


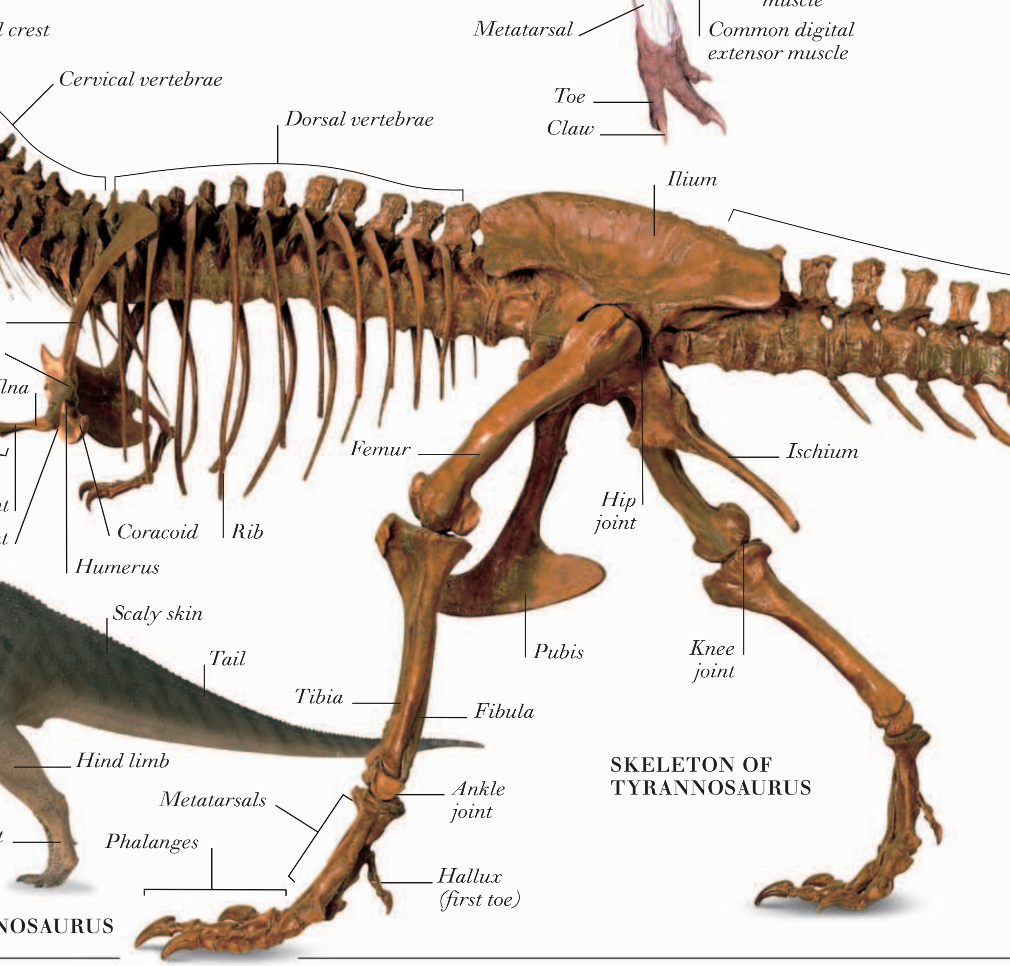
SKULL AND MANDIBLE OF BARYONYX

Theropods 1

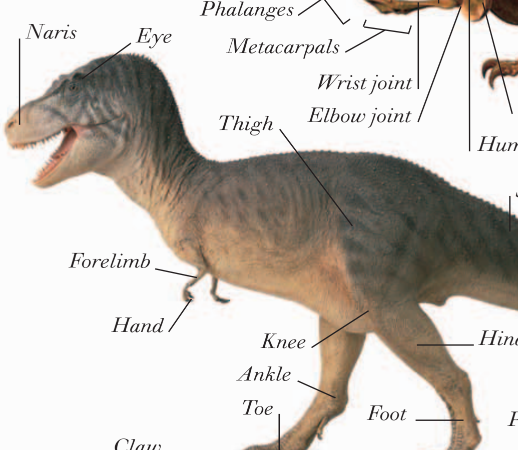
AN ENORMOUSLY SUCCESSFUL SUBGROUP of the Saurischia, the bipedal (two-footed) theropods ("beast feet") emerged 230 million years ago in Late Triassic times; the oldest known example comes from South America. Theropods spanned the age of most dinosaurs (230–65 million years ago) and beyond, and included most of the known predatory dinosaurs. The typical theropod had smallish arms with sharp, clawed fingers; powerful jaws lined with sharp teeth; an S-shaped neck; long, muscular hind limbs; and clawed, usually four-toed feet. Many theropods may have been warm-blooded; most were exclusively carnivorous. Theropods ranged from animals no larger than a chicken to huge creatures, such as *Tyrannosaurus* and *Baryonyx*. The group also included ostrichlike omnivores and herbivores with toothless beaks, such as *Struthiomimus* and *Gallimimus*. Birds are dinosaurs and evolved from within a group of tetanuran theropods called maniraptorans. *Archaeopteryx*, small and feathered, was the first known bird and lived alongside other dinosaurs.

INTERNAL ANATOMY OF ALBERTOSAURUS LEG



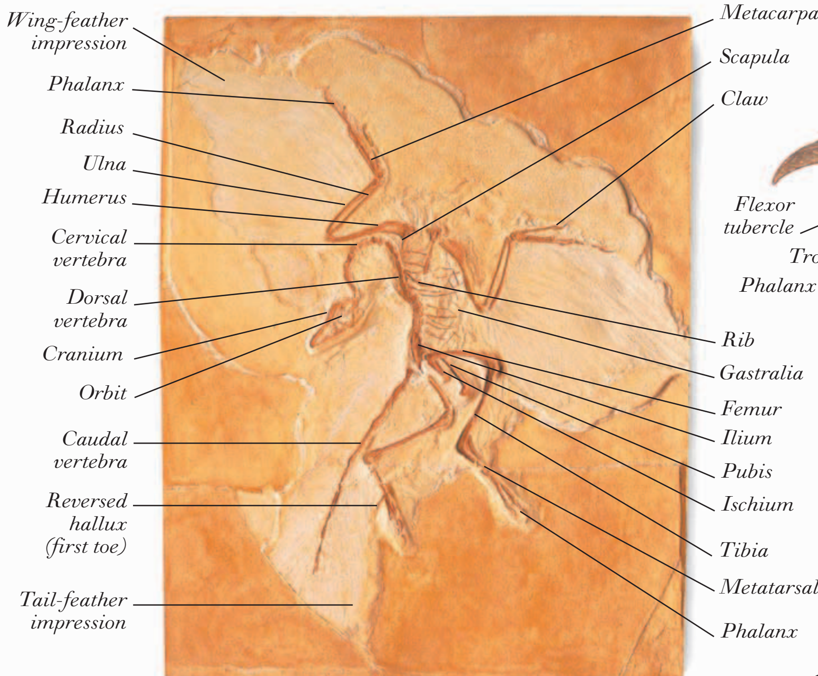


SKELETON OF TYRANNOSAURUS

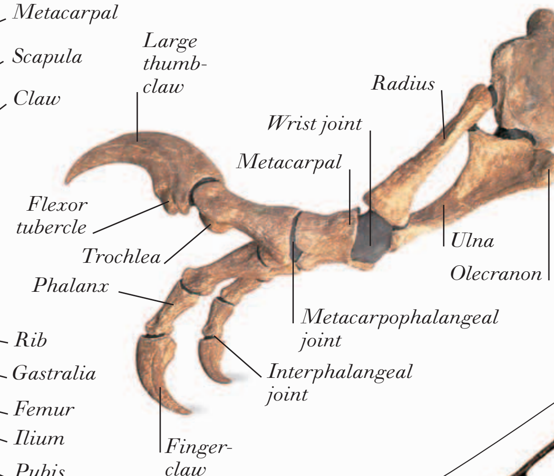


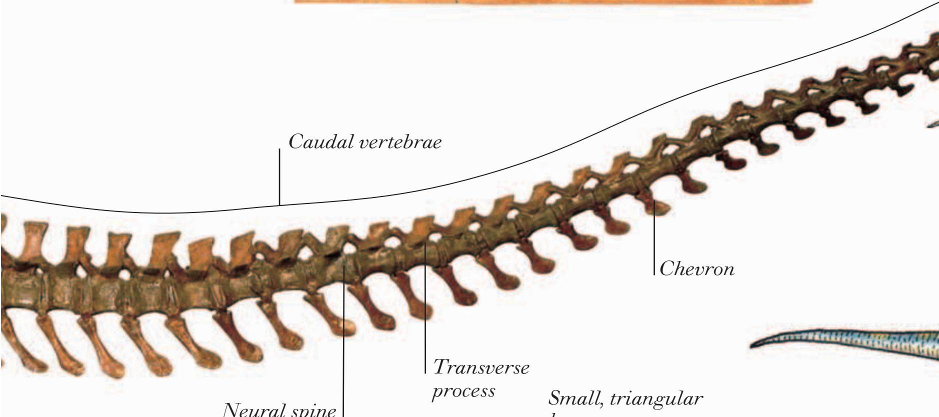
EXTERNAL FEATURES OF TYRANNOSAURUS

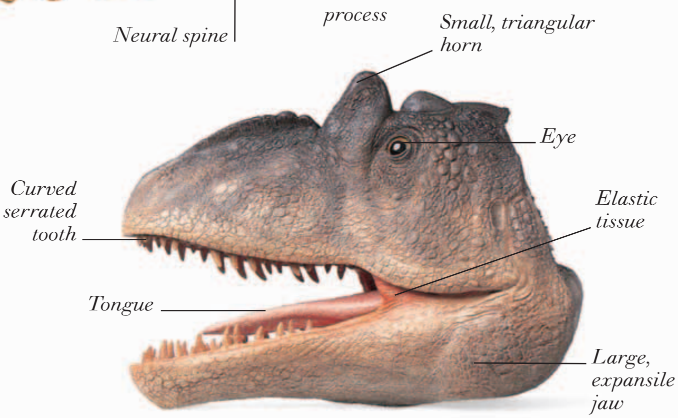
FOSSIL SKELETON OF ARCHAEOPTERYX



SKELETON OF BARYONYX HAND

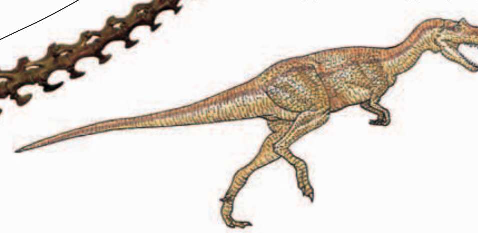




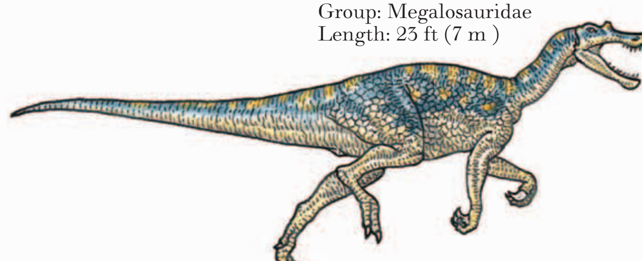


HEAD OF ALLOSAURUS

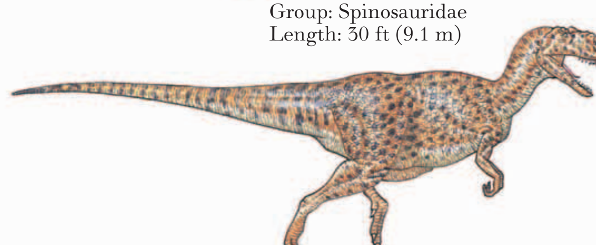
EXAMPLES OF LARGE THEROPODS



EUSTREPTOSPONDYLUS
Group: Megalosauridae
Length: 23 ft (7 m)



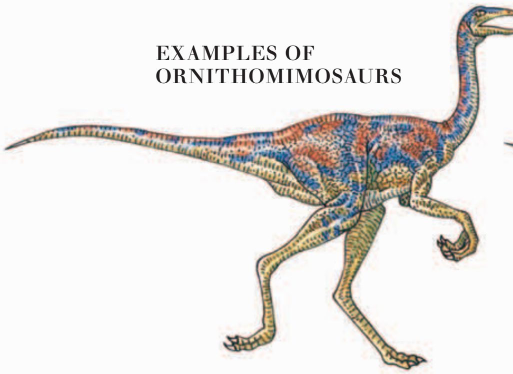
BARYONYX
Group: Spinosauridae
Length: 30 ft (9.1 m)



YANGCHUANOSAURUS
Group: Sinraptoridae
Length: 33 ft (10 m)

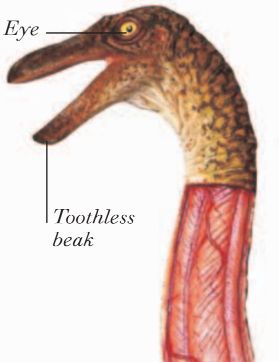
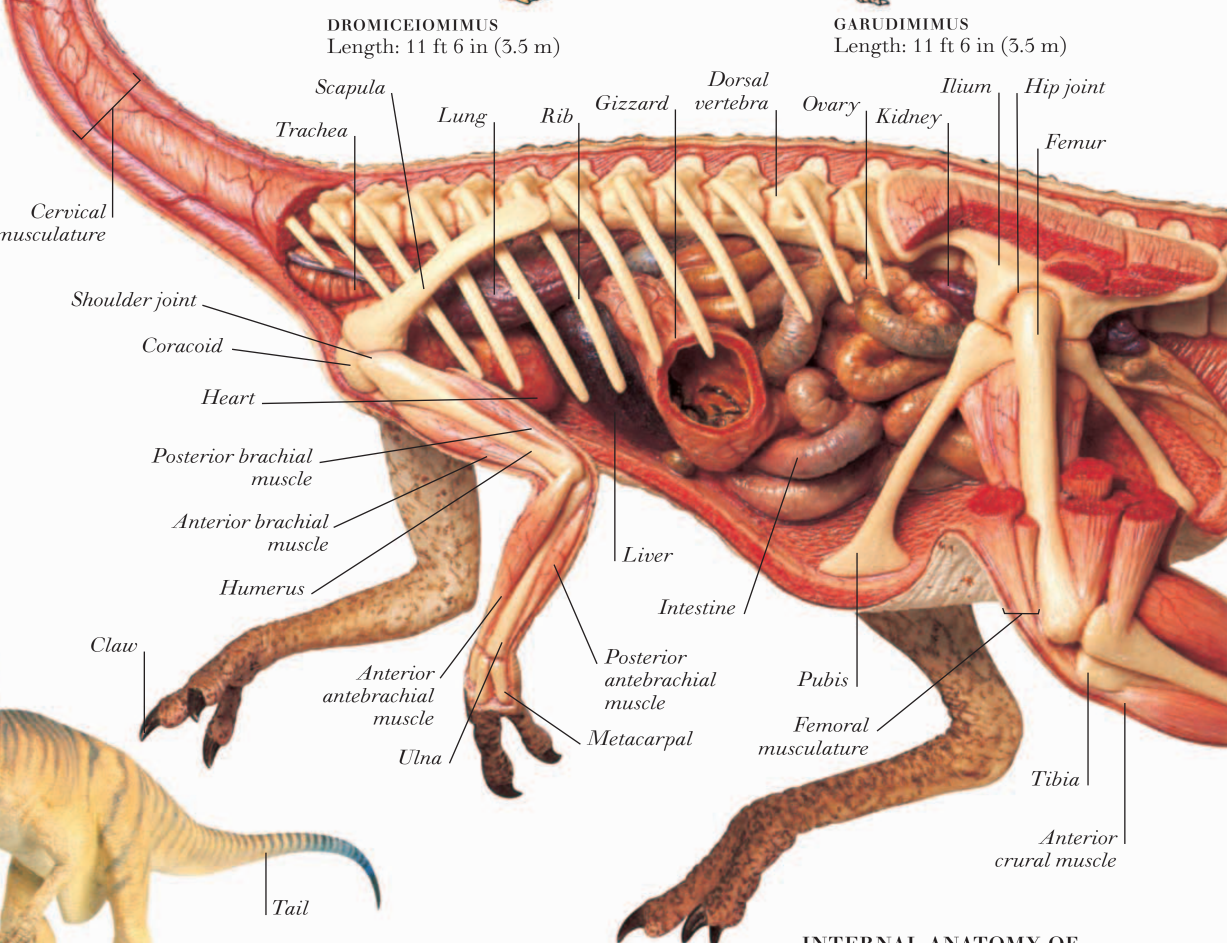
Theropods 2

EXAMPLES OF ORNITHOMIMOSAURS

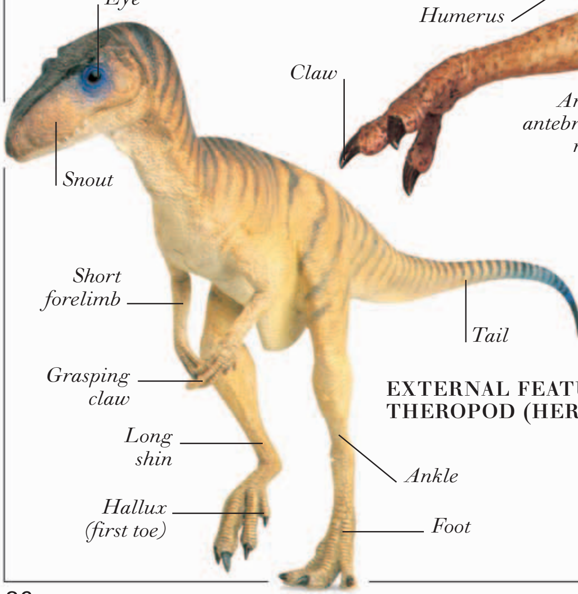


DROMICEIOMIMUS
Length: 11 ft 6 in (3.5 m)

GARUDIMIMUS
Length: 11 ft 6 in (3.5 m)

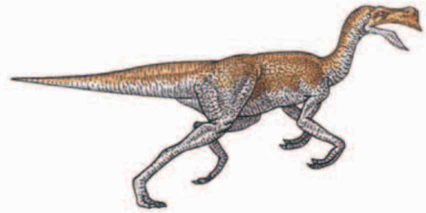
INTERNAL ANATOMY OF FEMALE GALLIMIMUS



EXTERNAL FEATURES OF AN EARLY THEROPOD (HERRERASAURUS)

EXAMPLES OF SMALL THEROPODS

STRUTHIOMIMUS
Length: 11 ft 6 in (3.5 m)

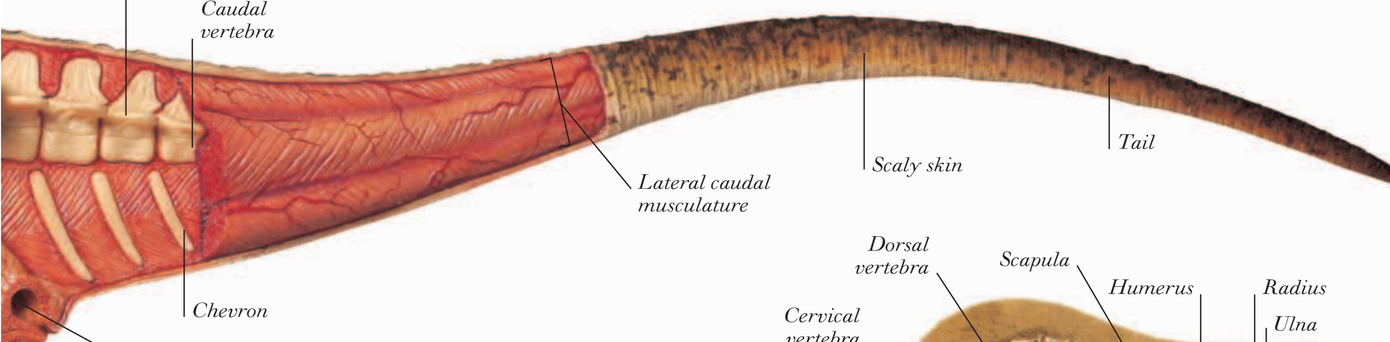


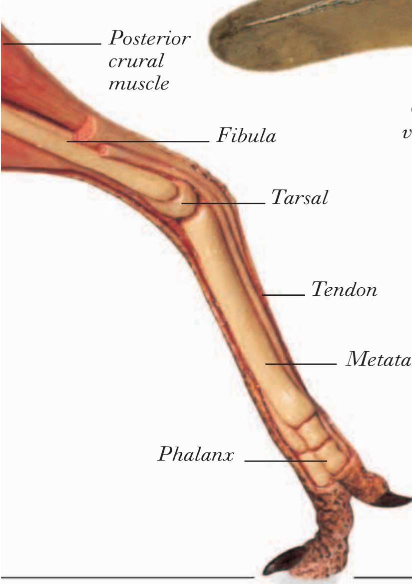
CHIROSTENOTES
Length: 6 ft 6 in (2 m)

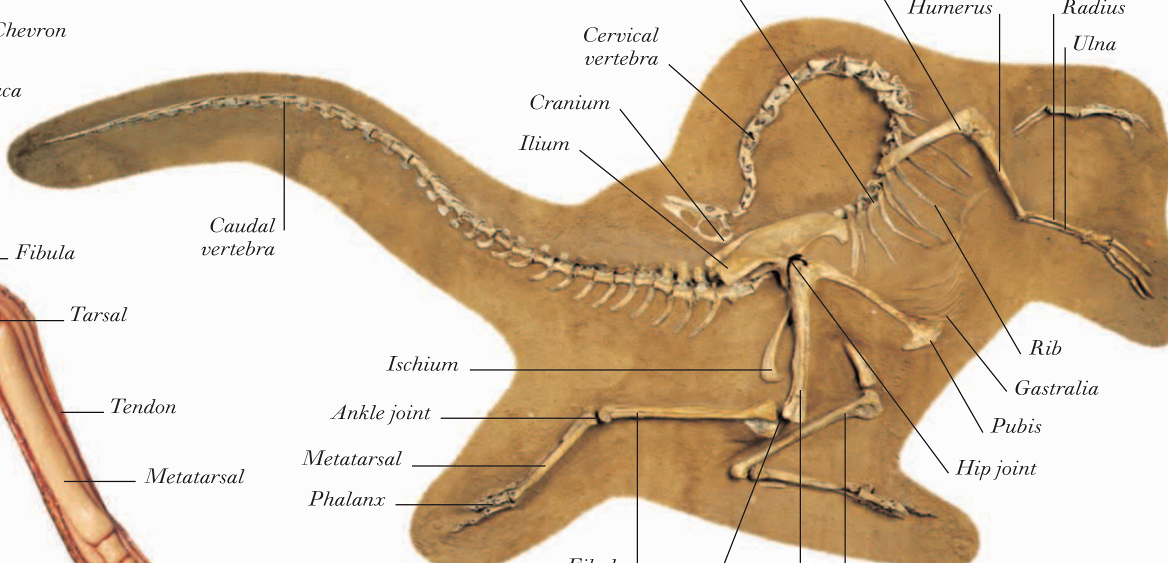
AVIMIMUS
Length: 5 ft (1.5 m)

COELURUS
Length: 6 ft (1.8 m)

PROCOMPSOGNATHUS
Length: 4 ft (1.2 m)







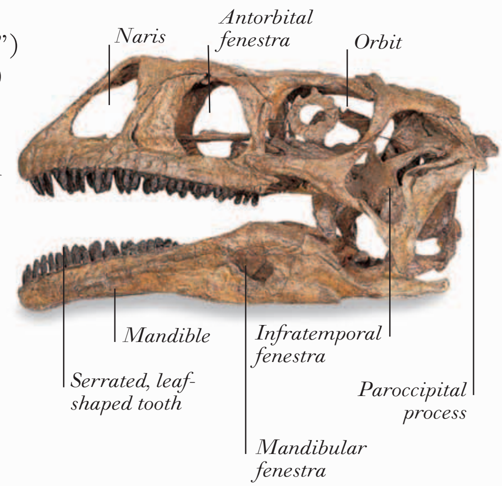
FOSSIL SKELETON OF STRUTHIOMIMUS

Sauropodomorphs 1

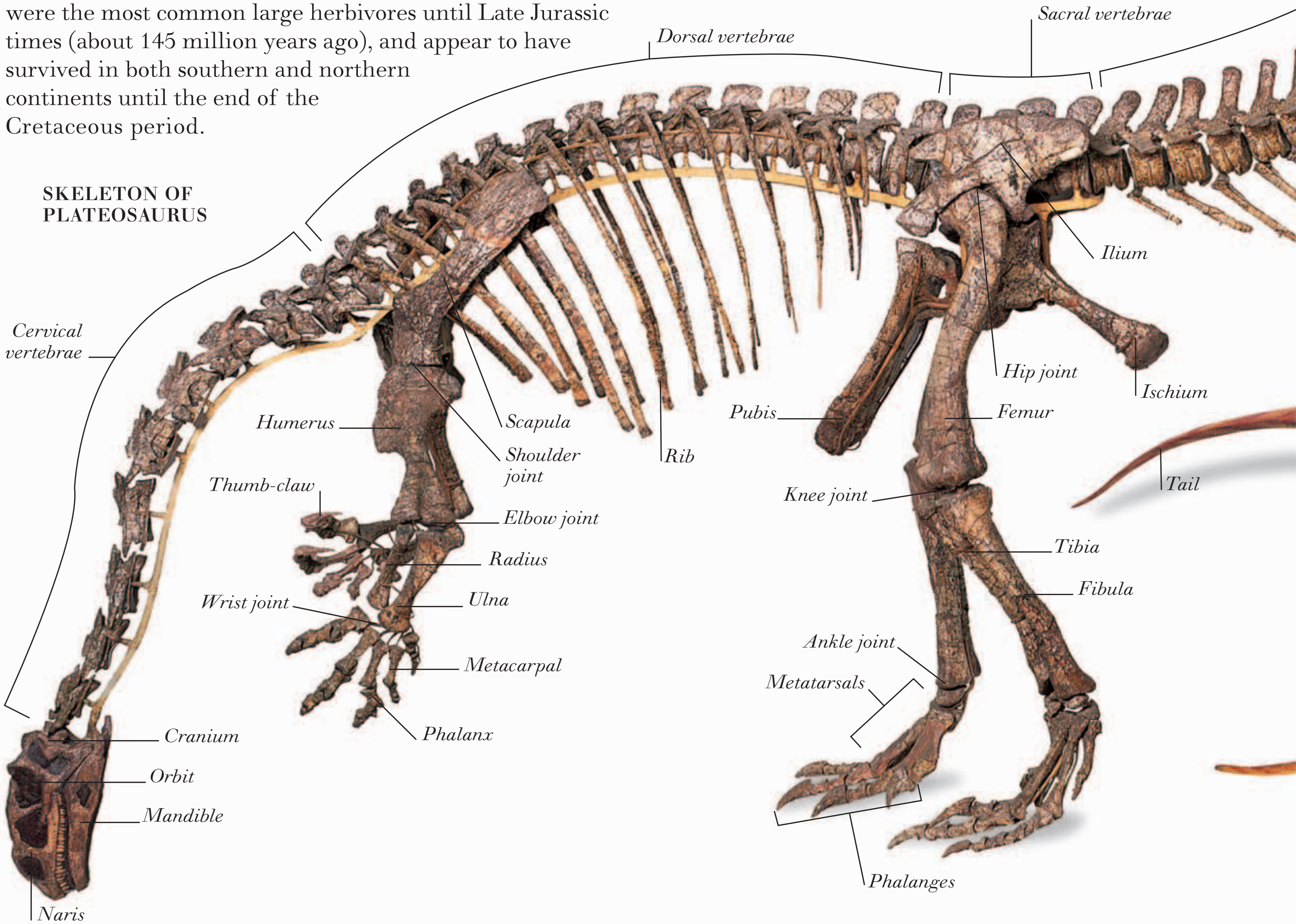
THECODONTOSAURUS

THE SAUROPODOMORPHA ("lizard-feet forms") were herbivorous, usually quadrupedal (four-footed) dinosaurs. A suborder of the Saurischia, they were characterized by small heads, bulky bodies, and long necks and tails. Sauropodomorphs have often been split into two groups: prosauropods and sauropods. Prosauropods lived from Late Triassic to Early Jurassic times (225–180 million years ago) and included beasts such as the small *Anchisaurus* and one of the first very large dinosaurs, *Plateosaurus*. By Middle Jurassic times (about 165 million years ago), sauropods had replaced prosauropods and spread worldwide. They included the heaviest and longest land animals ever, such as *Diplodocus* and *Brachiosaurus*. Sauropods persisted to the end of the Cretaceous period (65 million years ago). Many of these dinosaurs moved in herds, protected from predatory theropods by their huge bulk and powerful tails, which they could use to lash out at attackers. Sauropodomorphs were the most common large herbivores until Late Jurassic times (about 145 million years ago), and appear to have survived in both southern and northern continents until the end of the Cretaceous period.

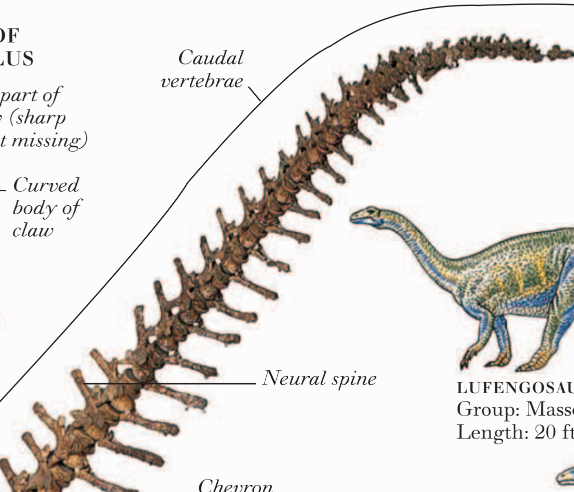
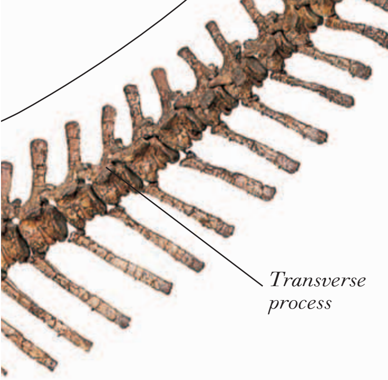
SKULL AND MANDIBLE OF PLATEOSAURUS



SKELETON OF PLATEOSAURUS



THUMB-CLAW OF MASSOSPONDYLUS

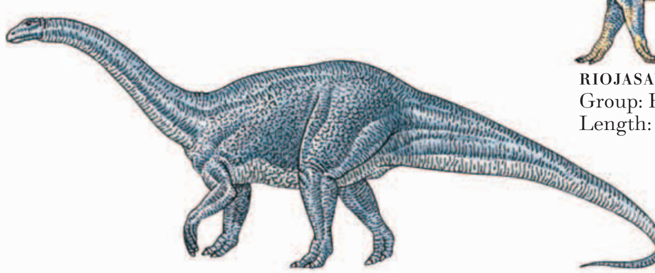



EXAMPLES OF PROSAUROPODS

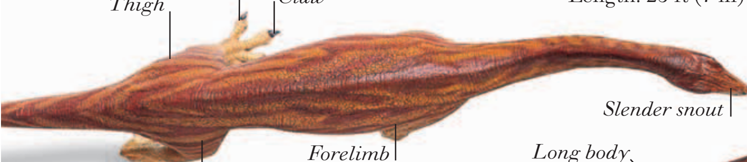
MASSOSPONDYLUS
Group: Massospondylidae
Length: 16 ft (5 m)

LUFENGOSAURUS
Group: Massospondylidae
Length: 20 ft (6.1 m)

RIOJASAURUS
Group: Riojasauridae
Length: 36 ft (11 m)

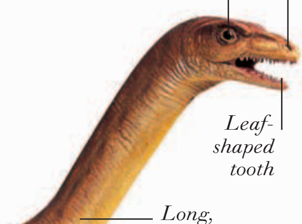
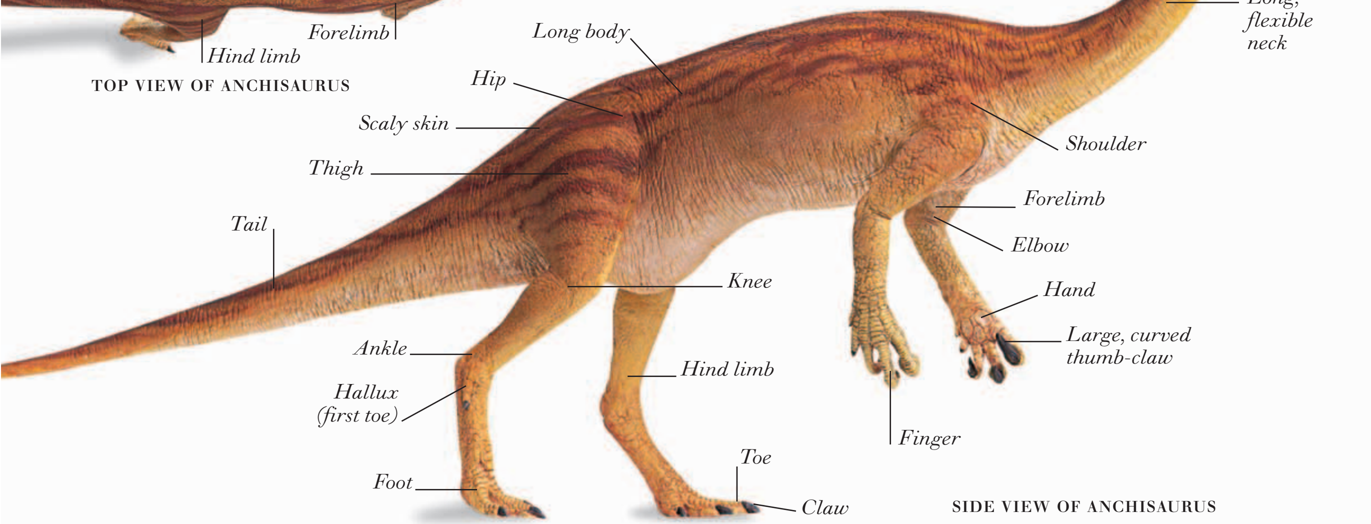


MELANOROSAURUS
Group: Melanorosauridae
Length: 23 ft (7 m)



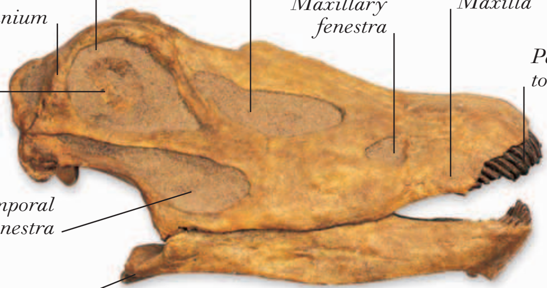
TOP VIEW OF ANCHISAURUS

EXTERNAL FEATURES OF ANCHISAURUS

SIDE VIEW OF ANCHISAURUS

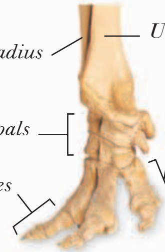
Sauropodomorphs 2



SKULL AND MANDIBLE OF DIPLODOCUS

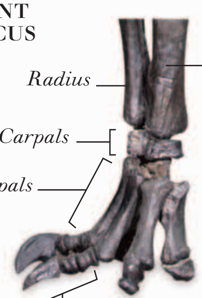
FOREFOOT OF ELEPHANT

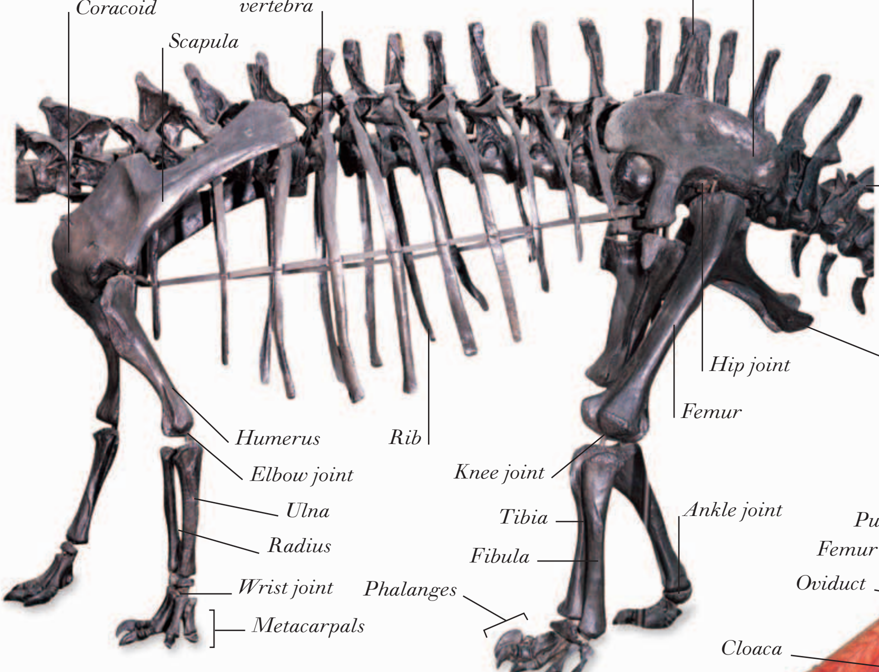
FOREFOOT BONES OF ELEPHANT



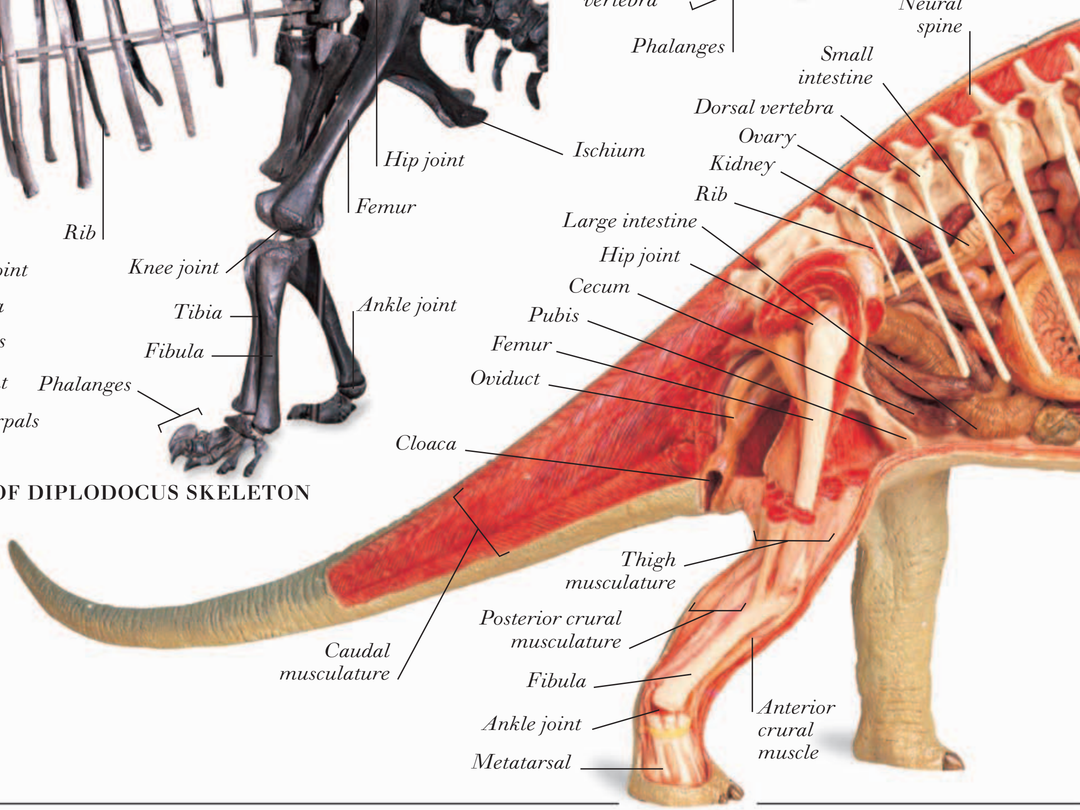
COMPARISON OF THE FOREFEET OF AN ELEPHANT AND DIPLODOCUS

FOREFOOT BONES OF DIPLODOCUS

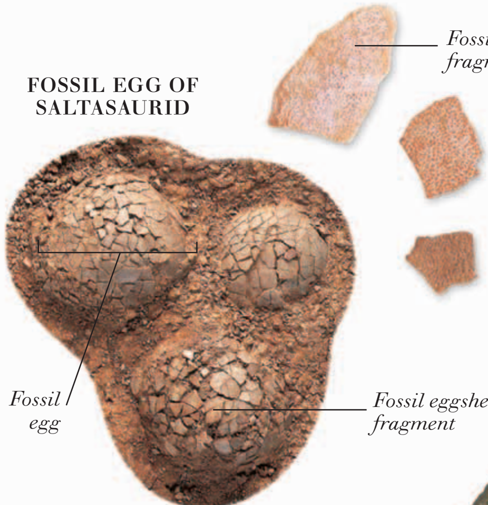




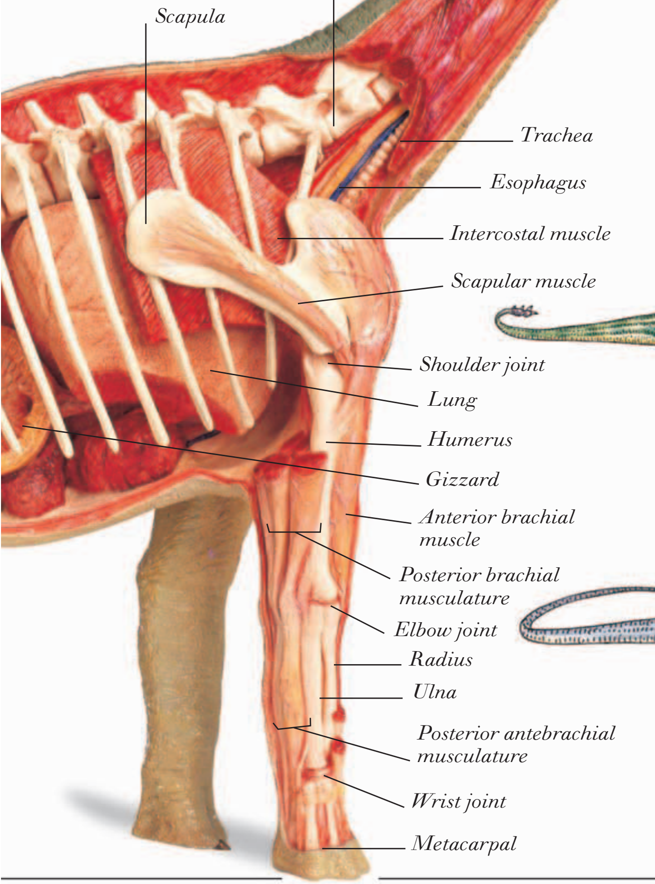
MIDDLE SECTION OF DIPLODOCUS SKELETON



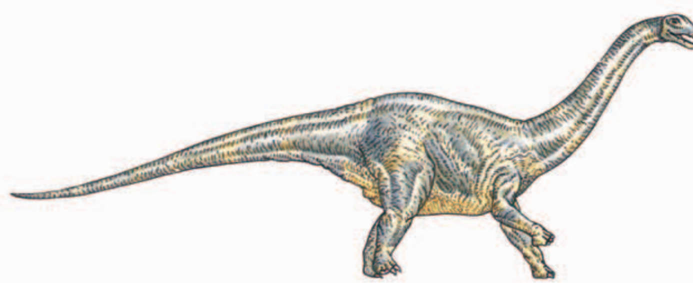
FOSSIL EGG OF SALTASAURID



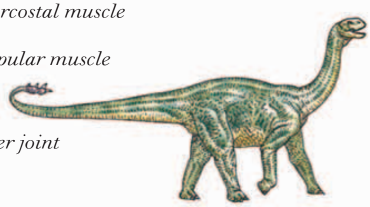
INTERNAL ANATOMY OF FEMALE BRACHIOSAURUS



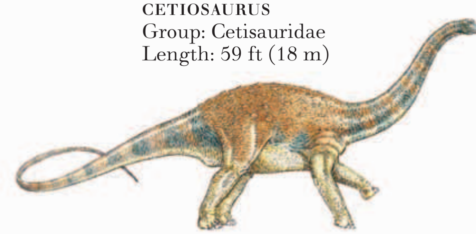
SKULL AND MANDIBLE OF CAMARASAURUS



CETIOSAURUS
Group: Cetisauridae
Length: 59 ft (18 m)



SHUNOSAURUS
Group: Eusauropoda
Length: 33 ft (10 m)

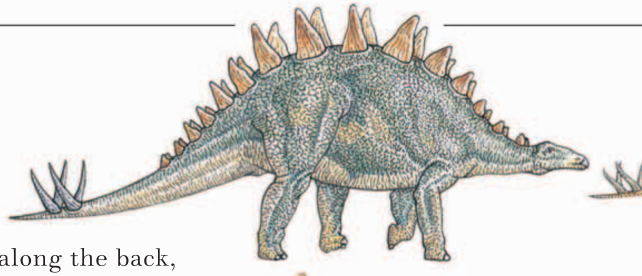


SALTASAURUS
Group: Saltasauridae
Length: 40 ft (12.2 m)

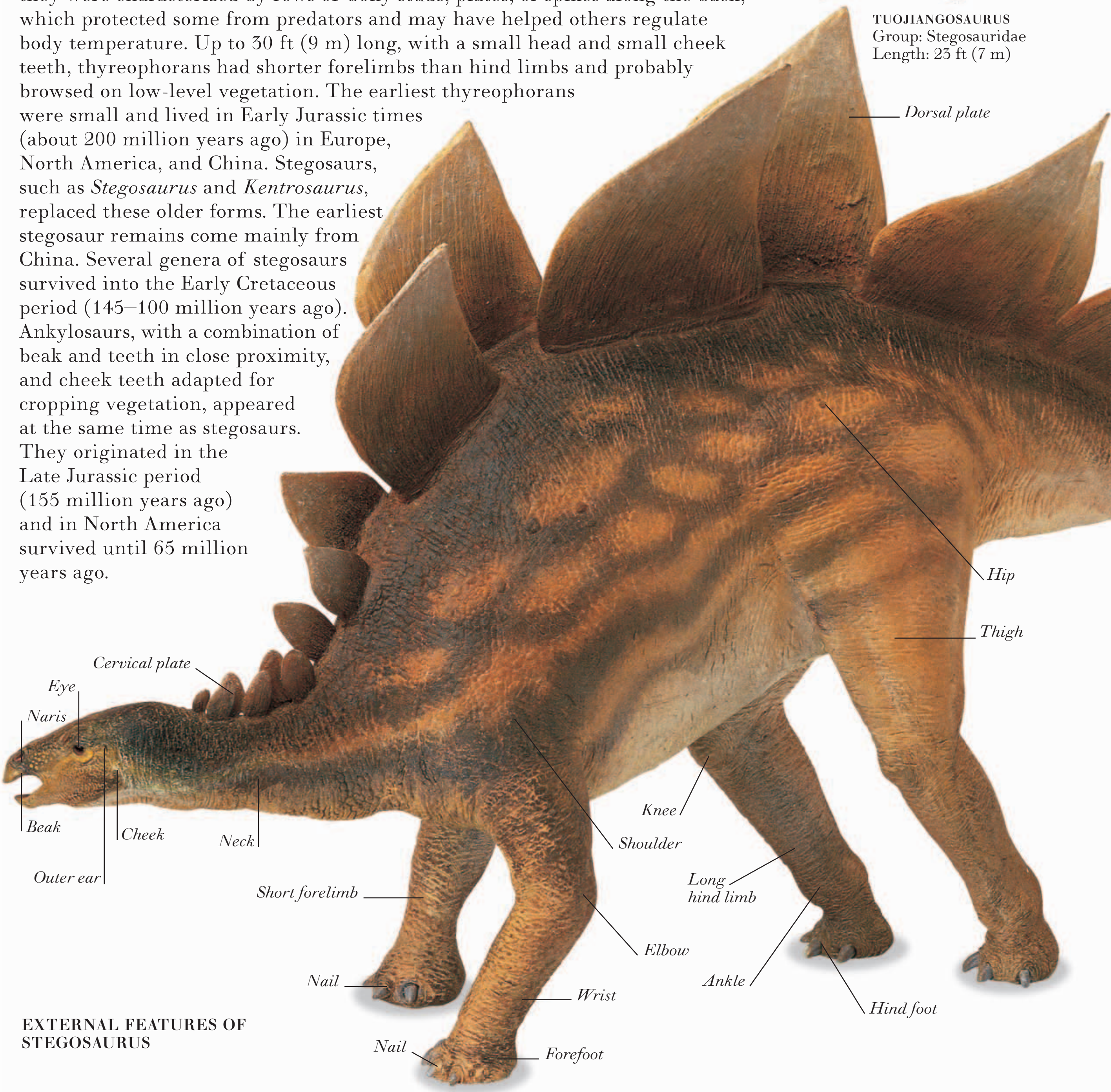
DIPLODOCUS
Group: Diplodocidae
Length: 90 ft (27.4 m)

Thyreophorans 1

THYREOPHORANS ("SHIELD BEARERS") were a group of quadrupedal armored dinosaurs. They were one clade among several within the Ornithischia (bird-hipped dinosaurs), they were characterized by rows of bony studs, plates, or spikes along the back, which protected some from predators and may have helped others regulate body temperature. Up to 30 ft (9 m) long, with a small head and small cheek teeth, thyreophorans had shorter forelimbs than hind limbs and probably browsed on low-level vegetation. The earliest thyreophorans were small and lived in Early Jurassic times (about 200 million years ago) in Europe, North America, and China. Stegosaurs, such as *Stegosaurus* and *Kentrosaurus*, replaced these older forms. The earliest stegosaur remains come mainly from China. Several genera of stegosaurs survived into the Early Cretaceous period (145–100 million years ago). Ankylosaurs, with a combination of beak and teeth in close proximity, and cheek teeth adapted for cropping vegetation, appeared at the same time as stegosaurs. They originated in the Late Jurassic period (155 million years ago) and in North America survived until 65 million years ago.

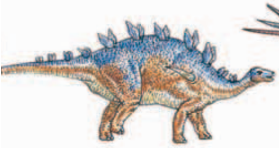


TUOJIANGOSAURUS
Group: Stegosauridae
Length: 23 ft (7 m)

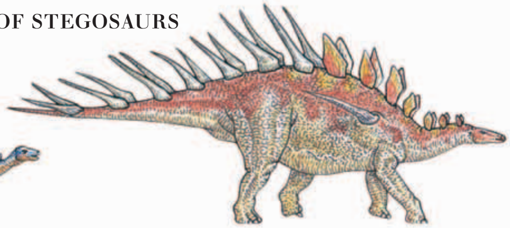


EXTERNAL FEATURES OF STEGOSAURUS

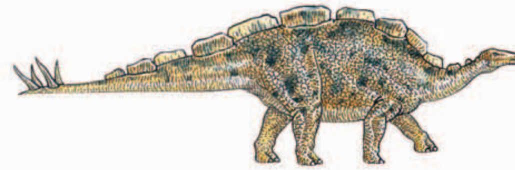
EXAMPLES OF STEGOSAURS



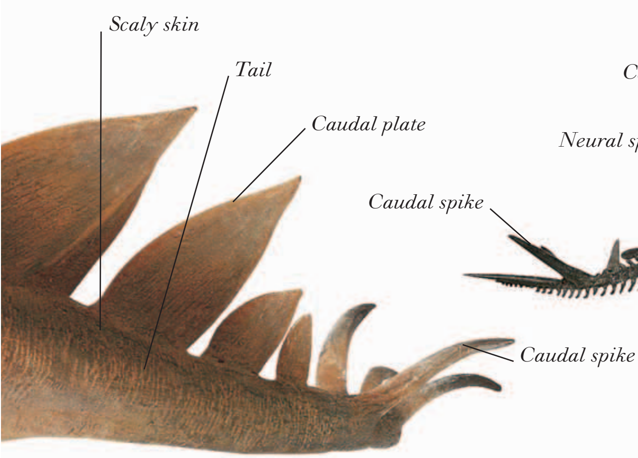
HUAYANGOSAURUS
Group: Huayangosauridae
Length: 13 ft (4 m)



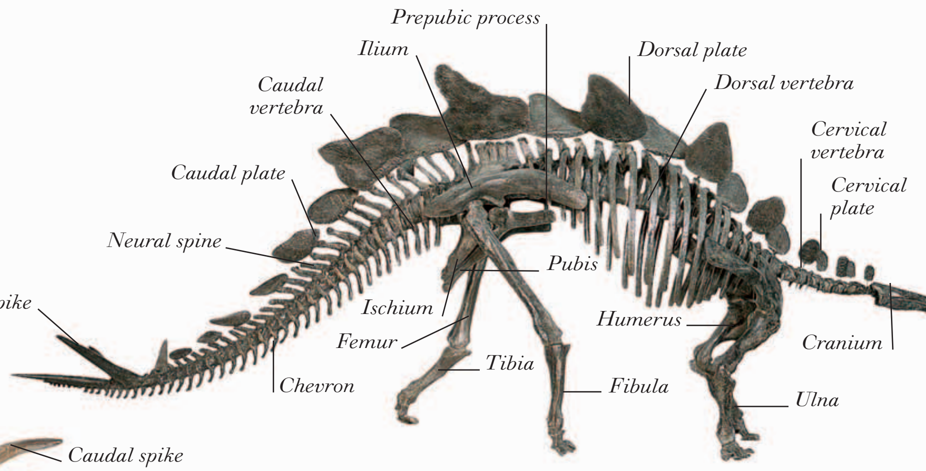
KENTROSAURUS
Group: Stegosauridae
Length: 16 ft (4.9 m)



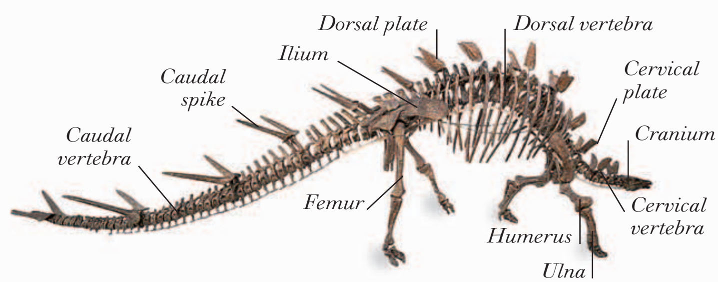
WUERHOSAURUS
Group: Stegosauridae
Length: 20 ft (6.1 m)



EXAMPLES OF STEGOSAUR SKELETONS

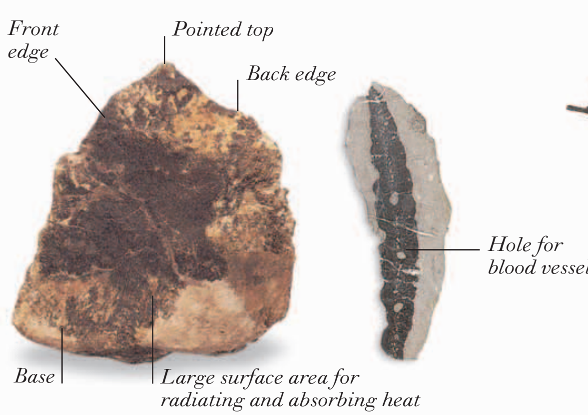


STEGOSAURUS



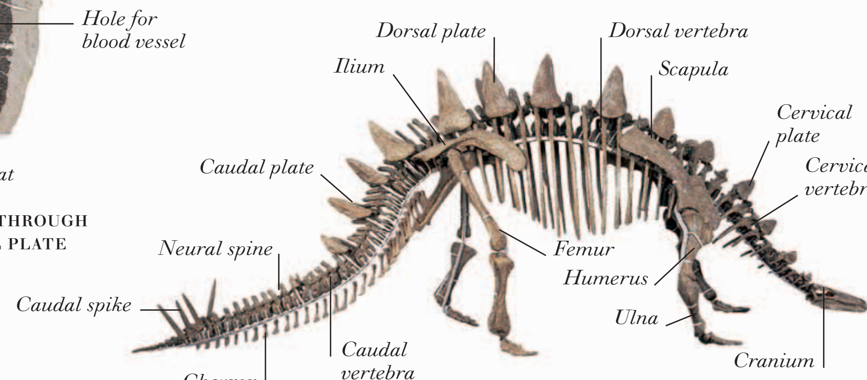
KENTROSAURUS

DORSAL PLATE OF STEGOSAURUS



SIDE VIEW OF DORSAL PLATE

SECTION THROUGH DORSAL PLATE

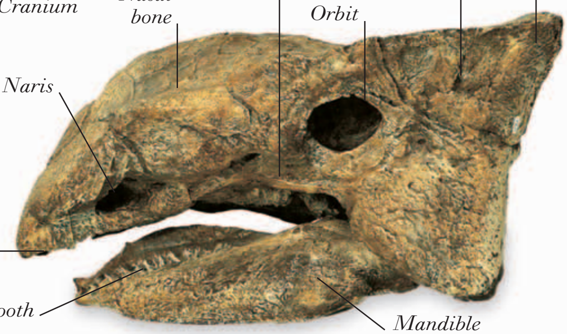


TUOJIANGOSAURUS

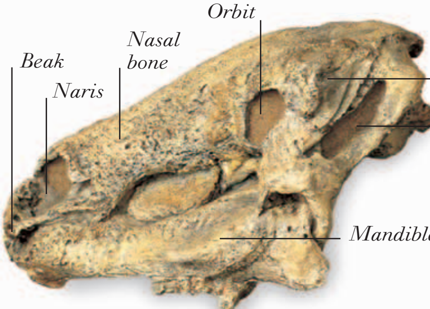
Thyreophorans 2

EXAMPLES OF ANKYLOSAUR SKULLS

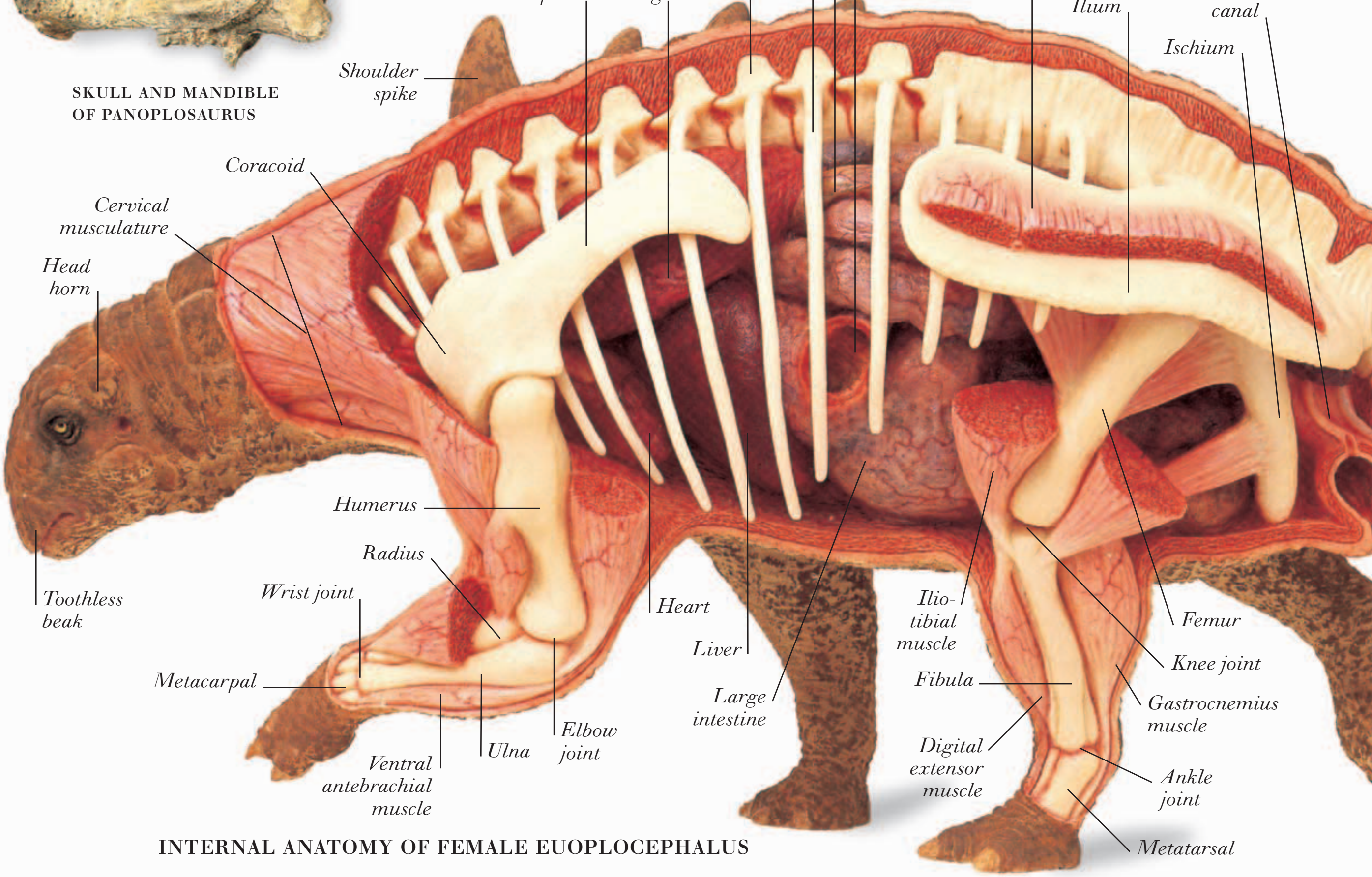
SKULL AND MANDIBLE OF EUOPLOCEPHALUS



SKULL AND MANDIBLE OF ANKYLOSAURUS

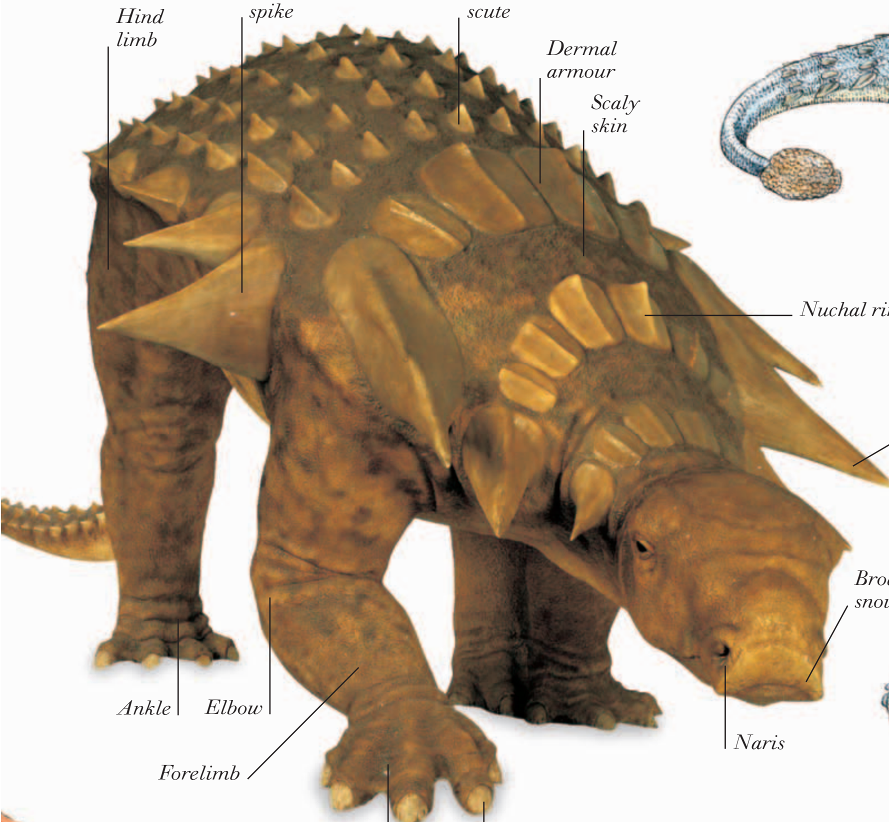


SKULL AND MANDIBLE OF PANOPLOSAURUS

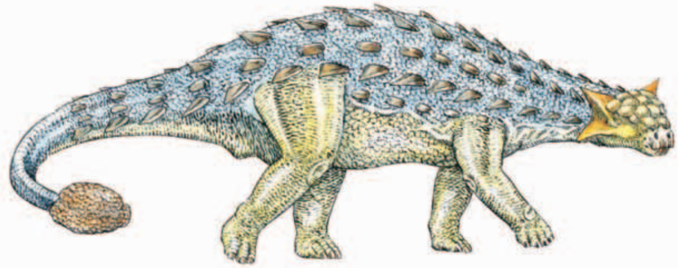


INTERNAL ANATOMY OF FEMALE EUOPLOCEPHALUS

EXTERNAL FEATURES OF EDMONTONIA

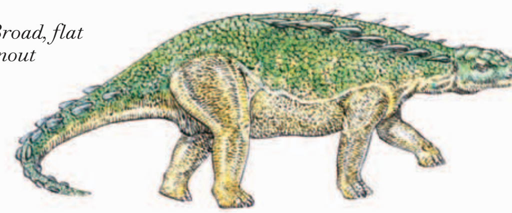


EXAMPLES OF ANKYLOSAURS



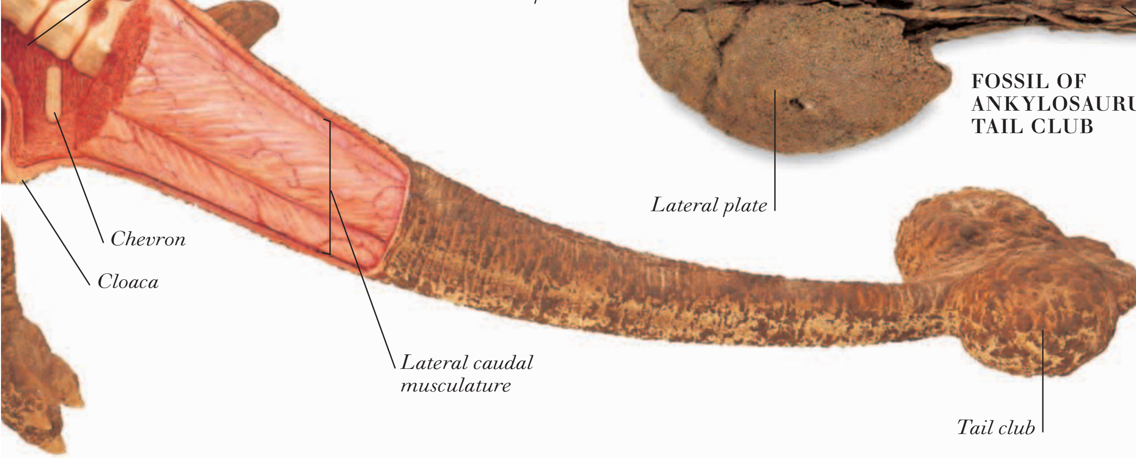
PINACOSAURUS
Group: Ankylosauridae
Length: 5 m (16 ft 6 in)

MINMI
Group: Ankylosauria
Length: 2.4 m (8 ft)



POLACANTHUS
Group: Polacanthidae
Length: 4 m (13 ft)

FOSSIL OF ANKYLOSAURUS TAIL CLUB

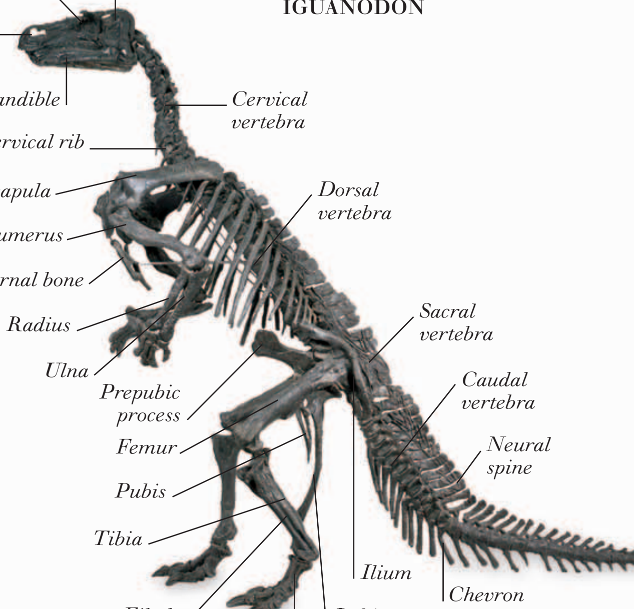


Ornithopods 1

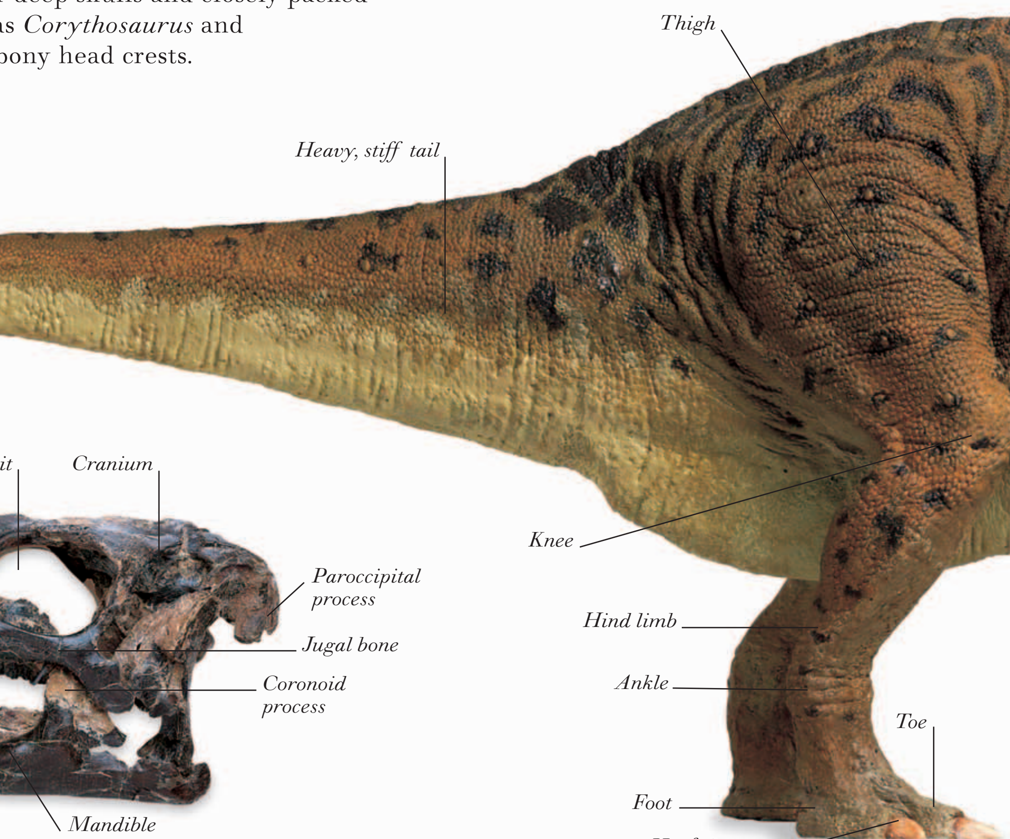
IGUANODON TOOTH

ORNITHOPODS ("BIRD FEET") were a group of ornithischian ("bird-hipped") dinosaurs. These bipedal and quadrupedal herbivores had a horny beak, plant-cutting or grinding cheek teeth, and a pelvic and tail region stiffened by bony tendons. They evolved teeth and jaws adapted to pulping vegetation and flourished from the Middle Jurassic to the Late Cretaceous period (165–65 million years ago) in North America, Europe, Africa, China, Australia, and Antarctica. Some ornithopods were no larger than a dog, while others were immense creatures up to 49 ft (15 m) long. Iguanodonts, an ornithopod group, had a broad, toothless beak at the end of a long snout, large jaws with long rows of ridged, closely packed teeth for grinding vegetation, a bulky body, and a heavy tail. *Iguanodon* and some other iguanodonts had large thumb-spikes that were strong enough to stab attackers. Another group, the hadrosaurs, such as *Gryposaurus* and *Hadrosaurus*, lived in Late Cretaceous times (97–65 million years ago) and with their broad beaks are sometimes known as "duckbills." They were characterized by their deep skulls and closely packed rows of teeth, while some, such as *Corythosaurus* and *Lambeosaurus*, had tall, hollow, bony head crests.

SKELETON OF IGUANODON

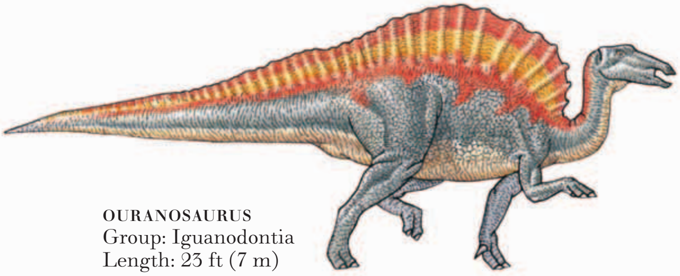


EXTERNAL FEATURES OF MANTELLISAURUS

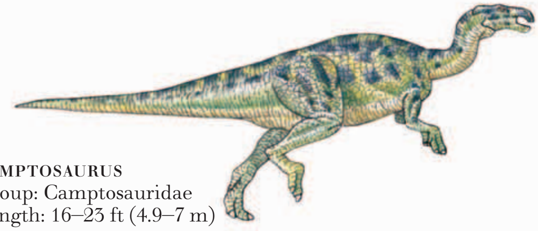


SKULL AND MANDIBLE OF YOUNG MANTELLISAURUS

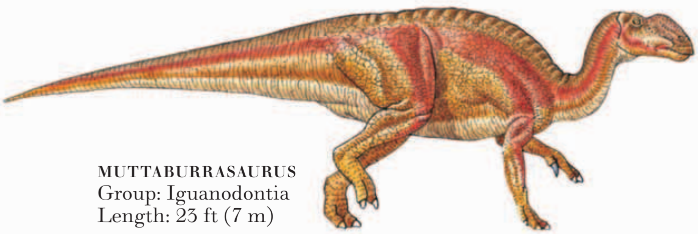
EXAMPLES OF IGUANODONTS



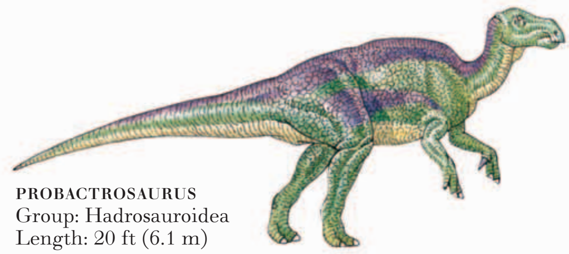
OURANOSAURUS
Group: Iguanodontia
Length: 23 ft (7 m)



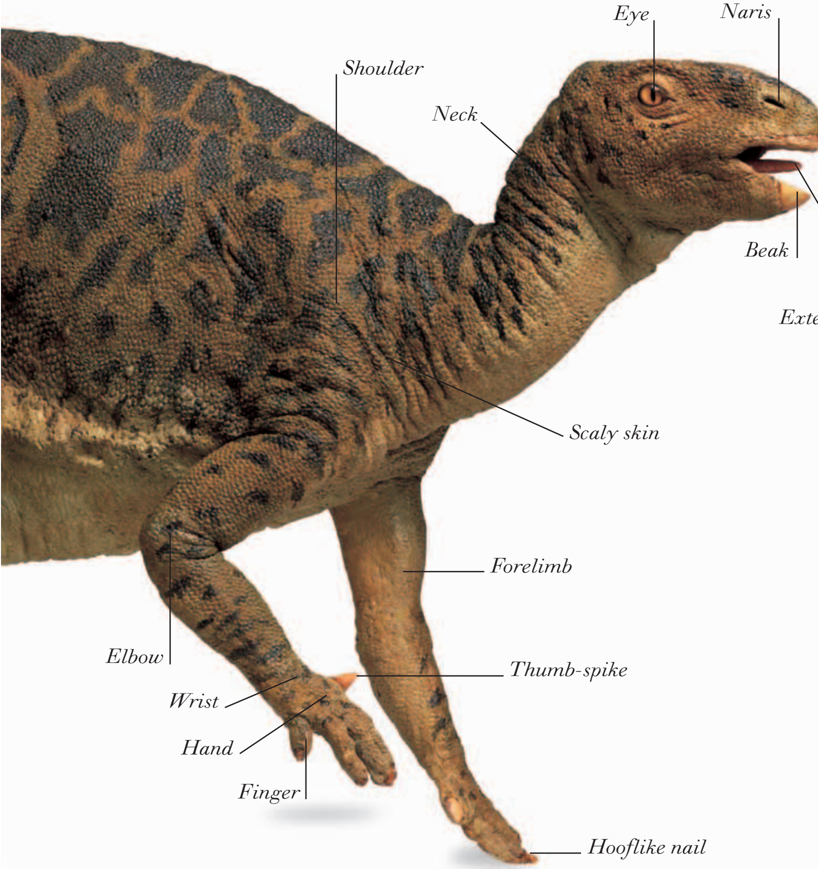
CAMPTOSAURUS
Group: Camptosauridae
Length: 16–23 ft (4.9–7 m)



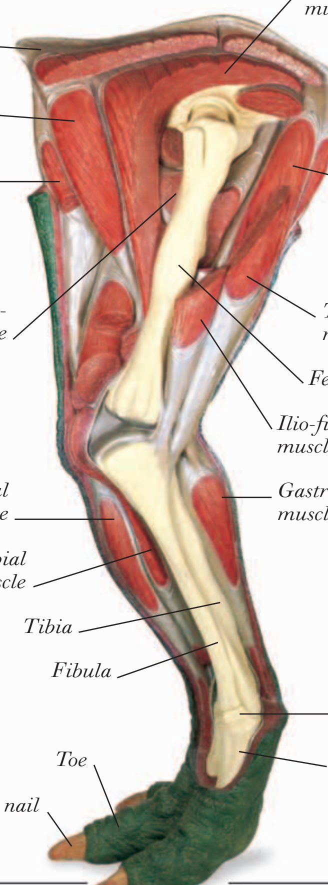
MUTTABURRASAURUS
Group: Iguanodontia
Length: 23 ft (7 m)



PROBACTROSAURUS
Group: Hadrosauroidea
Length: 20 ft (6.1 m)



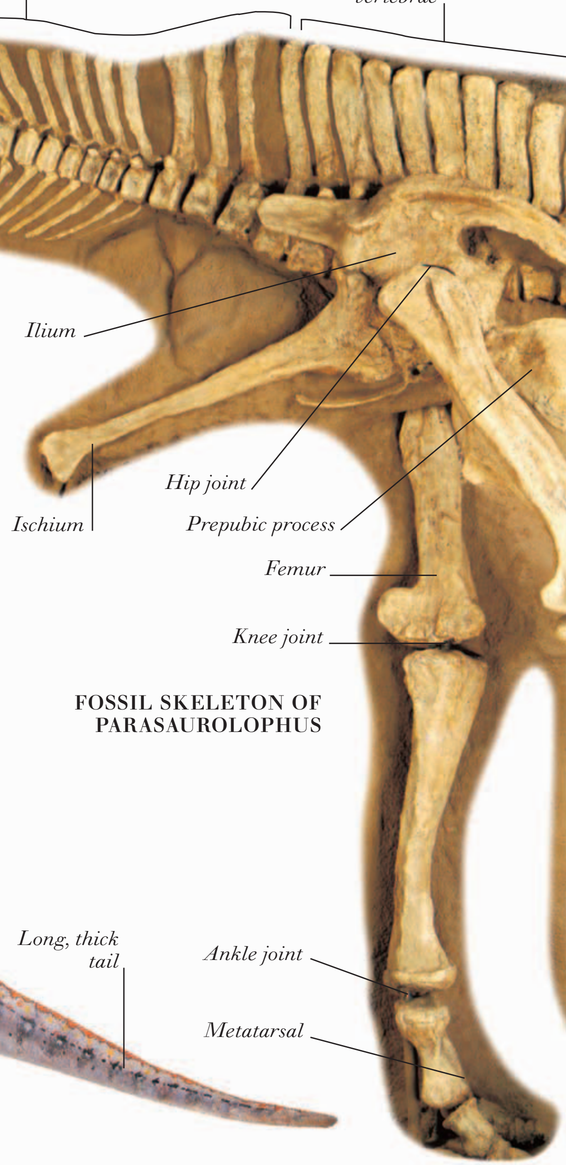
INTERNAL ANATOMY OF HIND LEG OF IGUANODON



Ornithopods 2

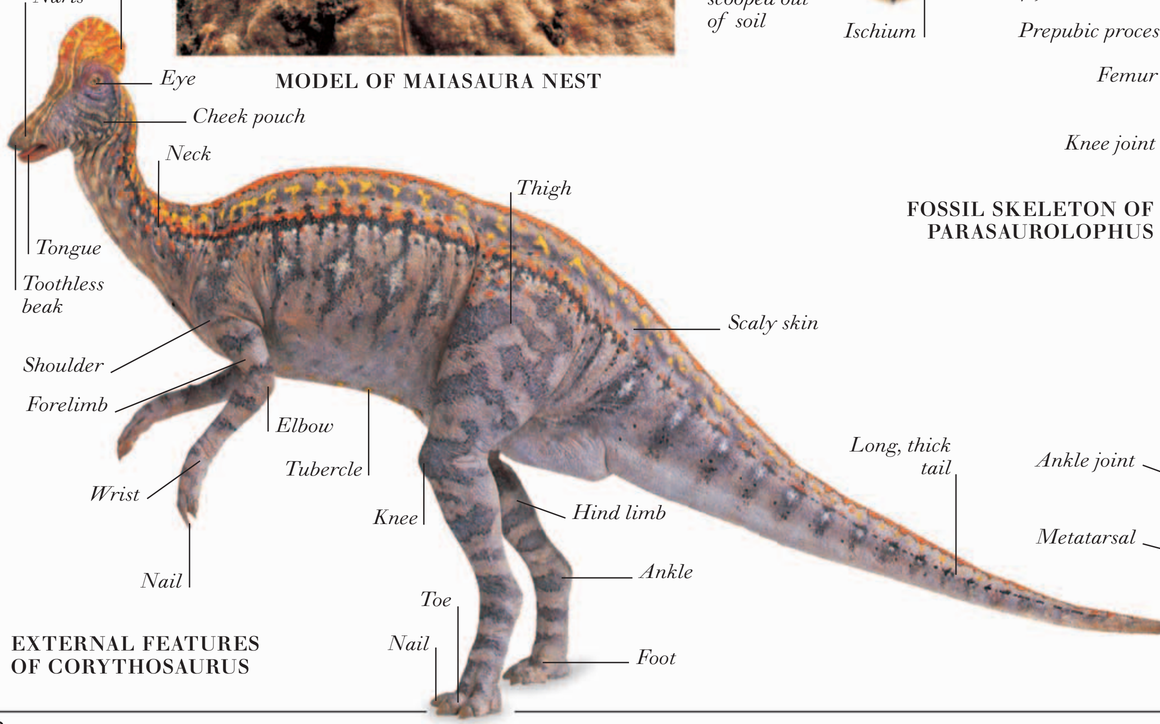
BRACHYLOPHOSAURUS
Length: 23 ft (7m)

LAMBEOSAURUS
Length: 49 ft (14.9 m)



FOSSIL SKELETON OF PARASAUROLOPHUS

MODEL OF MAIASAURA NEST



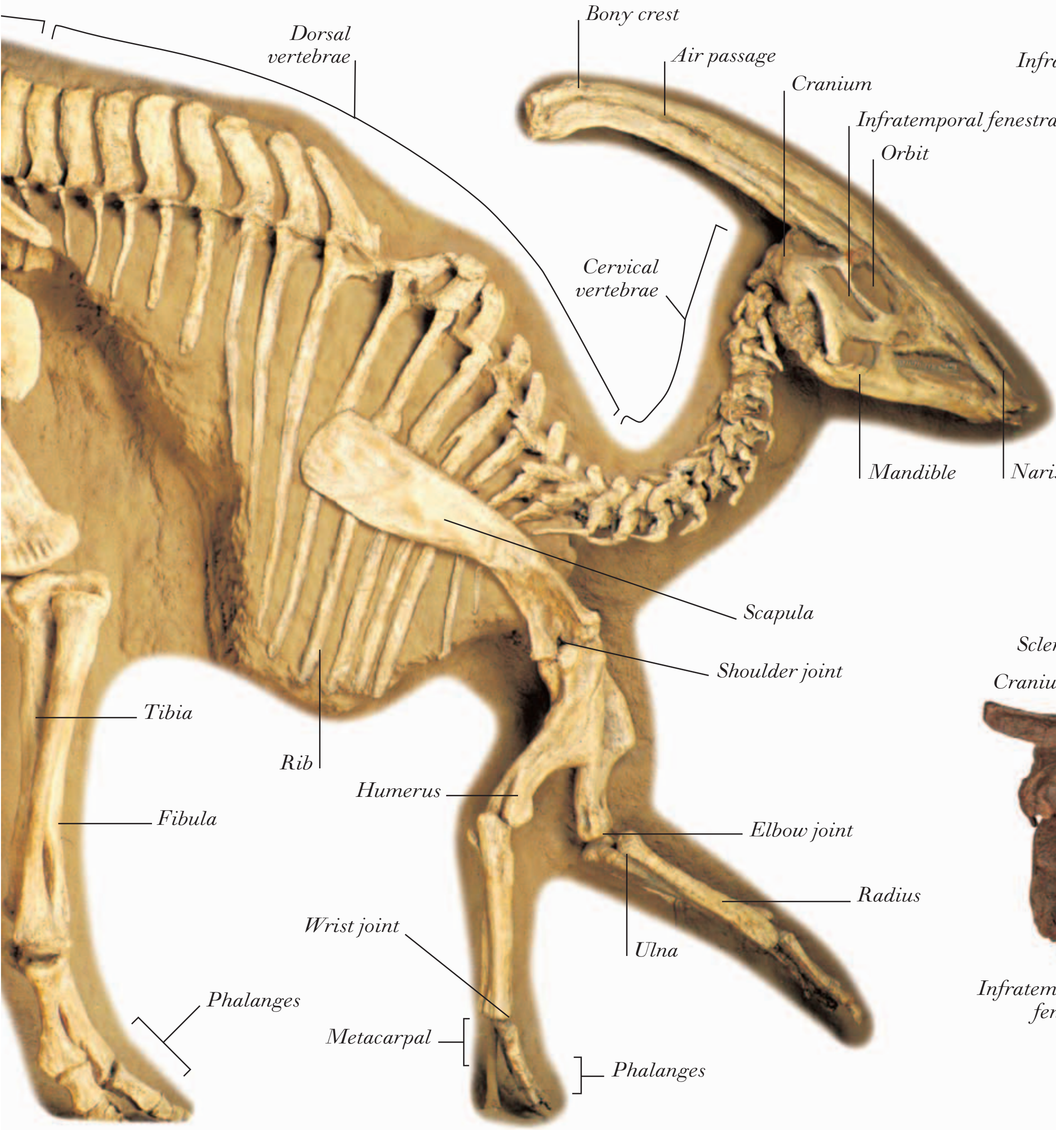
EXTERNAL FEATURES OF CORYTHOSAURUS

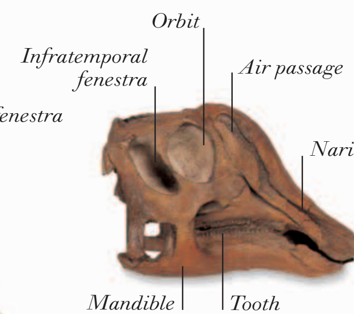
EXAMPLES OF HADROSAURS

HYPACROSAURUS
Length: 30 ft (9.1 m)

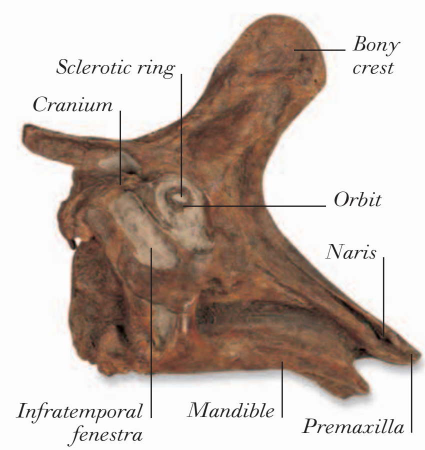
HADROSAURUS
Length: 26–33 ft (7.9–10 m)

GRYPOSAURUS
Length: 26–33 ft (7.9–10 m)





SKULL AND MANDIBLE OF JUVENILE LAMBEOSAURUS

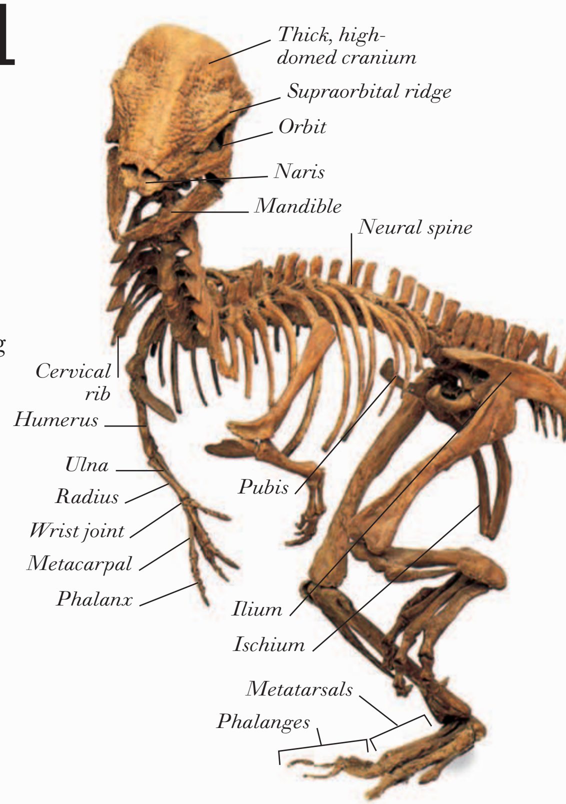


SKULL AND MANDIBLE OF ADULT LAMBEOSAURUS

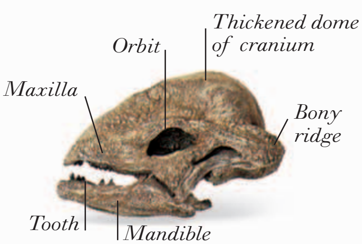
Marginocephalians 1

HEAD-BUTTING PRENOCEPHALES

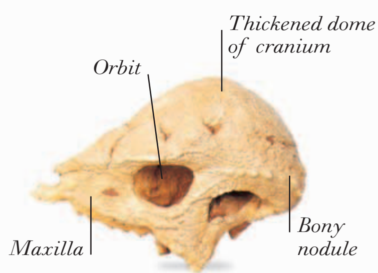
MARGINOCEPHALIA ("margined heads") were a group of bipedal and quadrupedal ornithischian dinosaurs with a narrow shelf or deep, bony frill at the back of the skull. Marginocephalians were probably descended from the same ancestor as the ornithopods and lived in what are now North America, Africa, Asia, and Europe during the Cretaceous period (145–65 million years ago). They were divided into two groups: Pachycephalosauria ("thick-headed lizards"), such as *Pachycephalosaurus* and *Stegoceras*, and Ceratopsia ("horned faces"), such as *Triceratops* and *Psittacosaurus*. The thick skulls of Pachycephalosauria may have protected their brains during possible head-butting contests fought to win territory and mates; their hips and spines may also have been strengthened to withstand the shock. The bony frill of Ceratopsia would have added to their frightening appearance when charging; the neck was strengthened for impact and to support the huge head, with its snipping beak and powerful slicing toothed jaws. A charging ceratopsian would have been a formidable opponent for even the largest predators. Ceratopsians were among the most abundant herbivorous dinosaurs of the Late Cretaceous period (97–65 million years ago).



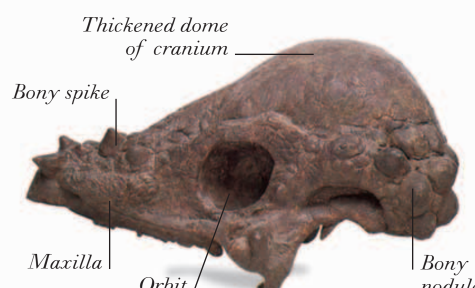
EXAMPLES OF SKULLS OF PACHYCEPHALOSAURS



SKULL AND MANDIBLE OF STEGOCERAS

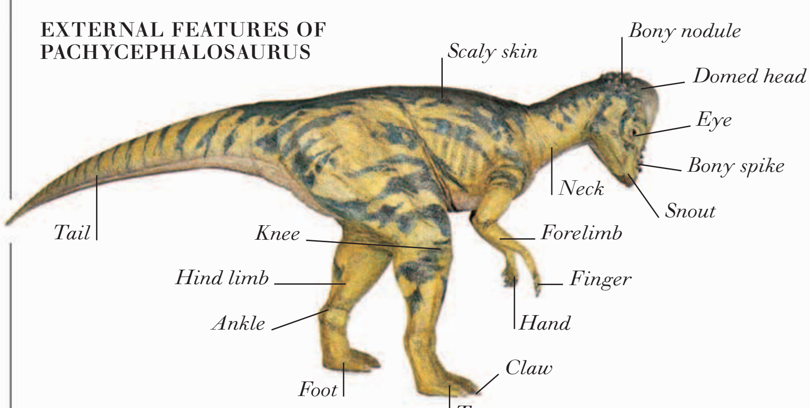


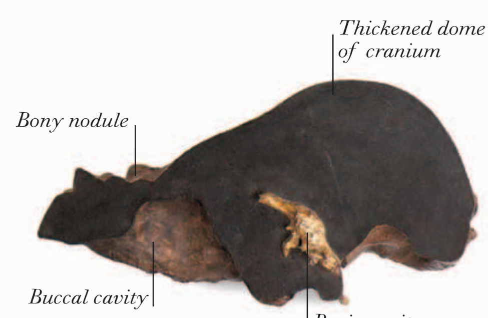
SKULL OF PRENOCEPHALE



SKULL OF PACHYCEPHALOSAURUS

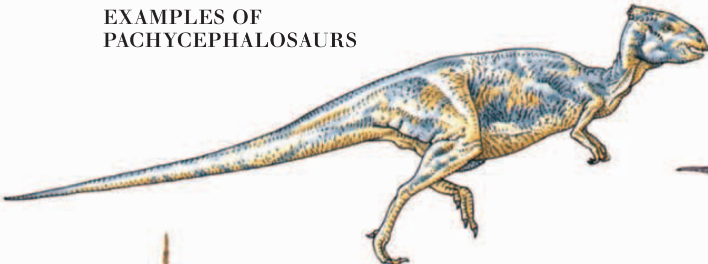
EXTERNAL FEATURES OF PACHYCEPHALOSAURUS





SECTION THROUGH SKULL OF PACHYCEPHALOSAURUS

EXAMPLES OF PACHYCEPHALOSAURS

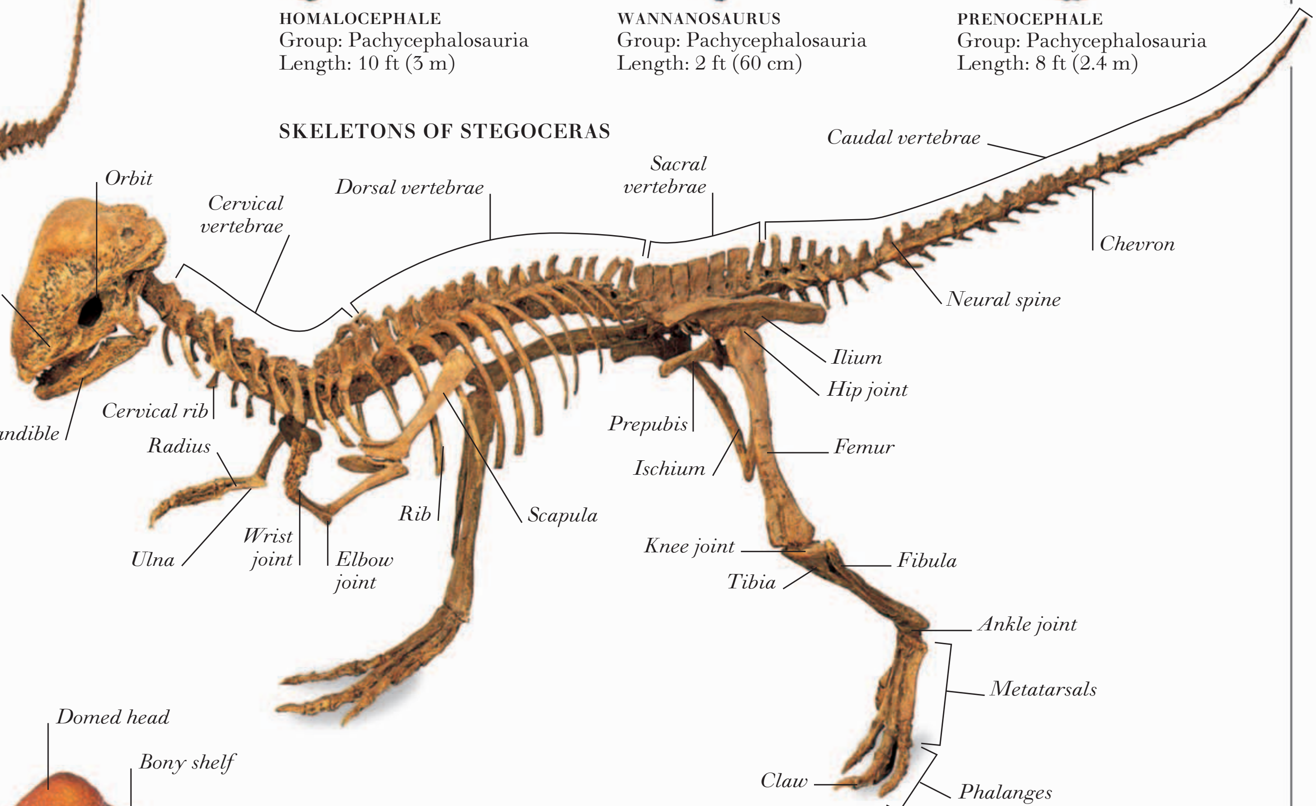


HOMALOCEPHALE
Group: Pachycephalosauria
Length: 10 ft (3 m)

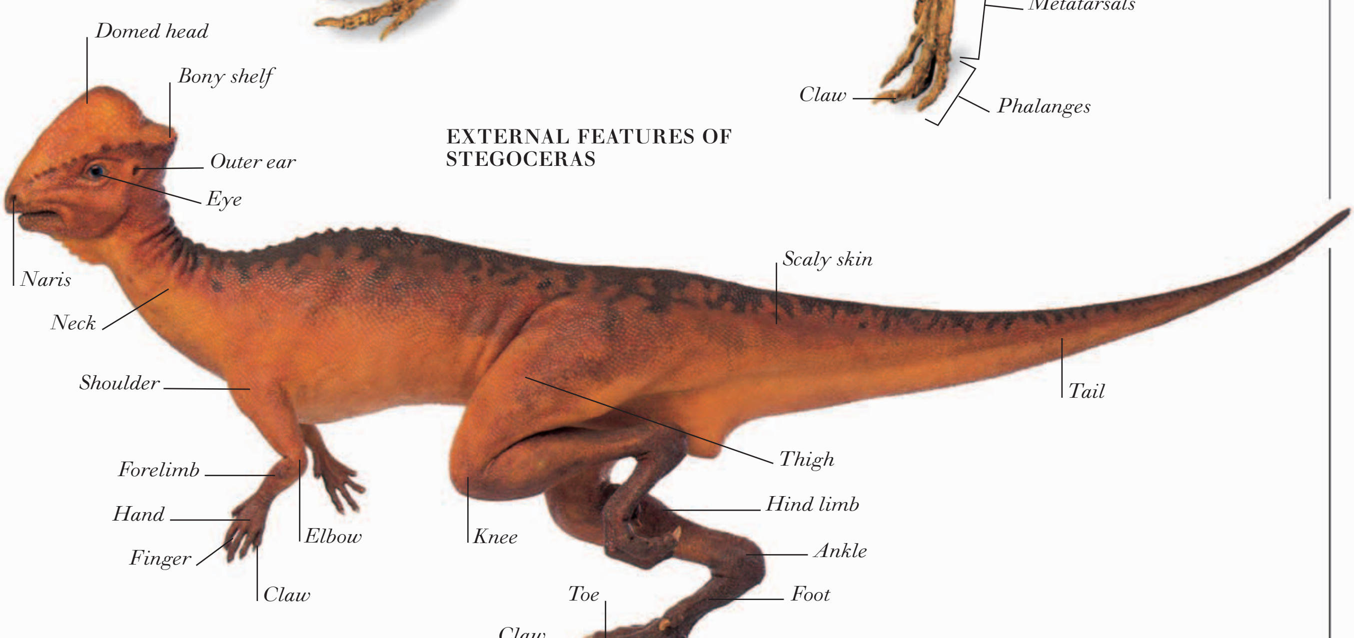
WANNANOSAURUS
Group: Pachycephalosauria
Length: 2 ft (60 cm)

PRENOCEPHALE
Group: Pachycephalosauria
Length: 8 ft (2.4 m)

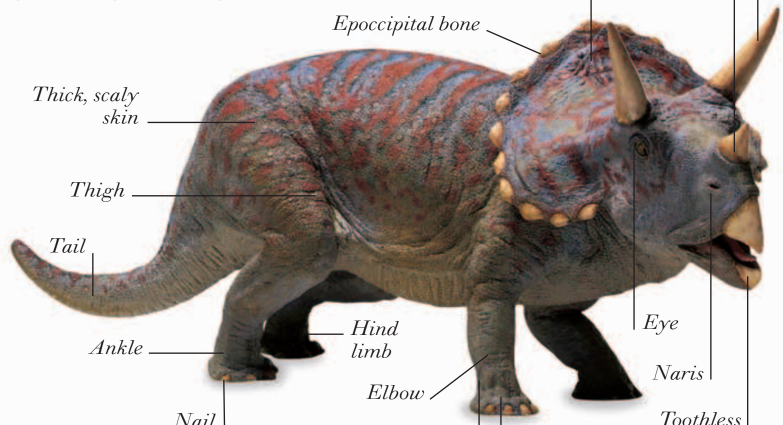
SKELETONS OF STEGOCERAS



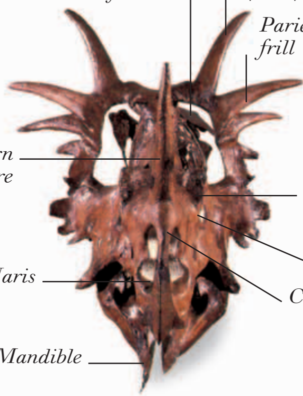
EXTERNAL FEATURES OF STEGOCERAS



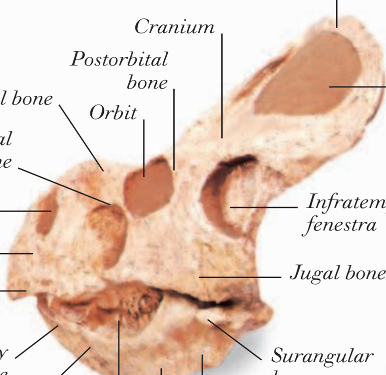
Marginocephalians 2



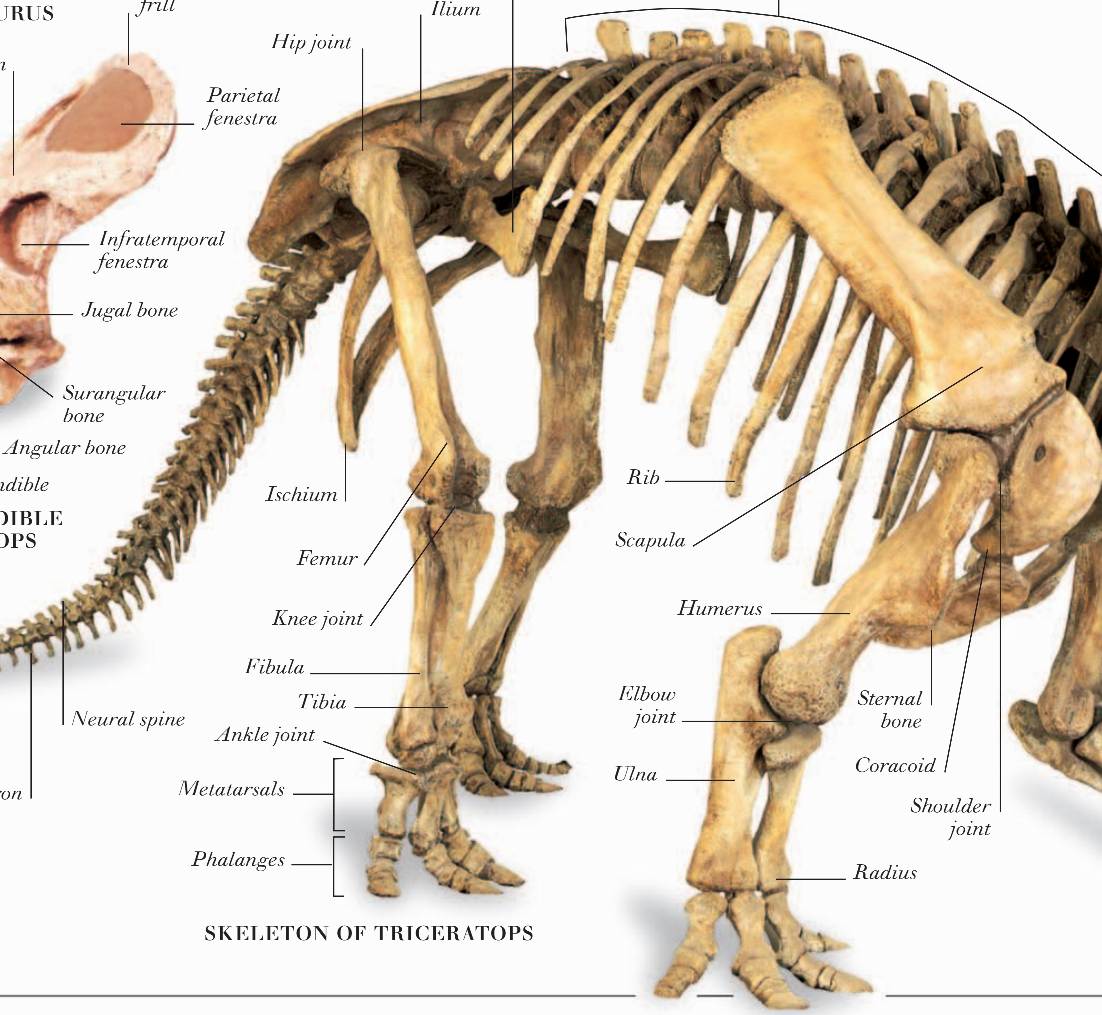
EXTERNAL FEATURES OF TRICERATOPS



SKULL AND MANDIBLE OF STYRACOSAURUS

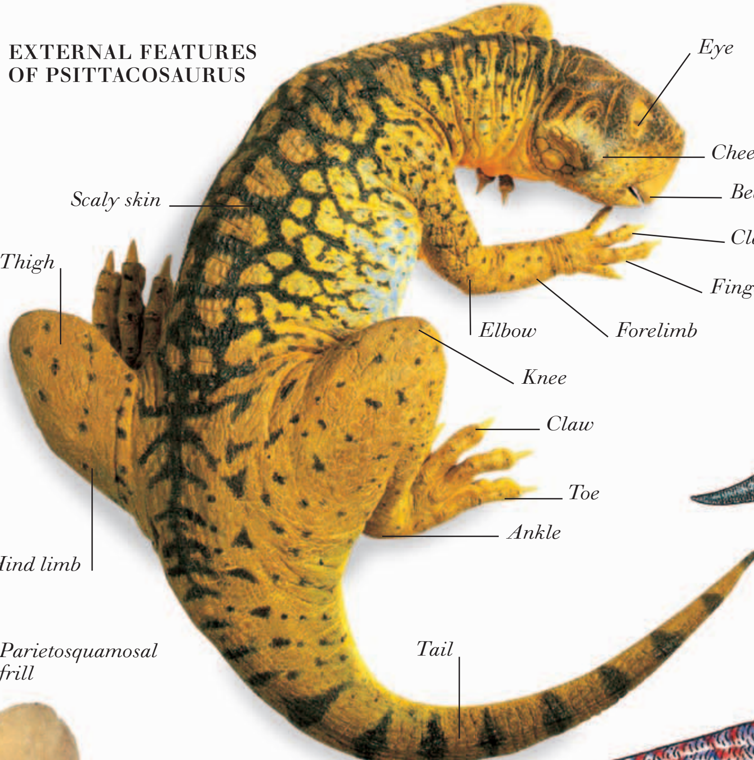


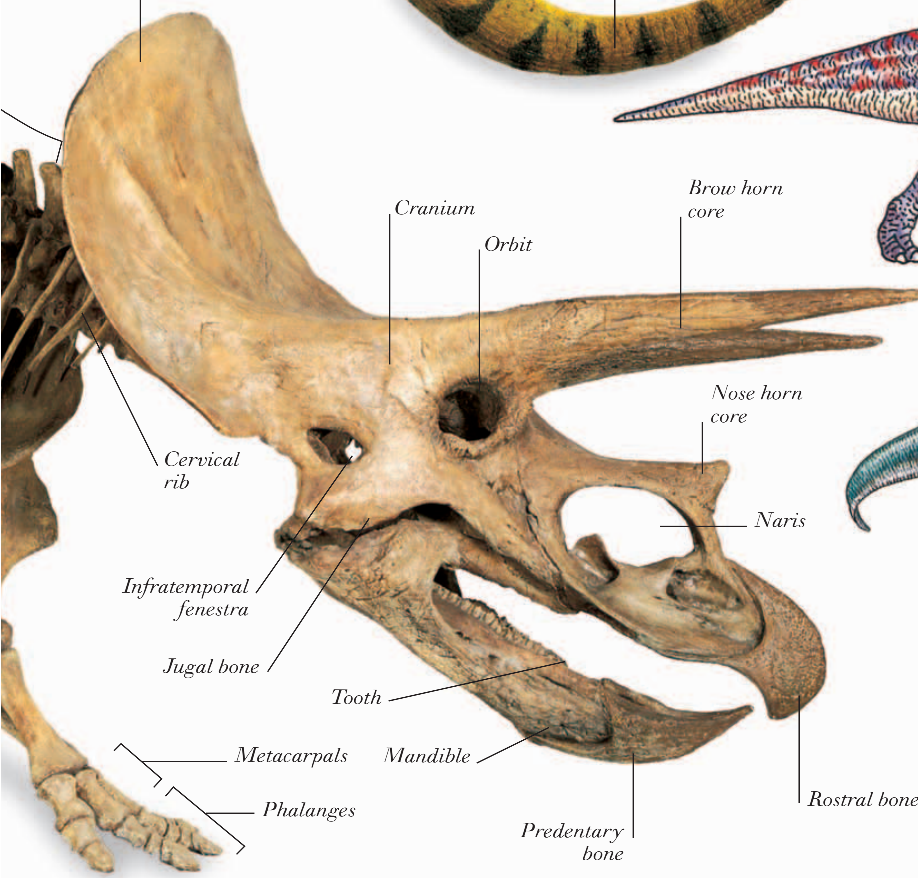
SKULL AND MANDIBLE OF PROTOCERATOPS



SKELETON OF TRICERATOPS

EXTERNAL FEATURES OF PSITTACOSAURUS



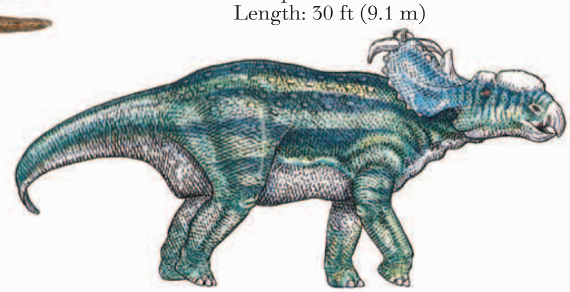


EXAMPLES OF CERATOPSIA

PROTOCERATOPS
Group: Protoceratopsidae
Length: 9 ft (2.7 m)

STYRACOSAURUS
Group: Centrosaurinae
Length: 18 ft (5.5 m)

TRICERATOPS
Group: Chasmosaurinae
Length: 30 ft (9.1 m)



PACHYRHINOSAURUS
Group: Centrosaurinae
Length: 18 ft (5.5 m)

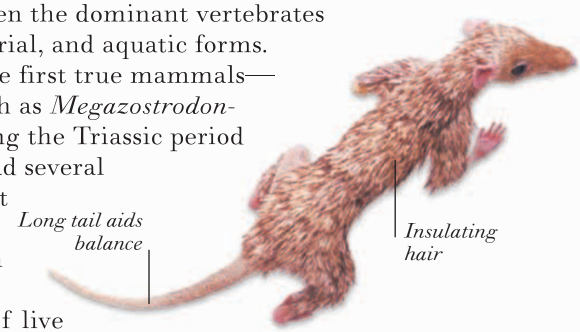
LEPTOCERATOPS
Group: Leptoceratopsidae
Length: 7 ft (2.1 m)

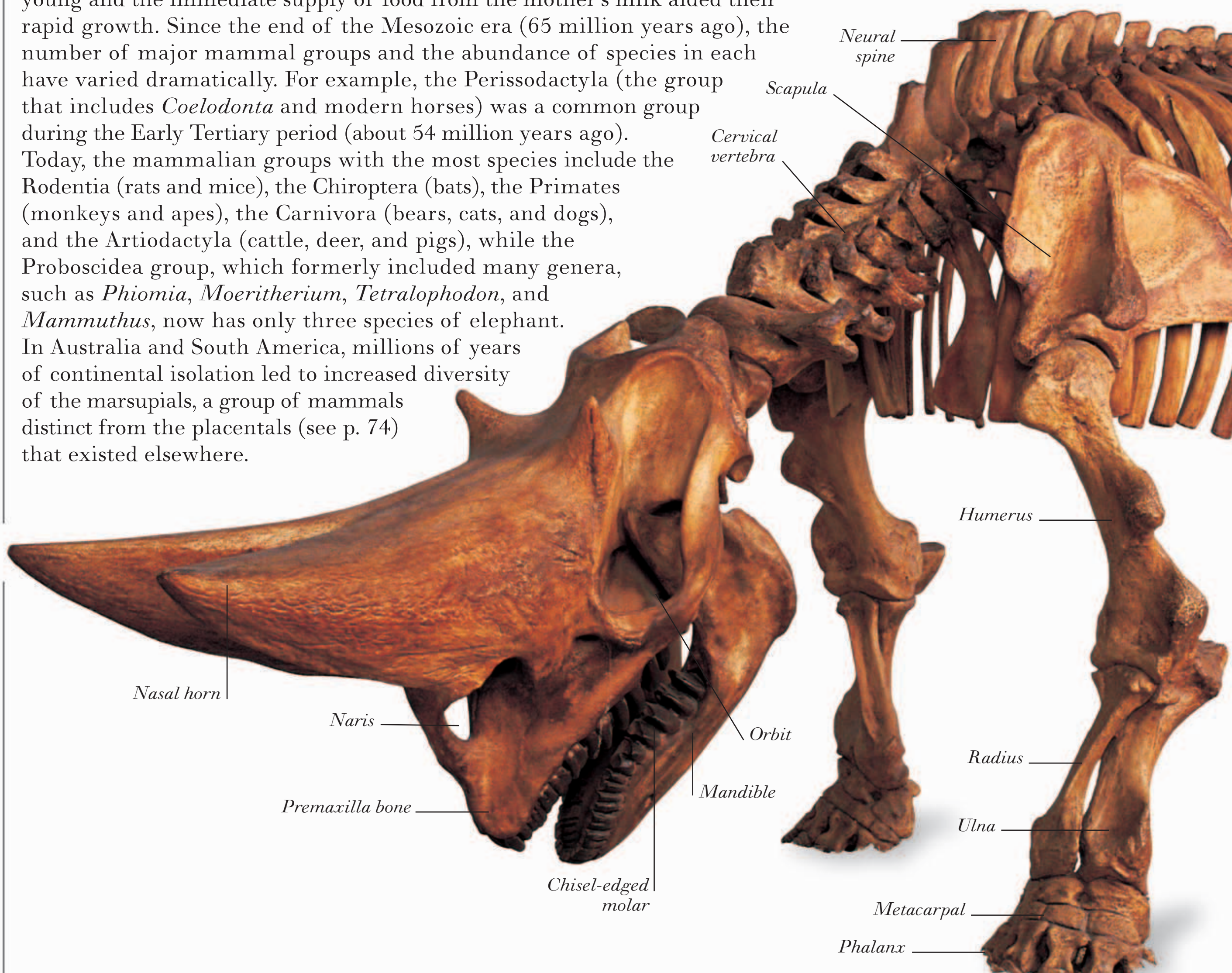
Mammals 1

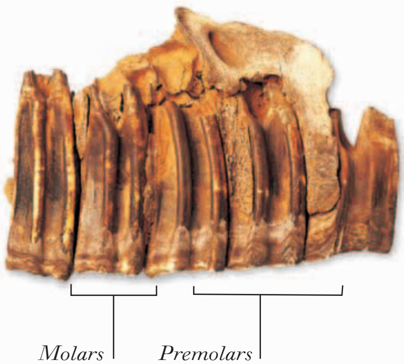
TETRALOPHODON CHEEK TEETH

SINCE THE EXTINCTION of most of the dinosaurs 65 million years ago, mammals (along with birds) have been the dominant vertebrates on land. This class includes terrestrial, aerial, and aquatic forms. Having developed from the therapsids, the first true mammals—small, nocturnal, shrewlike creatures, such as *Megazostrodon*-appeared over 200 million years ago during the Triassic period (250–200 million years ago). Mammals had several features that differed from those of their ancestors: an efficient four-chambered heart allowed these warm-blooded animals to sustain high levels of activity; a covering of hair helped them maintain a constant body temperature; an improved limb structure gave them more efficient locomotion; and the birth of live young and the immediate supply of food from the mother's milk aided their rapid growth. Since the end of the Mesozoic era (65 million years ago), the number of major mammal groups and the abundance of species in each have varied dramatically. For example, the Perissodactyla (the group that includes *Coelodonta* and modern horses) was a common group during the Early Tertiary period (about 54 million years ago). Today, the mammalian groups with the most species include the Rodentia (rats and mice), the Chiroptera (bats), the Primates (monkeys and apes), the Carnivora (bears, cats, and dogs), and the Artiodactyla (cattle, deer, and pigs), while the Proboscidea group, which formerly included many genera, such as *Phiomia*, *Moeritherium*, *Tetralophodon*, and *Mammuthus*, now has only three species of elephant. In Australia and South America, millions of years of continental isolation led to increased diversity of the marsupials, a group of mammals distinct from the placentals (see p. 74) that existed elsewhere.

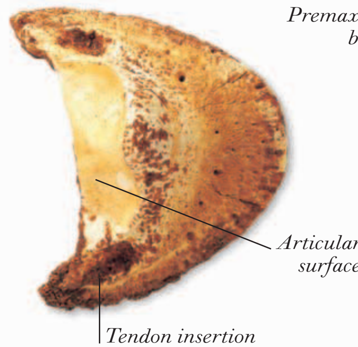
MODEL OF A MEGAZOSTRODON



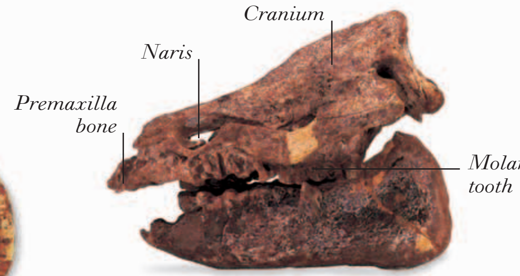




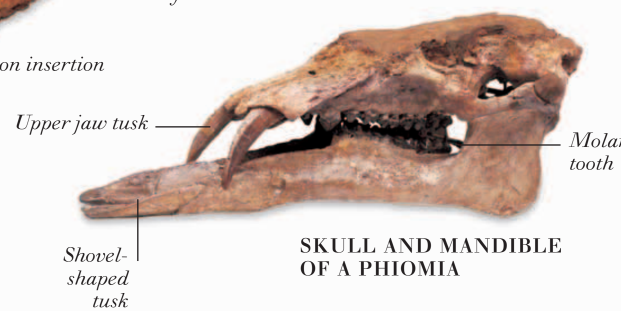
UPPER JAWBONE (MAXILLA) OF A HORSE



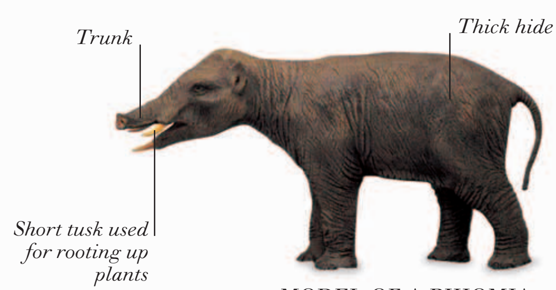
HOOFBONE (THIRD PHALANX) OF A HORSE



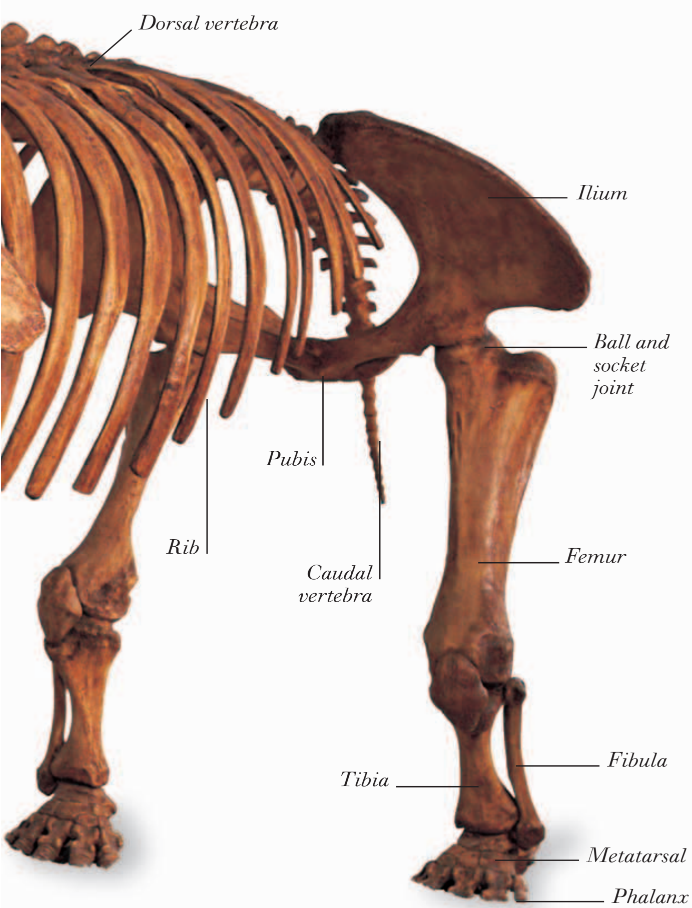
SKULL AND MANDIBLE OF A MOERITHERIUM



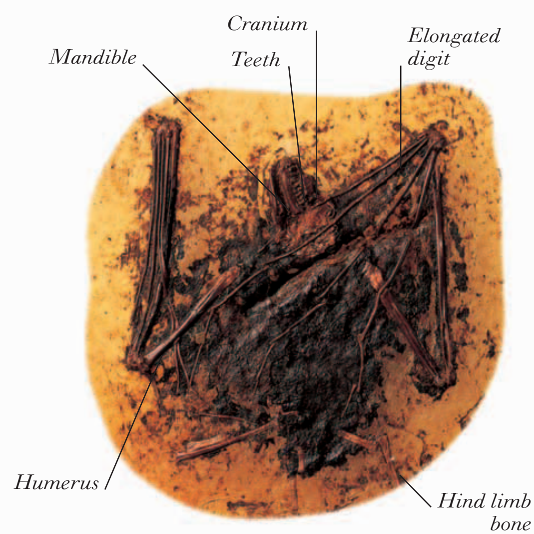
SKULL AND MANDIBLE OF A PHIOMIA



MODEL OF A PHIOMIA



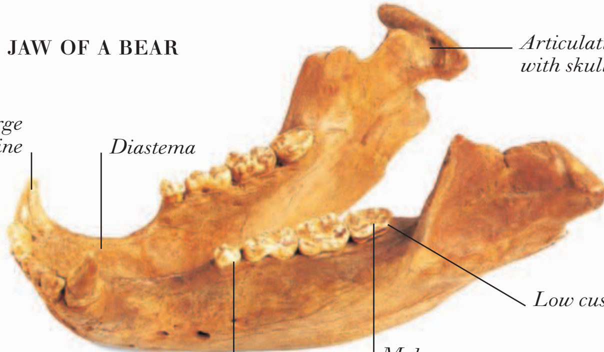
SKELETON OF AN ARSINOITHERIUM



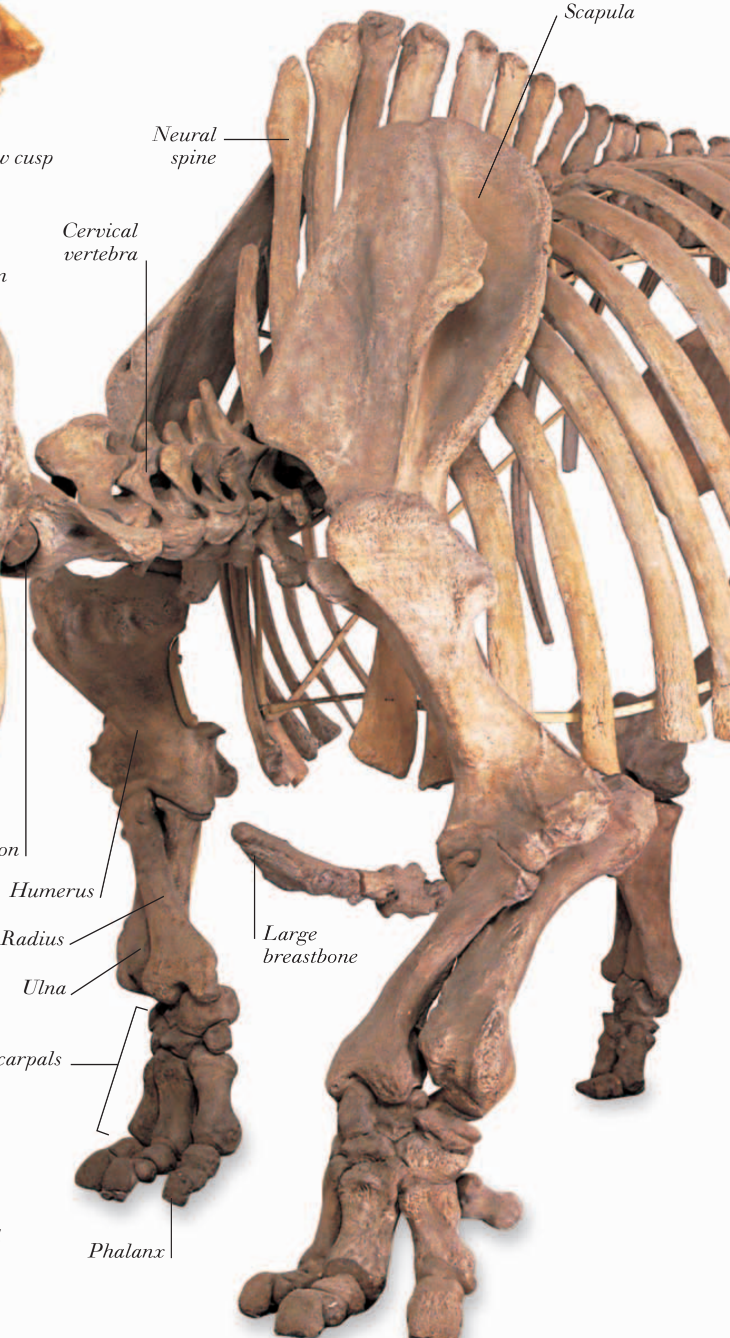
FOSSIL SKELETON OF A BAT

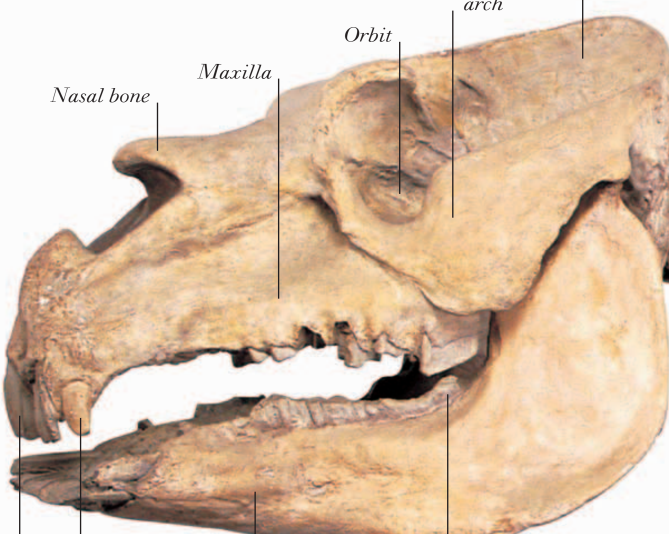
Mammals 2

LOWER JAW OF A BEAR

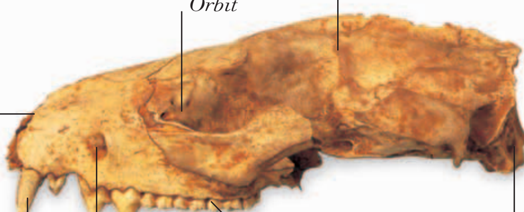


SKELETON OF A TOXODON

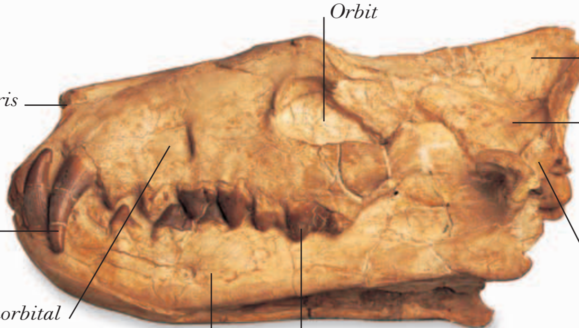




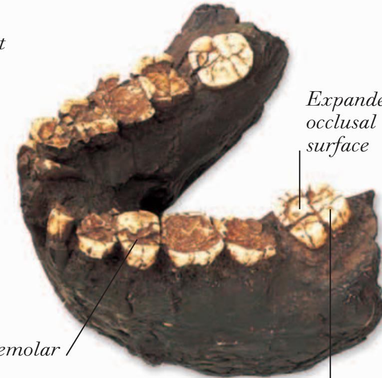
SKULL OF AN OPOSSUM

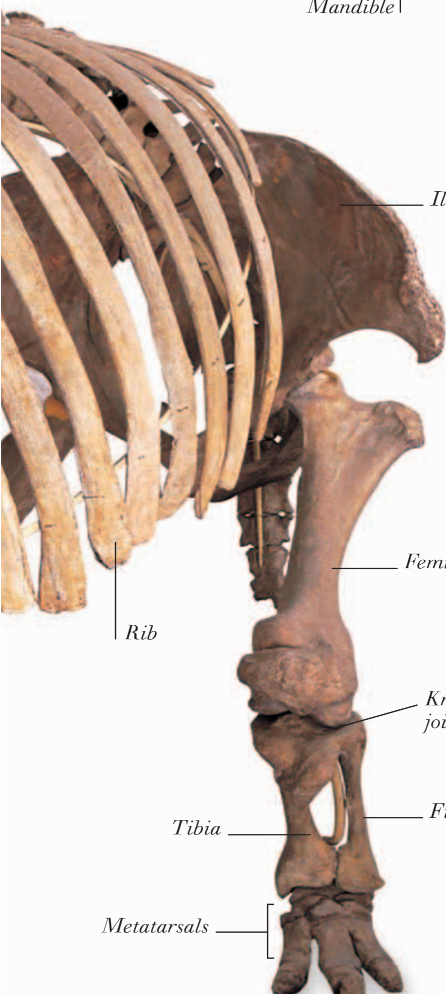


FOSSIL SKULL OF AN HYAENODON

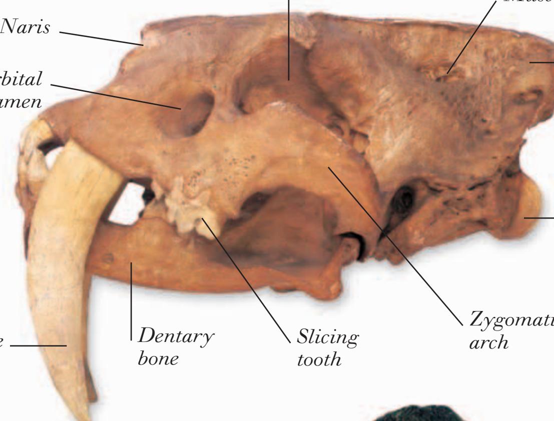


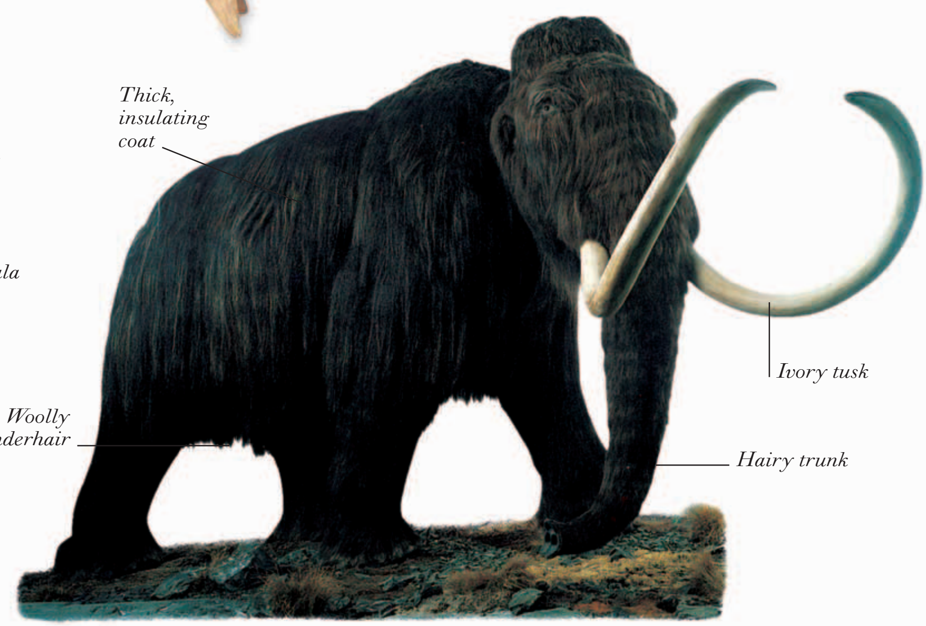
LOWER JAW OF AN AUSTRALOPITHECUS





SKULL OF A SMILODON



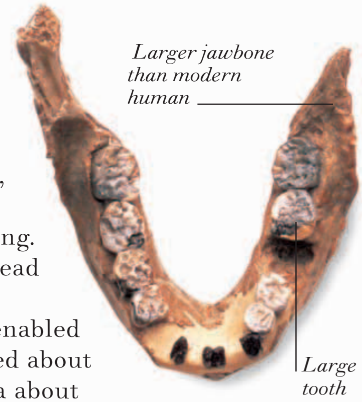


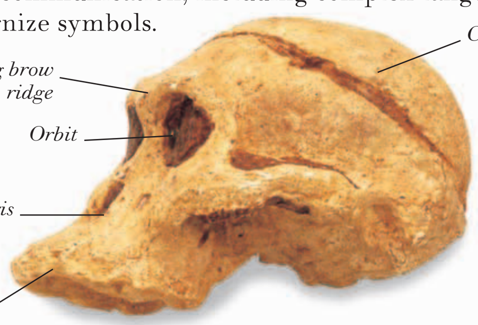
RECONSTRUCTION OF A MAMMOTH

The first humans

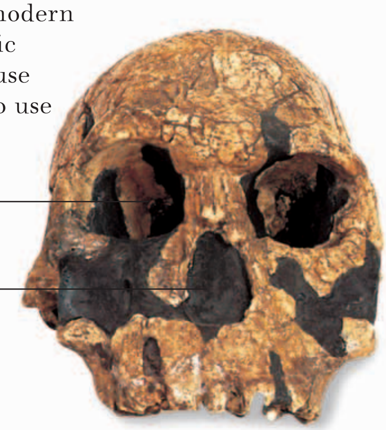
MODERN HUMANS BELONG TO THE MAMMALIAN order of primates (see pp. 202–203), which originated about 55 million years ago; primates included the only extant hominid species. The earliest hominid was *Ardipithecus* ("ground ape") and *Australopithecus* ("southern ape"), both small-brained intermediates between apes and humans that were capable of standing and walking upright. *Homo habilis*, the earliest member of the genus Homo, appeared at least 2 million years ago. This larger-brained "handy man" began making tools for hunting. *Homo ergaster* first appeared in Africa about 1.8 million years ago and spread into Asia about 800,000 years later. Smaller-toothed than *Homo habilis*, H. ergaster—followed by Homo erectus—developed fire as a tool, which enabled it to cook food. Neanderthals, a near relative of modern humans, originated about 200,000 years ago, and *Homo sapiens* (modern humans) appeared in Africa about 100,000 years later. The two coexisted for thousands of years, but by 30,000 years ago, *Homo sapiens* had become dominant and the Neanderthals had died out. Classification of *Homo sapiens* in relation to its ancestors is enormously problematic: modern humans must be classified not only by bone structure, but also by specific behavior—the ability to plan future action; to follow traditions; and to use symbolic communication, including complex language and the ability to use and recognize symbols.

JAWBONE OF AUSTRALOPITHECUS (SOUTHERN APE)

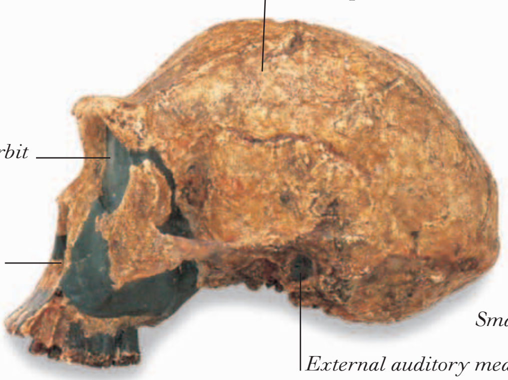




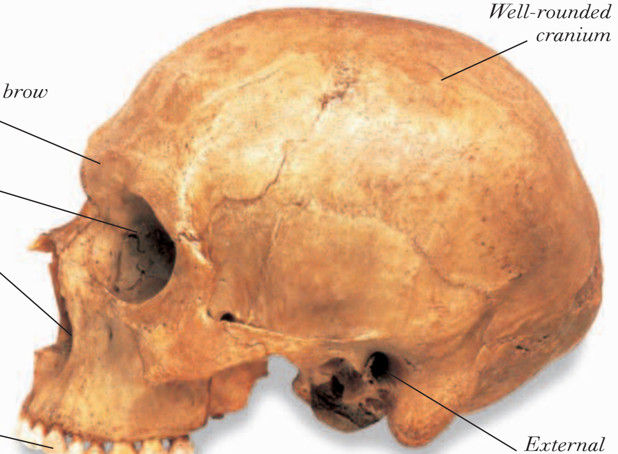
SKULL OF AUSTRALOPITHECUS (SOUTHERN APE)



SKULL OF HOMO HABILIS (FIRST MEMBER OF HOMO GENUS)

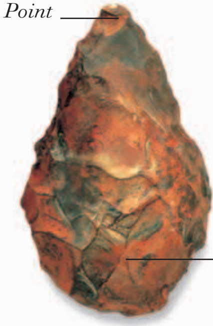


SKULL OF HOMO ERECTUS (UPRIGHT MAN)



SKULL OF HOMO SAPIENS (MODERN HUMAN)

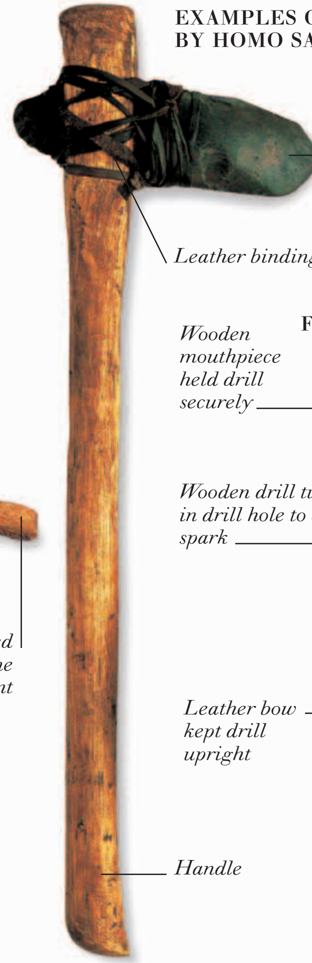
FLINT TOOL MADE ABOUT 250,000 YEARS AGO



FLINT HANDAXE

FLINT FLAKE

EXAMPLES OF TOOLS USED BY HOMO SAPIENS



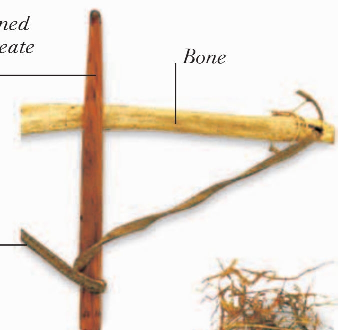
FARMING AX

ANTLER HAMMER

RED DEER ANTLER HAMMER

FIRE-MAKING TOOLS

WOODEN MOUTHPIECE

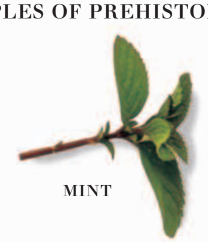


BOW DRILL

DRY STRAW

WOODEN HEARTH

EXAMPLES OF PREHISTORIC FOODS



MINT

WHEAT GRAINS

SALMON

SPEAR AND ARROW HEADS

HARPOON POINT

FISHING TACKLE

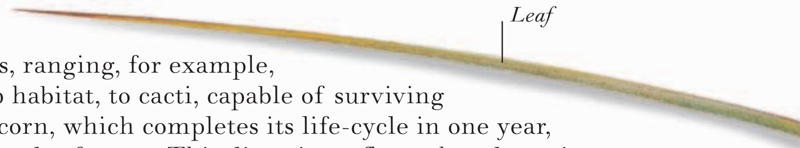
WOODEN ARROW

FLINT ARROW

PLANTS

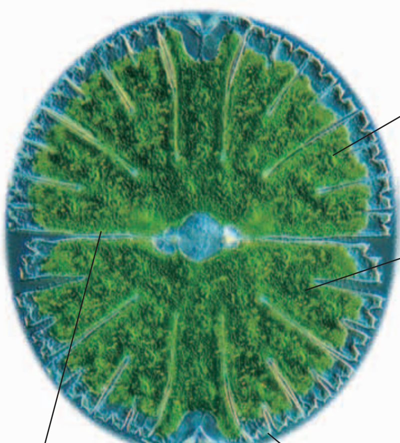
Plant varieties

FLOWERING PLANT
Bromeliad
(*Acanthostachys strobilacea*)

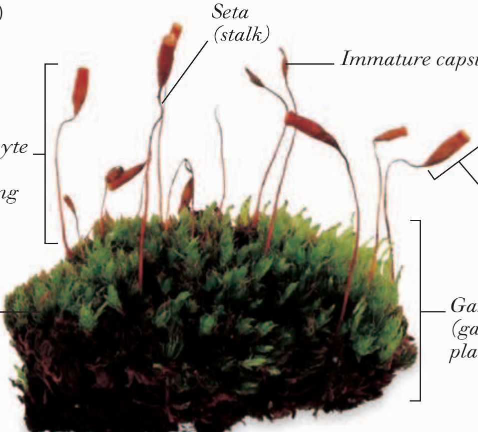


THERE ARE MORE THAN 300,000 SPECIES of plant. They show a wide diversity of forms and life-styles, ranging, for example, from delicate liverworts, adapted for life in a damp habitat, to cacti, capable of surviving in the desert, and from herbaceous plants, such as corn, which completes its life-cycle in one year, to the giant redwood tree, which can live for thousands of years. This diversity reflects the adaptations of plants to survive in a wide range of habitats. This is seen most clearly in the flowering plants (phylum Angiospermophyta), which are the most numerous, with over 250,000 species, and the most widespread, being found from the tropics to the poles. Despite their diversity, plants share certain characteristics: typically, plants are green, and make their food by photosynthesis; and most plants live in or on a substrate, such as soil, and do not actively move. Algae (kingdom Protista) and fungi (kingdom Fungi) have some plantlike characteristics and are often studied alongside plants, although they are not true plants.

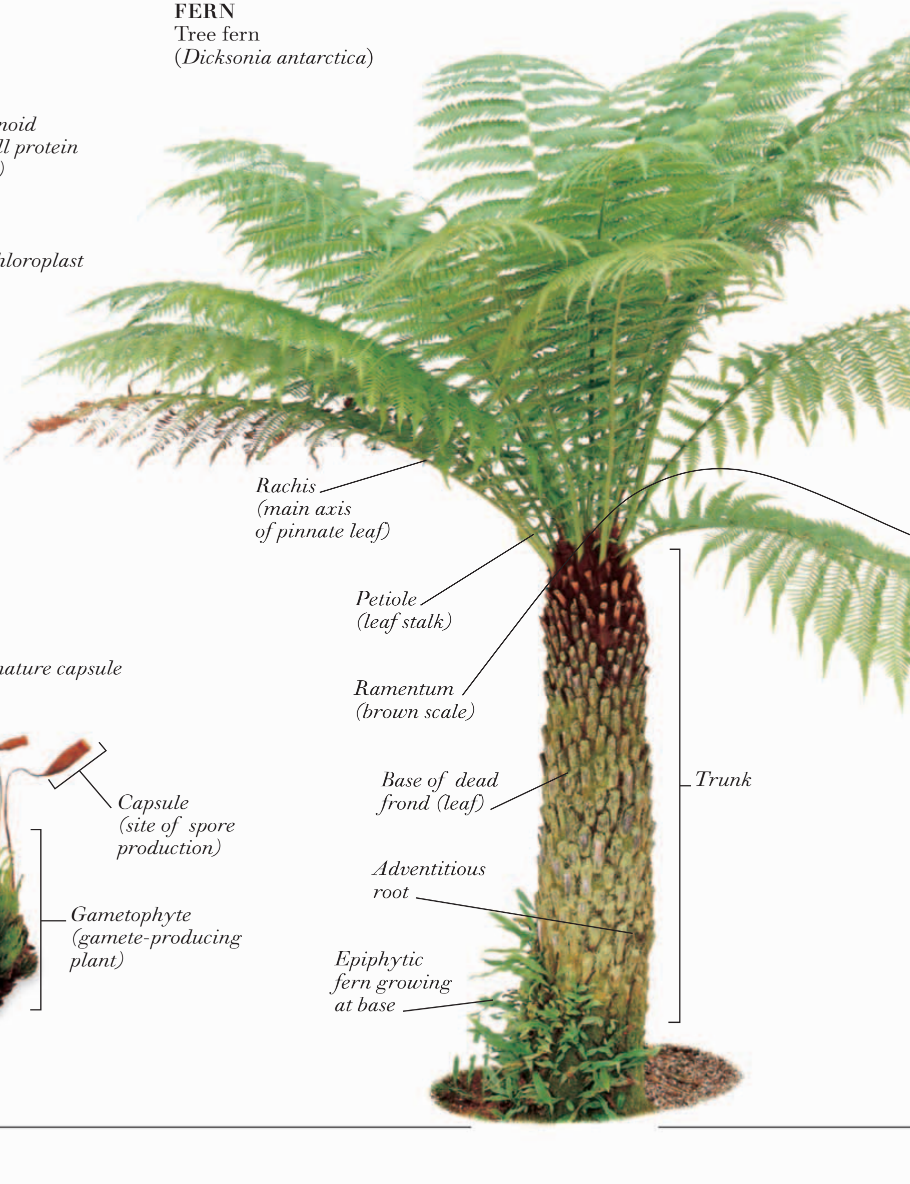
GREEN ALGA
Micrograph of desmid
(*Micrasterias sp.*)

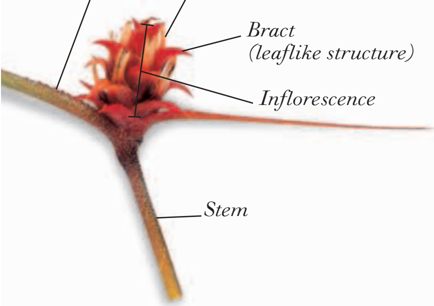


BRYOPHYTE
Moss
(*Bryum sp.*)

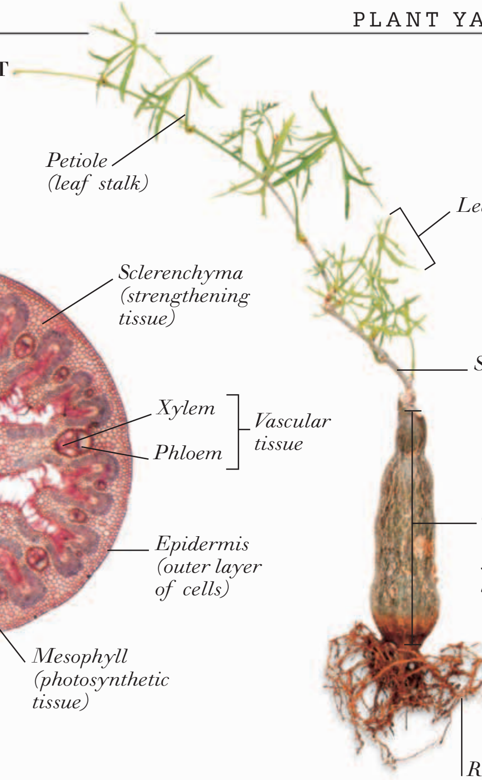


FERN
Tree fern
(*Dicksonia antarctica*)

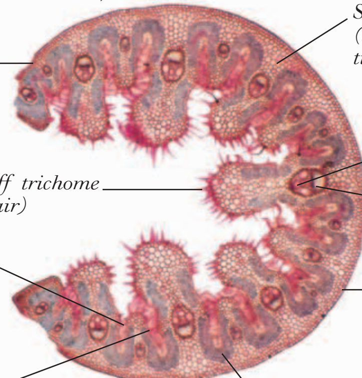


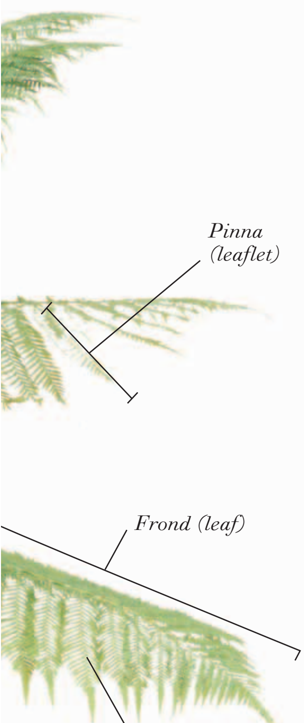


FLOWERING PLANT
Succulent
(*Kedrostis africana*)

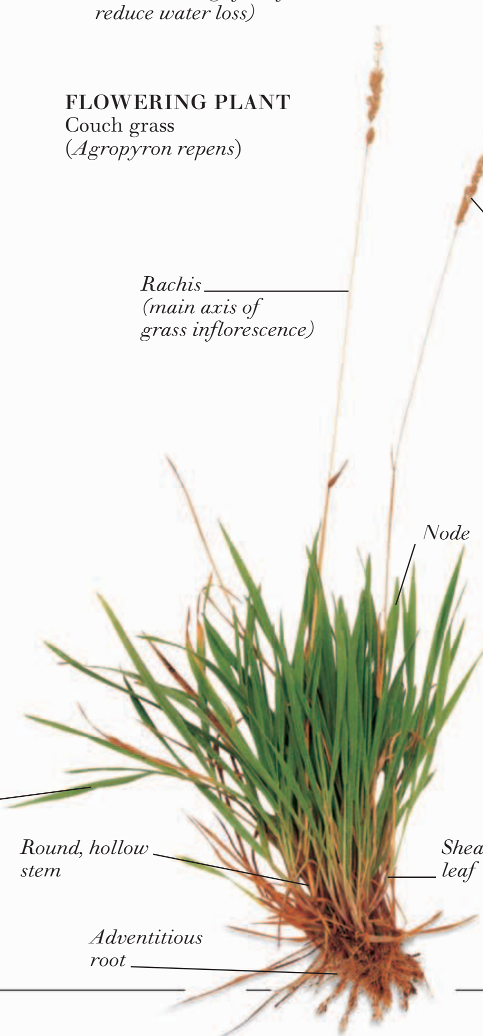


FLOWERING PLANT
Micrograph of cross-section through leaf of marram grass
(*Ammophila arenaria*)

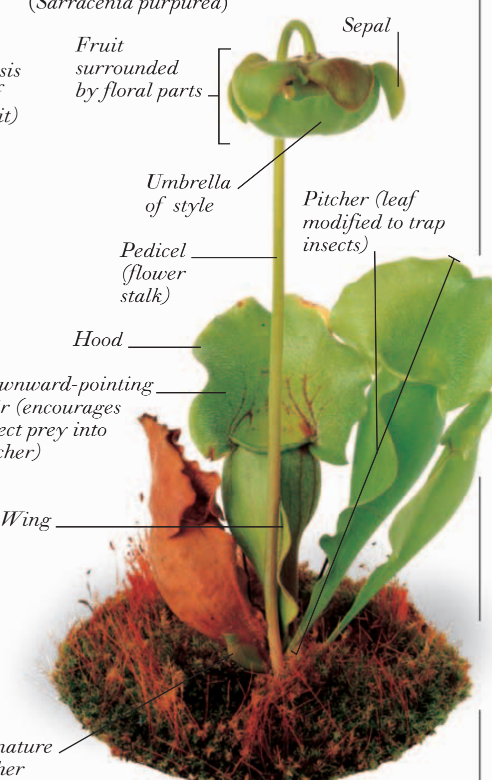




FLOWERING PLANT
Couch grass
(*Agropyron repens*)



FLOWERING PLANT
Pitcher plant
(*Sarracenia purpurea*)



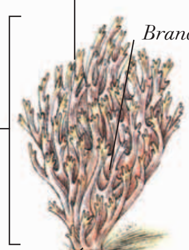
Fungi and lichens

FUNGI WERE ONCE THOUGHT OF AS PLANTS but are now classified as a separate kingdom. This kingdom includes not only the familiar mushrooms, puffballs, stinkhorns, and molds, but also yeasts, smuts, rusts, and lichens. Most fungi are multicellular, consisting of a mass of threadlike hyphae that together form a mycelium. However, the simpler fungi (e.g., yeasts) are microscopic, single-celled organisms. Typically, fungi reproduce by means of spores. Most fungi feed on dead or decaying matter, or on living organisms. A few fungi obtain their food from plants or algae, with which they have a symbiotic (mutually advantageous) relationship. Lichens are a symbiotic partnership between algae and fungi. Of the six types of lichens, the three most common are crustose (flat and crusty), foliose (leafy), and fruticose (shrublike). Some lichens (e.g., *Cladonia floerkeana*) are a combination of types. Lichens reproduce by means of spores or soredia (powdery vegetative fragments).

EXAMPLES OF FUNGI

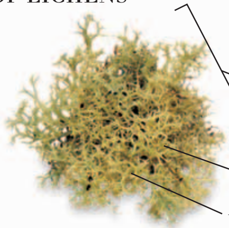
OYSTER FUNGUS
(*Pleurotus pulmonarius*)

STINKHORN
(*Phallus impudicus*)



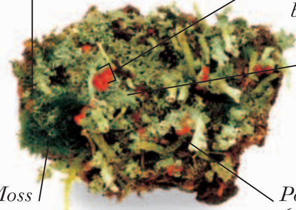
RAMARIA FORMOSA

EXAMPLES OF LICHENS



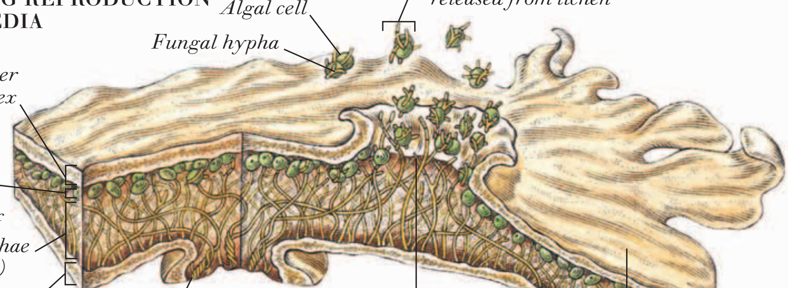
FRUTICOSE
Cladonia portentosa

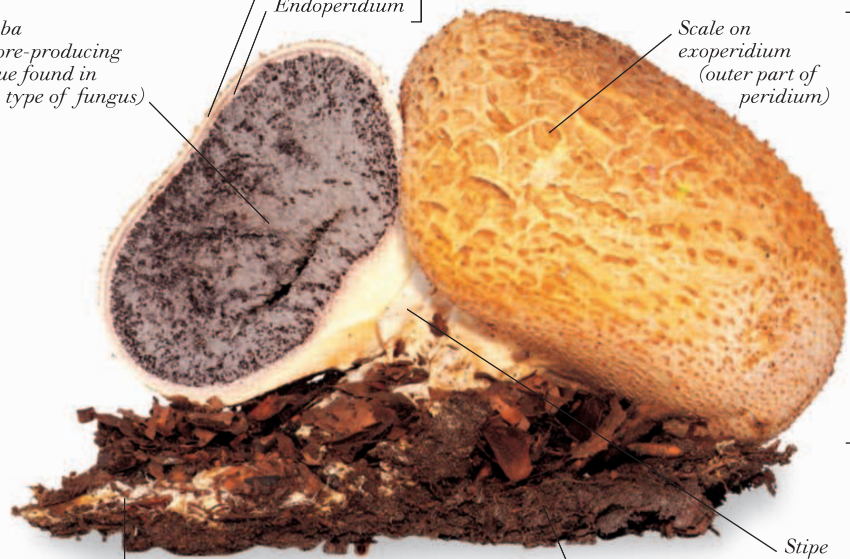
FOLIOSE
Hypogymnia physodes



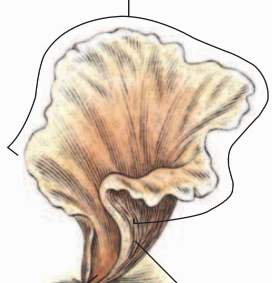
SQUAMULOSE (SCALY) AND FRUTICOSE THALLUS
Cladonia floerkeana

SECTION THROUGH FOLIOSE LICHEN SHOWING REPRODUCTION BY SOREDIA

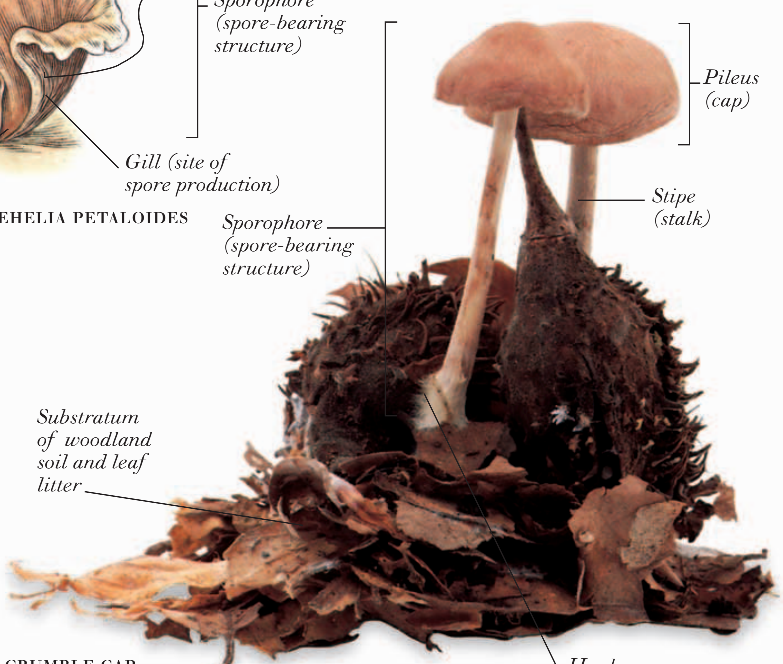




COMMON PUFFBALL
(*Scleroderma citrinum*)

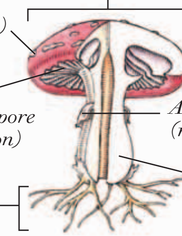


HOHENBUEHELIA PETALOIDES

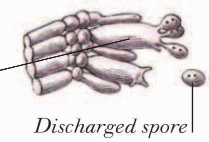


FRINGED CRUMBLE CAP
(*Psathyrella candolleana*)

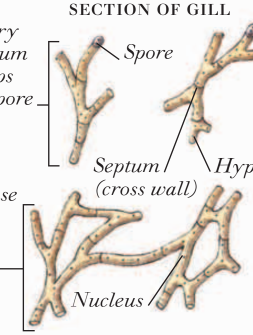
LIFE-CYCLE OF A MUSHROOM



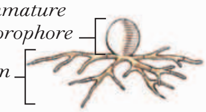
MATURE SPOROPHORE (SPORE-BEARING STRUCTURE)



SECTION OF GILL

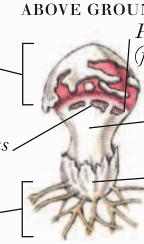


SPORES GERMINATE AND PRODUCE MYCELIUM



MYCELIUM FORMS SPOROPHORE

SPOROPHORE GROWS ABOVE GROUND



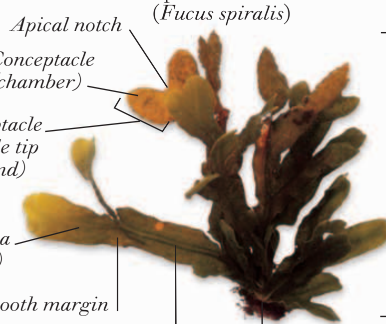
UNIVERSAL VEIL BREAKS

Algae and seaweeds

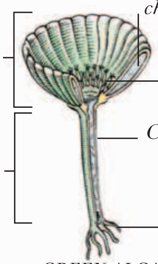
ALGAE ARE NOT TRUE PLANTS. They form a diverse group of plantlike organisms that belong to the kingdom Protista. Like plants, algae possess the green pigment chlorophyll and make their own food by photosynthesis (see pp. 138-139). Many algae also possess other pigments by which they can be classified; for example, the brown pigment fucoxanthin is found in the brown algae. Some of the 10 phyla of algae are exclusively unicellular (single-celled); others also contain aggregates of cells in filaments or colonies. Three phyla—the Chlorophyta (green algae), Rhodophyta (red algae), and Phaeophyta (brown algae)—contain larger, multicellular, thalloid (flat), marine organisms commonly known as seaweeds. Most algae can reproduce sexually. For example, in the brown seaweed *Fucus vesiculosus*, gametes (sex cells) are produced in conceptacles (chambers) in the receptacles (fertile tips of fronds); after their release into the sea, antherozoids (male gametes) and oospheres (female gametes) fuse; the resulting zygote settles on a rock and develops into a new seaweed.

BROWN SEAWEED
Channelled wrack
(*Pelvetia canaliculata*)

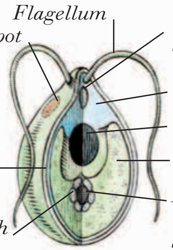
BROWN SEAWEED
Spiral wrack
(*Fucus spiralis*)



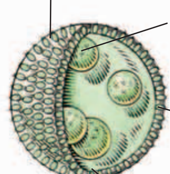
EXAMPLES OF ALGAE



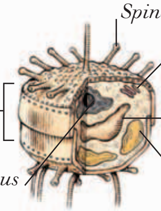
GREEN ALGA
Acetabularia sp.



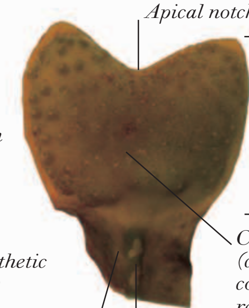
GREEN ALGA
Chlamydomonas sp.



GREEN ALGA
Volvox sp.



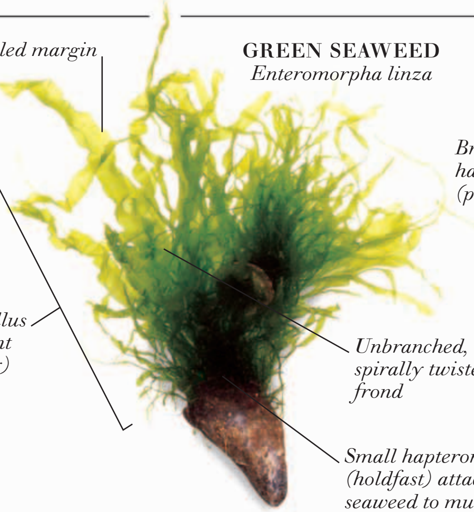
DIATOM
Thalassiosira sp.



RECEPTACLE
Spiral wrack
(*Fucus spiralis*)

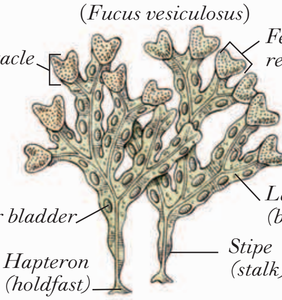
BROWN SEAWEED
Oarweed
(*Laminaria digitata*)

GREEN SEAWEED
Enteromorpha linza

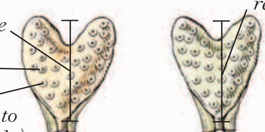


RED SEAWEED
Corallina officinalis

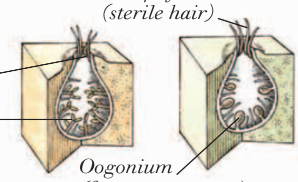
LIFE-CYCLE OF BROWN SEAWEED
Bladder wrack
(*Fucus vesiculosus*)



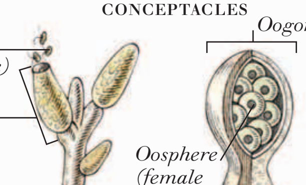
MALE AND FEMALE SEAWEEDS



MALE AND FEMALE RECEPTACLES

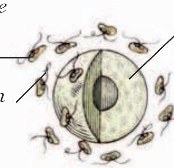


SECTIONS THROUGH MALE AND FEMALE CONCEPTACLES



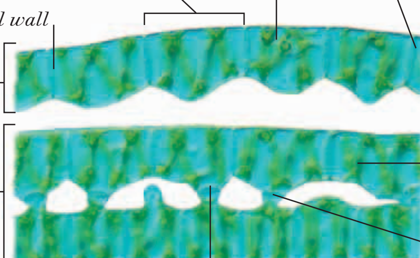
PRODUCTION OF GAMETES

RED SEAWEED
Dilsea carnosa



FERTILIZATION

GREEN ALGA
Spirogyra sp.



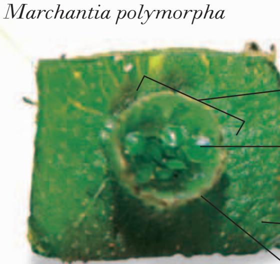
ZYGOTE DEVELOPS INTO A YOUNG SEAWEED

Liverworts and mosses

LIVERWORTS AND MOSSES ARE SMALL, LOW-GROWING PLANTS that belong to the phylum Bryophyta. Bryophytes do not have true stems, leaves, or roots (they are anchored to the ground by rhizoids), nor do they have the vascular tissues (xylem and phloem) that transport water and nutrients in higher plants. With no outer, waterproof cuticle, bryophytes are susceptible to drying out, and most grow in moist habitats. The bryophyte life-cycle has two stages. In stage one, the green plant (gametophyte) produces male and female gametes (sex cells), which fuse to form a zygote. In stage two, the zygote develops into a sporophyte that remains attached to the gametophyte. The sporophyte produces spores, which are released and germinate into new green plants. Liverworts (class Hepaticae) grow horizontally and may be thalloid (flat and ribbonlike) or "leafy." Mosses (class Musci) typically have an upright "stem" with spirally arranged "leaves."

A LEAFY LIVERWORT
Scapania undulata

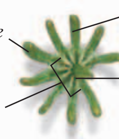
A THALLOID LIVERWORT
Marchantia polymorpha



DETAIL OF GEMMA CUP

FEMALE GAMETOPHYTE

SIDE VIEW OF ARCHEGONIOPHORE

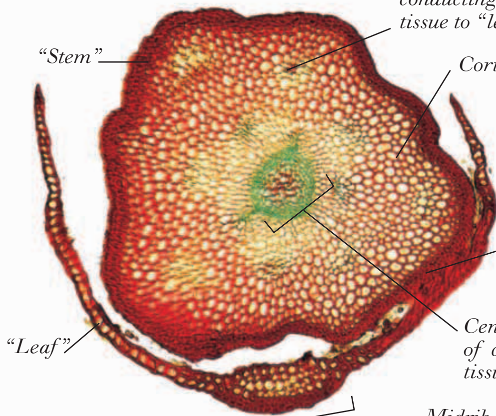


ARCHEGONIOPHORE FROM BELOW

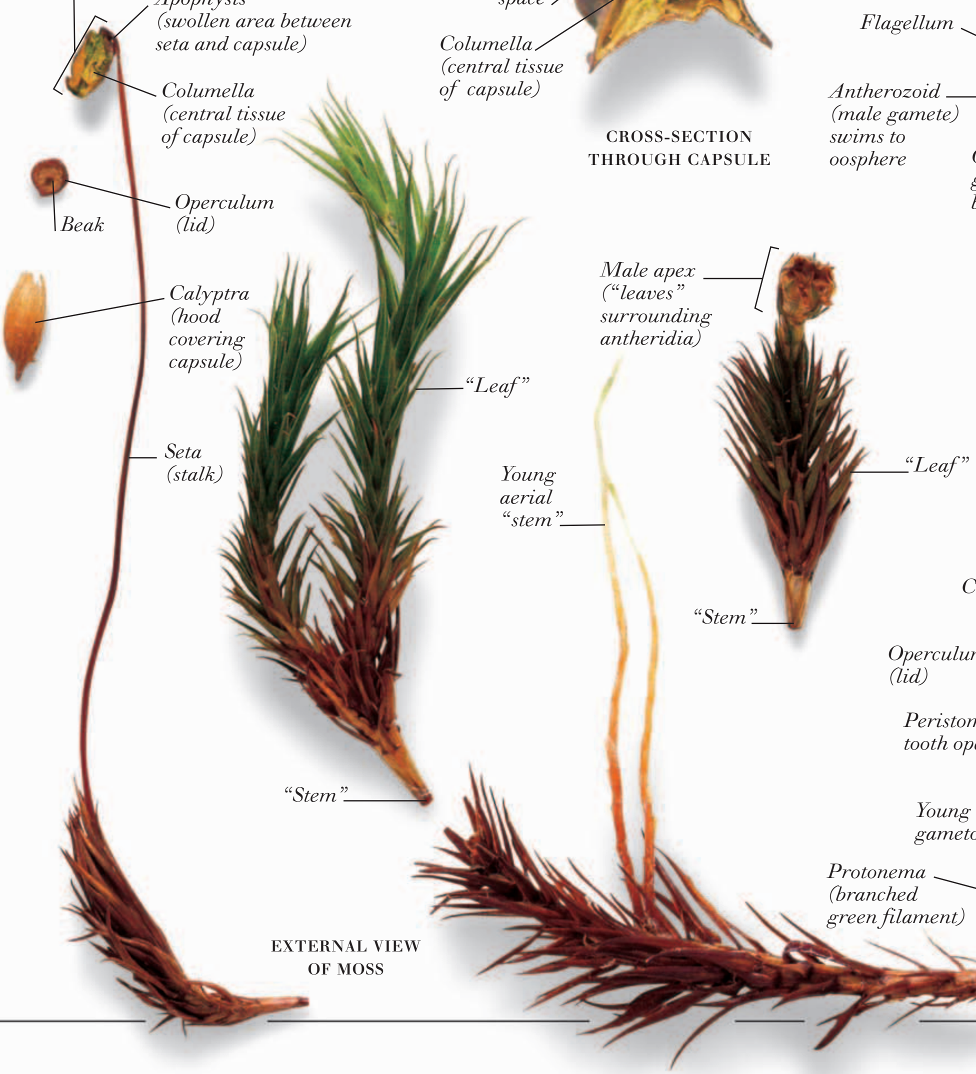
MICROGRAPH OF LOBE

MICROGRAPH OF THALLUS
Conocephalum conicum

A COMMON MOSS
Polytrichum commune

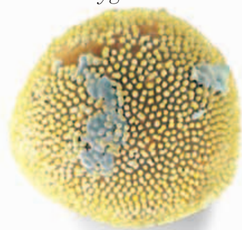


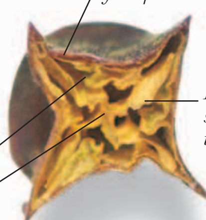
MICROGRAPH OF CROSS-SECTION THROUGH STEM AND LEAF



EXTERNAL VIEW OF MOSS

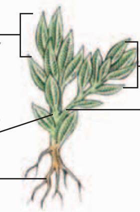
MICROGRAPH OF MOSS SPORE
Funaria hygrometrica



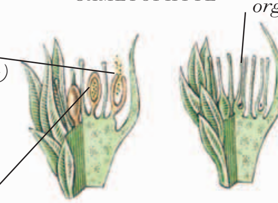


CROSS-SECTION THROUGH CAPSULE

LIFE-CYCLE OF MOSS
Funaria sp.

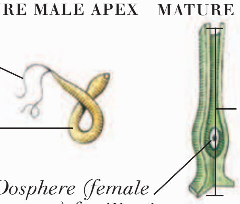


GAMETOPHYTE



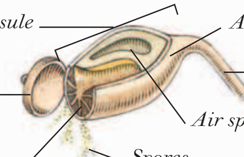
SECTION THROUGH MATURE MALE APEX

SECTION THROUGH MATURE FEMALE APEX

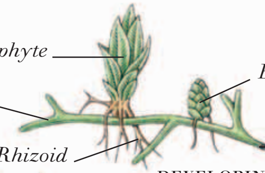


FERTILIZATION

SPOROPHYTE



RIPE CAPSULE



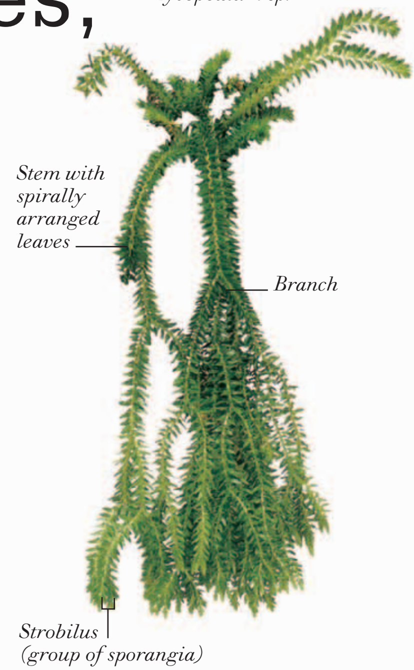
DEVELOPING GAMETOPHYTE

Horsetails, clubmosses, and ferns

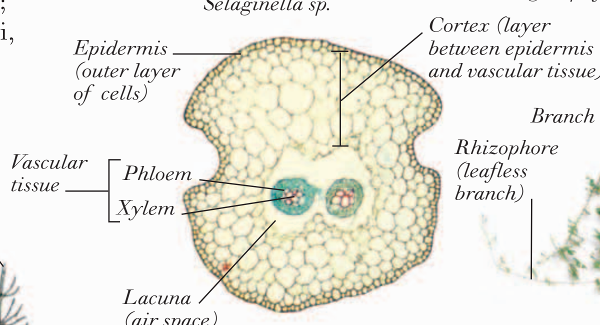
FROND
Male fern (*Dryopteris filix-mas*)

HORSETAILS, CLUBMOSSES, AND FERNS are primitive land plants, which, like higher plants, have stems, roots, and leaves, and vascular systems that transport water, minerals, and food. However, unlike higher plants, they do not produce seeds when reproducing. Their life-cycles involve two stages. In stage one, the sporophyte (green plant) produces spores in sporangia. In stage two, the spores germinate, developing into small, short-lived gametophyte plants that produce male and female gametes (sex cells); the gametes fuse to form a zygote from which a new sporophyte plant develops. Horsetails (phylum Sphenophyta) have erect, green stems with branches arranged in whorls; some stems are fertile and have a single spore-producing strobilus (group of sporangia) at the tip. Clubmosses (phylum Lycopodophyta) typically have small leaves arranged spirally around the stem, with spore-producing strobili at the tip of some stems. Ferns (phylum Filicinophyta) typically have large, pinnate fronds (leaves); sporangia, grouped together in sori, develop on the underside of fertile fronds.

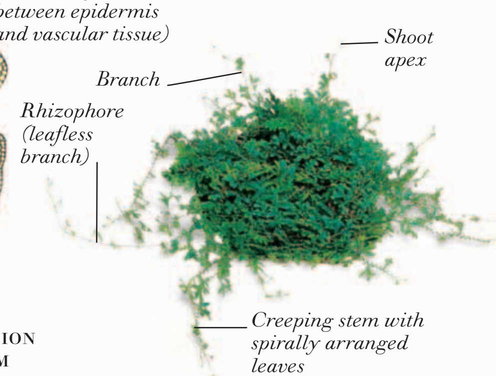
CLUBMOSS
Lycopodium sp.



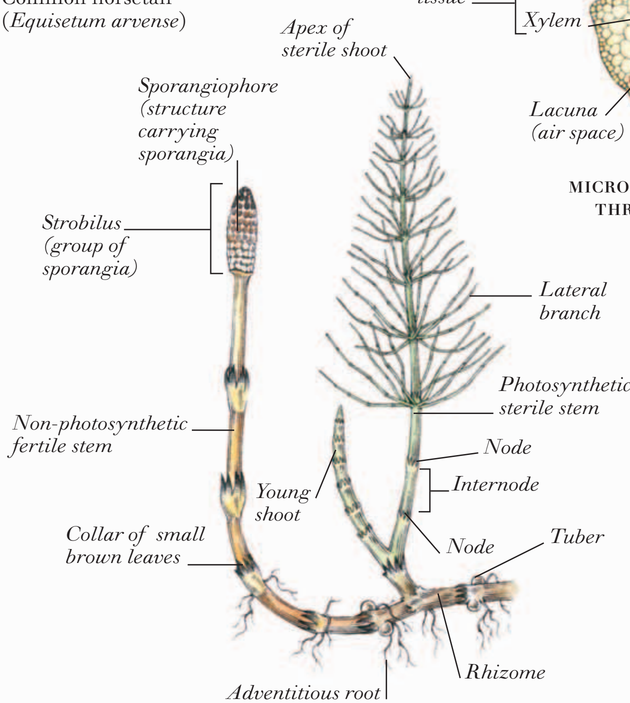
CLUBMOSS
Selaginella sp.

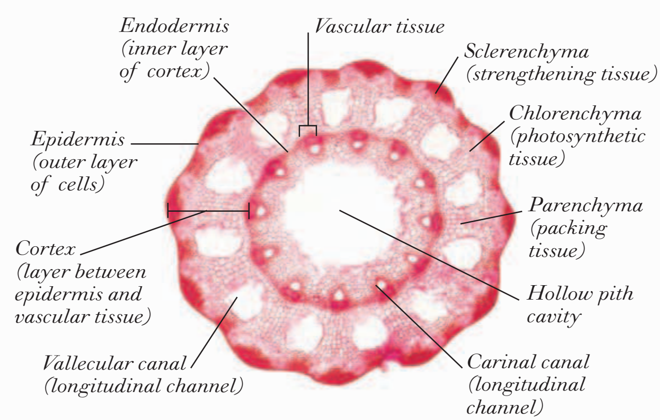


MICROGRAPH OF CROSS-SECTION THROUGH CLUBMOSS STEM



HORSETAIL
Common horsetail (*Equisetum arvense*)

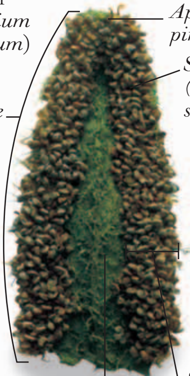




MICROGRAPH OF CROSS-SECTION THROUGH HORSETAIL STEM

SPORE PRODUCTION IN FERN

Bracken (*Pteridium aquilinum*)

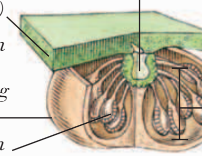


MICROGRAPH OF LOWER SURFACE OF FERTILE PINNULE

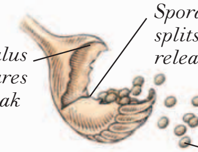
MICROGRAPH OF SPORANGIA ON LOWER SURFACE OF FERTILE PINNULE

LIFE-CYCLE OF FERN

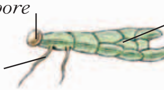
SPOROPHYTE



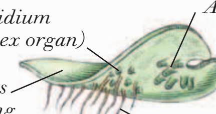
SECTION THROUGH MATURE PINNULE



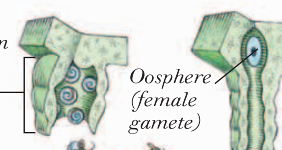
RELEASE OF SPORES FROM SPORANGIUM



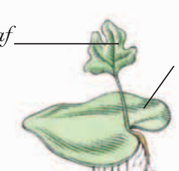
GERMINATION OF SPORE



GAMETOPHYTE PRODUCES GAMETES



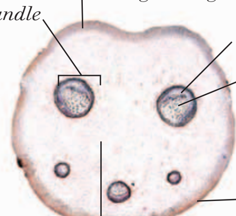
FERTILIZATION



FERTILIZED OOSPHERE GROWS INTO NEW SPOROPHYTE PLANT

FERN

Male fern (*Dryopteris filix-mas*)

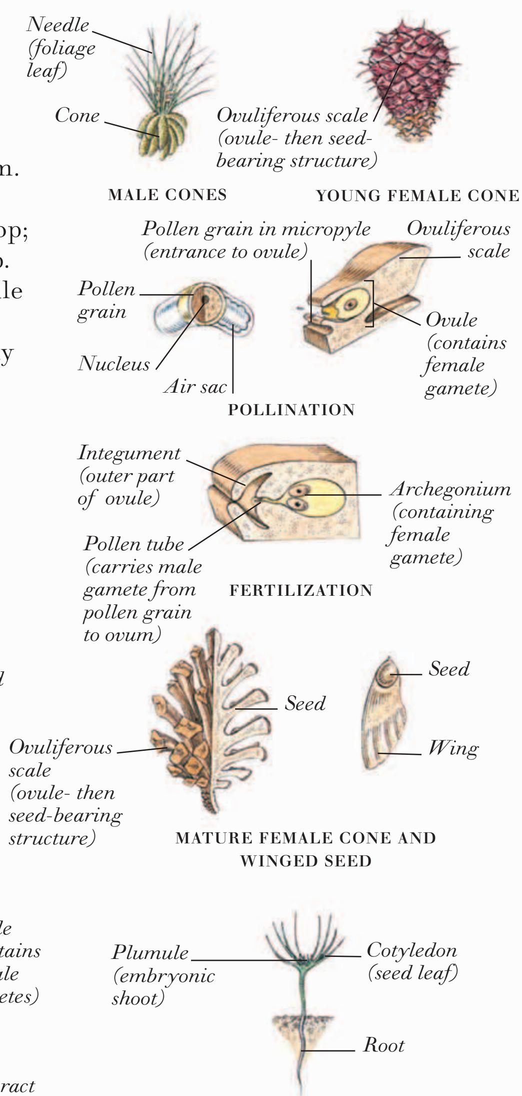


MICROGRAPH OF CROSS-SECTION THROUGH FERN RACHIS

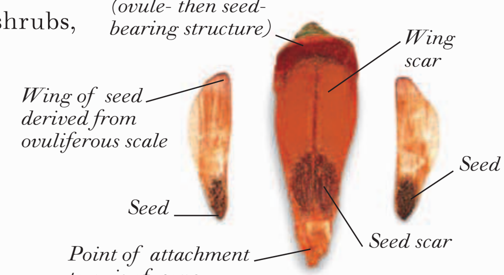
Gymnosperms 1

THE GYMNOSPERMS ARE FOUR RELATED PHYLA of seed-producing plants; their seeds, however, lack the protective, outer covering that surrounds the seeds of flowering plants. Typically, gymnosperms are woody, perennial shrubs or trees, with stems, leaves, and roots, and a well-developed vascular (transportat) system. The reproductive structures in most gymnosperms are cones: male cones produce microspores in which male gametes (sex cells) develop; female cones produce megaspores in which female gametes develop. Microspores are blown by the wind to female cones, male and female gametes fuse during fertilization, and a seed develops. The four gymnosperm phyla are the conifers (phylum Coniferophyta), mostly tall trees; cycads (phylum Cycadophyta), small palmlike trees; the ginkgo or maidenhair tree (phylum Ginkgophyta), a tall tree with bilobed leaves; and gnetophytes (phylum Gnetophyta), a diverse group of plants, mainly shrubs, but also including the horizontally growing welwitschia.

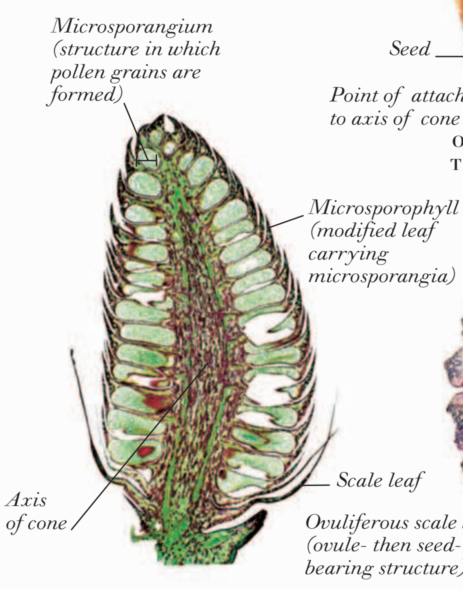
LIFE-CYCLE OF SCOTS PINE
(*Pinus sylvestris*)



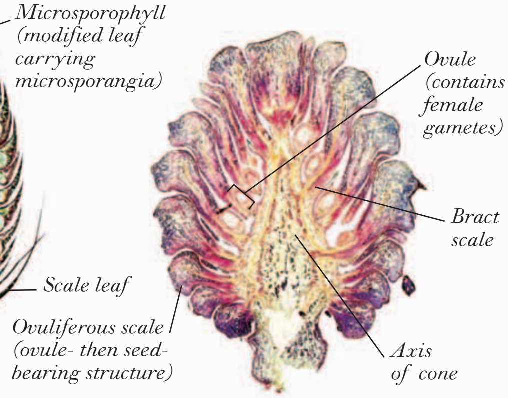
SCALE AND SEEDS
Pine
(*Pinus sp.*)



OVULIFEROUS SCALE FROM THIRD-YEAR FEMALE CONE



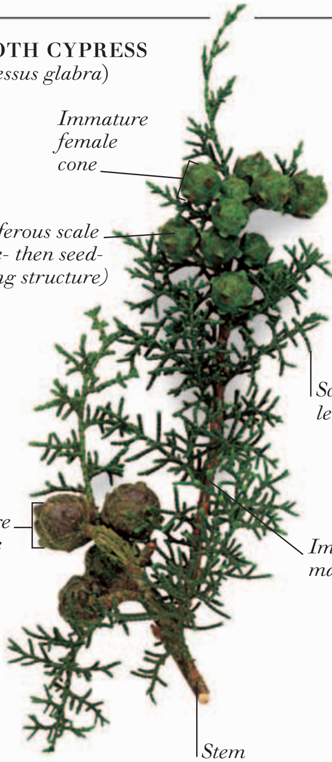
MICROGRAPH OF LONGITUDINAL SECTION THROUGH YOUNG MALE CONE

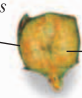


MICROGRAPH OF LONGITUDINAL SECTION THROUGH SECOND-YEAR FEMALE CONE

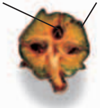
WELWITSCHIA
(*Welwitschia mirabilis*)

SMOOTH CYPRESS
(*Cupressus glabra*)





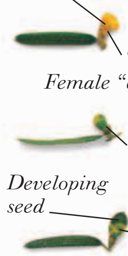
CROSS-SECTION THROUGH IMMATURE CONE



CROSS-SECTION THROUGH MATURE CONE

DISCARDED CONE

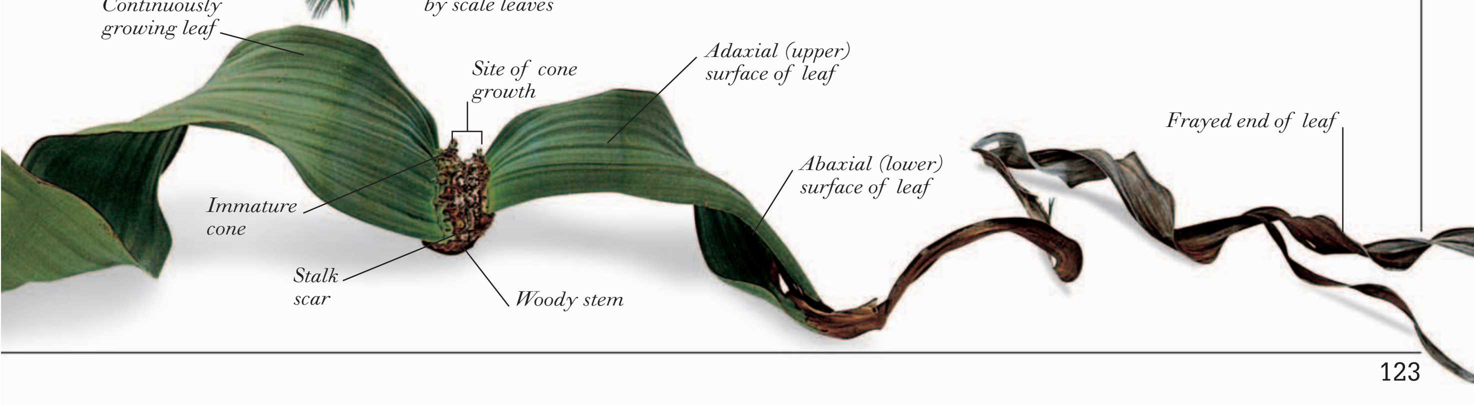
YEW
(*Taxus baccata*)



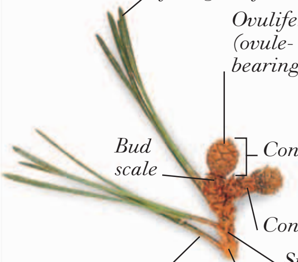
FEMALE "CONES" AT VARIOUS STAGES OF DEVELOPMENT

CYCAD
Sago palm
(*Cycas revoluta*)

MAIDENHAIR TREE
(*Ginkgo biloba*)



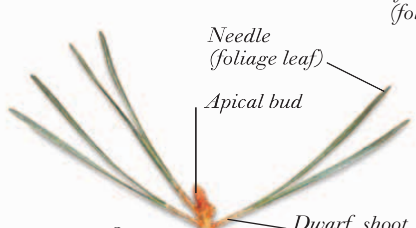
Gymnosperms 2



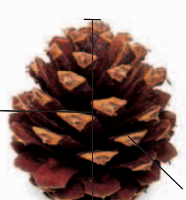
FEMALE CONE
(FIRST YEAR)

BRANCH OF BISHOP PINE
(*Pinus muricata*)

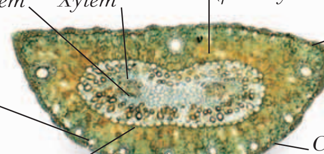




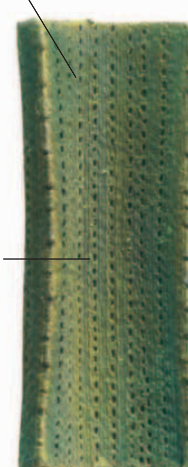
TERMINAL ZONE OF BRANCH



FEMALE CONE
(THIRD YEAR)



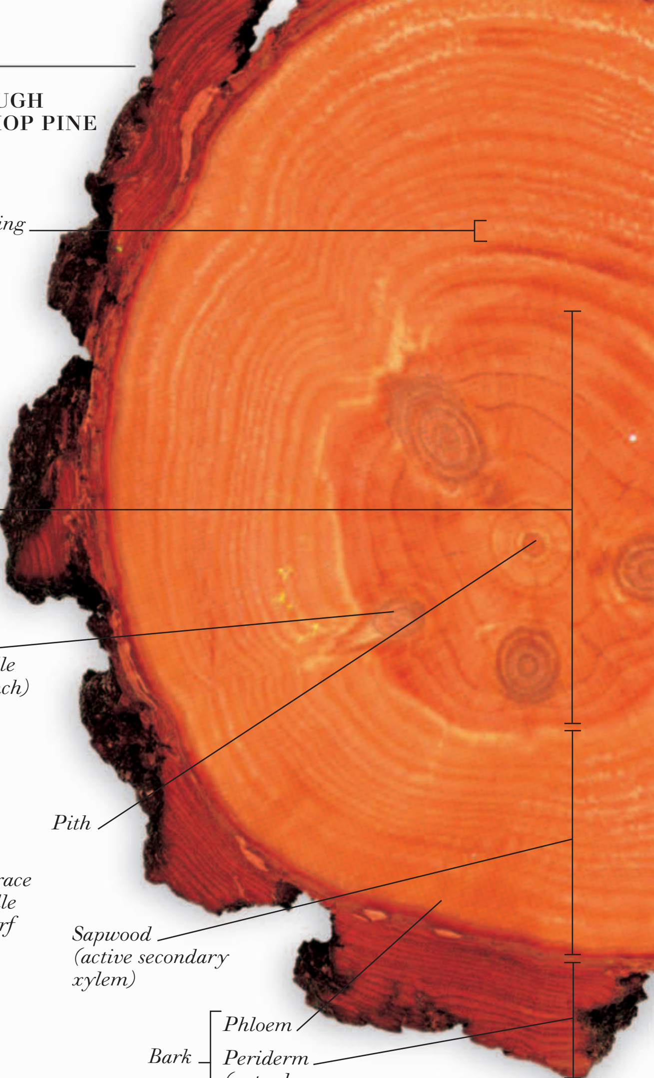
MICROGRAPH OF CROSS-SECTION
THROUGH NEEDLE (FOLIAGE LEAF)

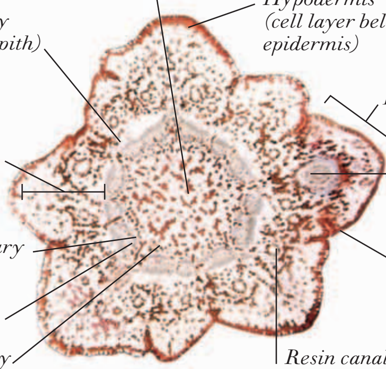


MICROGRAPH OF NEEDLE
(FOLIAGE LEAF) OF PINE
(*Pinus sp.*)

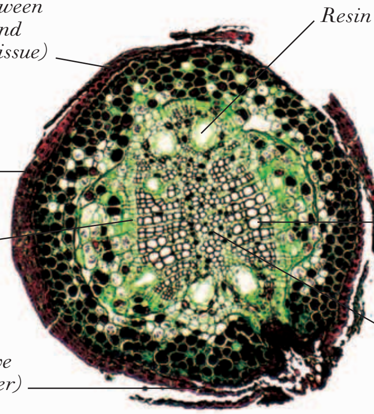
MICROGRAPH OF LONGITUDINAL SECTION THROUGH SHOOT APEX OF PINE
(*Pinus sp.*)

CROSS-SECTION THROUGH MATURE STEM OF BISHOP PINE
(*Pinus muricata*)

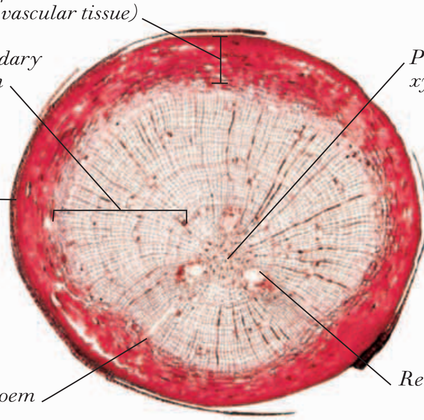




MICROGRAPH OF CROSS-SECTION THROUGH YOUNG STEM OF PINE
(*Pinus sp.*)



MICROGRAPH OF CROSS-SECTION THROUGH YOUNG ROOT OF PINE
(*Pinus sp.*)



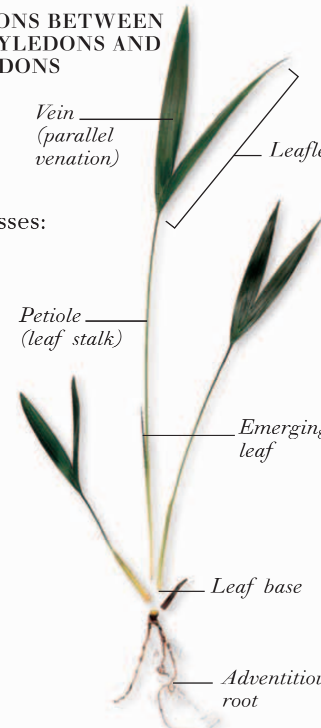
MICROGRAPH OF CROSS-SECTION THROUGH MATURE ROOT OF PINE
(*Pinus sp.*)

Monocotyledons and dicotyledons

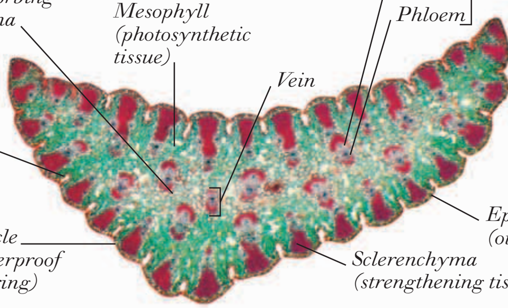
FLOWERING PLANTS (PHYLUM ANGIOSPERMOPHYTA) are divided into two classes: monocotyledons (class Monocotyledoneae) and dicotyledons (class Dicotyledoneae). Typically, monocotyledons have seeds with one cotyledon (seed leaf); their foliage leaves are narrow with parallel veins; the flower components occur in multiples of three; sepals and petals are indistinguishable and are known as tepals; vascular (transport) tissues are scattered in random bundles throughout the stem; and, since they lack stem cambium (actively dividing cells that produce wood), most monocotyledons are herbaceous (see pp. 128-129). Dicotyledons have seeds with two cotyledons; leaves are broad with a central midrib and branched veins; flower parts occur in multiples of four or five; sepals are generally small and green; petals are large and colorful; vascular bundles are arranged in a ring around the edge of the stem; and, because many dicotyledons possess wood-producing stem cambium, there are woody forms (see pp. 130-131) as well as herbaceous ones.

CROSS-SECTION THROUGH MONOCOTYLEDONOUS LEAF BASES

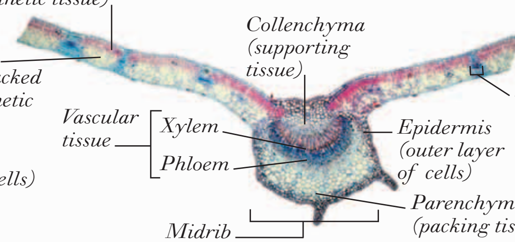
COMPARISONS BETWEEN MONOCOTYLEDONS AND DICOTYLEDONS



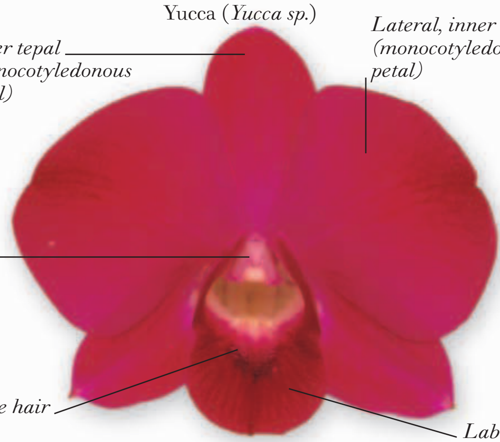
A MONOCOTYLEDON
Paradise palm
(*Howea forsteriana*)



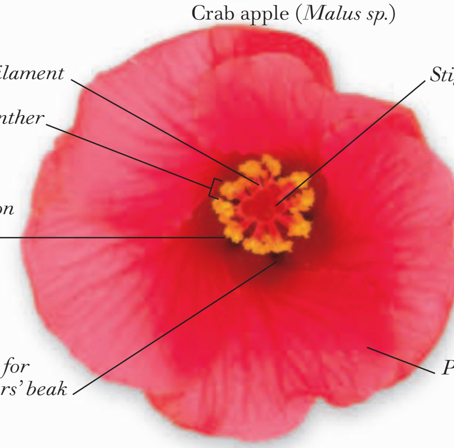
MICROGRAPH OF CROSS-SECTION THROUGH A MONOCOTYLEDONOUS LEAF
Yucca (*Yucca sp.*)



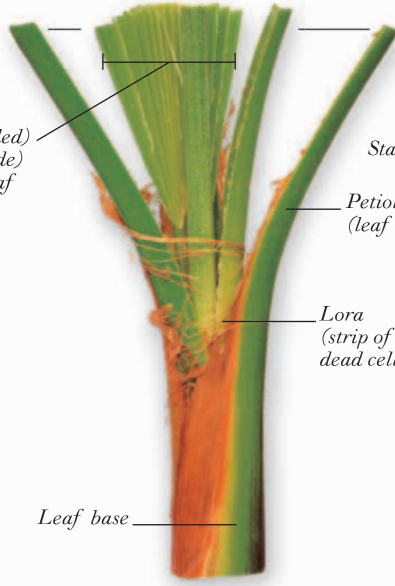
MICROGRAPH OF CROSS-SECTION THROUGH A DICOTYLEDONOUS LEAF
Crab apple (*Malus sp.*)



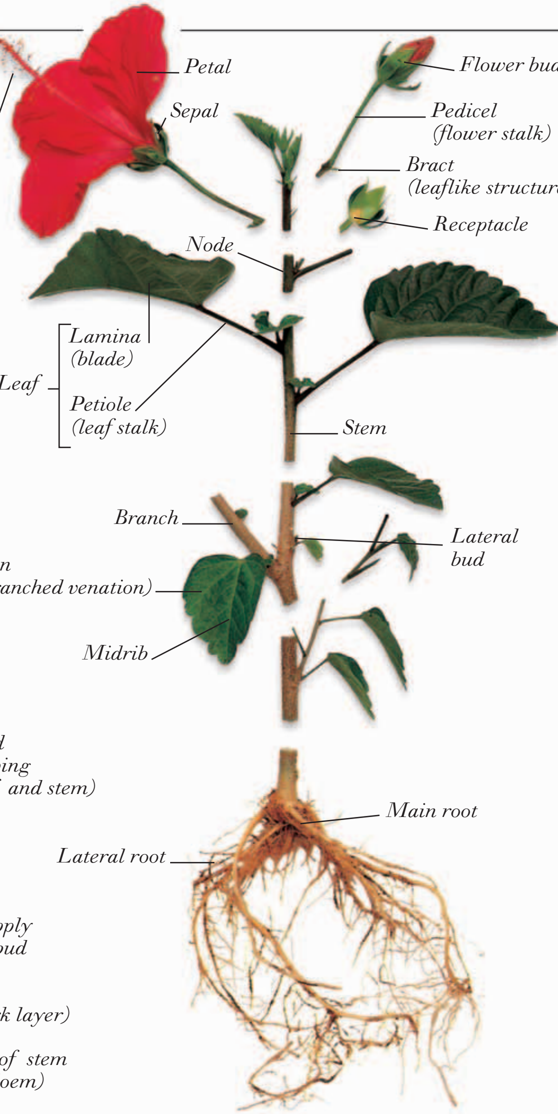
A MONOCOTYLEDONOUS FLOWER
Orchid
(*Phalaenopsis sp.*)



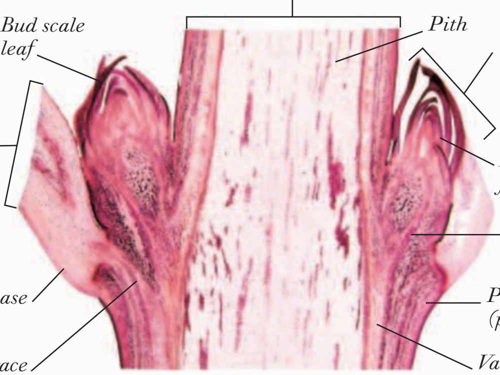
A DICOTYLEDONOUS FLOWER
Hibiscus
(*Hibiscus rosa-sinensis*)



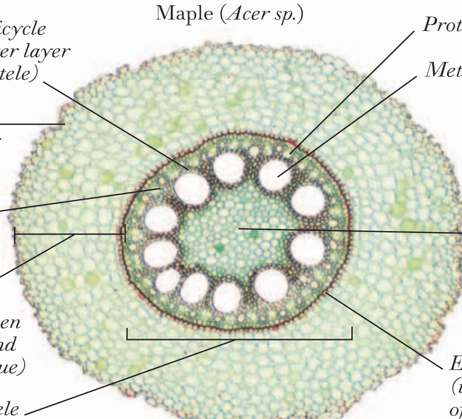
MONOCOTYLEDONOUS LEAF BASES FORMING STEM
Chusan palm
(*Trachycarpus fortunei*)



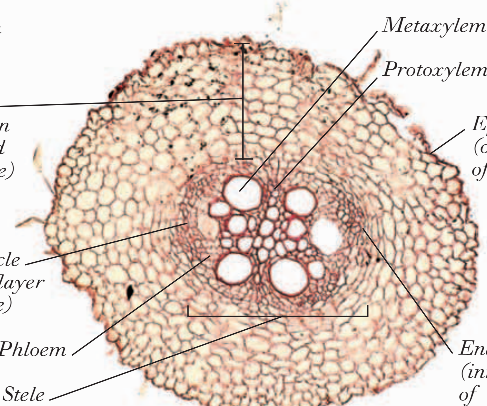
A DICOTYLEDON
Hibiscus (*Hibiscus rosa-sinensis*)



MICROGRAPH OF LONGITUDINAL SECTION THROUGH A WOODY DICOTYLEDONOUS STEM
Maple (*Acer sp.*)



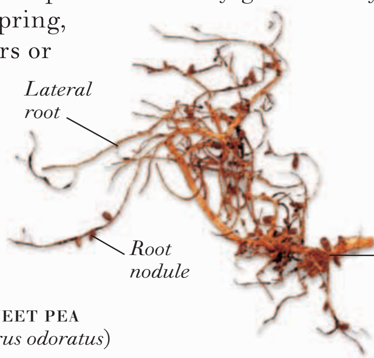
MICROGRAPH OF CROSS-SECTION THROUGH A MONOCOTYLEDONOUS ROOT
Corn (*Zea mays*)



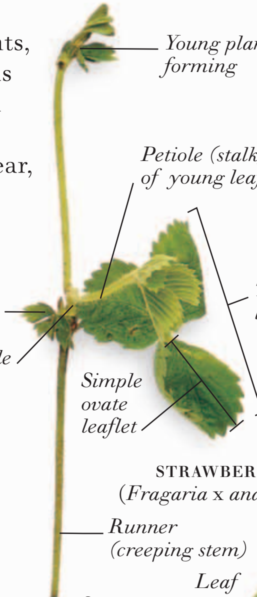
MICROGRAPH OF CROSS-SECTION THROUGH A DICOTYLEDONOUS ROOT
Buttercup (*Ranunculus sp.*)

Herbaceous flowering plants

HERBACEOUS FLOWERING PLANTS TYPICALLY HAVE GREEN, NON-WOODY STEMS, and tend to be relatively short-lived. Many herbaceous plants live for only one or two years. Annuals (e.g., sweet peas) grow from seed, produce flowers and then seeds, and die within a single year. Biennials (e.g., carrots) have a two-year life cycle. In the first year, seeds grow into plants, which produce leaves and store food in underground storage organs; the stems and foliage then die back in winter. In the second year, new stems grow from the storage organs, produce leaves, flowers, and seeds, and then die. Some herbaceous plants (e.g., potatoes) are perennial. They grow back year after year, producing shoots and flowers in spring, storing food in underground tubers or rhizomes during summer, dying back in the fall, and surviving underground during winter.

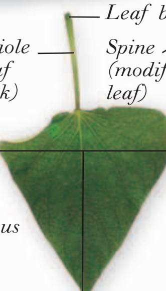


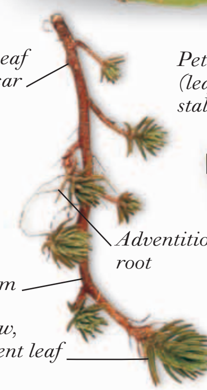
SWEET PEA
(*Lathyrus odoratus*)



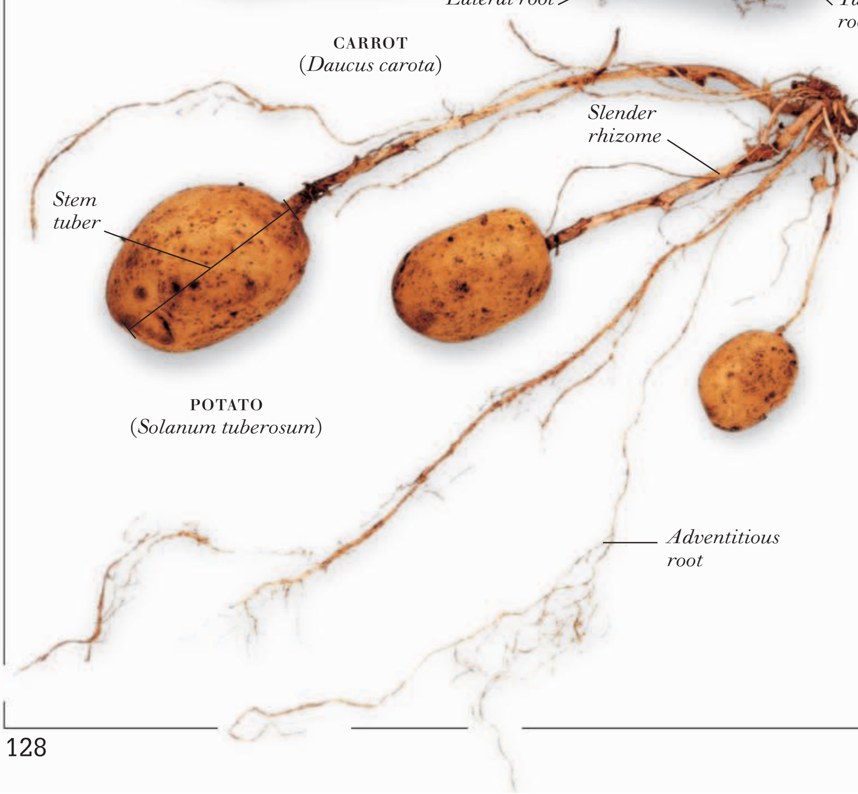
STRAWBERRY
(*Fragaria x ananassa*)

CARROT
(*Daucus carota*)



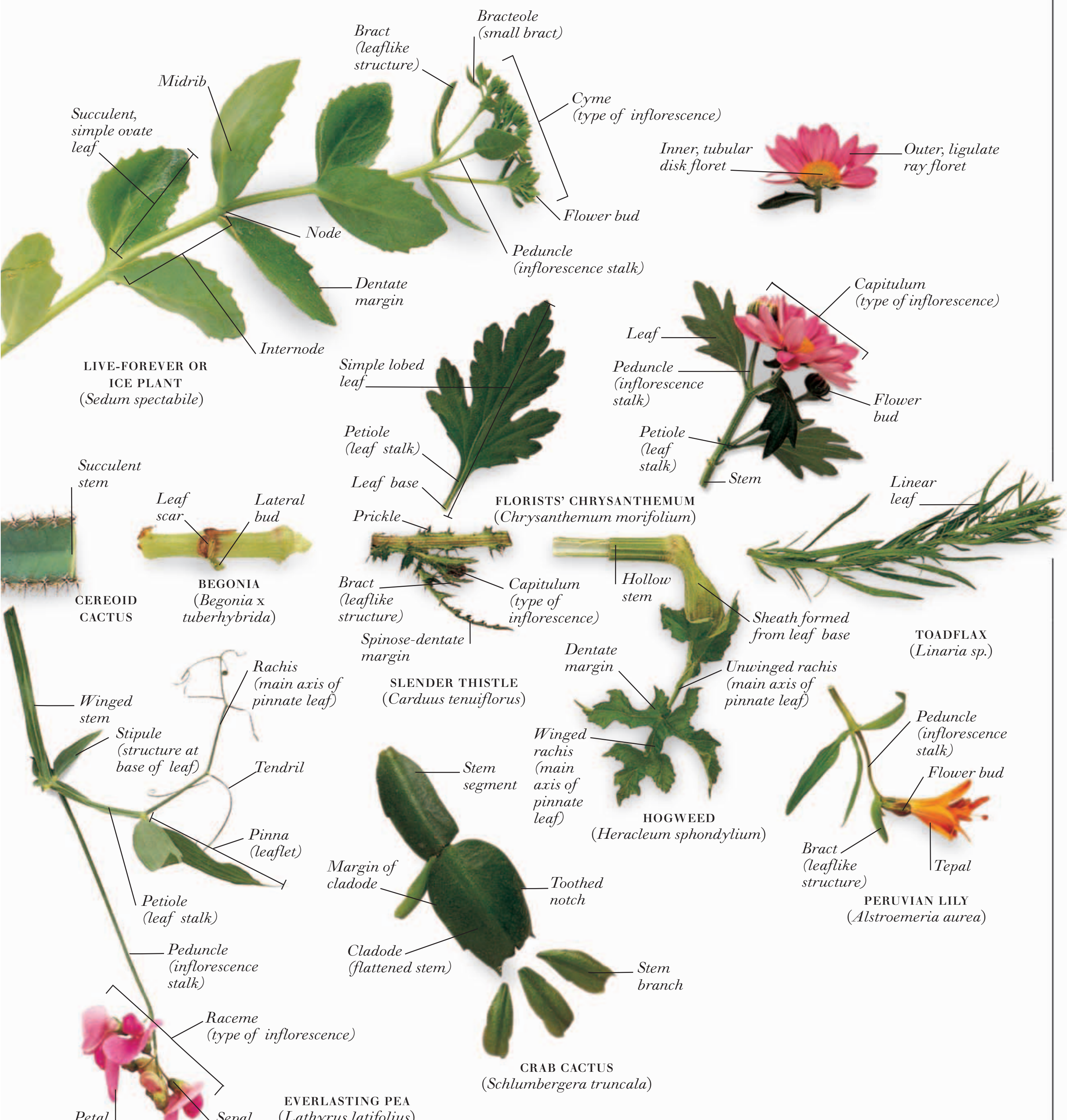


ROCK STONECROP
(*Sedum rupestre*)



POTATO
(*Solanum tuberosum*)

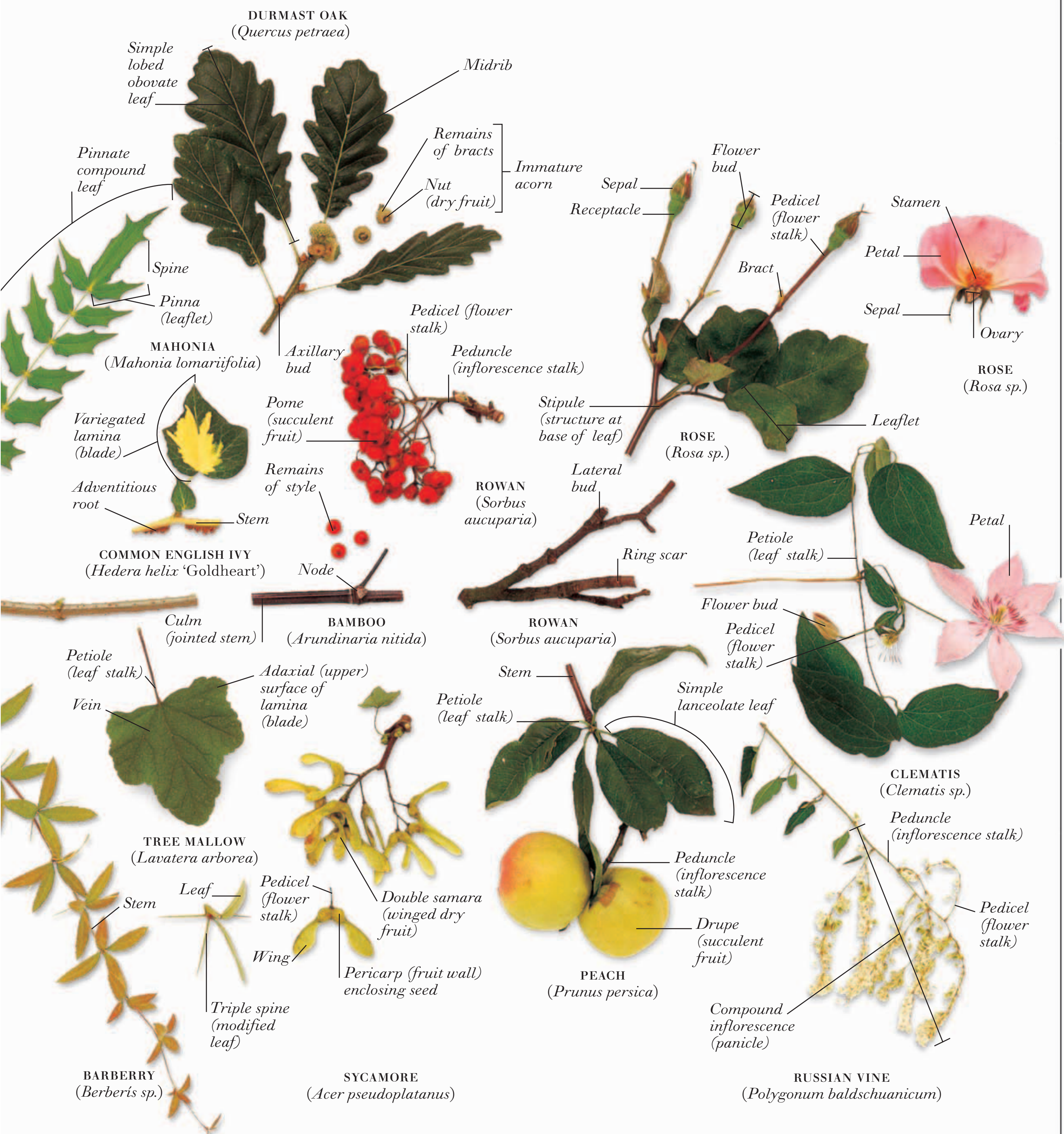
PARTS OF HERBACEOUS FLOWERING PLANTS



Woody flowering plants

WOODY FLOWERING PLANTS ARE PERENNIAL, that is, they continue to grow and reproduce for many years. They have one or more permanent stems above ground, and numerous smaller branches. The stems and branches have a strong woody core that supports the plant and contains vascular tissue for transporting water and nutrients. Outside the woody core is a layer of tough, protective bark, which has lenticels (tiny pores) in it to enable gases to pass through. Woody flowering plants may be shrubs, which have several stems arising from the soil; bushes, which are shrubs with dense branching and foliage; or trees, which typically have a single upright stem (the trunk) that bears branches. Deciduous woody plants (e.g., roses) shed all their leaves once a year and remain leafless during winter. Evergreen woody plants (e.g., ivy) shed their leaves gradually, so retaining full leaf cover throughout the year.

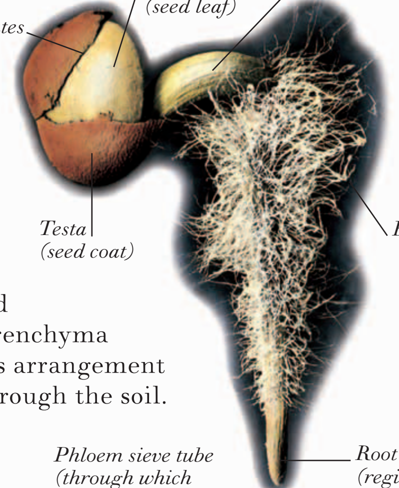
PARTS OF WOODY FLOWERING PLANTS



Roots

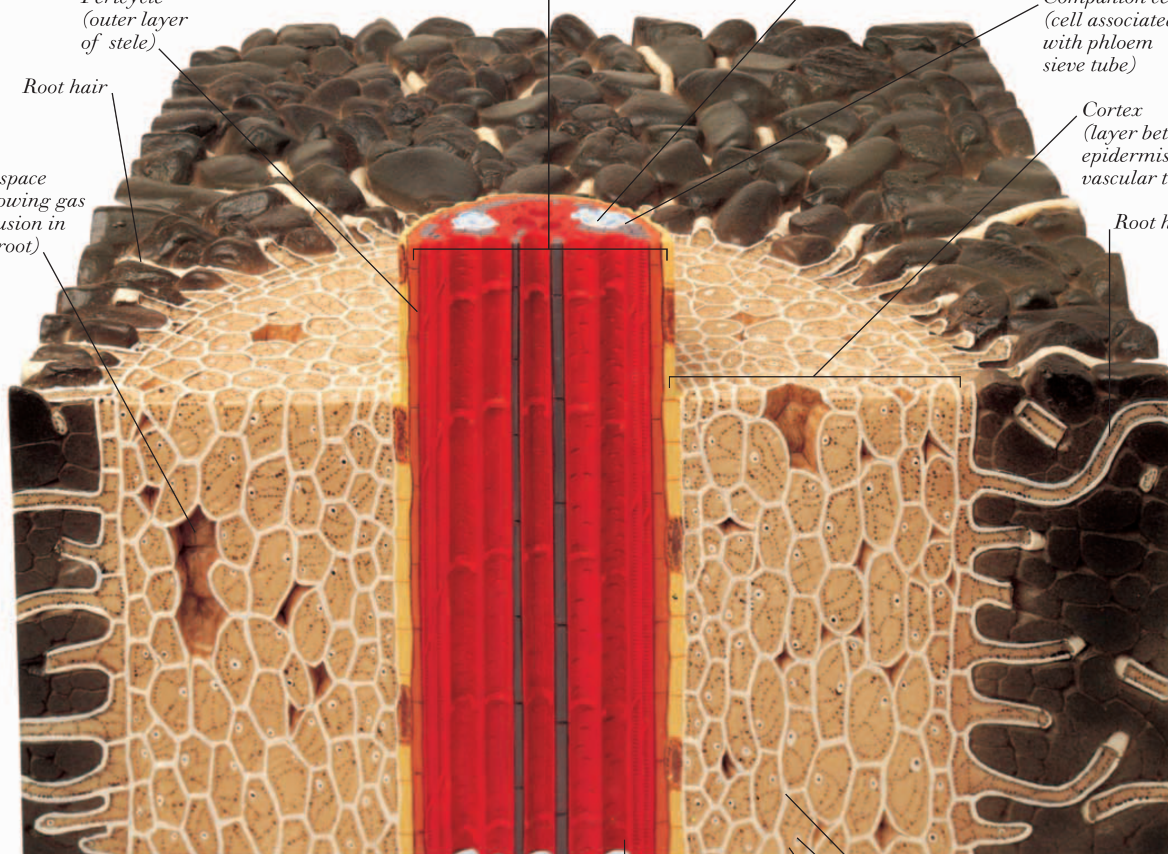
ROOTS ARE THE UNDERGROUND PARTS OF PLANTS. They have three main functions. First, they anchor the plant in the soil. Second, they absorb water and minerals from the spaces between soil particles; the roots' absorptive properties are increased by root hairs, which grow behind the root tip, allowing maximum uptake of vital substances. Third, the root is part of the plant's transport system: xylem carries water and minerals from the roots to the stem and leaves, and phloem carries nutrients from the leaves to all parts of the root system. In addition, some roots (e.g., carrots) are food stores. Roots have an outer epidermis covering a cortex of parenchyma (packing tissue), and a central cylinder of vascular tissue. This arrangement helps the roots resist the forces of compression as they grow through the soil.

MICROGRAPH OF PRIMARY ROOT DEVELOPMENT
Cabbage (*Brassica sp.*)

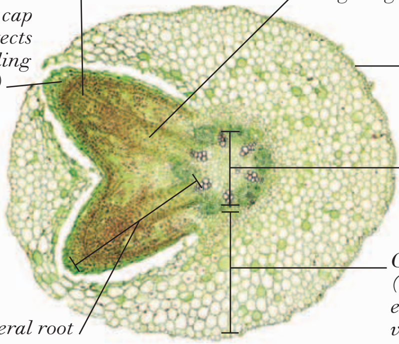


CARROT
(*Daucus carota*)

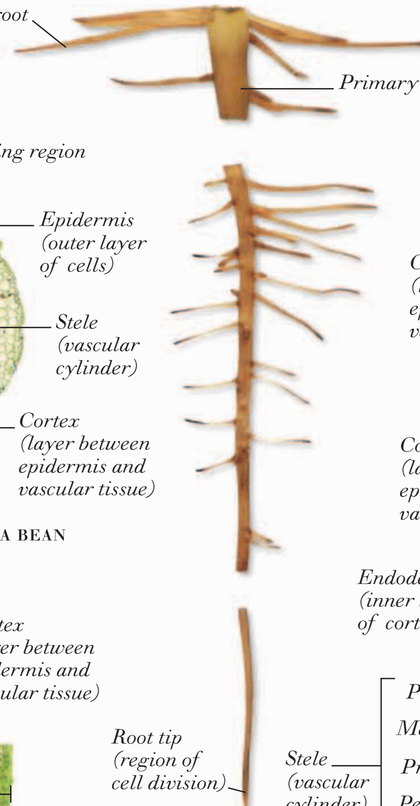
FEATURES OF A TYPICAL ROOT
Buttercup
(*Ranunculus sp.*)



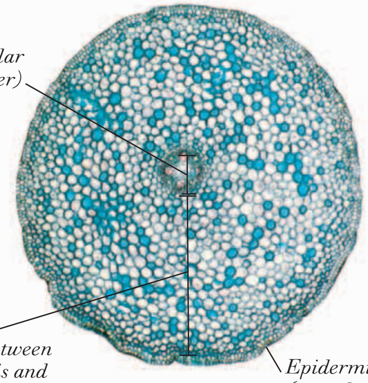
PRIMARY ROOT AND MICROGRAPHS OF SECTIONS THROUGH ROOTS



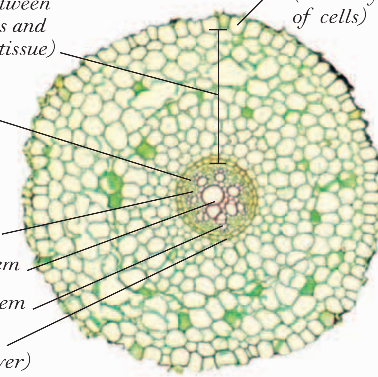
CROSS-SECTION THROUGH ROOT OF FAVA BEAN (*Vicia faba*)



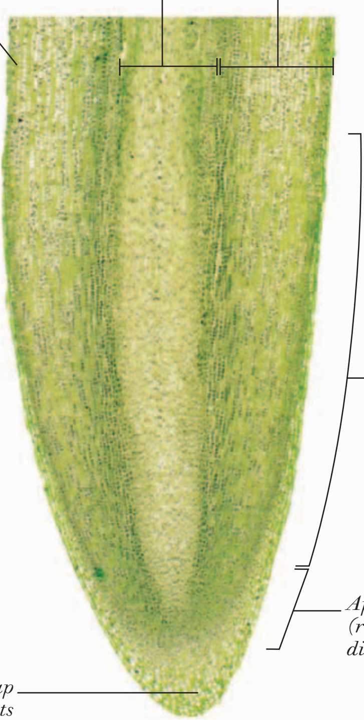
PRIMARY ROOT OF FAVA BEAN (*Vicia faba*)



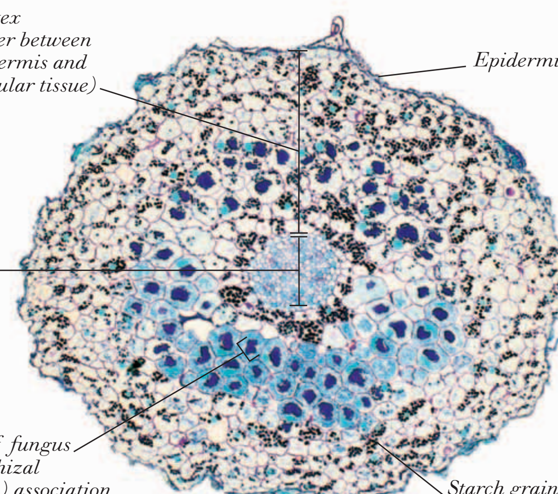
CROSS-SECTION THROUGH ROOT OF BUTTERCUP (*Ranunculus sp.*)



CROSS-SECTION THROUGH ROOT OF LILY (*Lilium sp.*)



LONGITUDINAL SECTION THROUGH ROOT TIP OF FAVA BEAN (*Vicia faba*)

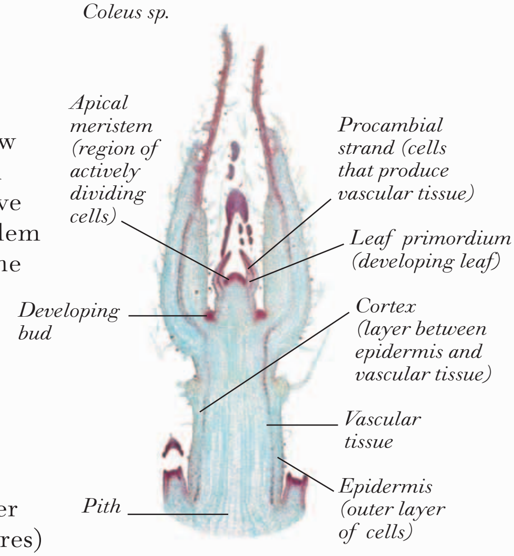


CROSS-SECTION THROUGH ROOT OF ORCHID IN MYCORRHIZAL ASSOCIATION WITH FUNGUS

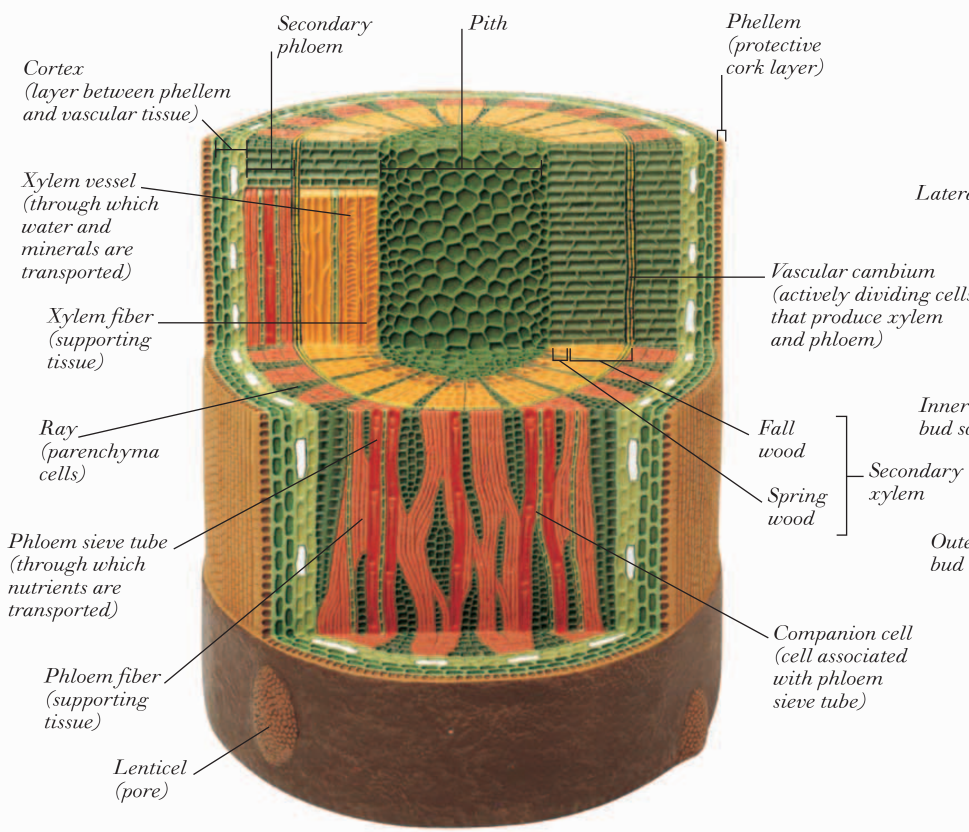
Stems

THE STEM IS THE MAIN SUPPORTIVE PART OF A PLANT that grows above ground. Stems bear leaves (organs of photosynthesis), which grow at nodes; buds (shoots covered by protective scales), which grow at the stem tip (apical or terminal buds) and in the angle between a leaf and the stem (axillary or lateral buds); and flowers (reproductive structures). The stem forms part of the plant's transport system: xylem tissue in the stem transports water and minerals from the roots to the aerial parts of the plant, and phloem tissue transports nutrients manufactured in the leaves to other parts of the plant. Stem tissues are also used for storing water and food. Herbaceous (non-woody) stems have an outer protective epidermis covering a cortex that consists mainly of parenchyma (packing tissue) but also has some collenchyma (supporting tissue). The vascular tissue of such stems is arranged in bundles, each of which consists of xylem, phloem, and sclerenchyma (strengthening tissue). Woody stems have an outer protective layer of tough bark, which is perforated with lenticels (pores) to allow gas exchange. Inside the bark is a ring of secondary phloem, which surrounds an inner core of secondary xylem.

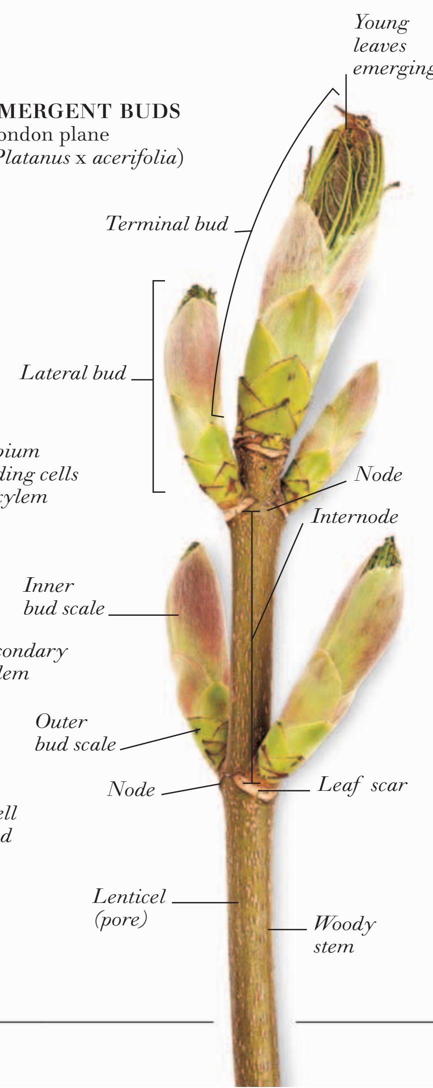
MICROGRAPH OF LONGITUDINAL SECTION THROUGH APEX OF STEM
Coleus sp.



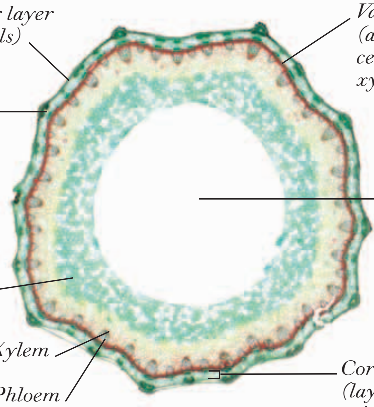
YOUNG WOODY STEM
Lime
(Tilia sp.)



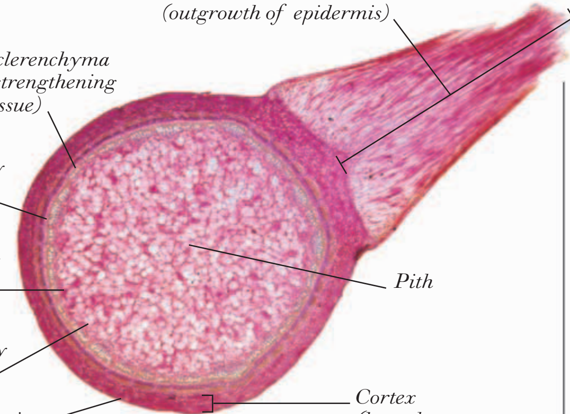
EMERGENT BUDS
London plane
(*Platanus* x *acerifolia*)



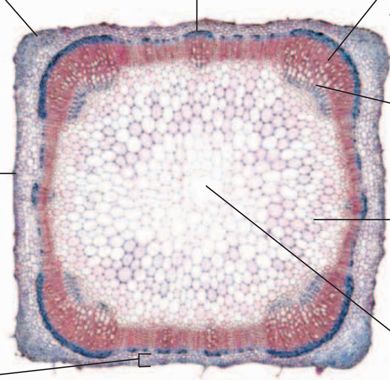
MICROGRAPHS OF CROSS-SECTIONS THROUGH VARIOUS STEMS



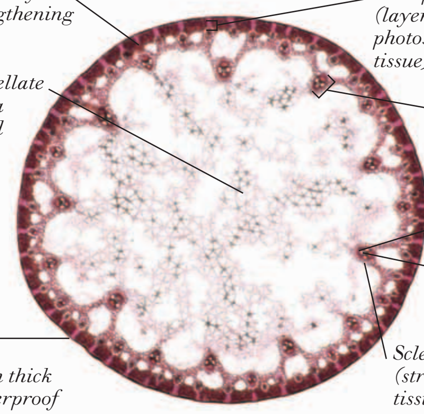
CHERVIL
(*Anthriscus sp.*)



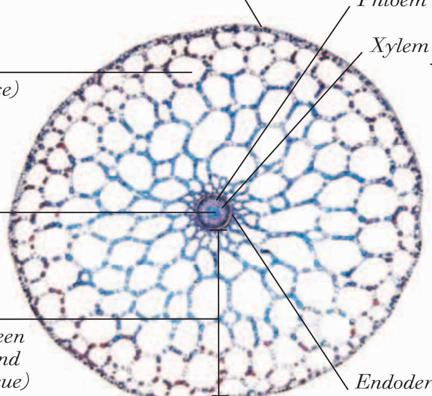
ROSE
(*Rosa sp.*)



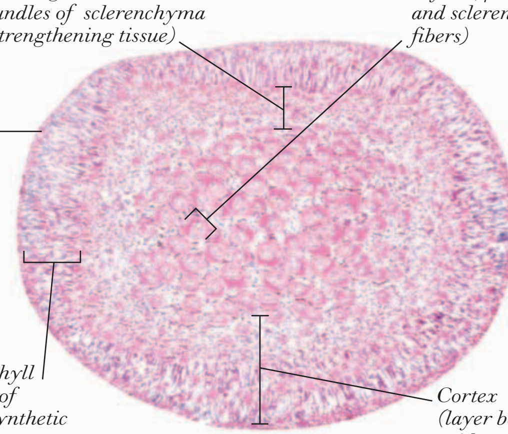
DEADNETTLE
(*Lamium sp.*)



RUSH
(*Juncus sp.*)



MARE'S TAIL
(*Hippuris vulgaris*)



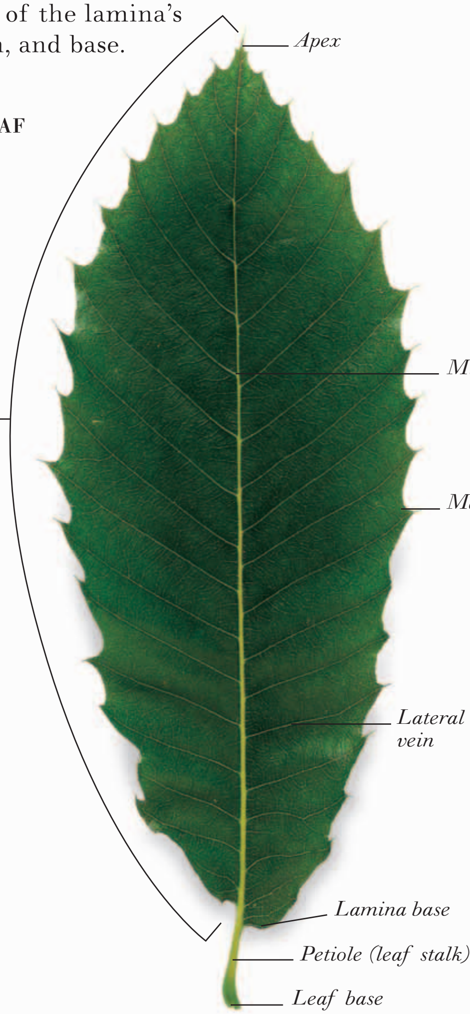
COCONUT PALM
(*Cocos nucifera*)

Leaves

CHECKERBLOOM
(Sidalcea malviflora)

LEAVES ARE THE MAIN SITES OF PHOTOSYNTHESIS (see pp. 138-139) and transpiration (water loss by evaporation) in plants. A typical leaf consists of a thin, flat lamina (blade) supported by a network of veins; a petiole (leaf stalk); and a leaf base, where the petiole joins the stem. Leaves can be classified as simple, in which the lamina is a single unit, or compound, in which the lamina is divided into separate leaflets. Compound leaves may be pinnate, with pinnae (leaflets) on both sides of a rachis (main axis), or palmate, with leaflets arising from a single point at the tip of the petiole. Leaves can be classified further by the overall shape of the lamina, and by the shape of the lamina's apex, margin, and base.

GENERAL LEAF FEATURES



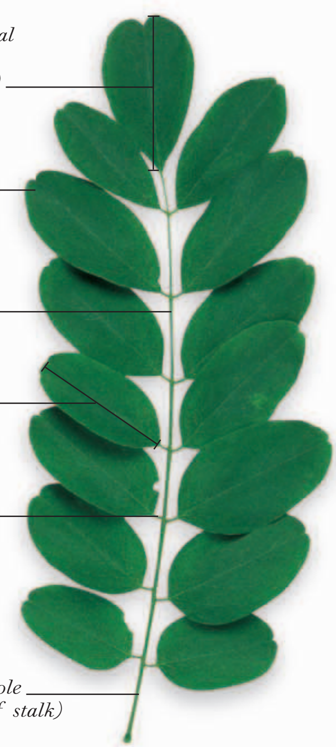
Sweet chestnut
(Castanea sativa)

SIMPLE LEAF SHAPES

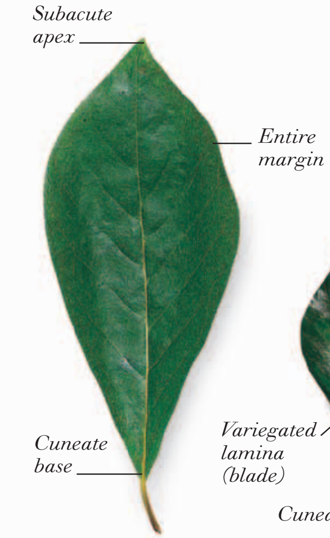
PANDURIFORM
Croton
(Codiaeum variegatum)

LANCEOLATE
Sea buckthorn
(Hippophae rhamnoides)

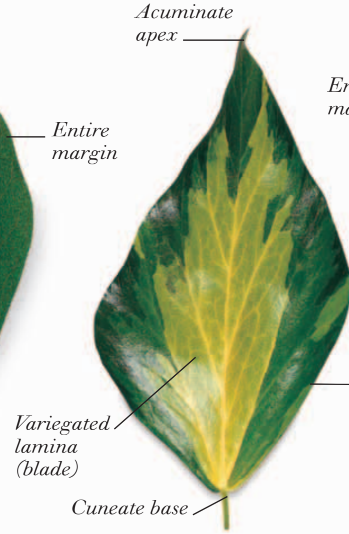
COMPOUND LEAF SHAPES



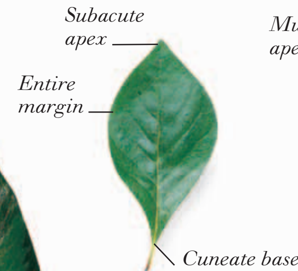
ODD PINNATE
False acacia
(Robinia pseudoacacia)



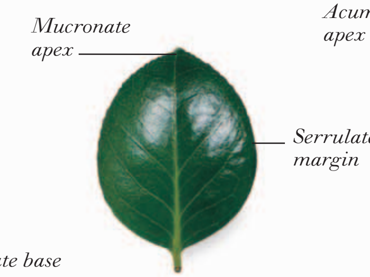
OBOVATE
Tupelo
(*Nyssa sylvatica*)



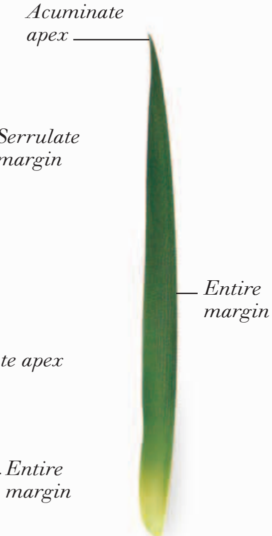
RHOMBOID
Persian ivy
(*Hedera colchica* 'Sulfur Heart')



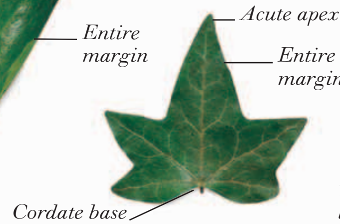
ELLIPTIC
Fig
(*Ficus sp.*)



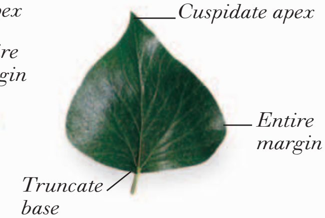
ORBICULAR
Camellia
(*Camellia japonica*)



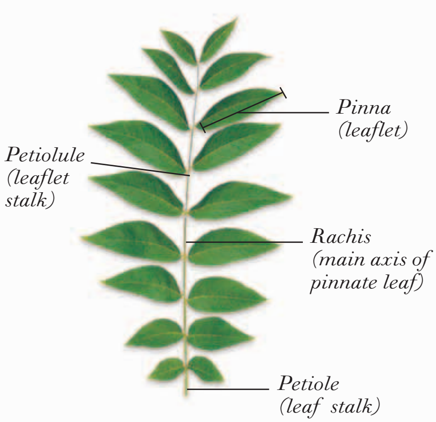
LINEAR
Iris
(*Iris lazica*)



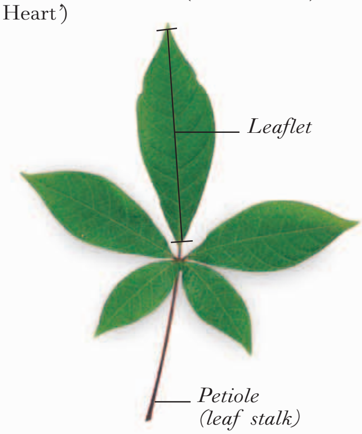
PALMATELY LOBED
Common ivy
(*Hedera helix*)



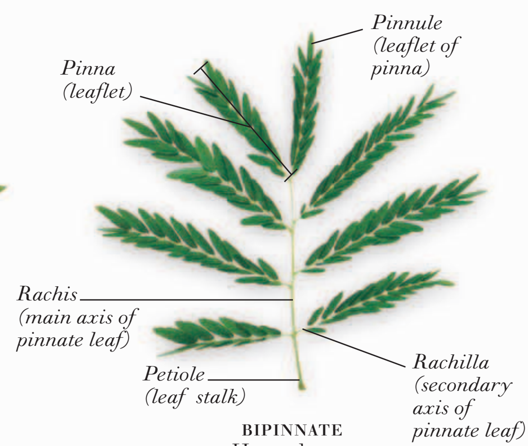
DELTOID
Persian ivy
(*Hedera colchica*)



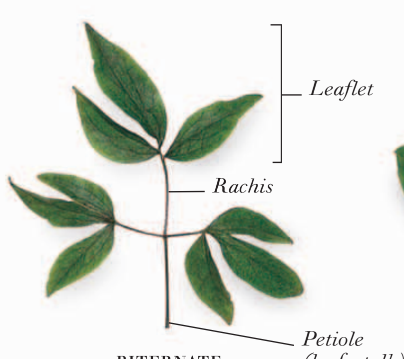
EVEN PINNATE
Black walnut
(*Juglans nigra*)



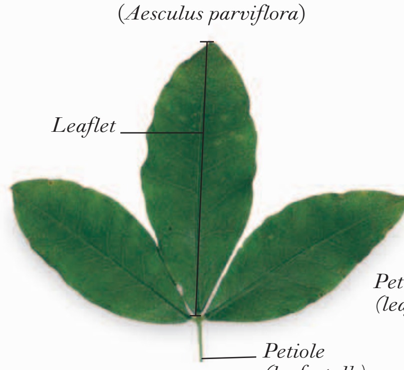
DIGITATE
Horse chestnut
(*Aesculus parviflora*)



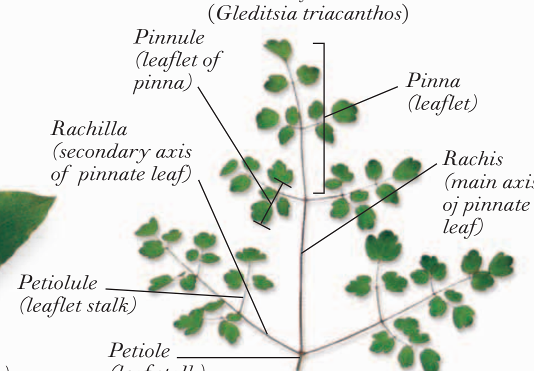
BIPINNATE
Honey locust
(*Gleditsia triacanthos*)



BITERNATE
Clematis
(*Clematis sp.*)



TRIFOLIATE
Laburnum
(*Laburnum* x *watereri*)

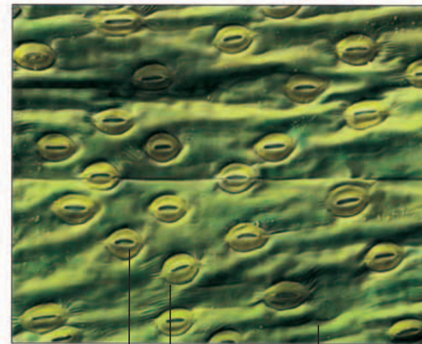


TRIPINNATE
Meadow rue
(*Thalictrum delavayi*)

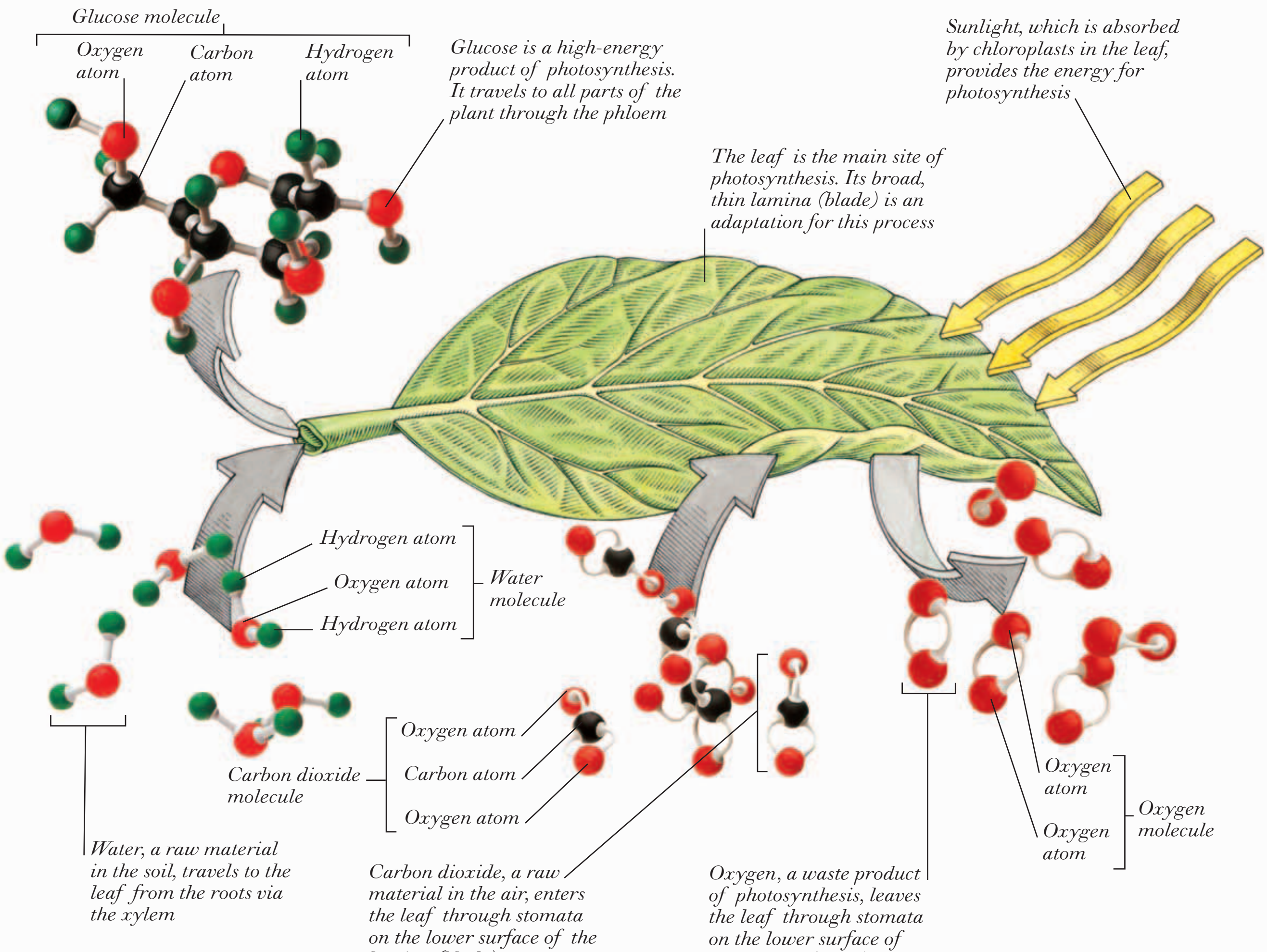
Photosynthesis

PHOTOSYNTHESIS IS THE PROCESS by which plants make their food using sunlight, water, and carbon dioxide. It takes place inside special structures in leaf cells called chloroplasts. The chloroplasts contain chlorophyll, a green pigment that absorbs energy from sunlight. During photosynthesis, the absorbed energy is used to join together carbon dioxide and water to form the sugar glucose, which is the energy source for the whole plant; oxygen, a waste product, is released into the air. Leaves are the main sites of photosynthesis, and have various adaptations for that purpose: flat laminae (blades) provide a large surface for absorbing sunlight; stomata (pores) in the lower surface of the laminae allow gases (carbon dioxide and oxygen) to pass into and out of the leaves; and an extensive network of veins brings water into the leaves and transports the glucose produced by photosynthesis to the rest of the plant.

MICROGRAPH OF LEAF
Lily (*Lilium sp.*)

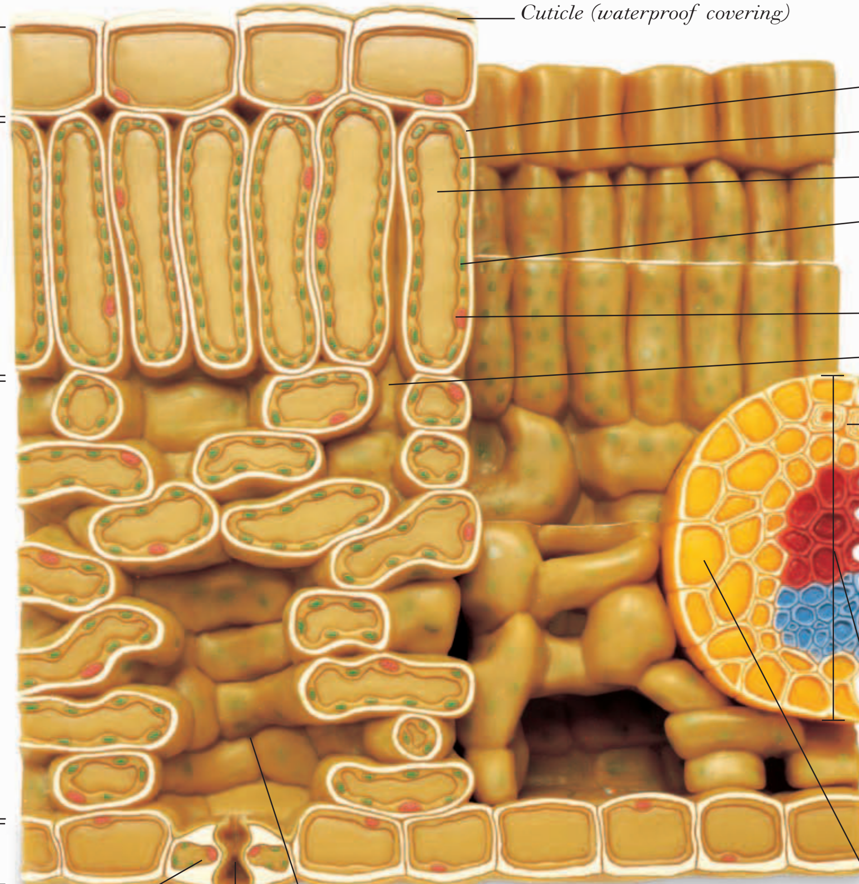


THE PROCESS OF PHOTOSYNTHESIS

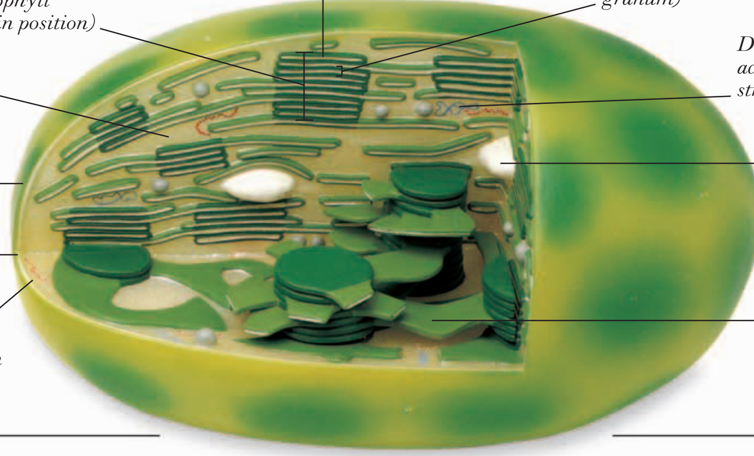


CROSS-SECTION THROUGH LEAF

Christmas rose
(*Helleborus niger*)

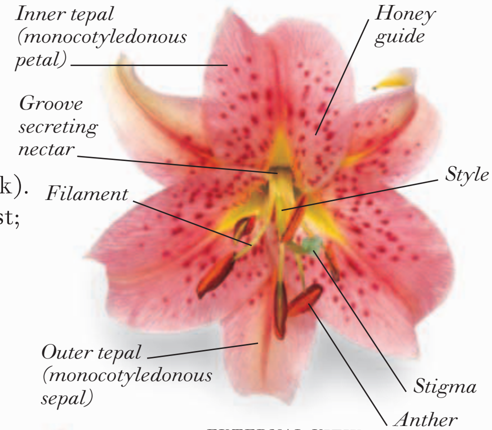


INTERNAL VIEW OF CHLOROPLAST



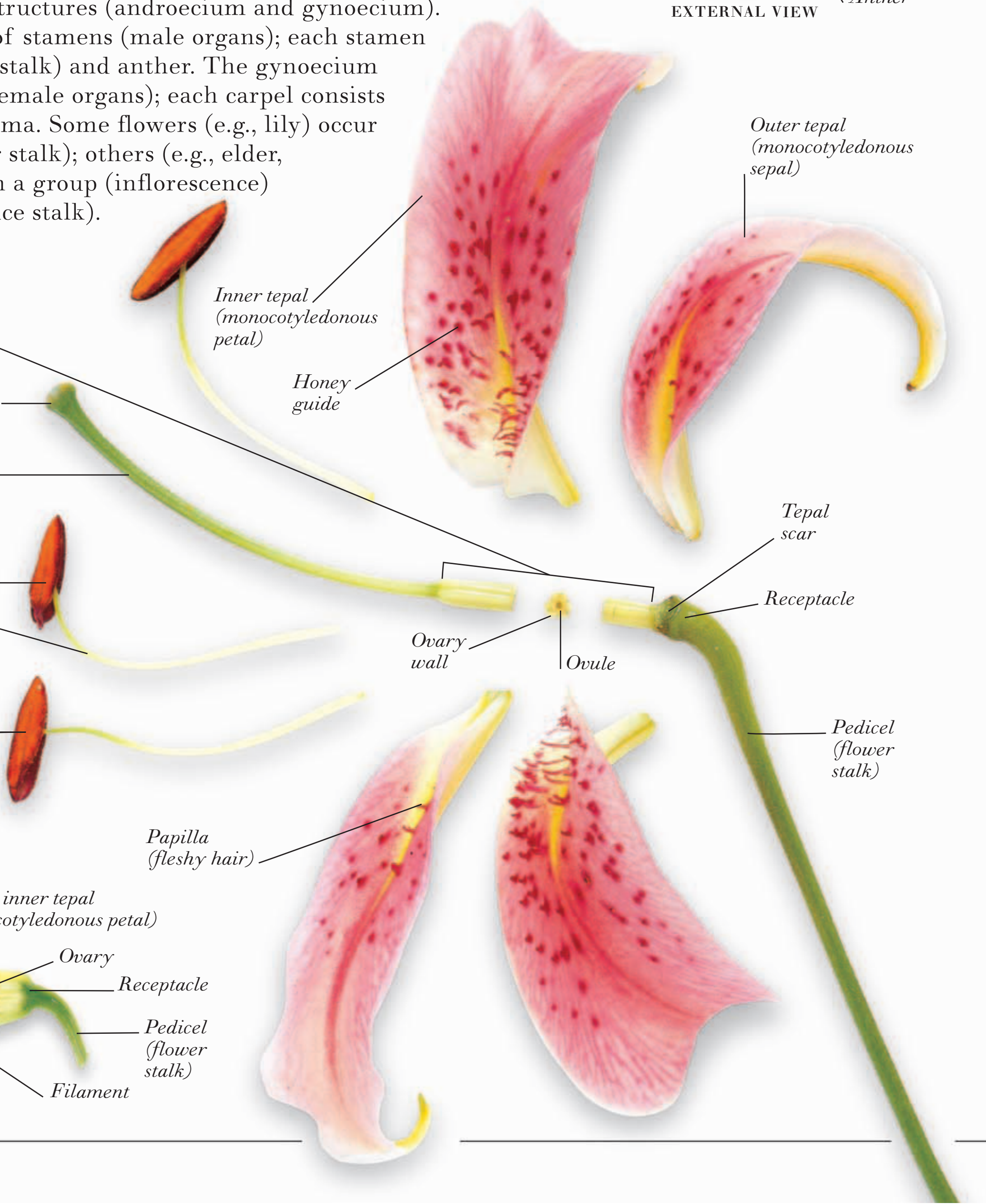
Flowers 1

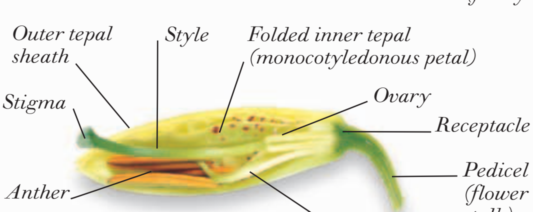
FLOWERS ARE THE SITES OF SEXUAL REPRODUCTION in flowering plants. Their component parts are arranged in whorls around the receptacle (tip of the flower stalk). The sepals (collectively called the calyx) are outermost; typically small and green, they protect the developing flower. The petals (collectively called the corolla) are typically large and brightly colored; they are found inside the sepals. In monocotyledonous flowers (see pp. 126-127), sepals and petals are indistinguishable; individually they are called tepals (collectively called the perianth). The petals surround the male and female reproductive structures (androecium and gynoecium). The androecium consists of stamens (male organs); each stamen is made up of a filament (stalk) and anther. The gynoecium has one or more carpels (female organs); each carpel consists of an ovary, style, and stigma. Some flowers (e.g., lily) occur singly on a pedicel (flower stalk); others (e.g., elder, sunflower) are arranged in a group (inflorescence) on a peduncle (inflorescence stalk).



EXTERNAL VIEW

A MONOCOTYLEDONOUS FLOWER
Lily
(*Lilium sp.*)

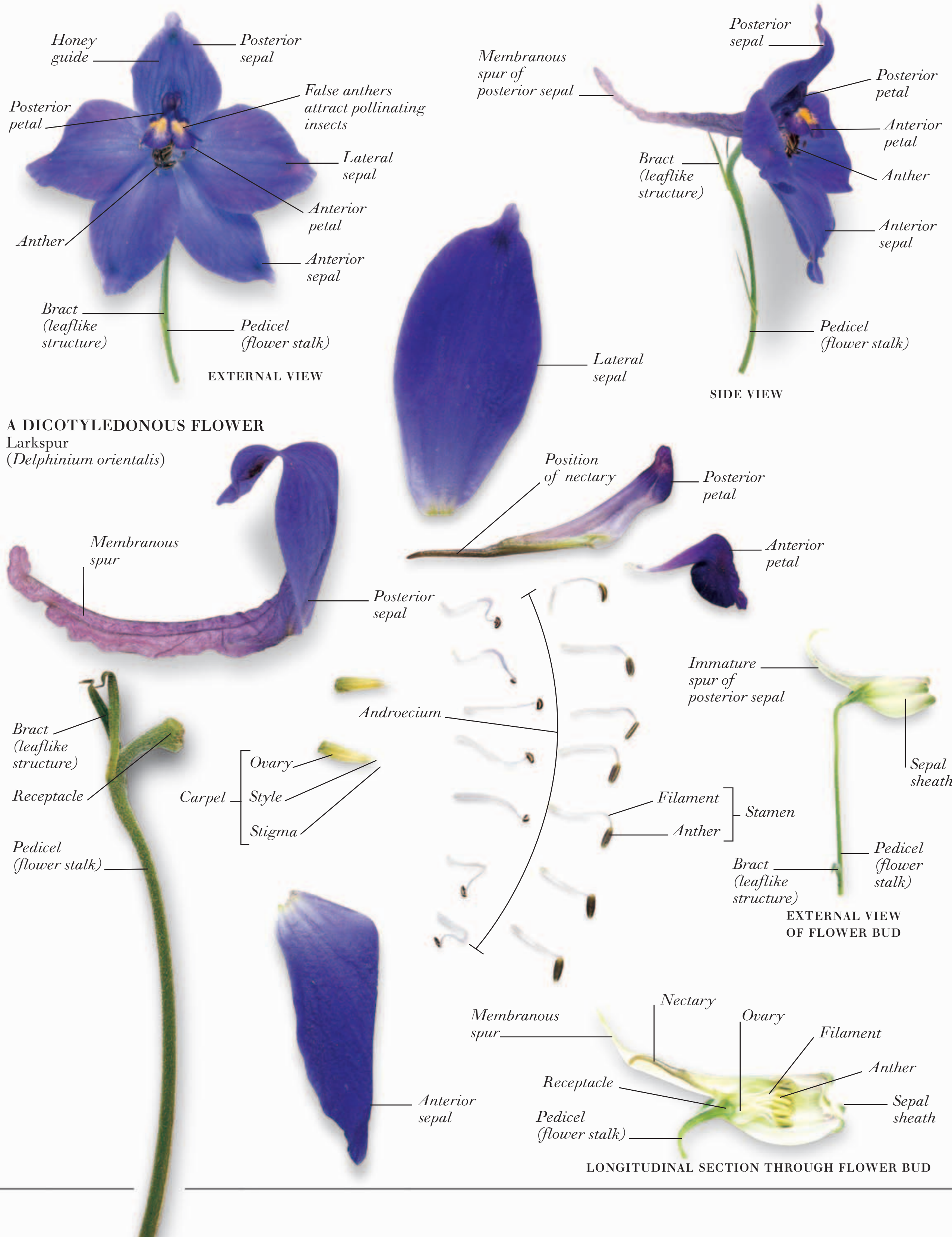




LONGITUDINAL SECTION THROUGH FLOWER BUD

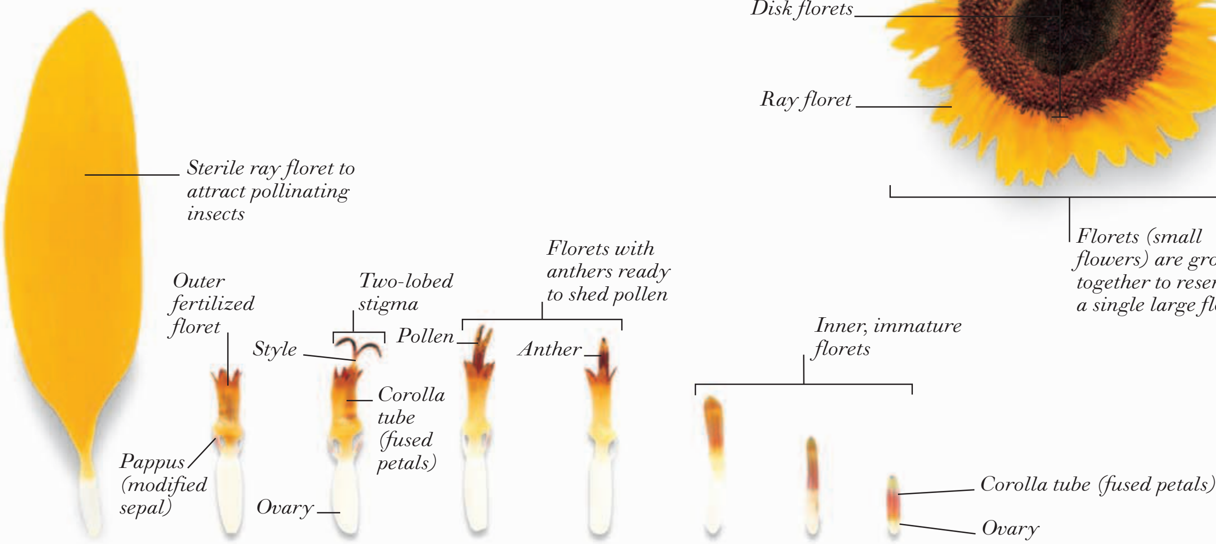
A DICOTYLEDONOUS FLOWER

Larkspur
(*Delphinium orientalis*)

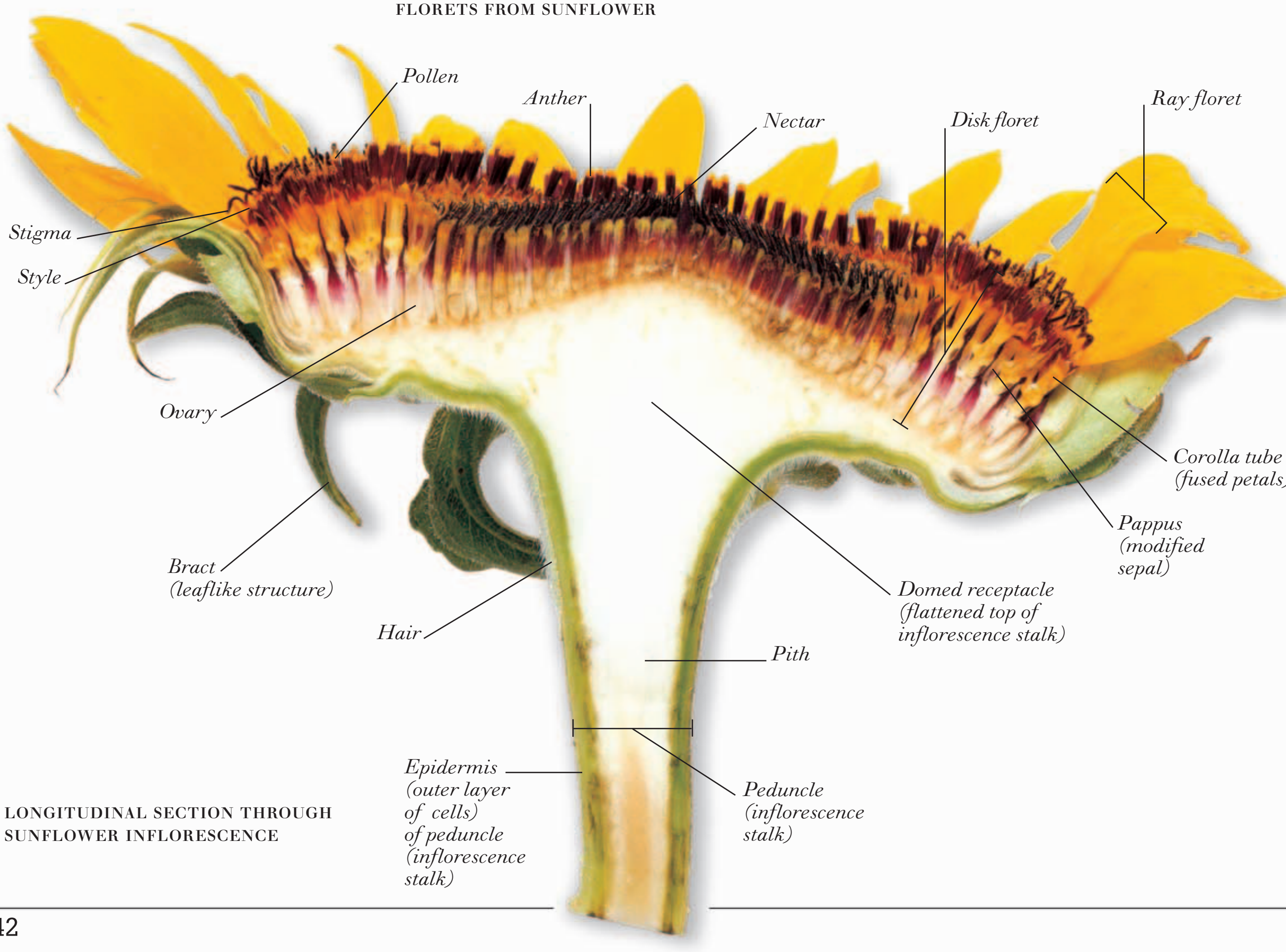


Flowers 2

COMPOUND INFLORESCENCE
(CAPITULUM)
Sunflower
(*Helianthus annulus*)

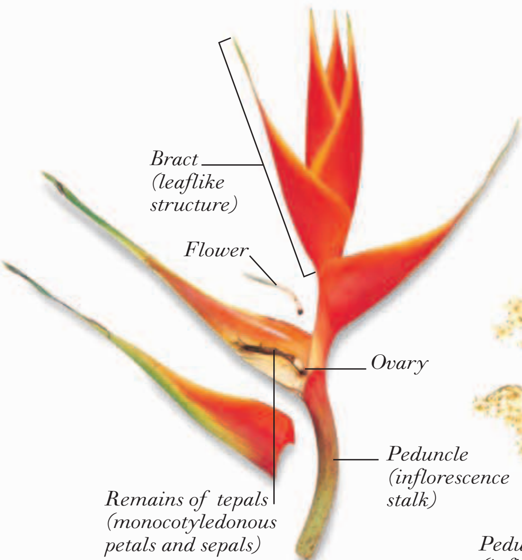


FLORETS FROM SUNFLOWER

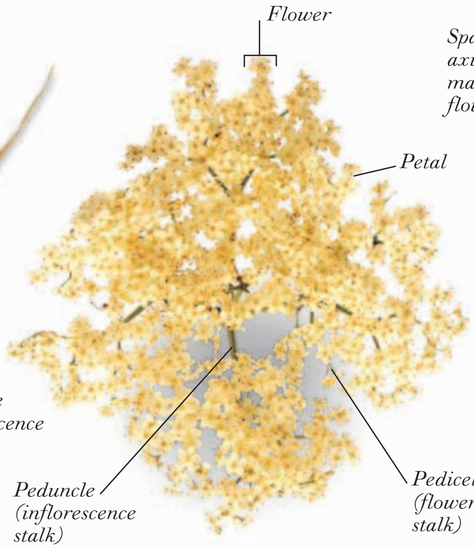


LONGITUDINAL SECTION THROUGH SUNFLOWER INFLORESCENCE

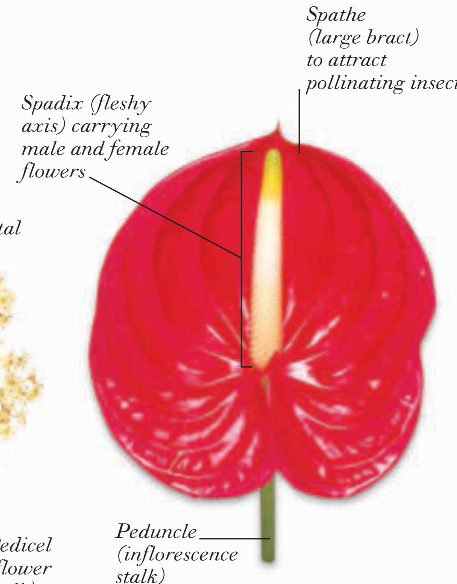
ARRANGEMENT OF FLOWERS ON STEM



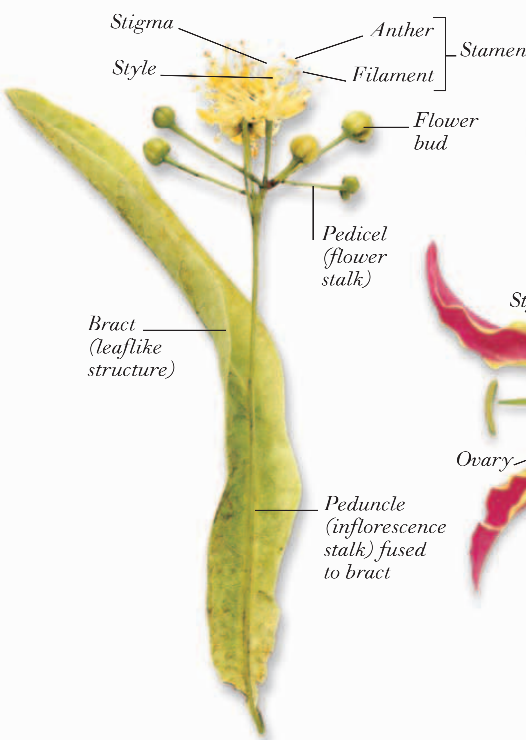
INFLORESCENCE (SPIKE)
Heliconia peruviana



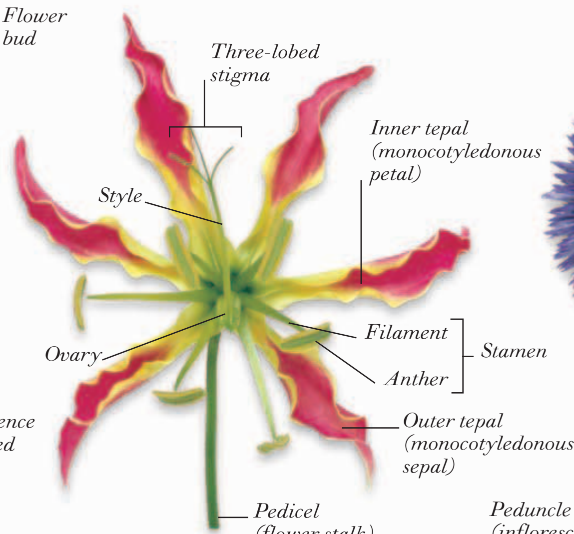
INFLORESCENCE
(COMPOUND UMBEL)
Common elder
(*Sambucus nigra*)



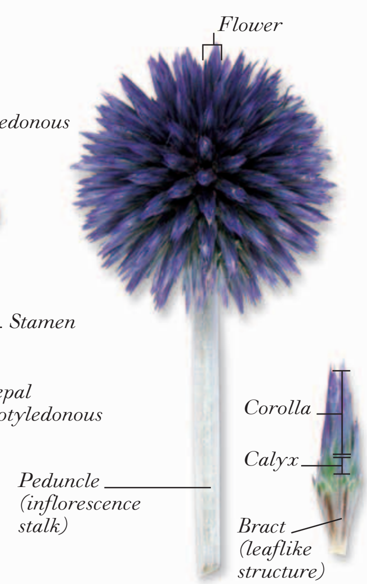
INFLORESCENCE (SPADIX)
Painter's palette
(*Anthurium andreanum*)



INFLORESCENCE
(DICHASIAL CYME)
Common lime
(*Tilia* x *europaea*)



SINGLE FLOWER
Glory lily
(*Gloriosa superba*)



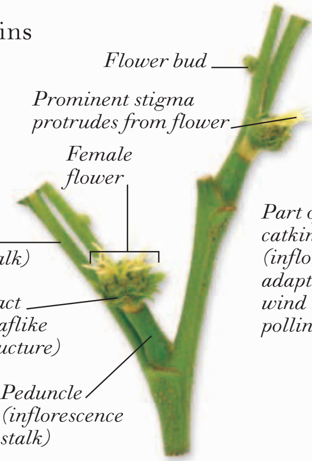
SINGLE FLOWER

INFLORESCENCE
(SPHERICAL UMBEL)
Allium sp.

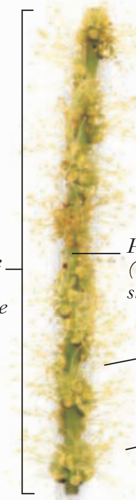
Pollination

POLLINATION IS THE TRANSFER OF POLLEN (which contains the male sex cells) from an anther (part of the male reproductive organ) to a stigma (part of the female reproductive organ). This process precedes fertilization (see pp. 146-147). Pollination may occur within the same flower (self-pollination), or between flowers on separate plants of the same species (cross-pollination). In most plants, pollination is carried out either by insects (entomophilous pollination) or by the wind (anemophilous pollination). Less commonly, birds, bats, or water are the agents of pollination. Insect-pollinated flowers are typically brightly colored, scented, and produce nectar, on which insects feed. Such flowers also tend to have patterns that are visible only in ultraviolet light, which many insects can see but which humans cannot. These features attract insects, which become covered with the sticky or hooked pollen grains when they visit one flower, and then transfer the pollen to the next flower they visit. Wind-pollinated flowers are generally small, relatively inconspicuous, and unscented. They produce large quantities of light pollen grains that are easily blown by the wind to other flowers.

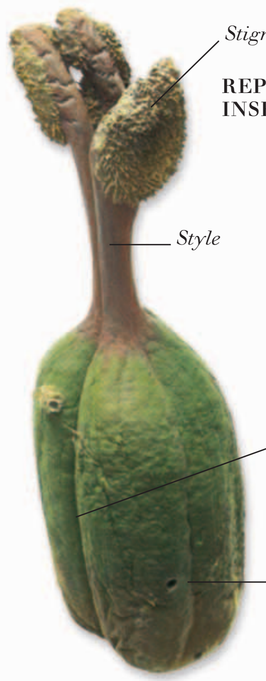
REPRODUCTIVE STRUCTURES IN WIND-POLLINATED PLANT
Sweet chestnut
(*Castanea saliva*)



FEMALE

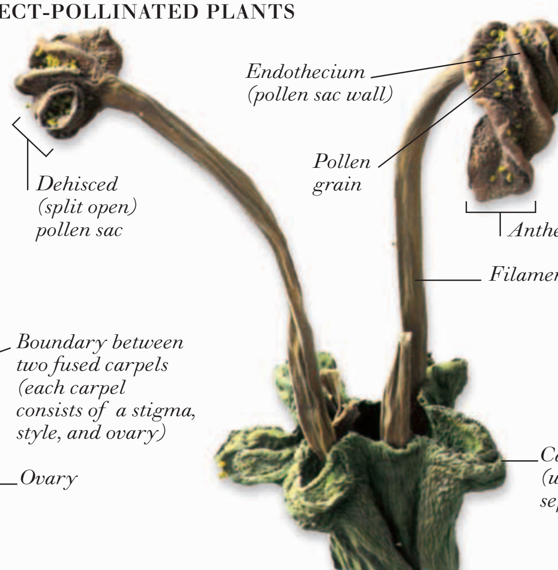


MALE



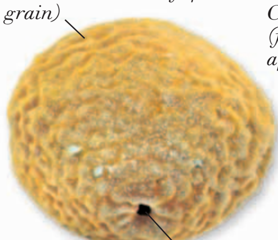
MICROGRAPH OF CARPELS (FEMALE ORGANS)
Yellow-wort
(*Blackstonia perfoliata*)

REPRODUCTIVE STRUCTURES IN INSECT-POLLINATED PLANTS

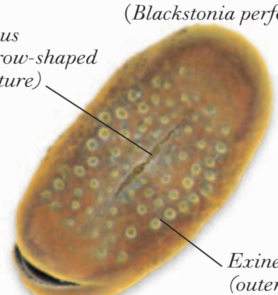


MICROGRAPH OF STAMENS (MALE ORGANS)
Common centaury
(*Centaurium erythraea*)

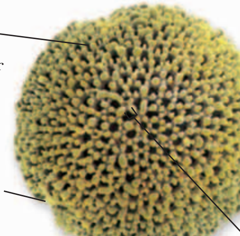
MICROGRAPHS OF POLLEN GRAINS



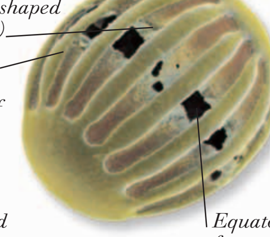
EUROPEAN FIELD ELM
(*Ulmus minor*)



JUSTICIA AUREA

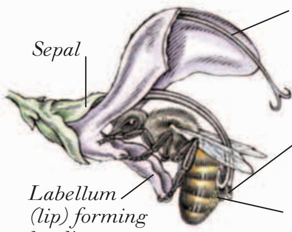


MEADOW CRANESBILL
(*Geranium pratense*)



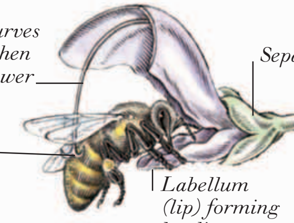
BOX-LEAVED MILKWORT
(*Polygala chamaebuxus*)

INSECT POLLINATION OF MEADOW SAGE



1. BEE VISITS FLOWER WITH MATURE ANTHERS BUT IMMATURE STIGMA

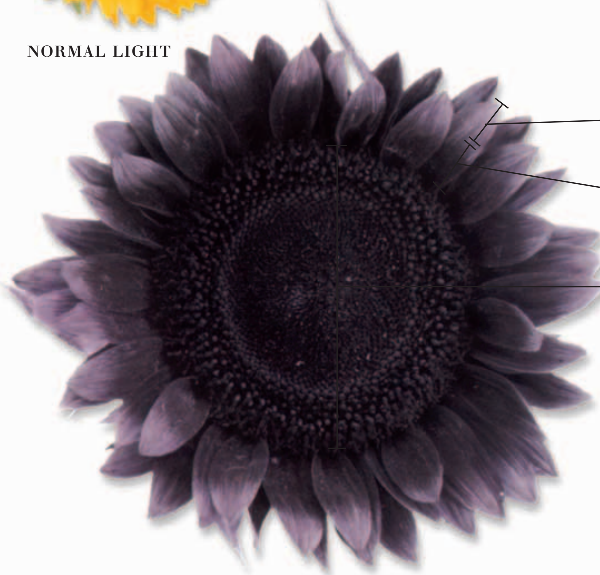
2. BEE FLIES TO OTHER FLOWERS



3. BEE VISITS FLOWER WHERE THE ANTHERS HAVE WITHERED AND THE STIGMA IS MATURE

SUNFLOWER UNDER NORMAL AND ULTRAVIOLET LIGHT

NORMAL LIGHT

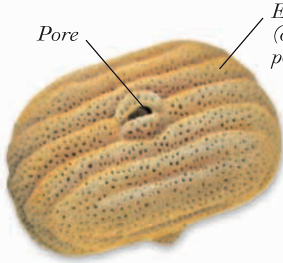


ULTRAVIOLET LIGHT

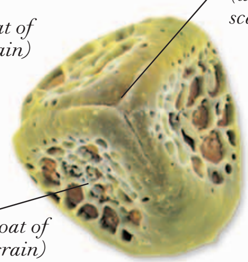
ST. JOHN'S WORT UNDER NORMAL AND ULTRAVIOLET LIGHT

NORMAL LIGHT

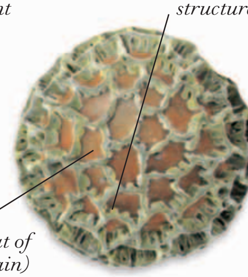
ULTRAVIOLET LIGHT



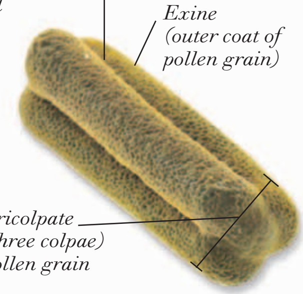
MIMULOPSIS SOLMSII



THESIUM ALPINIUM



RUELLIA GRANDIFLORA



CROSSANDRA NILOTICA

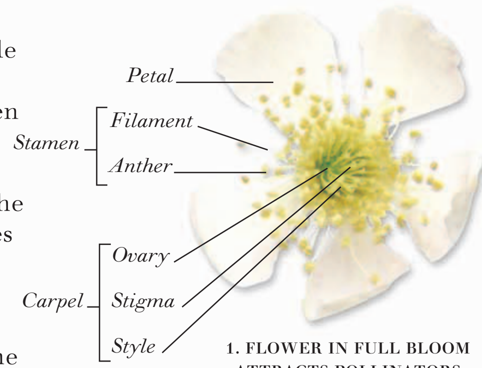
Fertilization

BANANA
(*Musa 'lacatan'*)

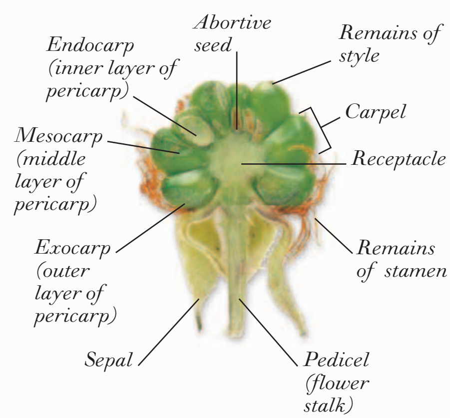
FERTILIZATION IS THE FUSION of male and female gametes (sex cells) to produce a zygote (embryo). Following pollination (see pp. 144-145), the pollen grains that contain the male gametes are on the stigma, some distance from the female gamete (ovum) inside the ovule. To enable the gametes to meet, the pollen grain germinates and produces a pollen tube, which grows down and enters the embryo sac (the inner part of the ovule that contains the ovum). Two male gametes, traveling at the tip of the pollen tube, enter the embryo sac. One gamete fuses with the ovum to produce a zygote that will develop into an embryo plant. The other male gamete fuses with two polar nuclei to produce the endosperm, which acts as a food supply for the developing embryo. Fertilization also initiates other changes: the integument (outer part of ovule) forms a testa (seed coat) around the embryo and endosperm; the petals fall off; the stigma and style wither; and the ovary wall forms a layer (called the pericarp) around the seed. Together, the pericarp and seed form the fruit, which may be succulent (see pp. 148-149) or dry (see pp. 150-151). In some species (e.g., blackberry), apomixis can occur: the seed develops without fertilization of the ovum by a male gamete but endosperm formation and fruit development take place as in other species.

DEVELOPMENT OF A SUCCULENT FRUIT

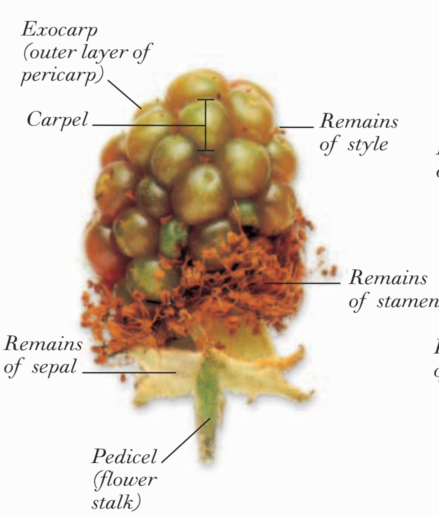
Blackberry
(*Rubus fruticosus*)



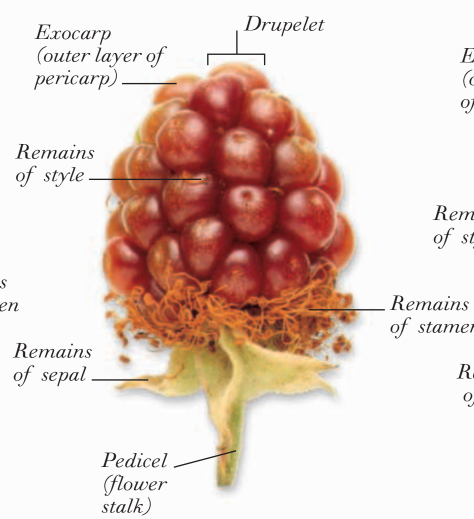
1. FLOWER IN FULL BLOOM ATTRACTS POLLINATORS



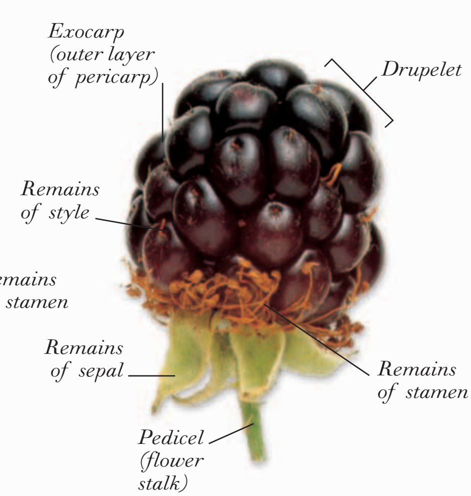
4. PERICARP FORMS FLESH, SKIN, AND A HARD INNER LAYER (SHOWN IN CROSS-SECTION)



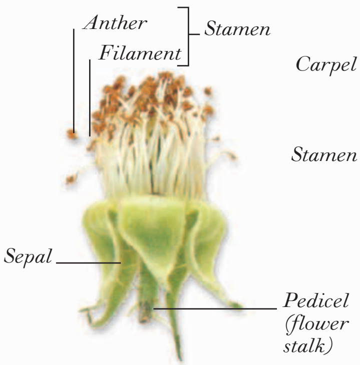
7. MESOCARP (FLESHY PART OF PERICARP) OF EACH CARPEL STARTS TO CHANGE COLOR



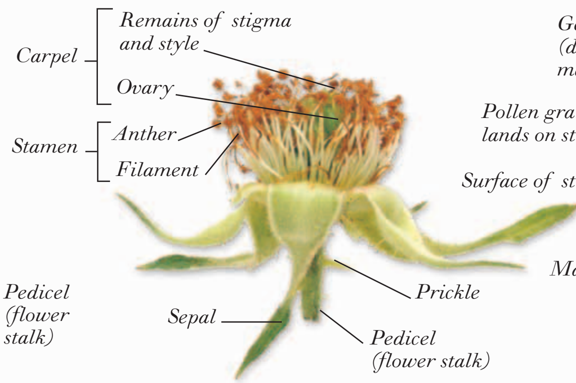
8. CARPELS MATURE INTO DRUPELETS (SMALL FLESHY FRUITS WITH SINGLE SEEDS SURROUNDED BY HARD ENDOCARP)



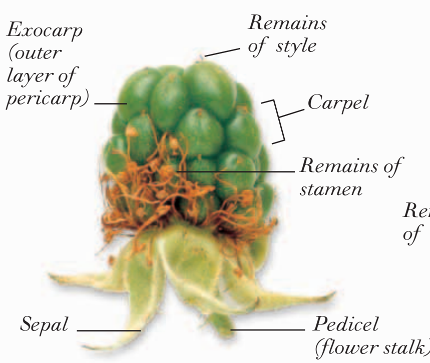
9. MESOCARP OF DRUPELET BECOMES DARKER AND SWEETER



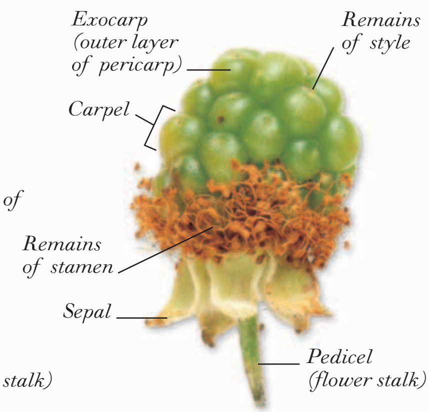
2. FERTILIZATION HAS TAKEN PLACE; PETALS FALL OFF



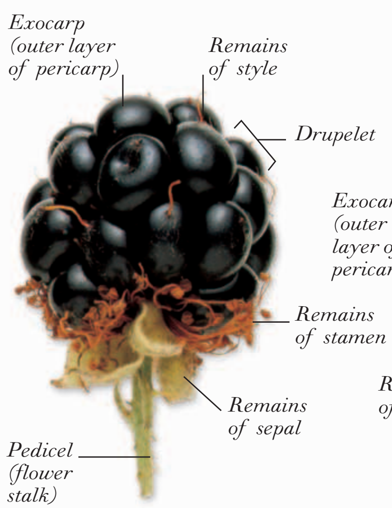
3. OVARIES BEGIN TO SWELL; STAMENS WITHER AND DIE



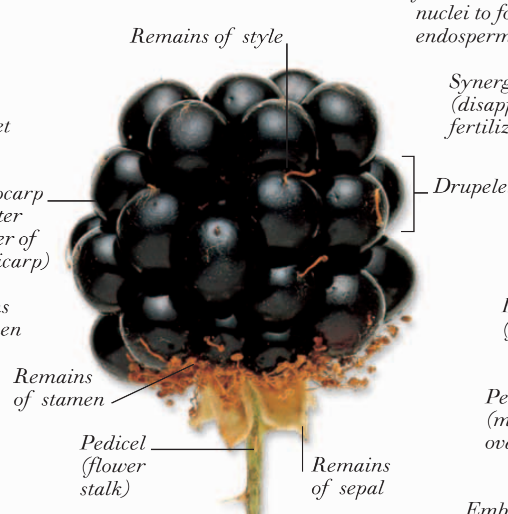
5. CARPELS EXPAND AND BECOME MORE FLESHY



6. CARPELS EXPAND FURTHER

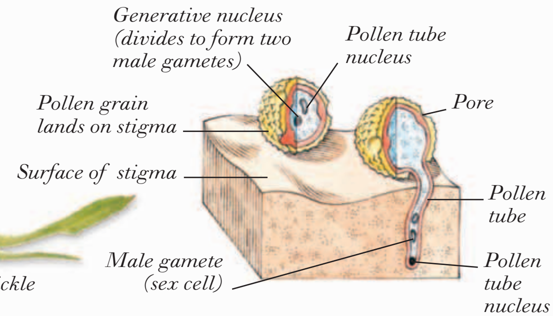


10. DRUPELETS (COLLECTIVELY AN AGGREGATE FRUIT) EXPAND

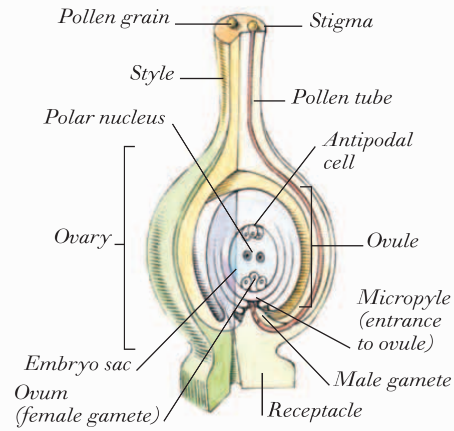


11. DRUPELETS RIPEN FULLY

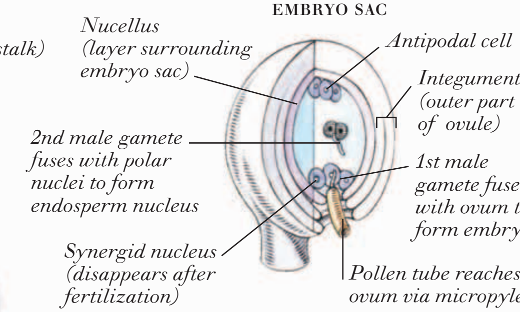
THE PROCESS OF FERTILIZATION



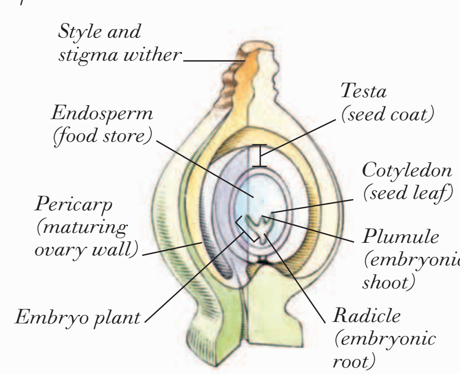
POLLEN GRAIN GERMINATES



MALE GAMETES TRAVEL TO EMBRYO SAC



FERTILIZATION



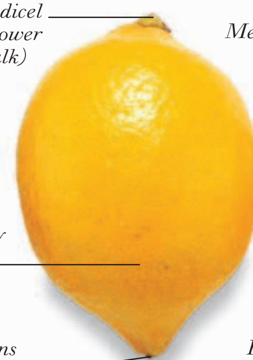
DEVELOPMENT OF EMBRYO

Succulent fruits

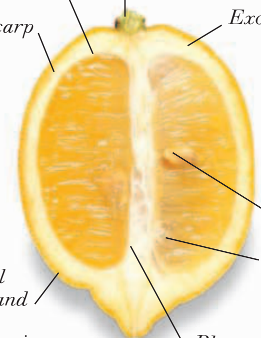
A FRUIT IS A FULLY DEVELOPED and ripened ovary (seed-producing part of a plant's female reproductive organs). Fruits may be succulent or dry (see pp. 150-151). Succulent fruits are fleshy and brightly colored, making them attractive to animals, which eat them and so disperse the seeds away from the parent plant. The wall (pericarp) of a succulent fruit has three layers: an outer exocarp, a middle mesocarp, and an inner endocarp. These three layers vary in thickness and texture in different types of fruits and may blend into each other. Succulent fruits can be classed as simple (derived from one ovary) or compound (derived from several ovaries). Simple succulent fruits include berries, which typically have many seeds, and drupes, which typically have a single stone or pit (e.g., cherry and peach). Compound succulent fruits include aggregate fruits, which are formed from many ovaries in one flower, and multiple fruits, which develop from the ovaries of many flowers. Some fruits, known as false fruits or pseudocarps, develop from parts of the flower in addition to the ovaries. For example, the flesh of the apple is formed from the receptacle (the upper end of the flower stalk).

BERRY
Cocoa
(*Theobroma cacao*)

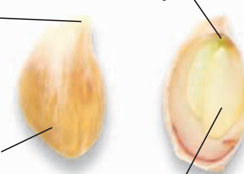
HESPERIDIUM (A TYPE OF BERRY)
Lemon
(*Citrus limon*)



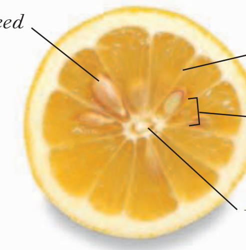
EXTERNAL VIEW OF FRUIT



LONGITUDINAL SECTION THROUGH FRUIT

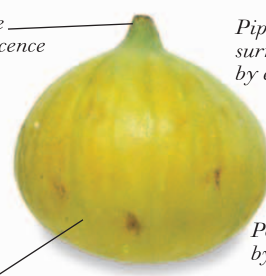


EXTERNAL VIEW AND SECTION THROUGH SEED

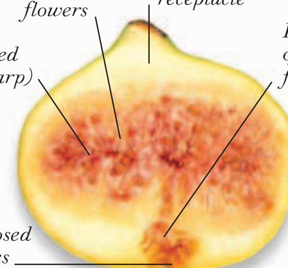


CROSS-SECTION THROUGH FRUIT

SYCONIUM (A TYPE OF FALSE FRUIT)
Fig
(*Ficus carica*)

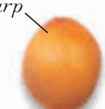


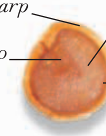
EXTERNAL VIEW OF FRUIT



LONGITUDINAL SECTION THROUGH FRUIT

REMAINS OF A SINGLE FEMALE FLOWER





EXTERNAL VIEW AND SECTION THROUGH PIT

FRUIT WITH FLESHY ARIL
Lychee
(*Litchi chinensis*)

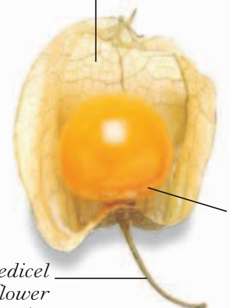
EXTERNAL VIEW OF FRUIT

LONGITUDINAL SECTION THROUGH FRUIT

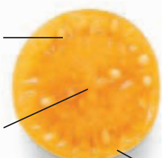
BERRY

Cape gooseberry
(*Physalis peruviana*)

EXTERNAL VIEW OF FRUIT



INTERNAL VIEW OF FRUIT

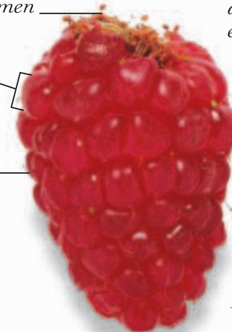


CROSS-SECTION THROUGH FRUIT

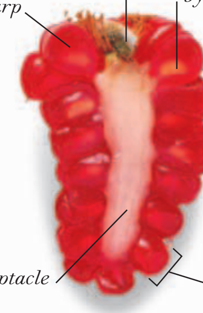
EXTERNAL VIEW OF SEED

AGGREGATE FRUIT

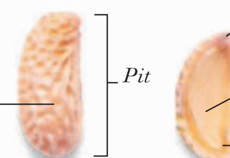
Raspberry
(*Rubus idaeus*)



EXTERNAL VIEW OF FRUIT



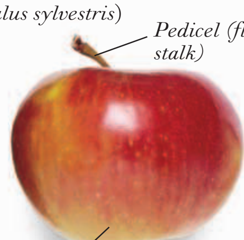
LONGITUDINAL SECTION THROUGH FRUIT



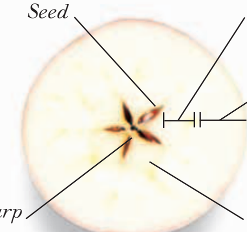
EXTERNAL VIEW AND SECTION THROUGH PIT

POME (A TYPE OF FALSE FRUIT)

Apple
(*Malus sylvestris*)



EXTERNAL VIEW OF FRUIT



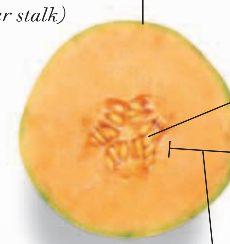
CROSS-SECTION THROUGH FRUIT

EXTERNAL VIEW AND SECTION THROUGH SEED

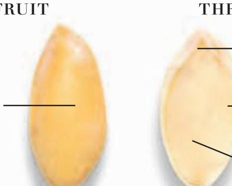
PEPO (A TYPE OF BERRY)

Charentais melon
(*Cucumis melo*)

EXTERNAL VIEW OF FRUIT



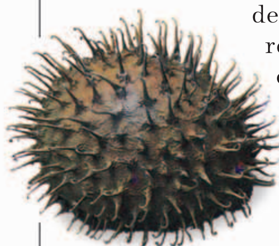
CROSS-SECTION THROUGH FRUIT



EXTERNAL VIEW AND SECTION THROUGH SEED

Dry fruits

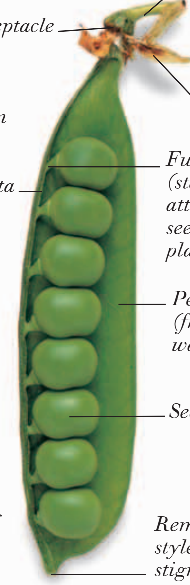
DRY FRUITS HAVE A HARD, DRY PERICARP (fruit wall) around their seeds unlike succulent fruits, which have fleshy pericarps (see pp. 148-149). Dry fruits are divided into three types: dehiscent, in which the pericarp splits open to release the seeds; indehiscent, which do not split open; and schizocarpic, in which the fruit splits but the seeds are not exposed. Dehiscent dry fruits include capsules (e.g., love-in-a-mist), follicles (e.g., delphinium), legumes (e.g., pea), and siliquas (e.g., honesty). Typically, the seeds of dehiscent fruits are dispersed by the wind. Indehiscent dry fruits include nuts (e.g., sweet chestnut), nutlets (e.g., goosegrass), achenes (e.g., strawberry), caryopses (e.g., wheat), samaras (e.g., elm), and cypselas (e.g., dandelion). Some indehiscent dry fruits are dispersed by the wind, assisted by "wings" (e.g., elm) or "parachutes" (e.g., dandelion); others (e.g., goosegrass) have hooked pericarps to aid dispersal on animals' fur. Schizocarpic dry fruits include cremocarps (e.g., hogweed), and double samaras (e.g., sycamore maple); these are dispersed by the wind.



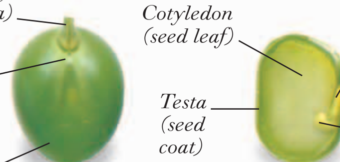
NUTLET
Goosegrass
(*Galium aparine*)

LEGUME
Pea
(*Pisum sativum*)

EXTERNAL VIEW OF FRUIT

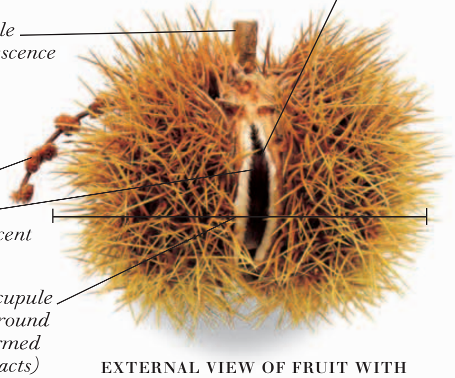


INTERNAL VIEW OF FRUIT

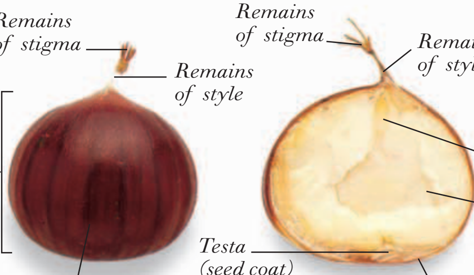


EXTERIOR VIEW AND SECTION THROUGH SEED

NUT
Sweet chestnut
(*Castanea sativa*)

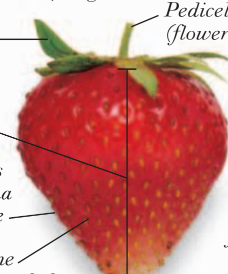


EXTERNAL VIEW OF FRUIT WITH SURROUNDING CUPULE

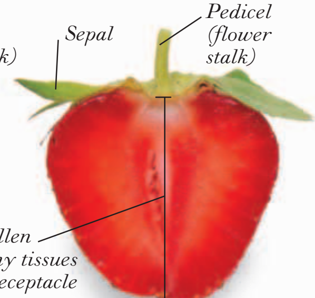


EXTERNAL VIEW AND SECTION THROUGH FRUIT

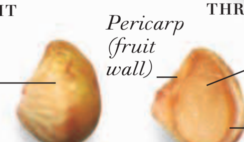
ACHENE
Strawberry
(*Fragaria x ananassa*)



EXTERNAL VIEW OF FRUIT

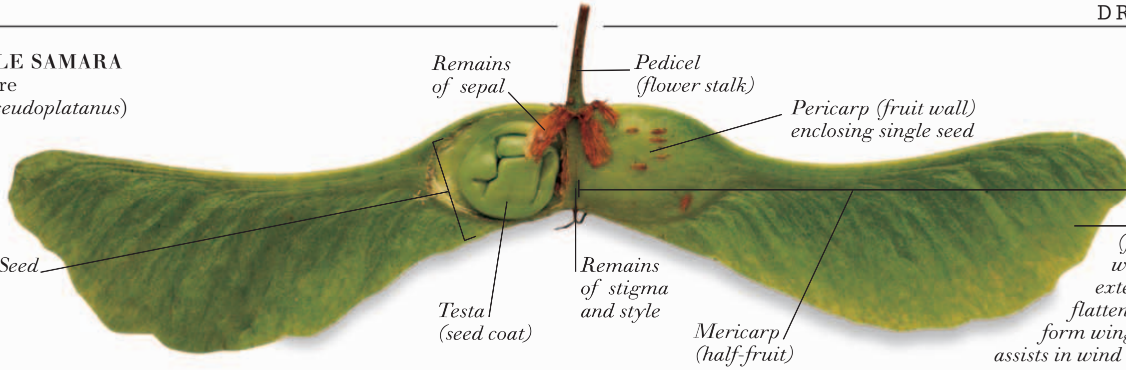


LONGITUDINAL SECTION THROUGH FRUIT

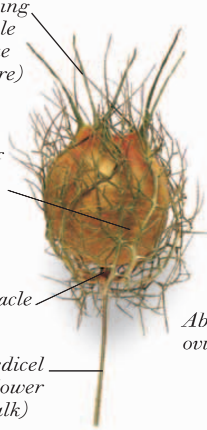


EXTERNAL VIEW AND SECTION THROUGH SEED

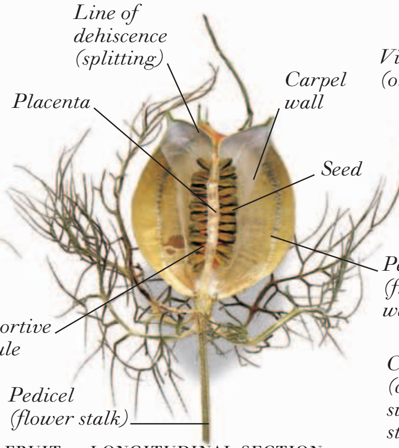
DOUBLE SAMARA
Sycamore
(*Acer pseudoplatanus*)



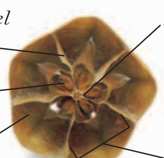
CAPSULE
Love-in-a-mist
(*Nigella damascena*)



EXTERNAL VIEW OF FRUIT



LONGITUDINAL SECTION THROUGH FRUIT



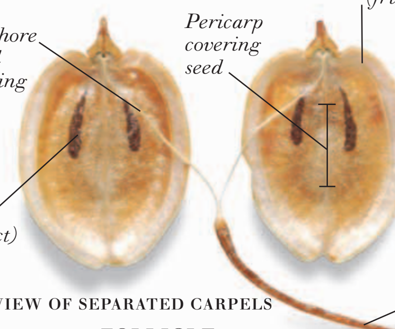
CROSS-SECTION THROUGH FRUIT

EXTERIOR VIEW AND SECTION THROUGH SEED

CREMOCARP
Hogweed
(*Heracleum sp.*)

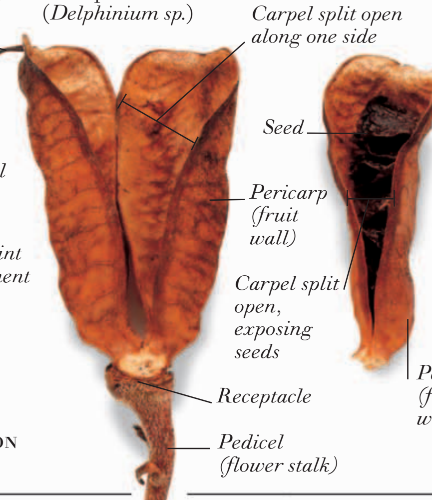
EXTERNAL VIEW OF FRUIT

EXTERNAL VIEW OF SEED

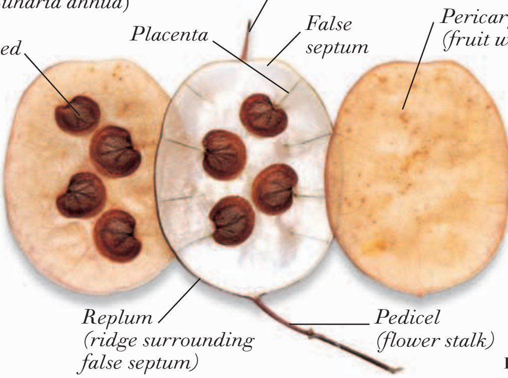


VIEW OF SEPARATED CARPELS

FOLLICLE
Larkspur
(*Delphinium sp.*)



SILIQUA
Honesty
(*Lunaria annua*)



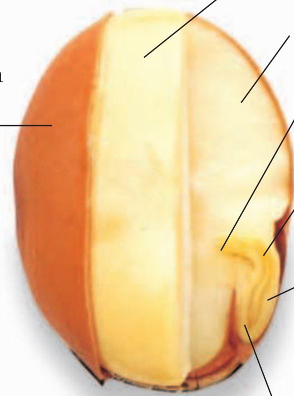
PARTS OF SPLIT-OPEN FRUIT

EXTERNAL VIEW AND SECTION THROUGH SEED

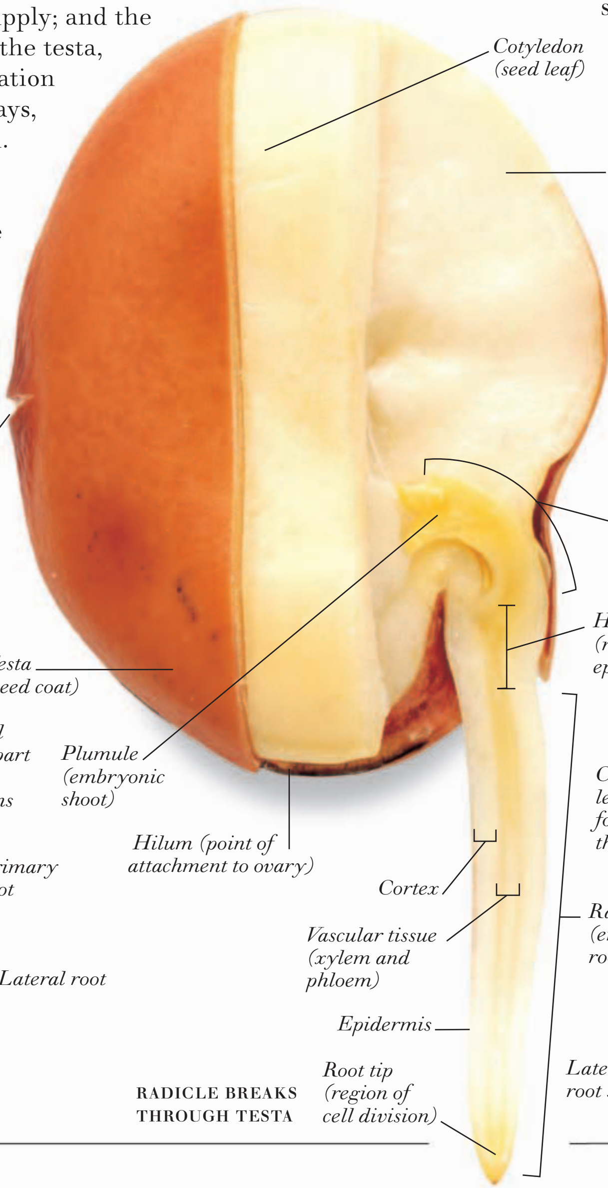
Germination

GERMINATION IS THE GROWTH OF SEEDS INTO SEEDLINGS. It starts when seeds become active below ground, and ends when the first foliage leaves appear above ground. A seed consists of an embryo and its food supply, surrounded by a testa (seed coat). The embryo is made up of one or two cotyledons (seed leaves) attached to a central axis. The upper part of the axis consists of an epicotyl, which has a plumule (embryonic shoot) at its tip. The lower part of the axis consists of a hypocotyl and a radicle (embryonic root). After dispersal from the parent plant, the seeds dehydrate and enter a period of dormancy. Following this dormant period, germination begins, provided that the seeds have enough water, oxygen, warmth, and, in some cases, light. In the first stages of germination, the seed takes in water; the embryo starts to use its food supply; and the radicle swells, breaks through the testa, and grows downward. Germination then proceeds in one of two ways, depending on the type of seed. In epigeal germination, the hypocotyl lengthens, pulling the plumule and its protective cotyledons out of the soil. In hypogeal germination, the cotyledons remain below ground and the epicotyl lengthens, pushing the plumule upward.

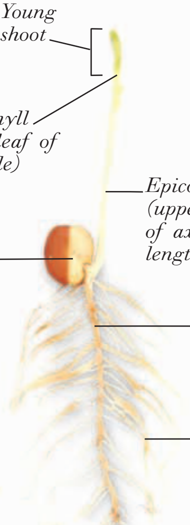
HYPOGEAL GERMINATION
Fava bean
(*Vicia faba*)



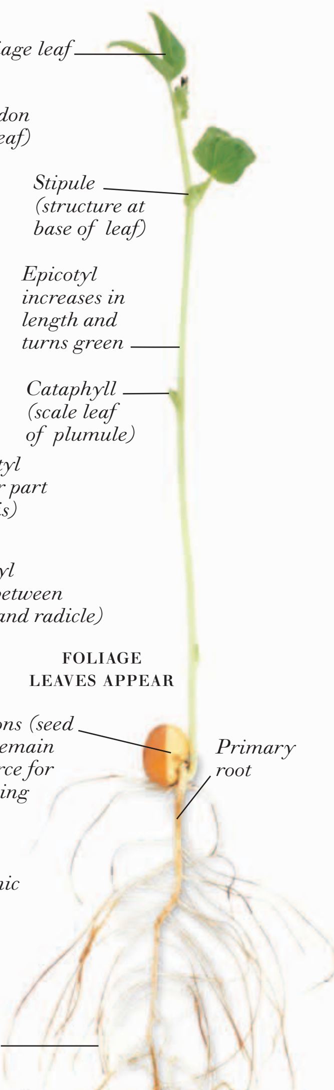
SEED AT START OF GERMINATION



RADICLE BREAKS THROUGH TESTA



SHOOT APPEARS ABOVE SOIL



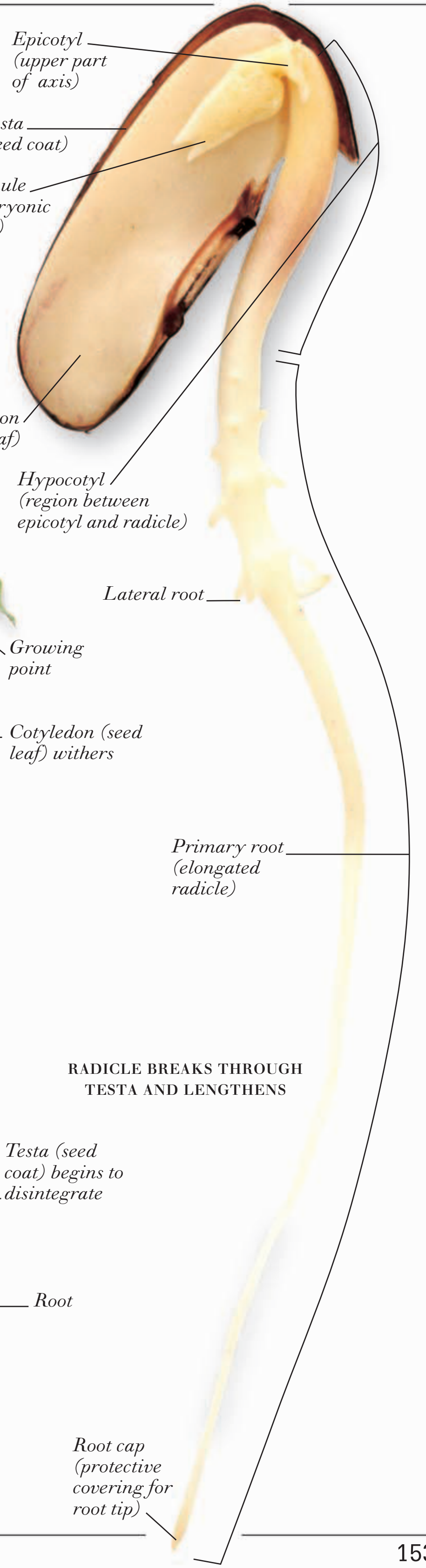
FOLIAGE LEAVES APPEAR

EPIGEAL GERMINATION

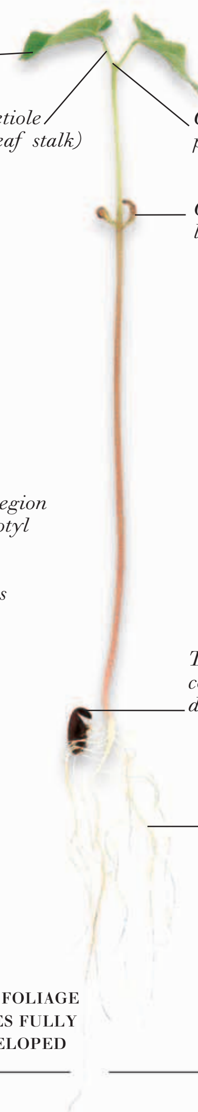
Black bean (*Phaseolus sp.*)

EXTERNAL VIEW OF SEED AT START OF GERMINATION

LONGITUDINAL SECTION THROUGH SEED AT START OF GERMINATION



RADICLE BREAKS THROUGH TESTA AND LENGTHENS



FIRST FOLIAGE LEAVES FULLY DEVELOPED

HYPOCOTYL STRAIGHTENS, PULLING LEAVES AND COTYLEDONS OUT OF SOIL

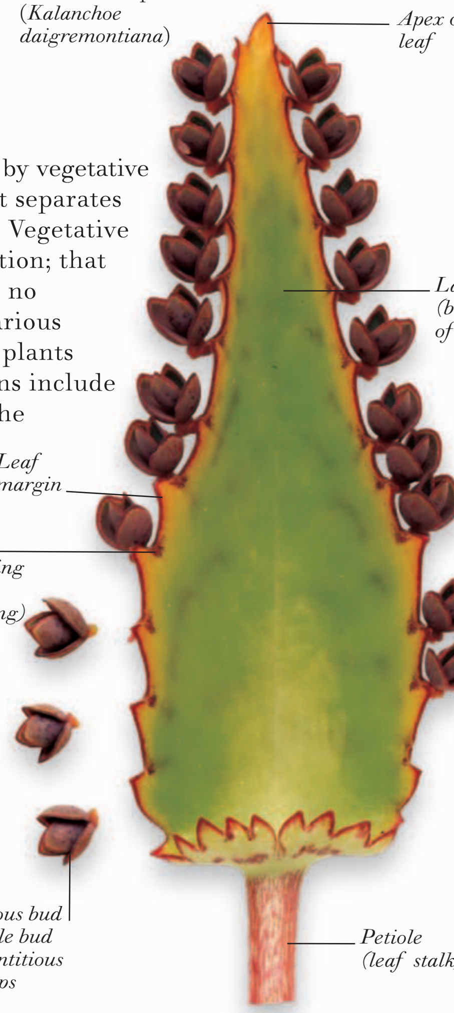
HYPOCOTYL "HOOK" APPEARS ABOVE SOIL

Vegetative reproduction

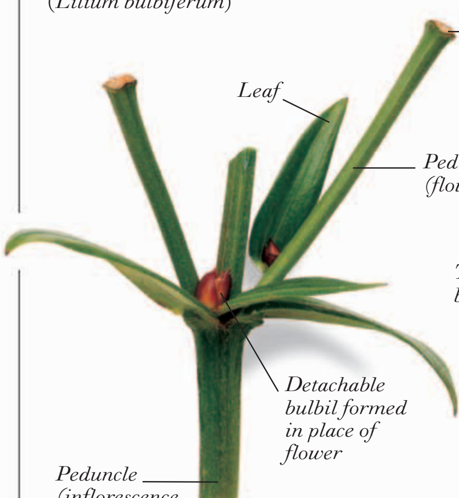
CORM
Gladiolus
(*Gladiolus sp.*)

MANY PLANTS CAN PROPAGATE THEMSELVES by vegetative reproduction. In this process, part of a plant separates off, takes root, and grows into a new plant. Vegetative reproduction is a type of asexual reproduction; that is, it involves only one parent, and there is no fusion of gametes (sex cells). Plants use various structures to reproduce vegetatively. Some plants use underground storage organs. Such organs include rhizomes (horizontal, underground stems), the branches of which produce new plants; bulbs (swollen leaf bases) and corms (swollen stems), which produce daughter bulbs or corms that separate off from the parent; and stem tubers (thickened underground stems) and root tubers (swollen adventitious roots), which also separate off from the parent. Other propagative structures include runners and stolons, creeping horizontal stems that take root and produce new plants; bulbils, small bulbs that develop on the stem or in the place of flowers, and then drop off and grow into new plants; and adventitious buds, miniature plants that form on leaf margins before dropping to the ground and growing into mature plants.

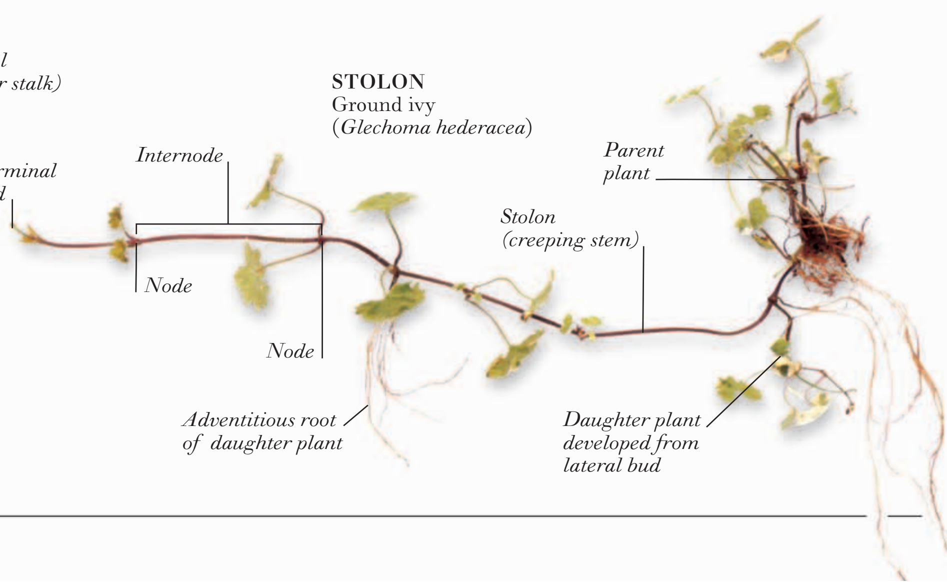
ADVENTITIOUS BUD
Mexican hat plant
(*Kalanchoe daigremontiana*)



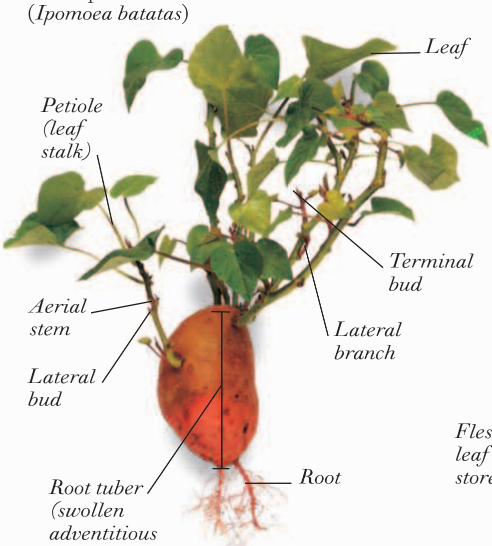
BULBIL IN PLACE OF FLOWER
Orange lily
(*Lilium bulbiferum*)



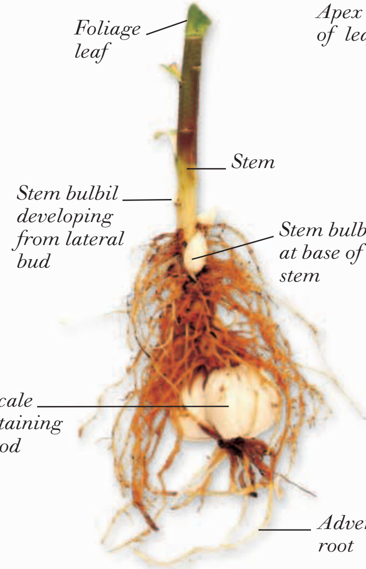
STOLON
Ground ivy
(*Glechoma hederacea*)



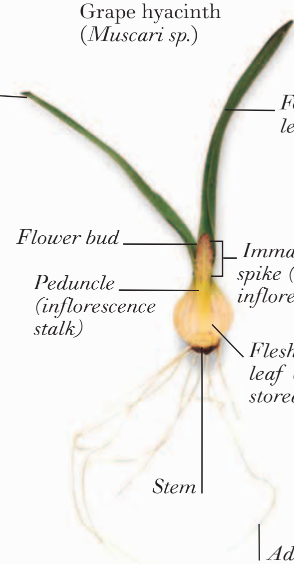
ROOT TUBER
Sweet potato
(*Ipomoea batatas*)



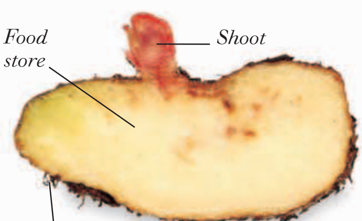
STEM BULBIL
Lily
(*Lilium sp.*)



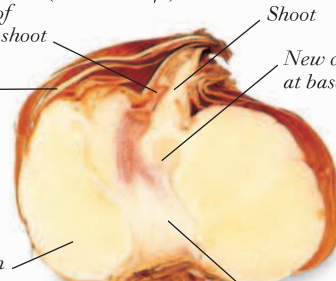
GROWING BULB
Grape hyacinth
(*Muscari sp.*)



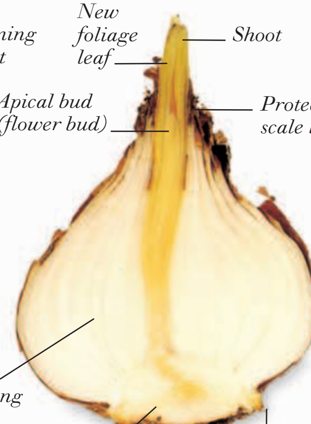
ROOT TUBER
Begonia
(*Begonia* x *tuberhybrida*)



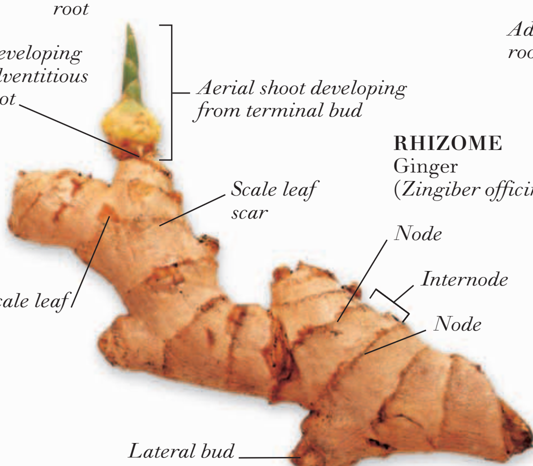
CORM
Gladiolus
(*Gladiolus sp.*)



BULB WITH SHOOT
Amaryllis
(*Hippeastrum sp.*)

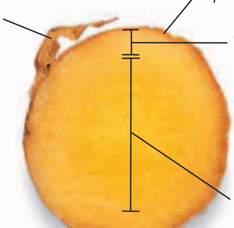


RHIZOME
Ginger
(*Zingiber officinale*)



EXTERNAL VIEW

LONGITUDINAL SECTION THROUGH AERIAL SHOOT



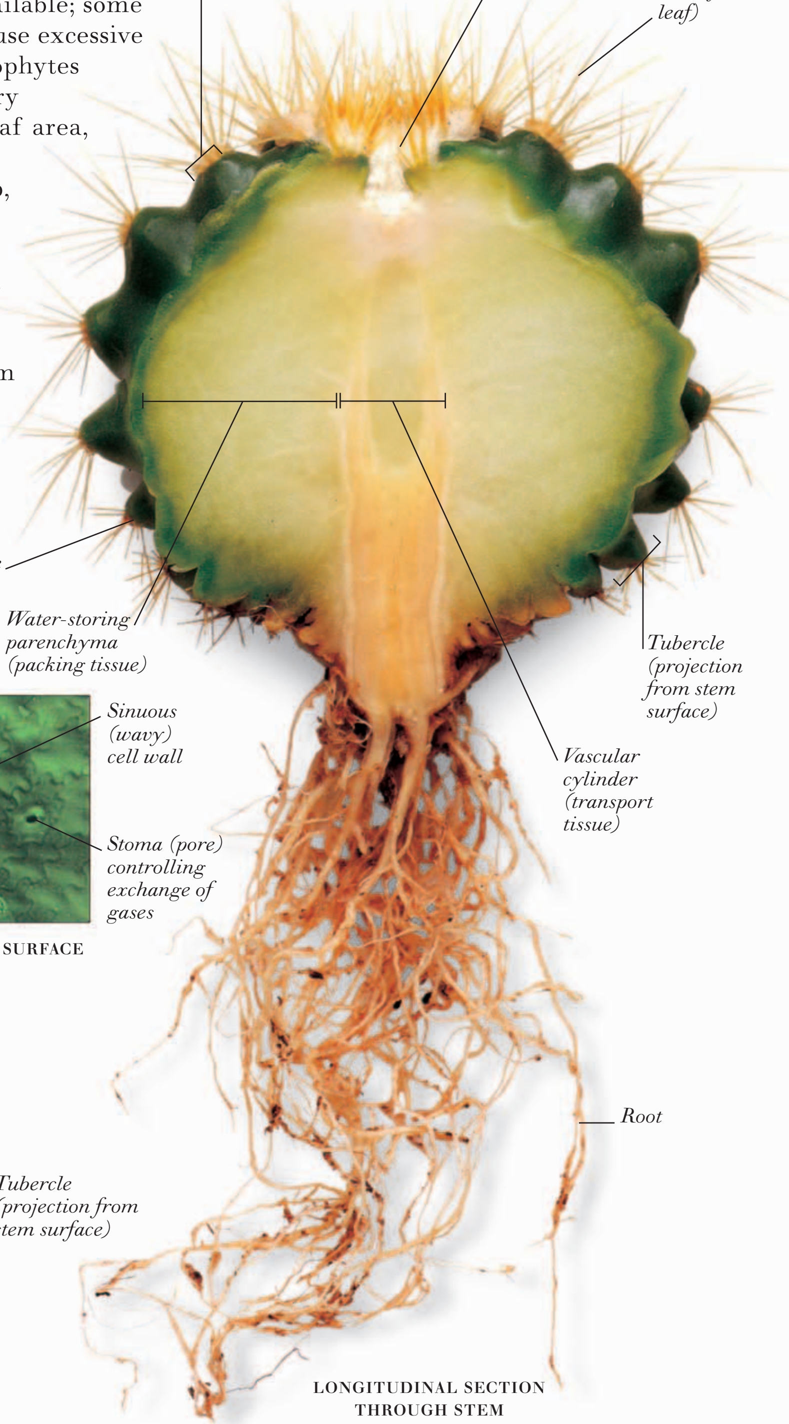
CROSS-SECTION THROUGH RHIZOME

Dryland plants

LEAF SUCCULENT
Lithops sp.

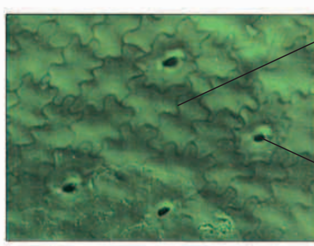
DRYLAND PLANTS (XEROPHYTES) are able to survive in unfavorable habitats. All are found in places where little water is available; some live in high temperatures that cause excessive loss of water from the leaves. Xerophytes show a number of adaptations to dry conditions; these include reduced leaf area, rolled leaves, sunken stomata, hairs, spines, and thick cuticles. One group, succulent plants, stores water in specially enlarged spongy tissues found in leaves, roots, or stems. Leaf succulents have enlarged, fleshy, water-storing leaves. Root succulents have a large, underground water-storage organ with short-lived stems and leaves above ground. Stem succulents are represented by the cacti (family Cactaceae). Cacti stems are fleshy, green, and photosynthetic; they are typically ribbed or covered by tubercles in rows, with leaves being reduced to spines or entirely absent.

STEM SUCCULENT
Golden barrel cactus
(*Echinocactus grusonii*)

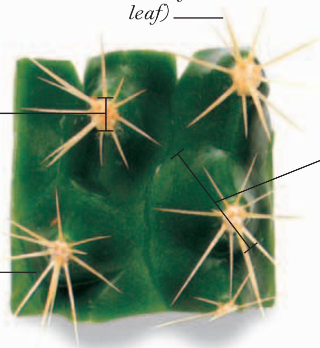


LONGITUDINAL SECTION THROUGH STEM

EXTERNAL VIEW

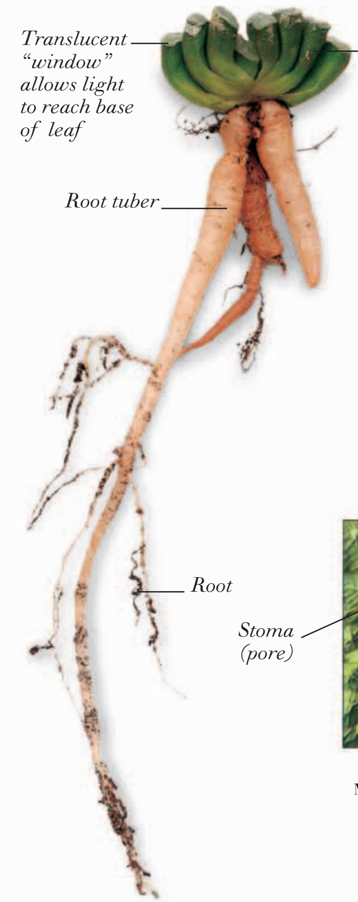


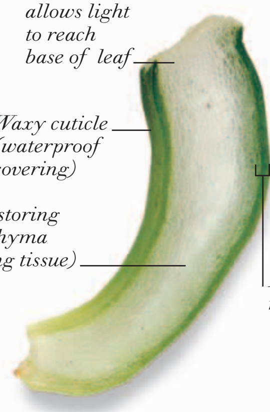
MICROGRAPH OF STEM SURFACE



DETAIL OF STEM SURFACE

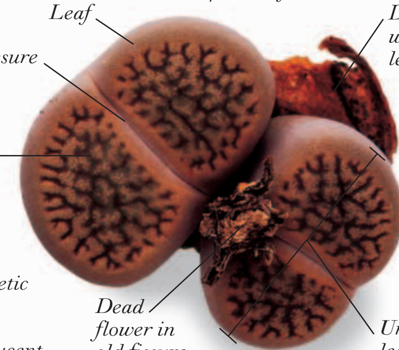
LEAF SUCCULENT
Haworthia truncata

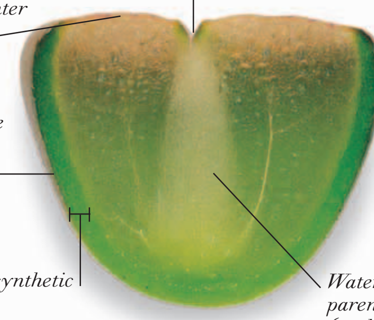




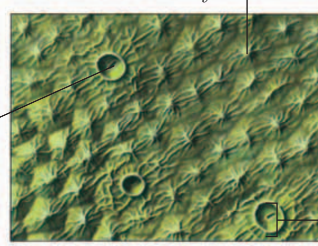
LONGITUDINAL SECTION THROUGH LEAF

LEAF SUCCULENT
Lithops bromfieldii



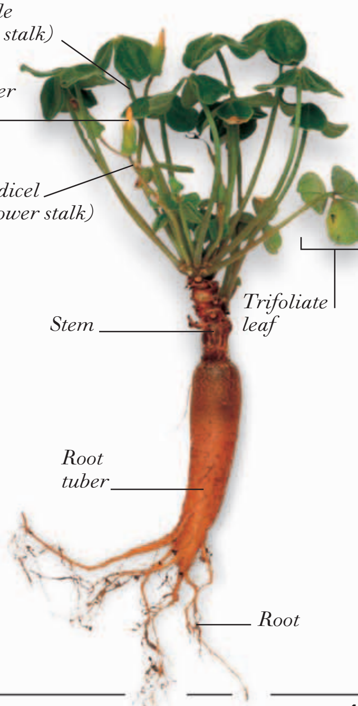


LONGITUDINAL SECTION THROUGH LEAF PAIR

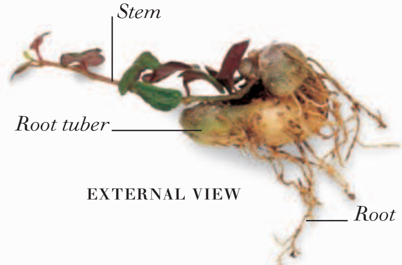


MICROGRAPH OF LEAF SURFACE

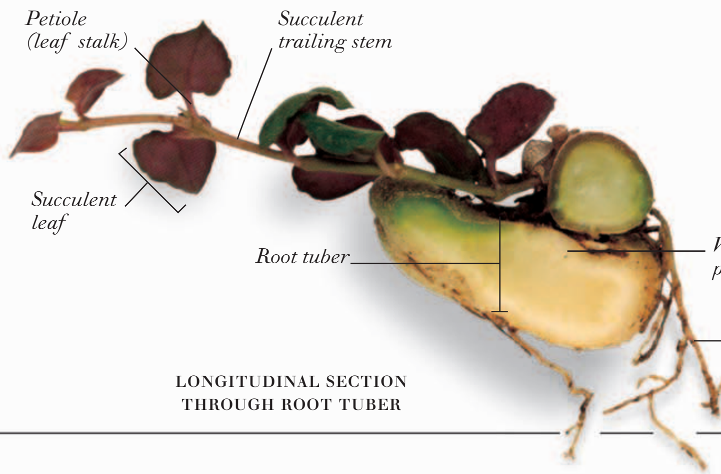
ROOT SUCCULENT
Oxalis sp.



STEM AND ROOT SUCCULENT
String of hearts
(*Ceropegia woodii*)



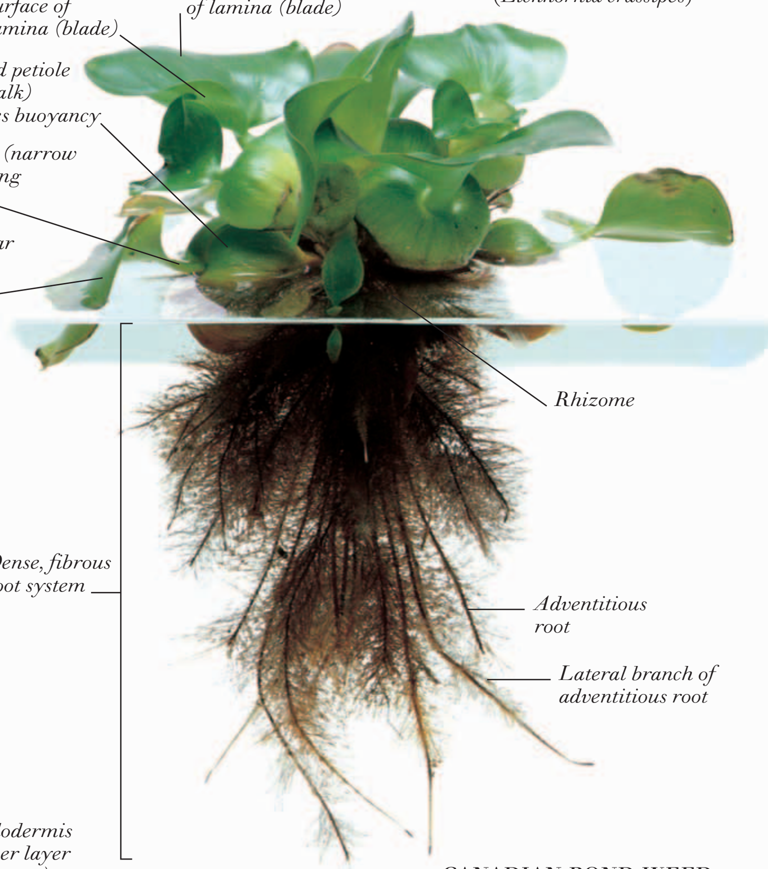
EXTERNAL VIEW

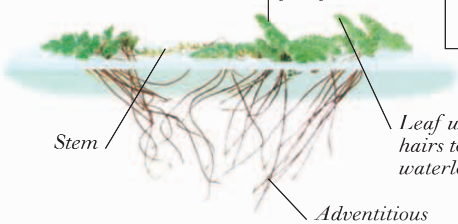


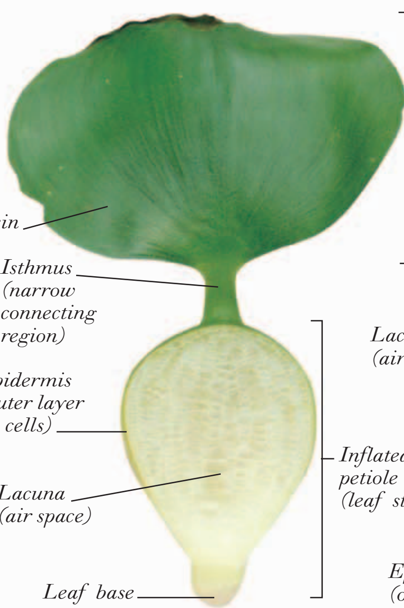
LONGITUDINAL SECTION THROUGH ROOT TUBER

Wetland plants

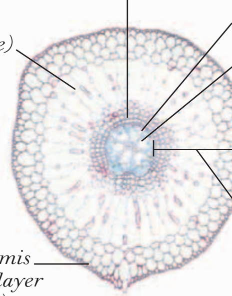
WETLAND PLANTS GROW SUBMERGED IN WATER, either partially (e.g., water hyacinth) or completely (e.g., pond weeds), and show various adaptations to this habitat. Typically, there are numerous air spaces inside the stems, leaves, and roots; these aid gas exchange and buoyancy. Submerged parts generally have no cuticle (waterproof covering), enabling the plants to absorb minerals and gases directly from the water; in addition, being supported by the water, they need little of the supportive tissue found in land plants. Stomata, the gas exchange pores, are absent from plants that are completely submerged; in partially submerged plants with floating leaves (e.g., water lilies), stomata are found on the upper leaf surfaces, where they cannot be flooded.



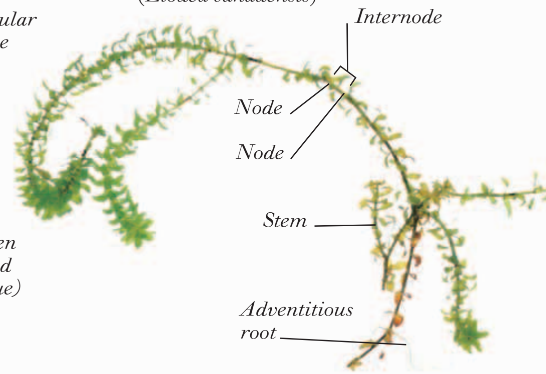




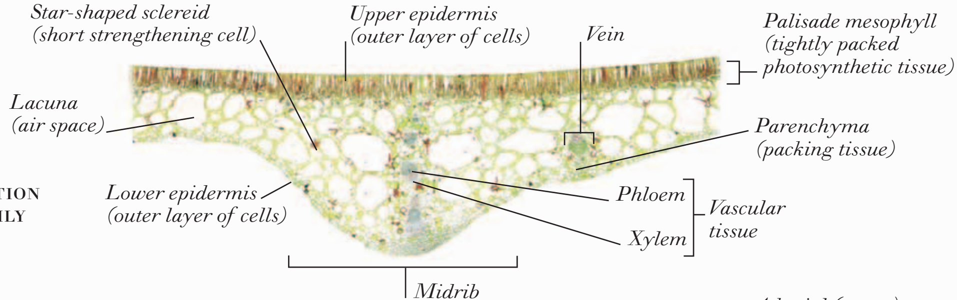
LAMINA AND SECTION THROUGH INFLATED PETIOLE OF WATER HYACINTH



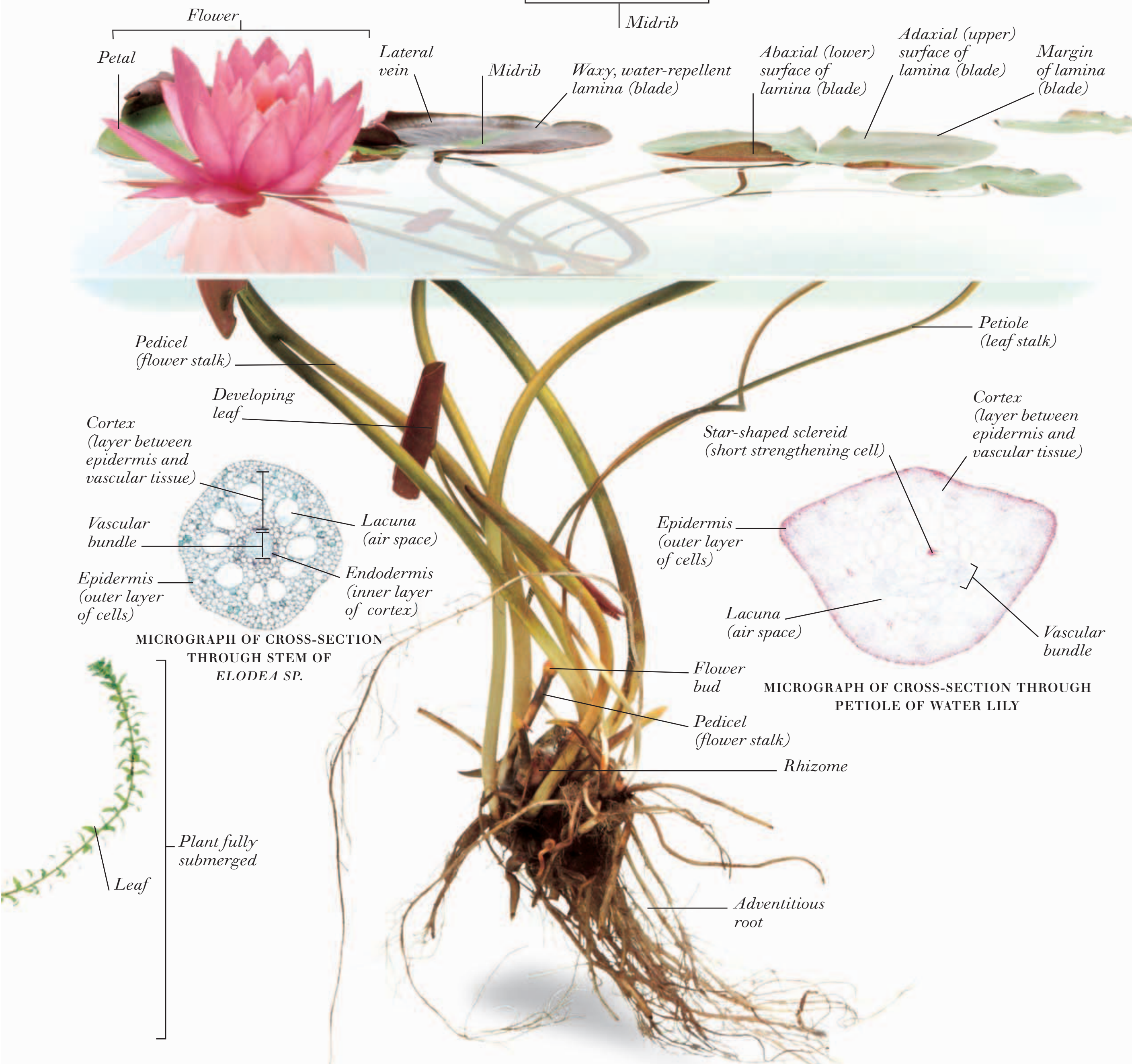
MICROGRAPH OF CROSS-SECTION THROUGH ROOT OF WATER HYACINTH



WATER LILY
(*Nymphaea sp.*)



MICROGRAPH OF CROSS-SECTION THROUGH LEAF OF WATER LILY

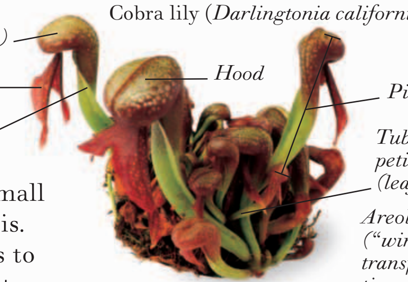


MICROGRAPH OF CROSS-SECTION THROUGH STEM OF *ELODEA SP.*

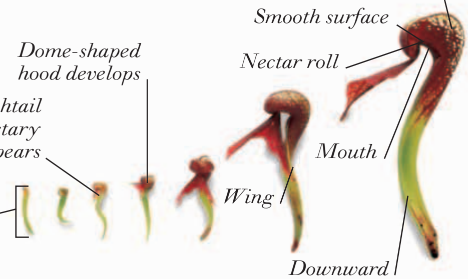
MICROGRAPH OF CROSS-SECTION THROUGH PETIOLE OF WATER LILY

Carnivorous plants

CARNIVOROUS (INSECTIVOROUS) PLANTS FEED ON INSECTS and other small animals, in addition to producing food in their leaves by photosynthesis. The nutrients absorbed from trapped insects enable carnivorous plants to thrive in acid, boggy soils that lack essential minerals, especially nitrates, where most other plants could not survive. All carnivorous plants have some leaves modified as traps; many use bright colors and scented nectar to attract prey; and most use enzymes to digest the prey. There are three types of traps. Pitcher plants, such as the monkey cup and cobra lily, have leaves modified as pitcher-shaped pitfall traps, half-filled with water; once lured inside the mouth of the trap, insects lose their footing on the slippery surface, fall into the liquid, and either decompose or are digested. Venus fly traps use a spring-trap mechanism; when an insect touches trigger hairs on the inner surfaces of the leaves, the two lobes of the trap snap shut. Butterworts and sundews entangle prey by sticky droplets on the leaf surface, while the edges of the leaves slowly curl over to envelop and digest the prey.

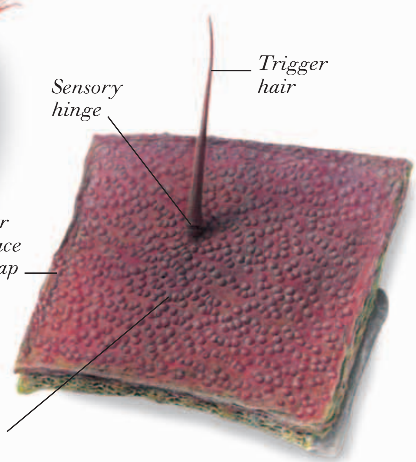


PITCHER PLANT
Cobra lily (*Darlingtonia californica*)



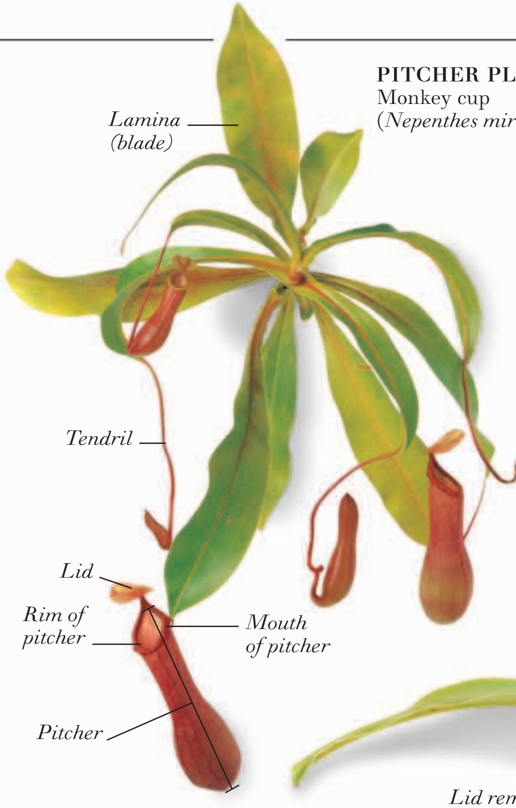
DEVELOPMENT OF MODIFIED LEAF IN COBRA LILY

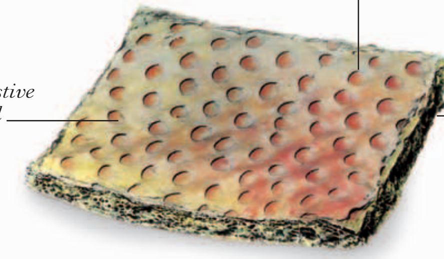
VENUS FLY TRAP
(*Dionaea muscipula*)



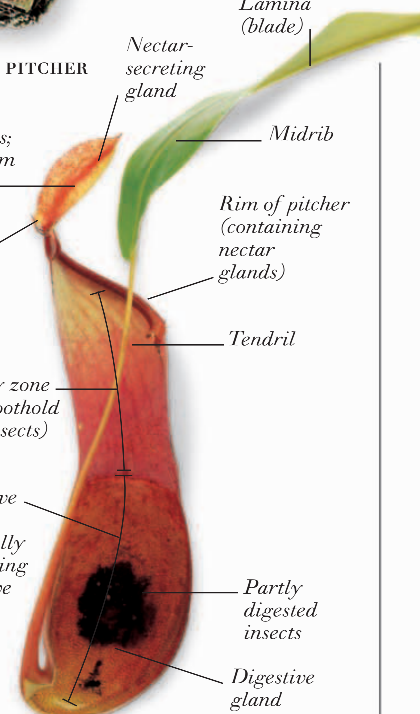
MICROGRAPH OF LOBE OF VENUS FLY TRAP

PITCHER PLANT
Monkey cup
(*Nepenthes mirabalis*)

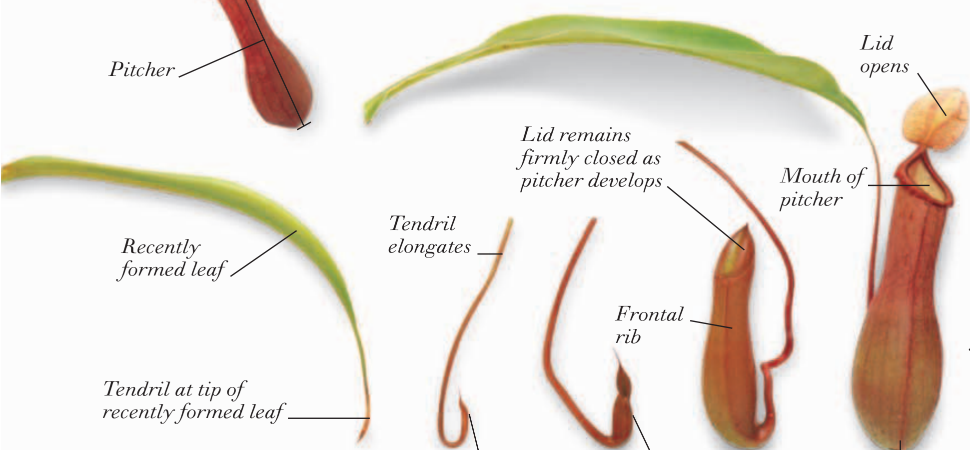




MICROGRAPH OF WALL OF PITCHER

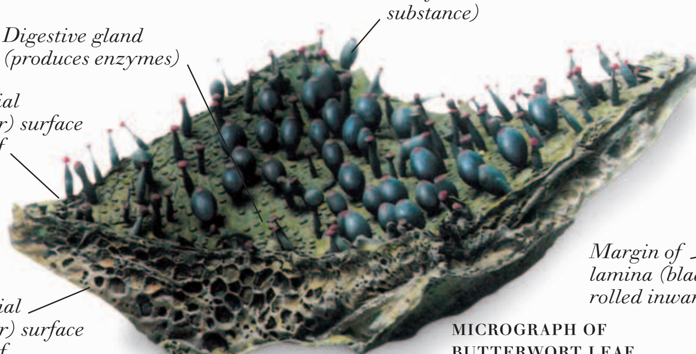


SECTION THROUGH PITCHER

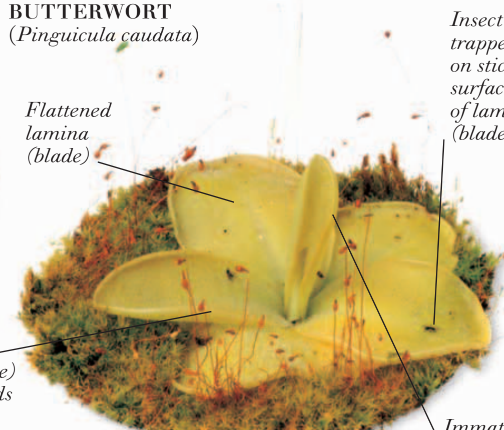


DEVELOPMENT OF MODIFIED LEAF IN PITCHER PLANT

BUTTERWORT
(*Pinguicula caudata*)

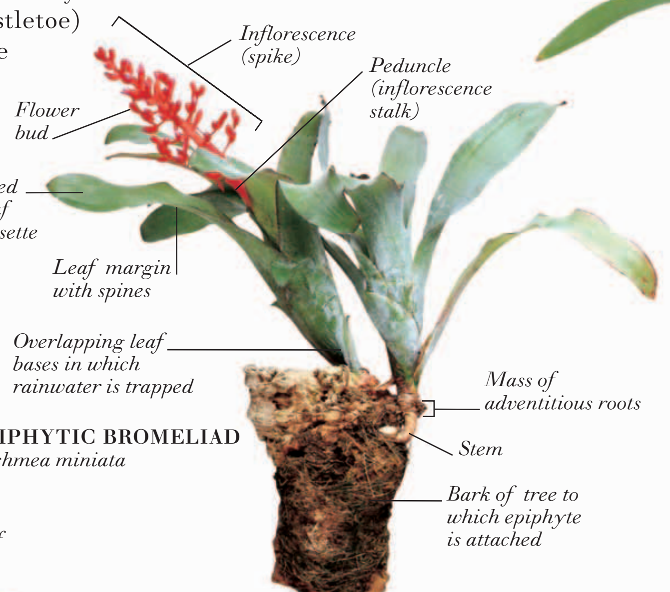


MICROGRAPH OF BUTTERWORT LEAF



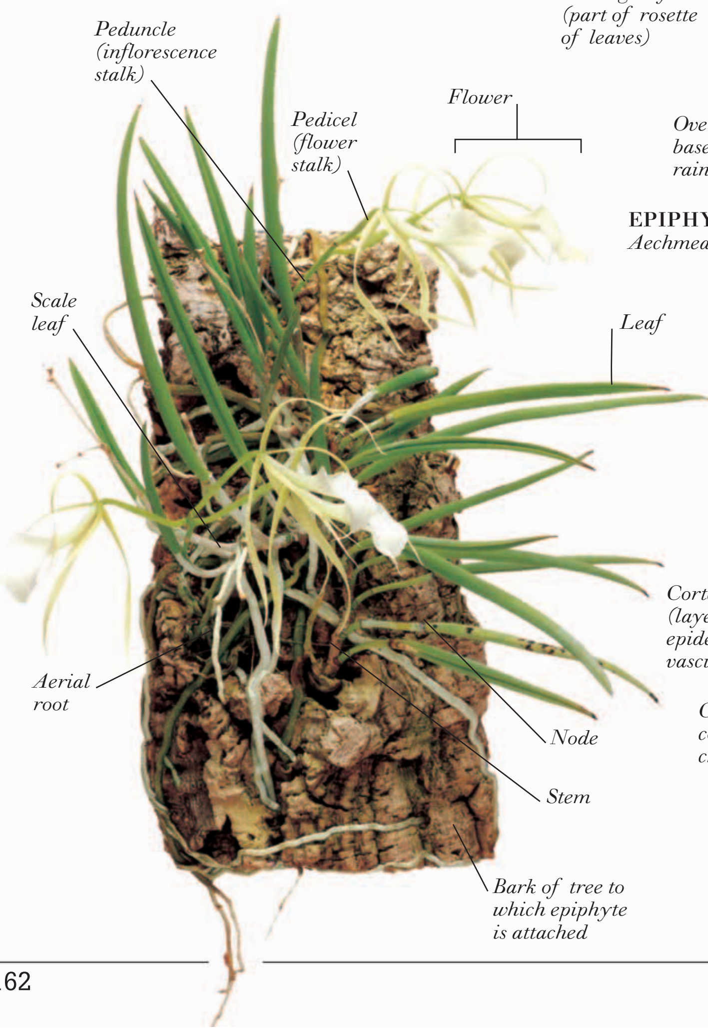
Epiphytic and parasitic plants

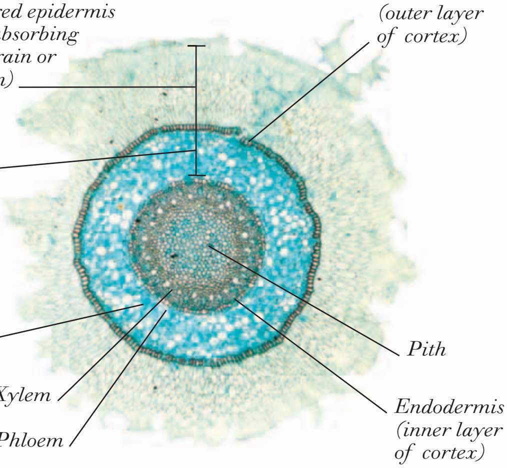
EPIPHYTIC AND PARASITIC PLANTS GROW ON OTHER LIVING PLANTS. Typically, epiphytic plants are not rooted in the soil; instead, they live above ground level on the stems and branches of other plants. Epiphytes obtain water from trapped rainwater and from moisture in the air, and minerals from organic matter that has accumulated on the surface of the plant on which they are growing. Like other green plants, epiphytes produce their food by photosynthesis. Epiphytes include tropical orchids and bromeliads (air plants), and some mosses that live in temperate regions. Parasitic plants obtain all their nutrient requirements from the host plants on which they grow. The parasites produce haustoria, rootlike organs that penetrate the stem or roots of the host and grow inward to merge with the host's vascular tissue, from which the parasite extracts water, minerals, and manufactured nutrients. As they have no need to produce their own food, parasitic plants lack chlorophyll, the green photosynthetic pigment, and they have no foliage leaves. Partial parasitic plants (e.g., mistletoe) obtain water and minerals from the host plant but have green leaves and stems and are therefore able to produce their own food by photosynthesis.



EPIPHYTIC BROMELIAD
Aechmea miniata

EPIPHYTIC ORCHID
Brassavola nodosa

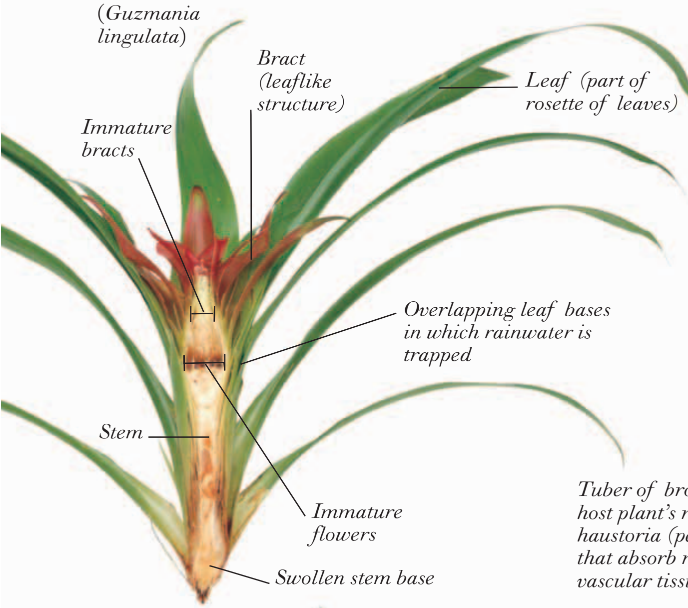




MICROGRAPH OF CROSS-SECTION THROUGH AERIAL ROOT OF EPIPHYTIC ORCHID

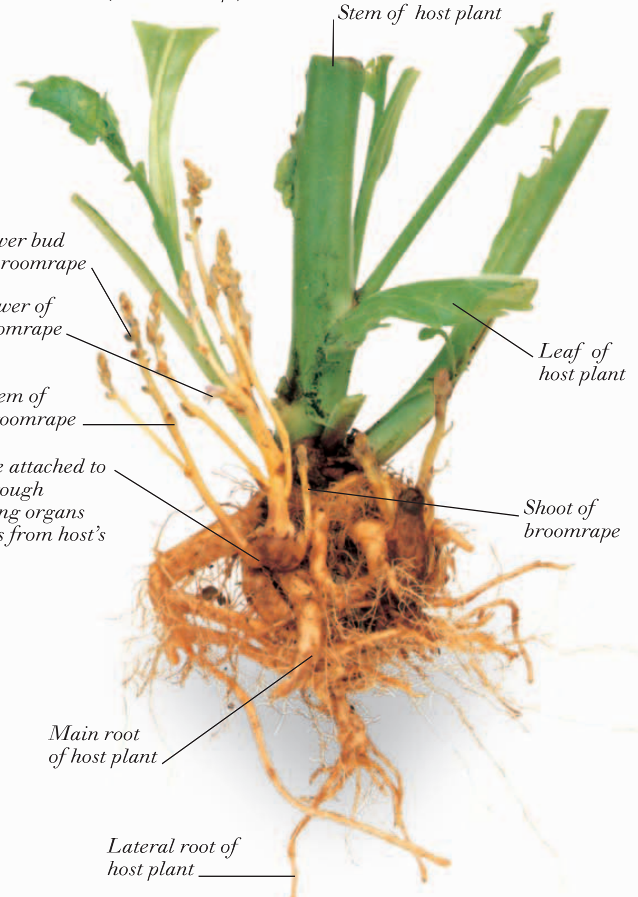
LONGITUDINAL SECTION THROUGH EPIPHYTIC BROMELIAD

Scarlet star
(*Guzmania lingulata*)



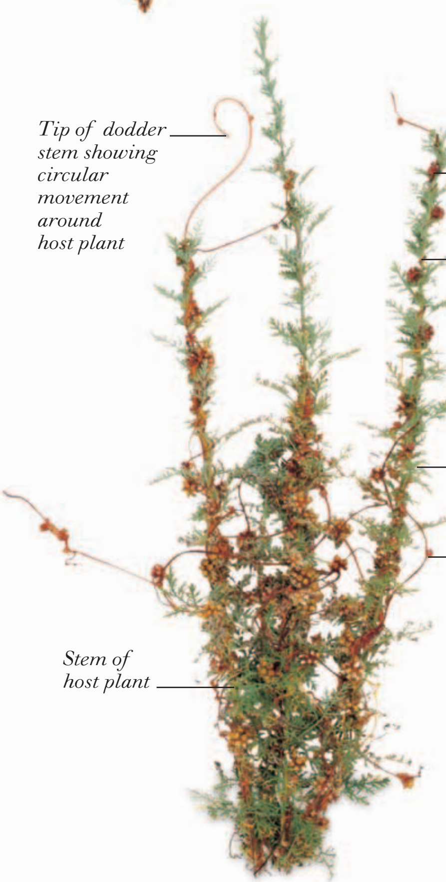
ROOT PARASITE

Broomrape
(*Orobanche sp.*)

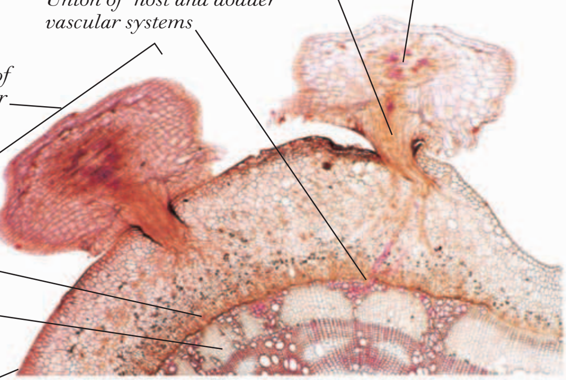


STEM PARASITE

Dodder
(*Cuscuta europaea*)



EXTERNAL VIEW OF PLANT PARASITIZED BY DODDER



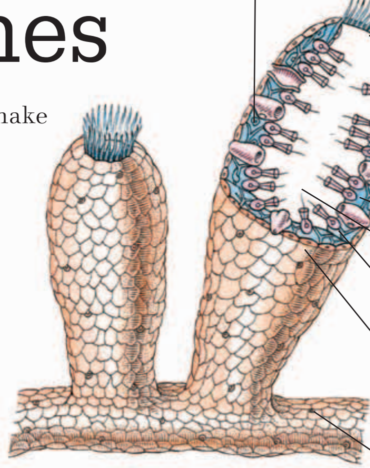
MICROGRAPH OF CROSS-SECTION THROUGH STEM OF PLANT PARASITIZED BY DODDER

Animals

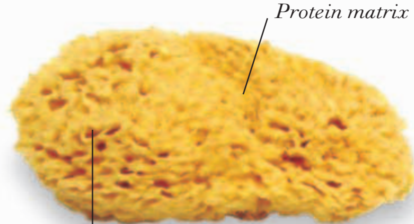
Sponges, jellyfish, and sea anemones

SPONGES ARE MAINLY MARINE animals that make up the phylum Porifera. They are among the simplest of all animals, having no tissues or organs. Their bodies consist of two layers of cells separated by a jellylike layer (mesohyal) that is strengthened by mineral spicules or protein fibers. The body is perforated by a system of pores and water channels called the aquiferous system. Special cells (choanocytes) with whiplike structures (flagella) draw water through the aquiferous system, thereby bringing tiny food particles to the sponge's cells. Jellyfish (class Scyphozoa), sea anemones (class Anthozoa), and corals (also class Anthozoa) belong to the phylum Cnidaria, also known as Coelenterata. More complex than sponges, coelenterates have simple tissues, such as nervous tissue; a radially symmetrical body; and a mouth surrounded by tentacles with unique stinging cells (cnidocytes).

INTERNAL ANATOMY OF A SPONGE



SKELETON OF A SPONGE

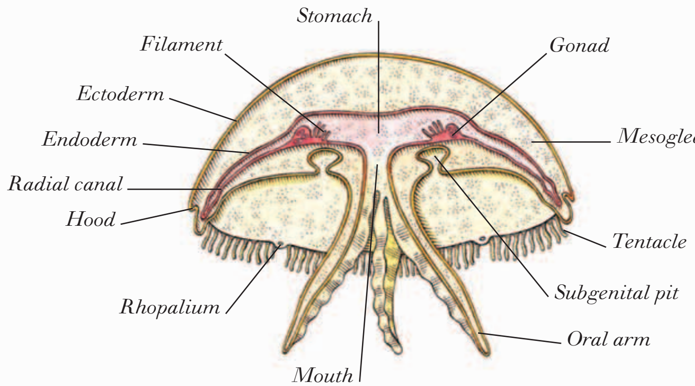


EXTERNAL FEATURES OF A SEA ANEMONE

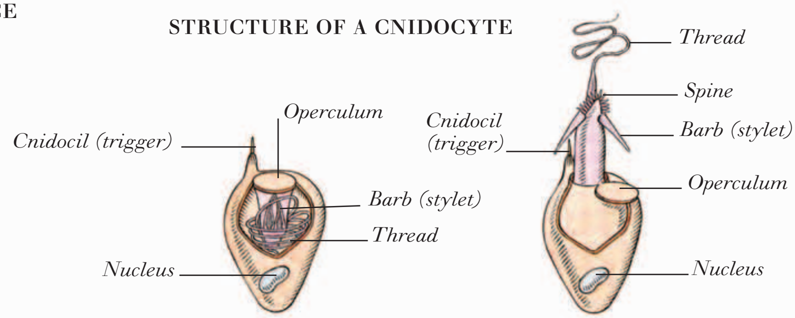
EXAMPLES OF SEA ANEMONES

EXTERNAL APPEARANCE OF A JELLYFISH

INTERNAL ANATOMY OF A JELLYFISH



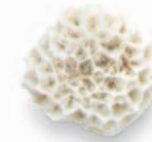
STRUCTURE OF A CNIDOCYTE



BEFORE DISCHARGE

AFTER DISCHARGE

EXAMPLES OF CORALS

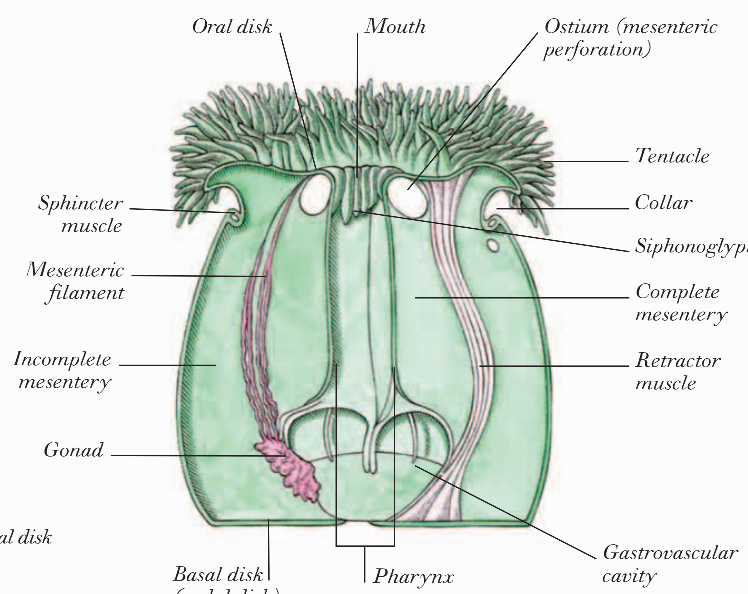


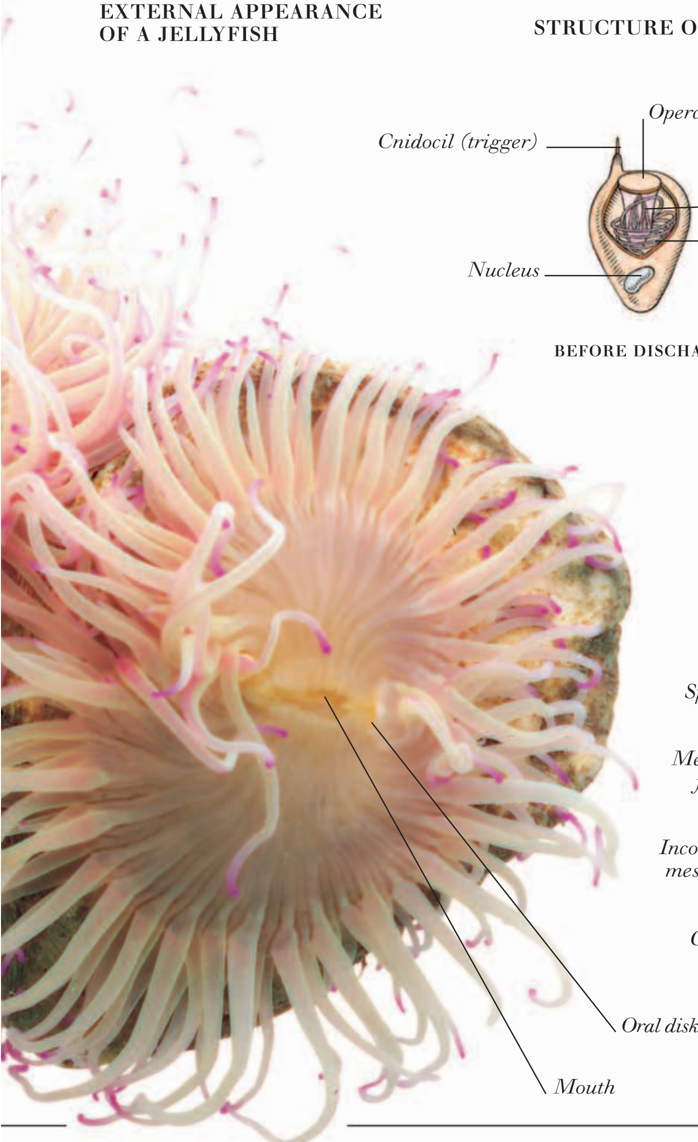
HONEYCOMB CORAL
(Goniastrea aspera)

MUSHROOM CORAL
(Fungia fungites)

STAR CORAL
(Balanophyllia regia)

INTERNAL ANATOMY OF A SEA ANEMONE



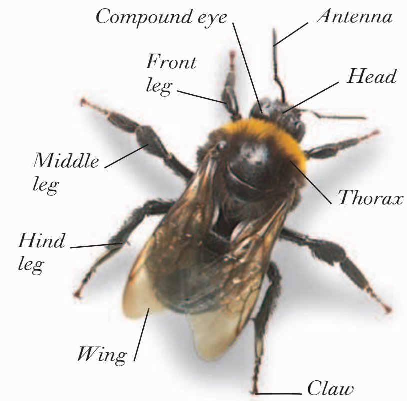


Insects

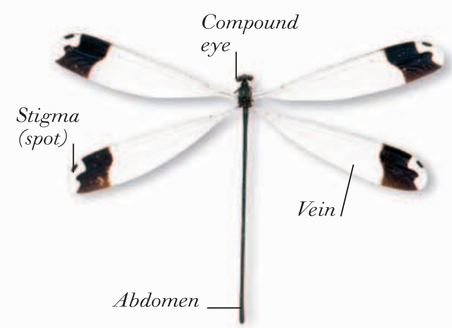
PUPA (CHRYSALIS)

THE WORD INSECT REFERS to small invertebrate creatures, especially those with bodies divided into sections. Insects, including beetles, ants, bees, butterflies, and moths, belong to various orders in the class Insecta, which is a division of the phylum Arthropoda. Features common to all insects are an exoskeleton (external skeleton); three pairs of jointed legs; three body sections (head, thorax, and abdomen); and one pair of sensory antennae. Beetles (order Coleoptera) are the biggest group of insect, with about 300,000 species (about 30 percent of all known insects). They have a pair of hard elytra (wing cases), which are modified front wings. The principal function of the elytra is to protect the hind wings, which are used for flying. Ants, together with bees and wasps, form the order Hymenoptera, which contains about 200,000 species. This group is characterized by a marked narrowing between the thorax and abdomen. Butterflies and moths form the order Lepidoptera, which has about 150,000 species. They have wings covered with tiny scales, hence the name of their order (Lepidoptera means "scale wings"). The separation of lepidopterans into butterflies and moths is largely artificial, since there are no features that categorically distinguish one group from the other. In general, however, most butterflies fly by day, whereas most moths are night-flyers. Some insects, including butterflies and moths, undergo complete metamorphosis (transformation) during their life-cycle. A butterfly metamorphoses from an egg to a larva (caterpillar), then to a pupa (chrysalis), and finally to an imago (adult).

EXAMPLES OF INSECTS



BUMBLEBEE



DAMSELFLY

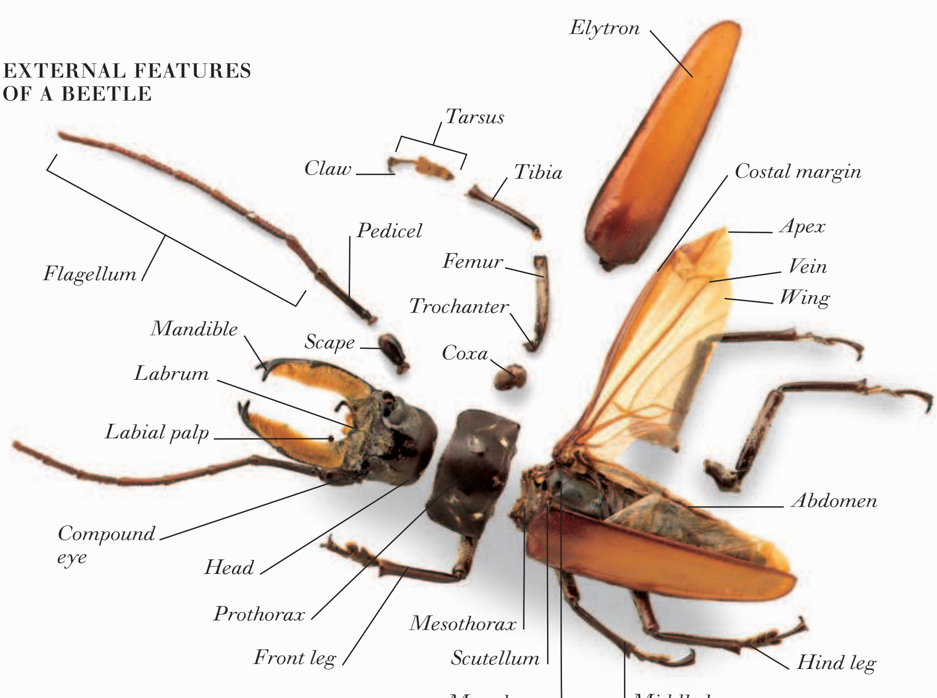
CRICKET

ANT

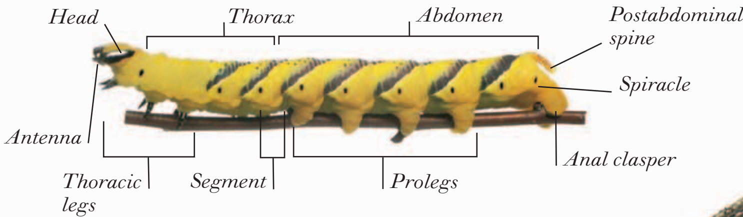
FLY

EARWIG

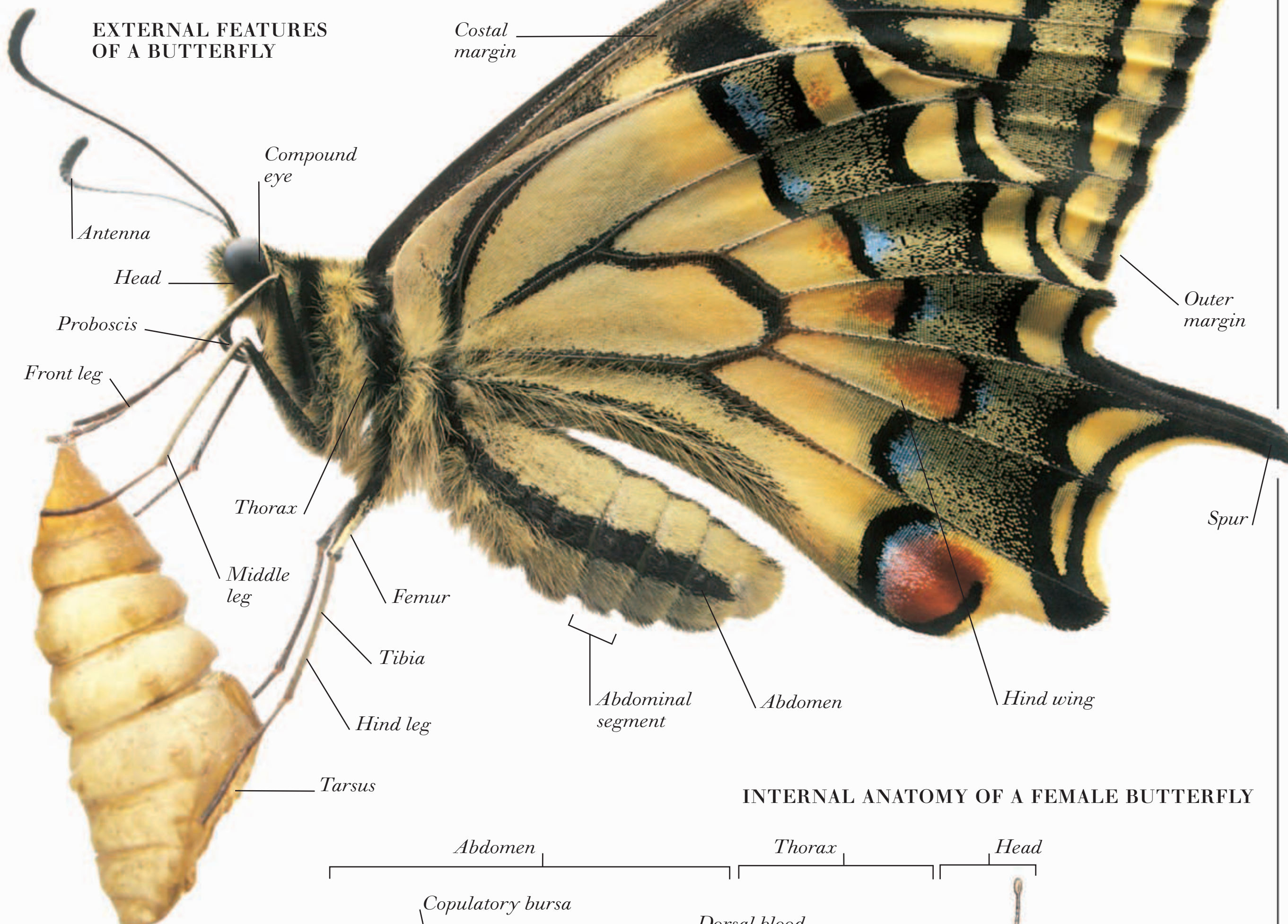
EXTERNAL FEATURES OF A BEETLE



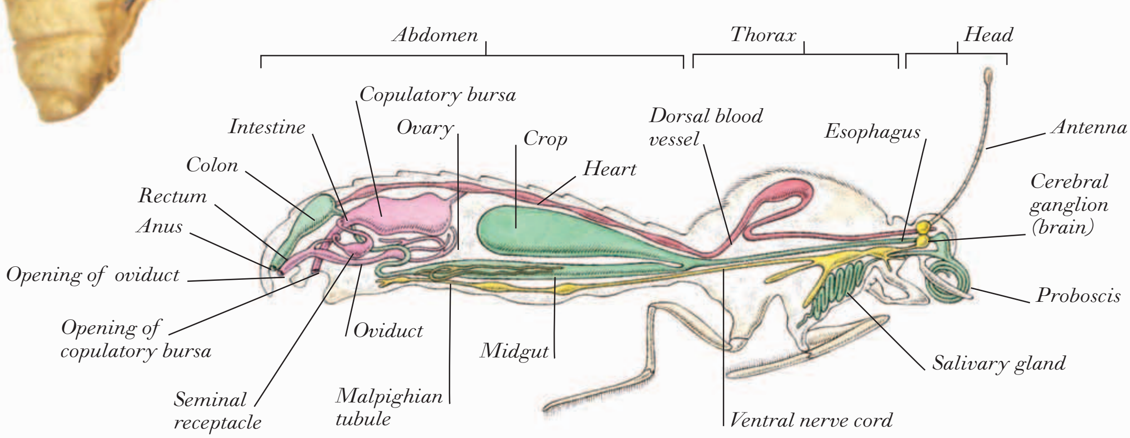
EXTERNAL FEATURES OF A CATERPILLAR



EXTERNAL FEATURES OF A BUTTERFLY



INTERNAL ANATOMY OF A FEMALE BUTTERFLY

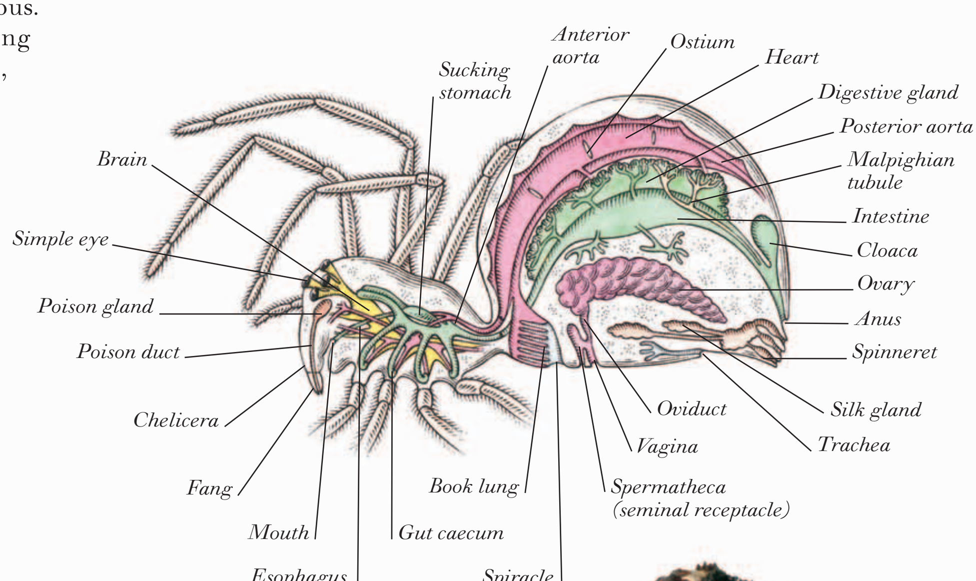


Arachnids

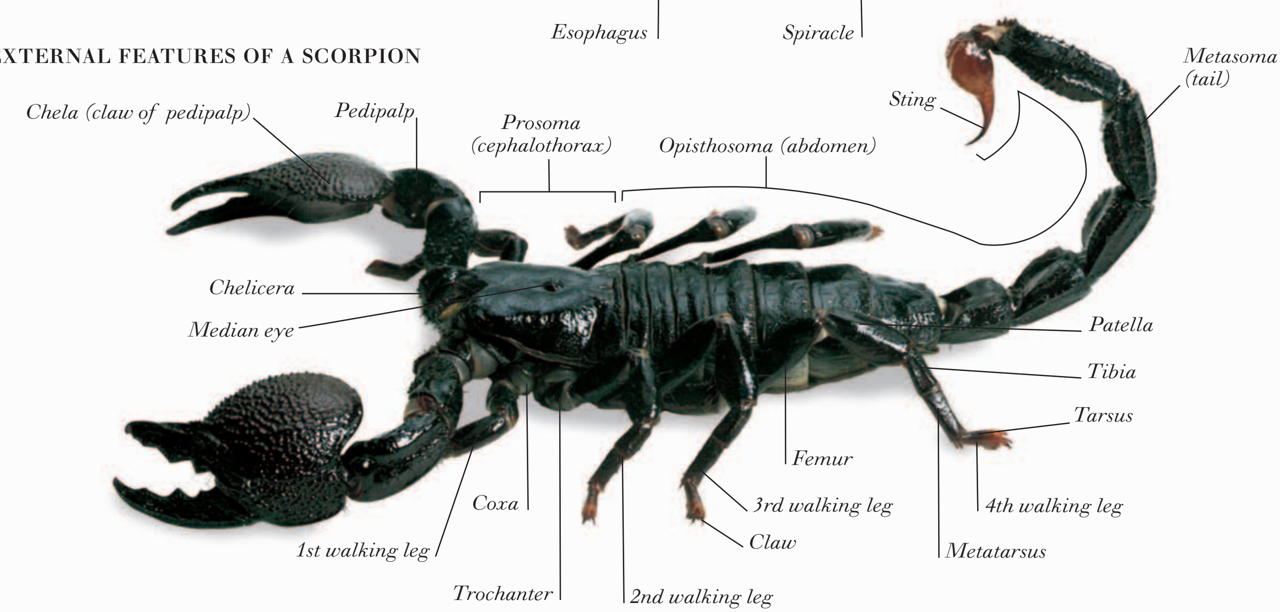
THE CLASS ARACHNIDA INCLUDES SPIDERS (order Araneae) and scorpions (order Scorpiones). The class is part of the phylum Arthropoda, which also includes insects and crustaceans. Spiders and scorpions are characterized by having four pairs of walking legs; a pair of pincerlike mouthparts called chelicerae; another pair of frontal appendages called pedipalps, which are sensory in spiders but used for grasping in scorpions; and a body divided into two sections (a combined head and thorax called a cephalothorax or prosoma, and an abdomen or opisthosoma). Unlike other arthropods, spiders and scorpions lack antennae. Spiders and scorpions are carnivorous. Spiders poison prey by biting with the fanged chelicerae, scorpions by stinging with the end of the metasoma (tail).

MEXICAN TRUE RED-LEGGED TARANTULA
(Euathlus emilia)

INTERNAL ANATOMY OF A FEMALE SPIDER



EXTERNAL FEATURES OF A SCORPION



EXAMPLES OF SPIDERS

RAFT SPIDER
(Dolomedes fimbriatus)

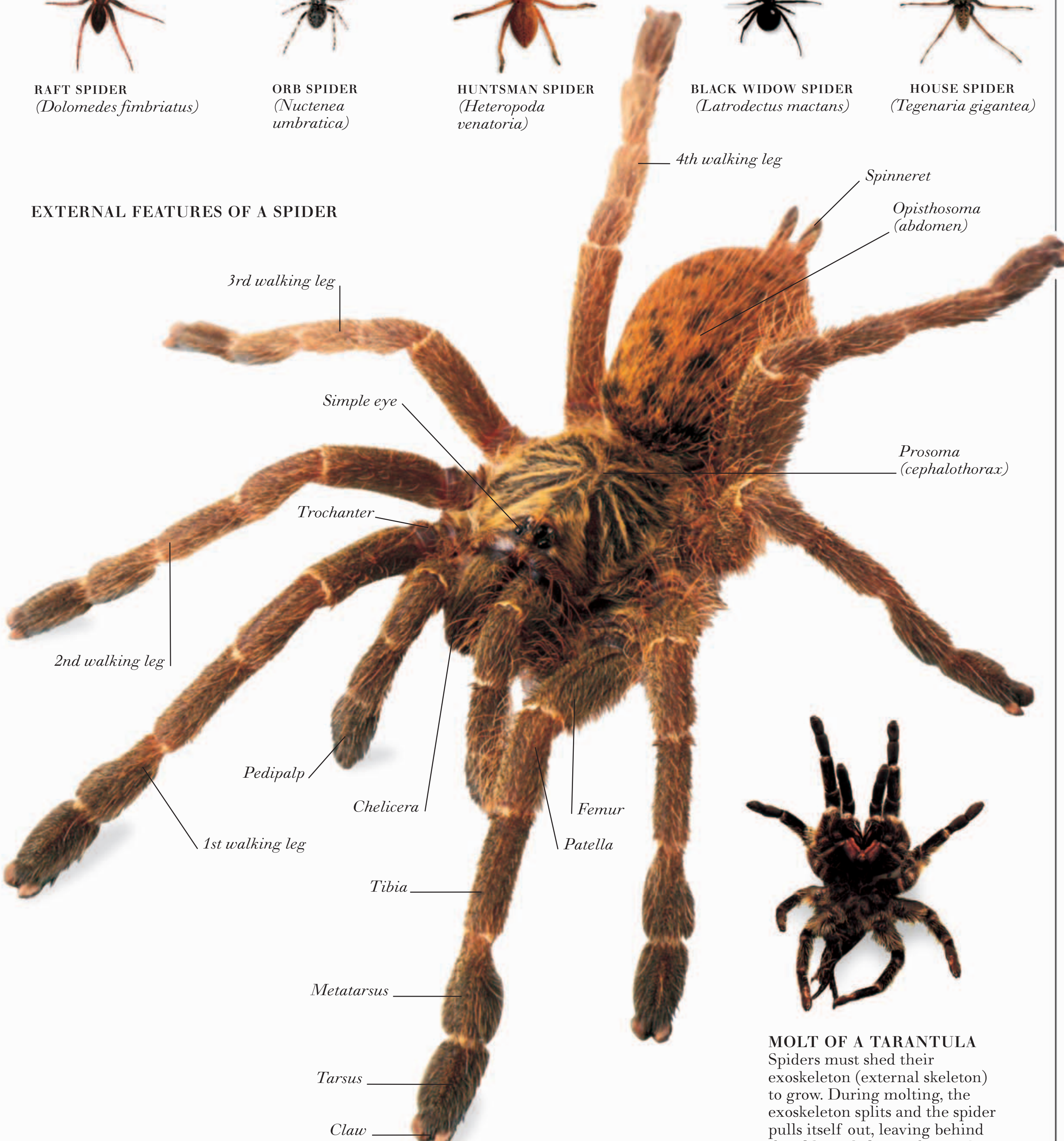
ORB SPIDER
(Nuctenea umbratica)

HUNTSMAN SPIDER
(Heteropoda venatoria)

BLACK WIDOW SPIDER
(Latrodectus mactans)

HOUSE SPIDER
(Tegenaria gigantea)

EXTERNAL FEATURES OF A SPIDER

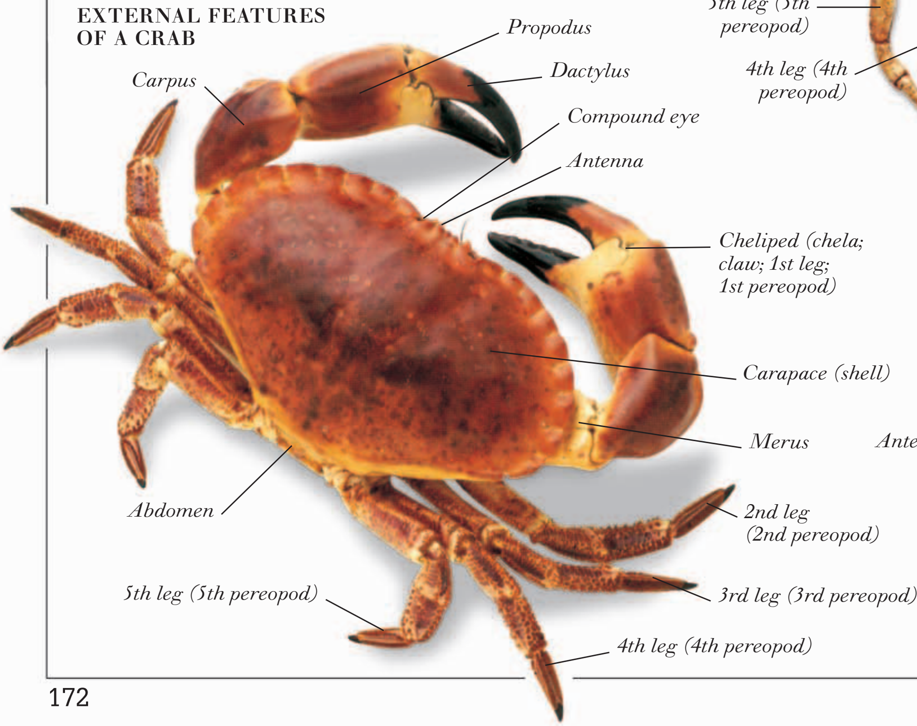


MOLT OF A TARANTULA
Spiders must shed their exoskeleton (external skeleton) to grow. During molting, the exoskeleton splits and the spider pulls itself out, leaving behind the old exoskeleton, shown above.

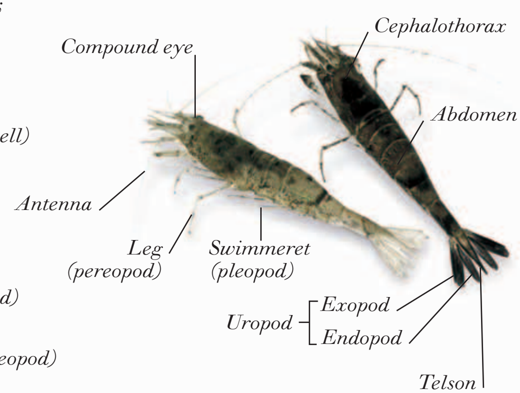
Crustaceans

THE SUBPHYLUM CRUSTACEA is one of the largest groups in the phylum Arthropoda. The subphylum is divided into several classes, the most important of which are Malacostraca and Cirripedia. The class Malacostraca includes crayfish, crabs, lobsters, and shrimps. Typical features of malacostracans include a body divided into two sections (a combined head and thorax called a cephalothorax, and an abdomen); an exoskeleton (external skeleton) with a large plate (carapace) covering the cephalothorax; stalked, compound eyes; and two pairs of antennae. The class Cirripedia includes barnacles, which, unlike other crustaceans, spend their adult lives attached to a surface, such as a rock. Other characteristics of cirripedes include an exoskeleton of overlapping calcareous plates; a body consisting almost entirely of thorax (the abdomen and head are minute); and six pairs of thoracic appendages (cirri) used for filter feeding.

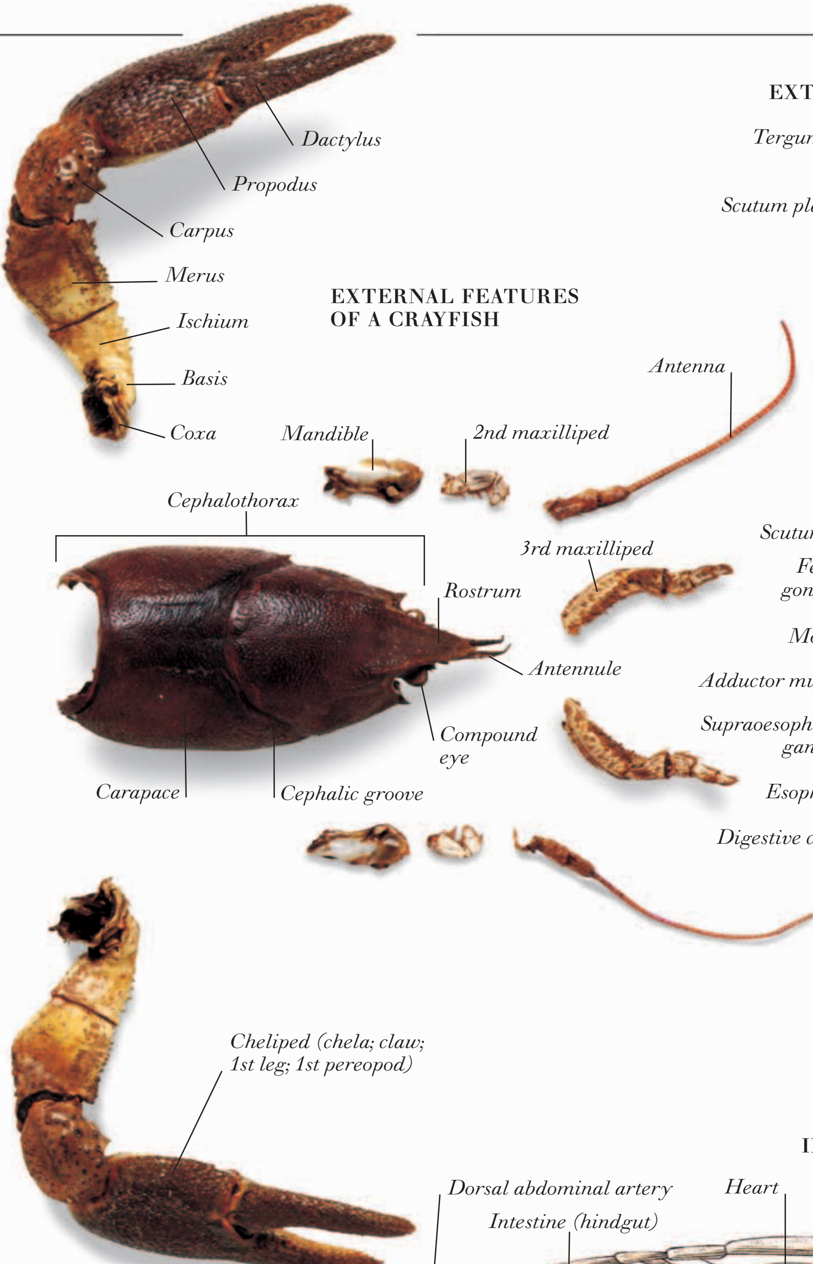
EXTERNAL FEATURES OF A CRAB



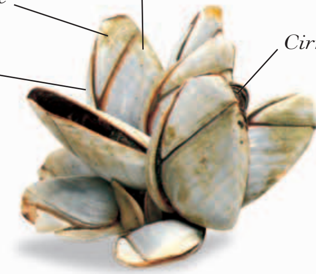
EXTERNAL FEATURES OF A SHRIMP



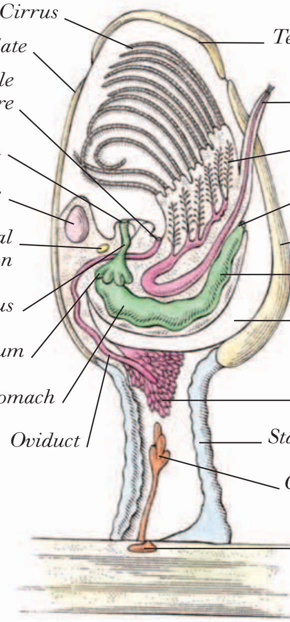
EXTERNAL FEATURES OF A CRAYFISH



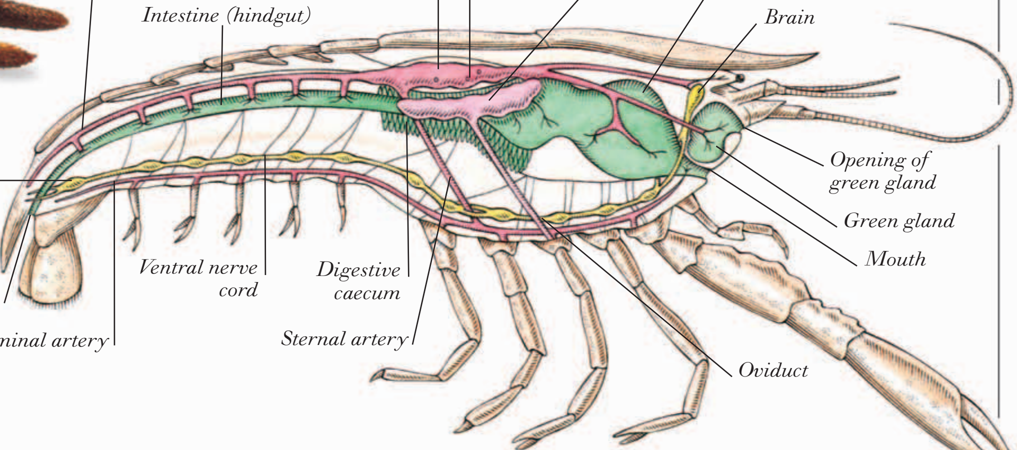
EXTERNAL FEATURES OF A STALKED BARNACLE



INTERNAL ANATOMY OF A STALKED BARNACLE



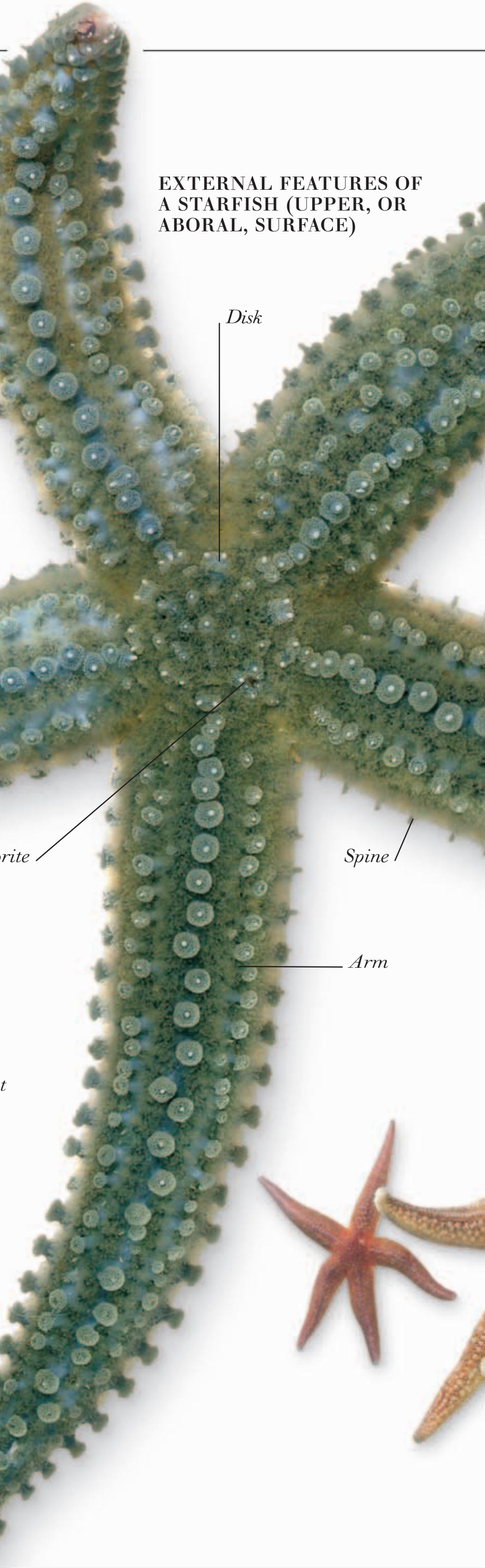
INTERNAL ANATOMY OF A FEMALE CRAYFISH



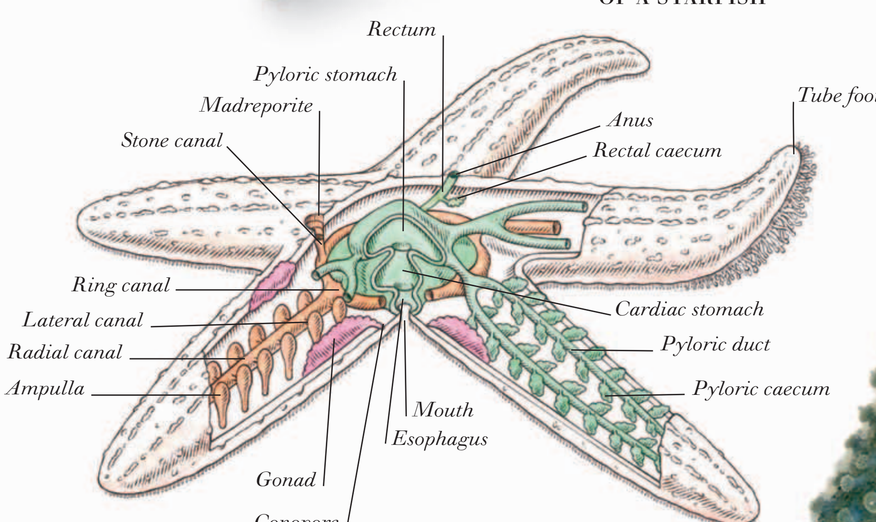
Starfish and sea urchins

STARFISH, SEA URCHINS, AND THEIR relatives (including feather stars, brittle stars, basket stars, sea daisies, sea lilies, and sea cucumbers) make up the phylum Echinodermata. A unique feature of echinoderms is the water vascular system, which consists of a series of water-filled canals from which protrude thousands of tiny tube feet. The tube feet may be used for movement, feeding, or respiration. Other features include pentaradiate symmetry (that is, the body can be divided into five parts radiating from the center); no head; a diffuse, decentralized nervous system that lacks a brain; and no excretory organs. Typically, echinoderms also have an endoskeleton (internal skeleton) consisting of hard calcite ossicles embedded in the body wall and often bearing protruding spines or tubercles. The ossicles may fit together to form a test (as in sea urchins) or remain separate (as in sea cucumbers).

EXTERNAL FEATURES OF A STARFISH (UPPER, OR ABORAL, SURFACE)



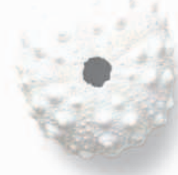
INTERNAL ANATOMY OF A STARFISH



EXAMPLES OF SEA URCHINS

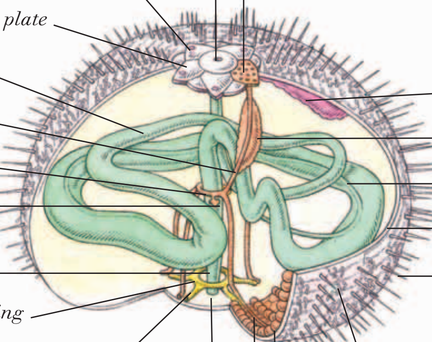
EDIBLE SEA URCHIN
(Echinus escelentus)

CALIFORNIAN PURPLE SEA URCHIN
(Strongylocentrotus purpuratus)

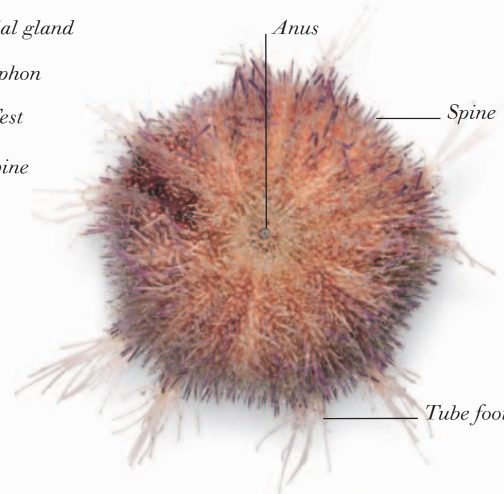


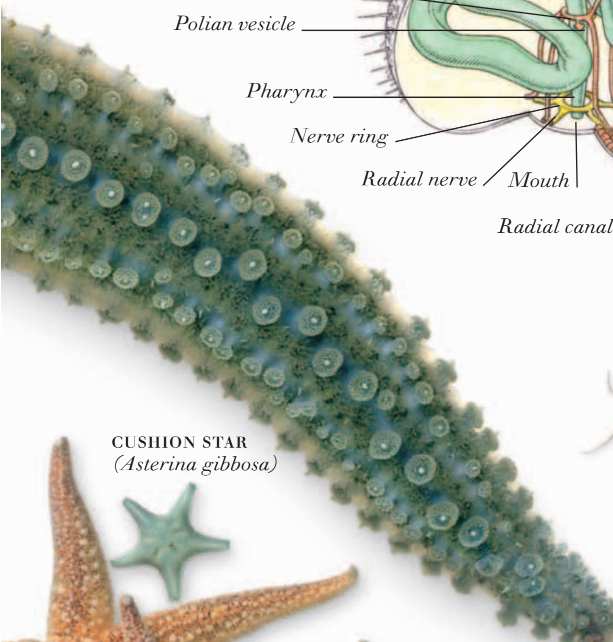
PENCIL SLATE SEA URCHIN
(Heterocentrotus mammillatus)

INTERNAL ANATOMY OF A SEA URCHIN



EXTERNAL FEATURES OF A SEA URCHIN (UPPER, OR ABORAL, SURFACE)





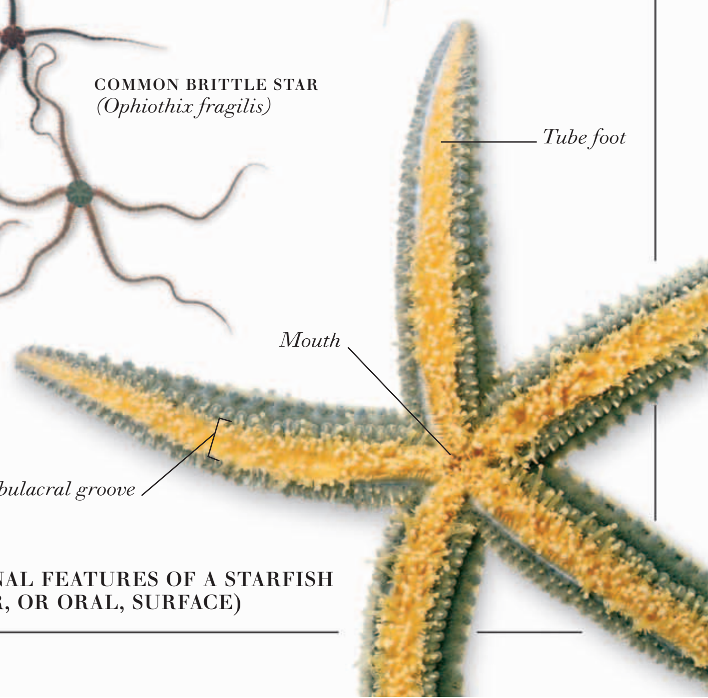
EXAMPLES OF STARFISH

CUSHION STAR
(Asterina gibbosa)

COMMON BRITTLE STAR
(Ophiothix fragilis)

COMMON STARFISH
(Asterias rubens)

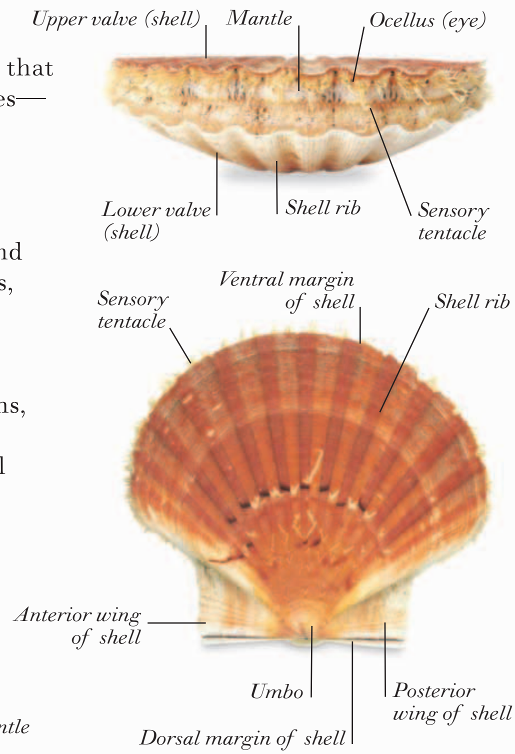
EXTERNAL FEATURES OF A STARFISH (LOWER, OR ORAL, SURFACE)



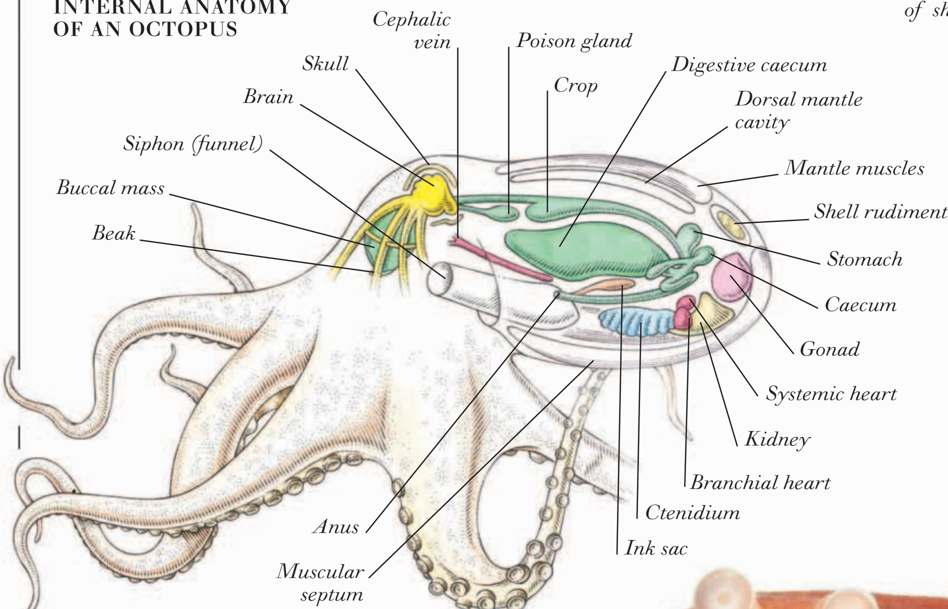
Mollusks

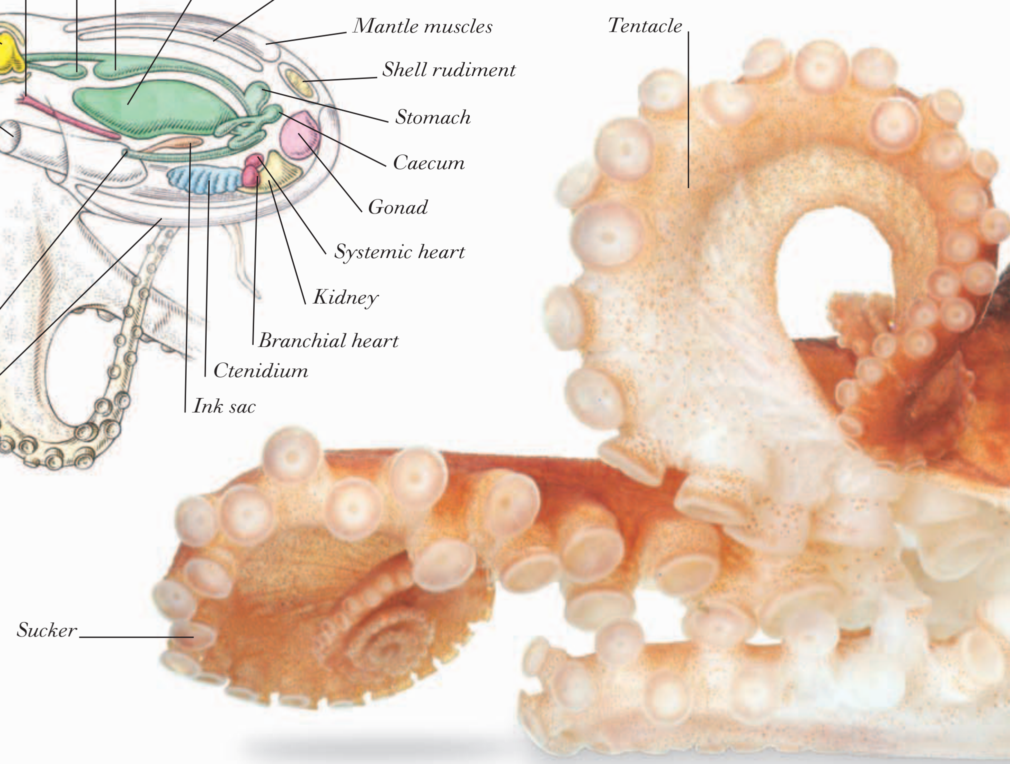
THE PHYLUM MOLLUSCA (MOLLUSKS) is a large group of animals that includes octopuses, snails, and scallops. Octopuses and their relatives—including squid and cuttlefish—form the class Cephalopoda. Cephalopods typically have a head with a radula (a filelike feeding organ) and beak; a well-developed nervous system; sucker-bearing tentacles; a muscular mantle (part of the body wall) that can expel water through the siphon, enabling movement by jet propulsion; and a small shell or no shell. Snails and their relatives—including slugs, limpets, and abalones—make up the class Gastropoda. Gastropods typically have a coiled external shell, although some, such as slugs, have a small internal shell or no shell; a flat foot; and a head with tentacles and a radula. Scallops and their relatives—including clams, mussels, and oysters—make up the class Bivalvia (also called Pelecypoda). Features of bivalves include a shell with two halves (valves); large gills that are used for breathing and filter feeding; and no radula.

EXTERNAL FEATURES OF A SCALLOP

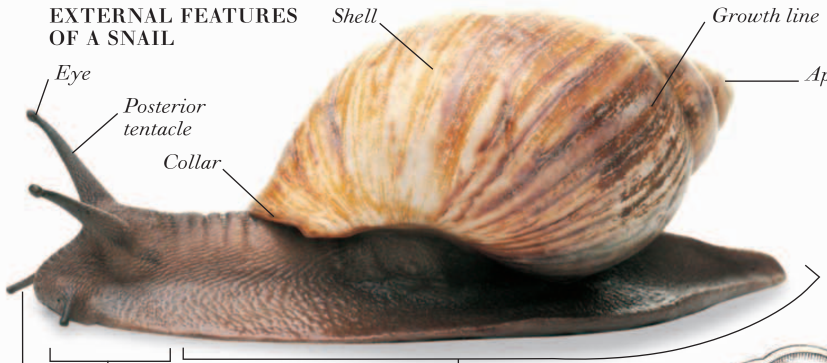


INTERNAL ANATOMY OF AN OCTOPUS

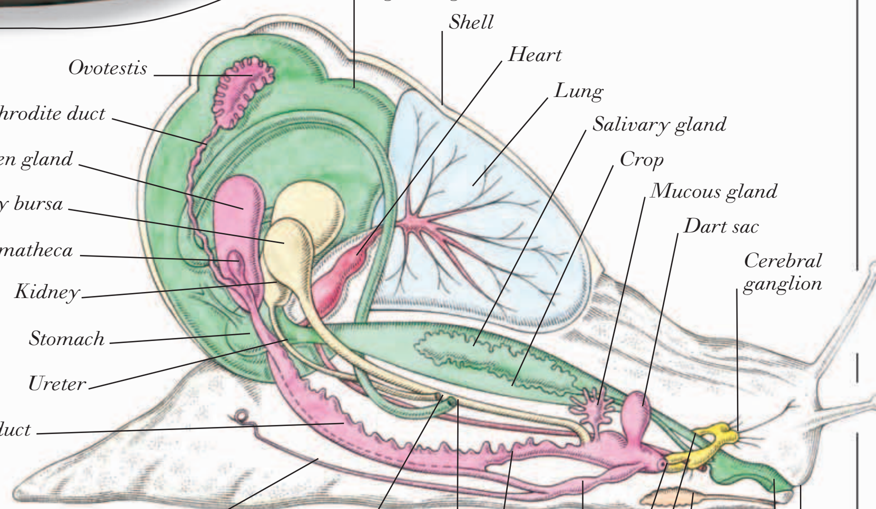




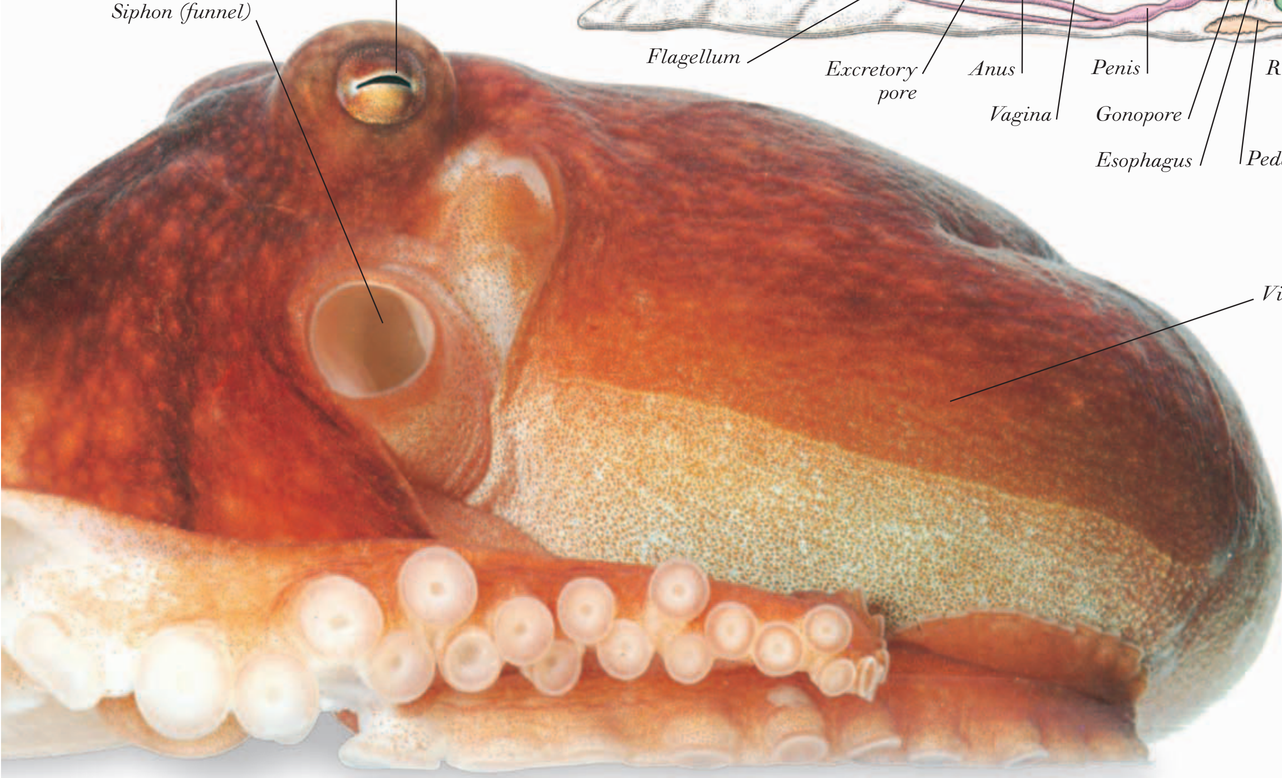
EXTERNAL FEATURES OF A SNAIL



INTERNAL ANATOMY OF A SNAIL



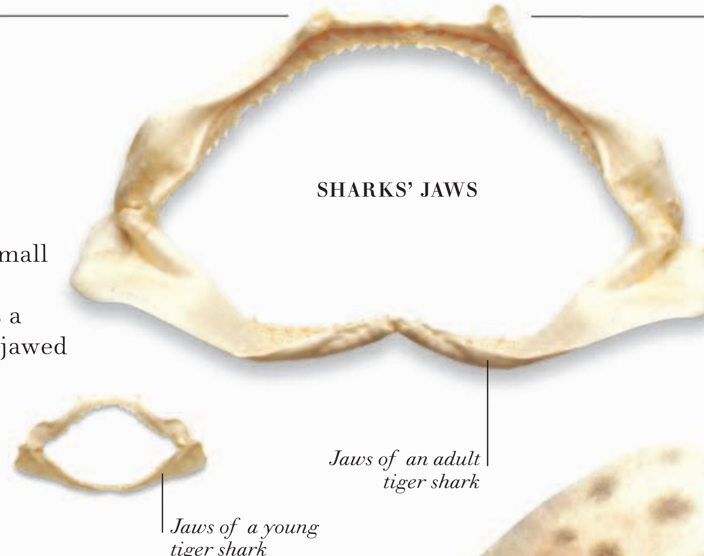
EXTERNAL FEATURES OF AN OCTOPUS



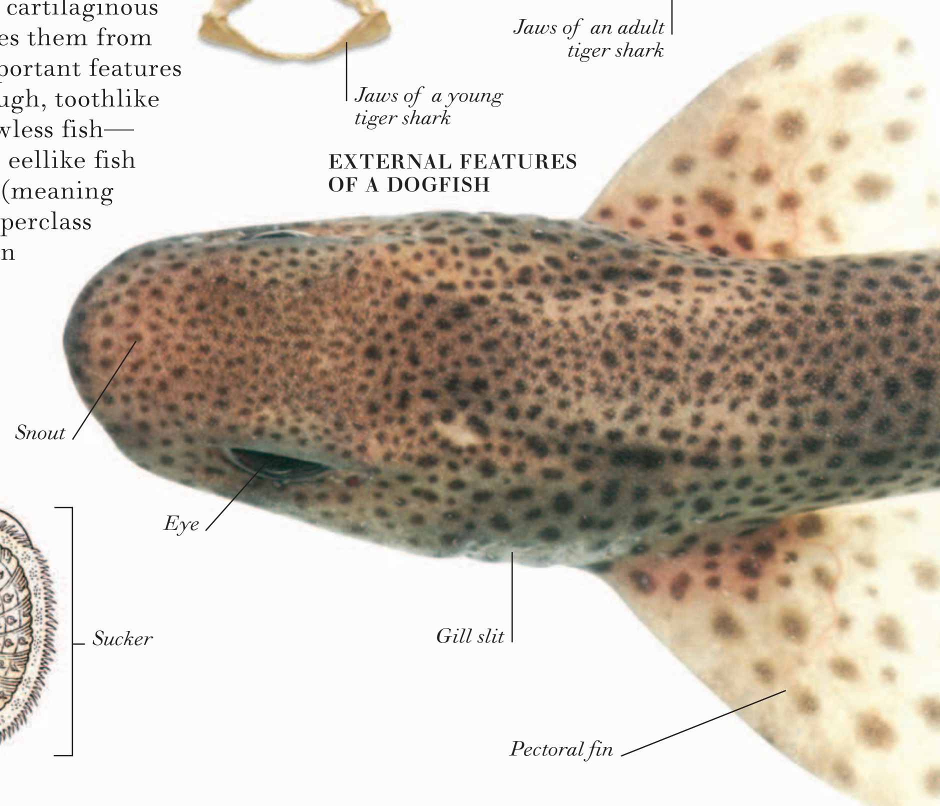
Sharks and jawless fish

SHARKS, DOGFISH (WHICH ARE actually small sharks), skates, and rays belong to a class of fishes called Chondrichthyes, which is a division of the superclass Gnathostomata (meaning “jawed mouths”). Also sometimes known as elasmobranchs, sharks and their relatives have a skeleton made of cartilage (hence their common name, cartilaginous fish), a characteristic that distinguishes them from bony fish (see pp. 180-181). Other important features of cartilaginous fish are extremely tough, toothlike scales, and lack of a swim bladder. Jawless fish—lampreys and hagfish—are primitive, eellike fish that make up the order Cyclostomata (meaning “round mouths”), a division of the superclass Agnatha (meaning “without jaws”). In addition to their characteristic round, suckerlike mouths and lack of jaws, cyclostomes also have smooth, slimy skin without scales, and unpaired fins.

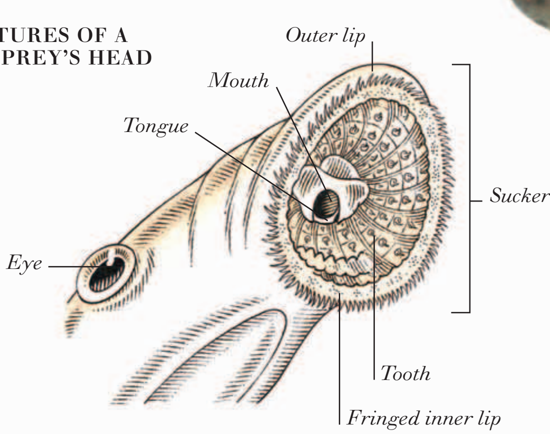
SHARKS’ JAWS



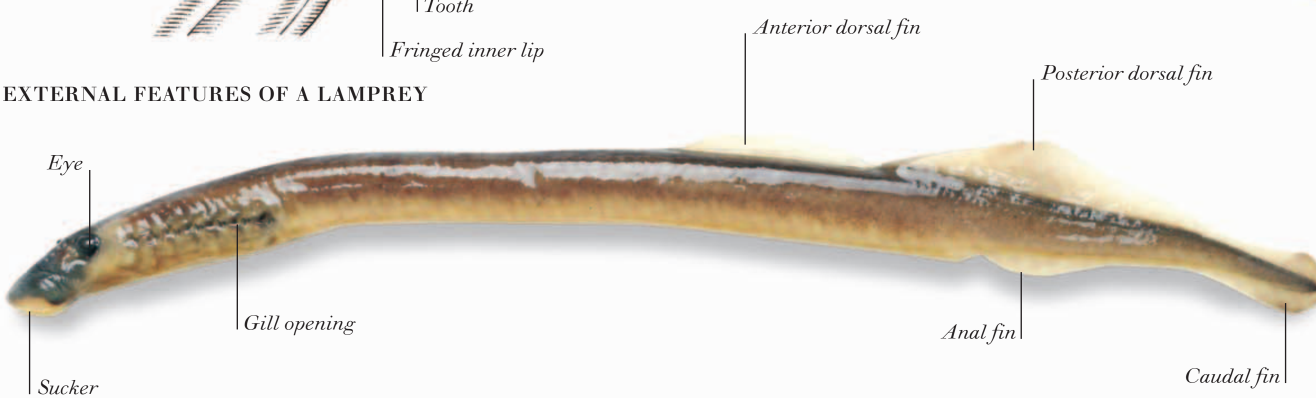
EXTERNAL FEATURES OF A DOGFISH



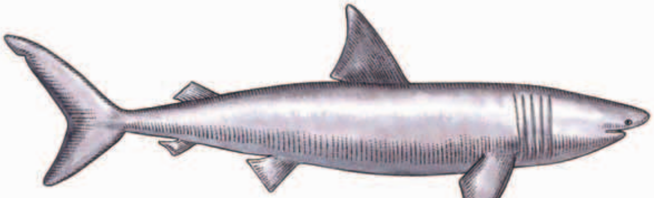
FEATURES OF A LAMPREY’S HEAD



EXTERNAL FEATURES OF A LAMPREY

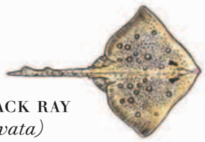


EXAMPLES OF CARTILAGINOUS FISH

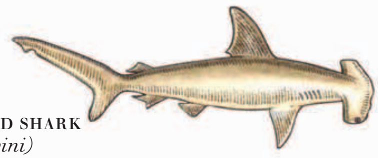


BASKING SHARK
(Cetorhinus maximus)

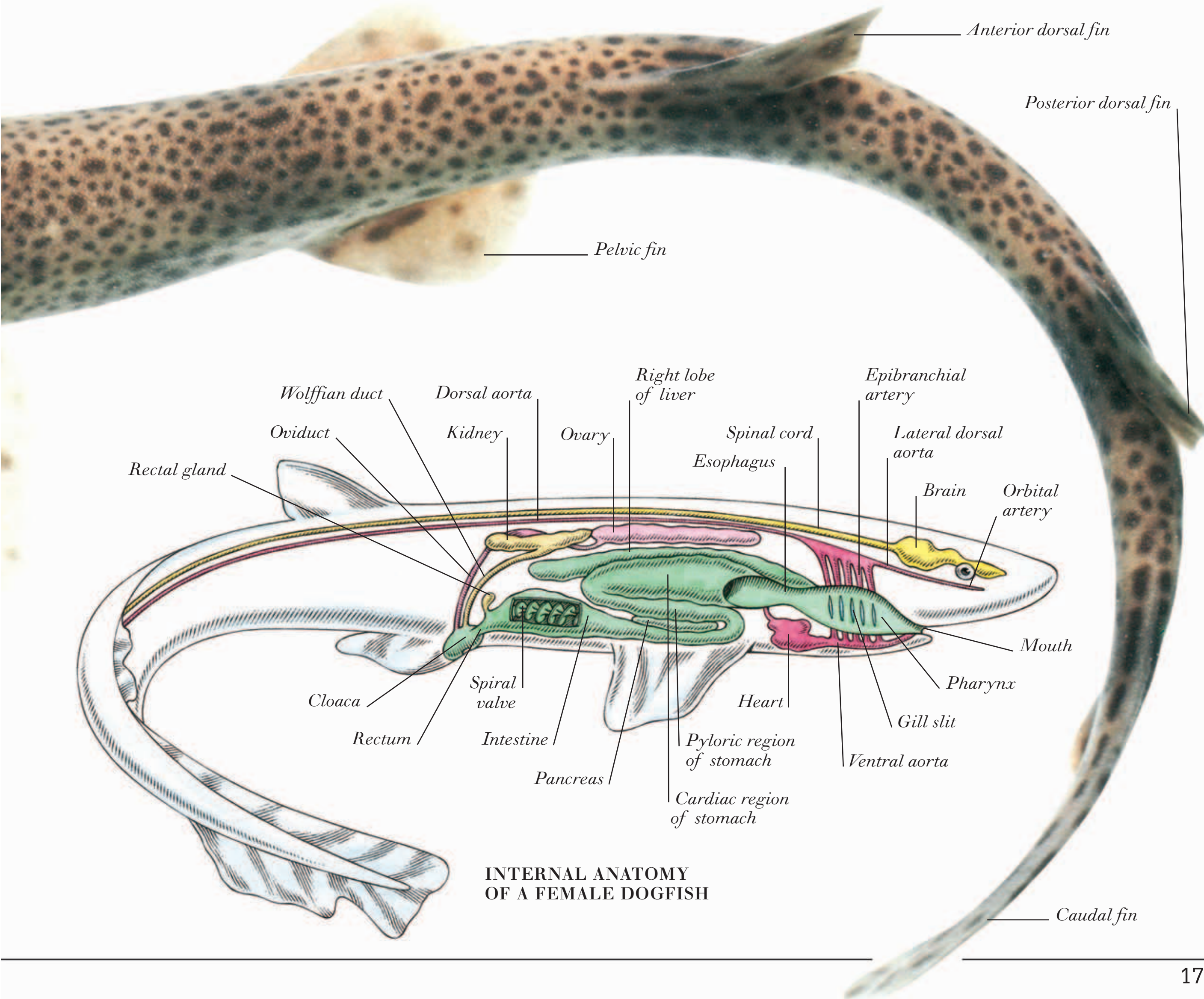
TIGER SHARK
(Galeocerdo cuvier)



THORNBACK RAY
(Raja clavata)



SCALLOPED
HAMMERHEAD SHARK
(Sphyrna lewini)



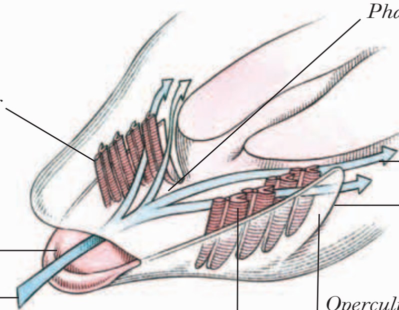
INTERNAL ANATOMY
OF A FEMALE DOGFISH

Bony fish

Bony fish, such as carp, trout, salmon, perch, and cod, are by far the best known and largest group of fish, with more than 20,000 species (over 95 percent of all known fish). As their name suggests, bony fish have skeletons made of bone, in contrast to the cartilaginous skeletons of sharks, jawless fish, and their relatives (see pp. 178-179). Other typical features of bony fish include a swim bladder, which functions as a variable-buoyancy organ, enabling a fish to remain effortlessly at whatever depth it is swimming; relatively thin, bonelike scales; a flap (called an operculum) covering the gills; and paired pelvic and pectoral fins. Scientifically, bony fish belong to the class Osteichthyes, which is a division of the superclass Gnathostomata (meaning "jawed mouths").

HOW FISH BREATHE

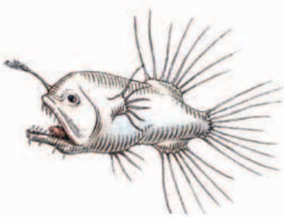
Fish "breathe" by extracting oxygen from water through their gills. Water is sucked in through the mouth; simultaneously, the opercula close to prevent the water from escaping. The mouth is then closed, and muscles in the walls of the mouth, pharynx, and opercular cavity contract to pump the water inside over the gills and out through the opercula. Some fish rely on swimming with their mouths open to keep water flowing over the gills.



EXAMPLES OF BONY FISH

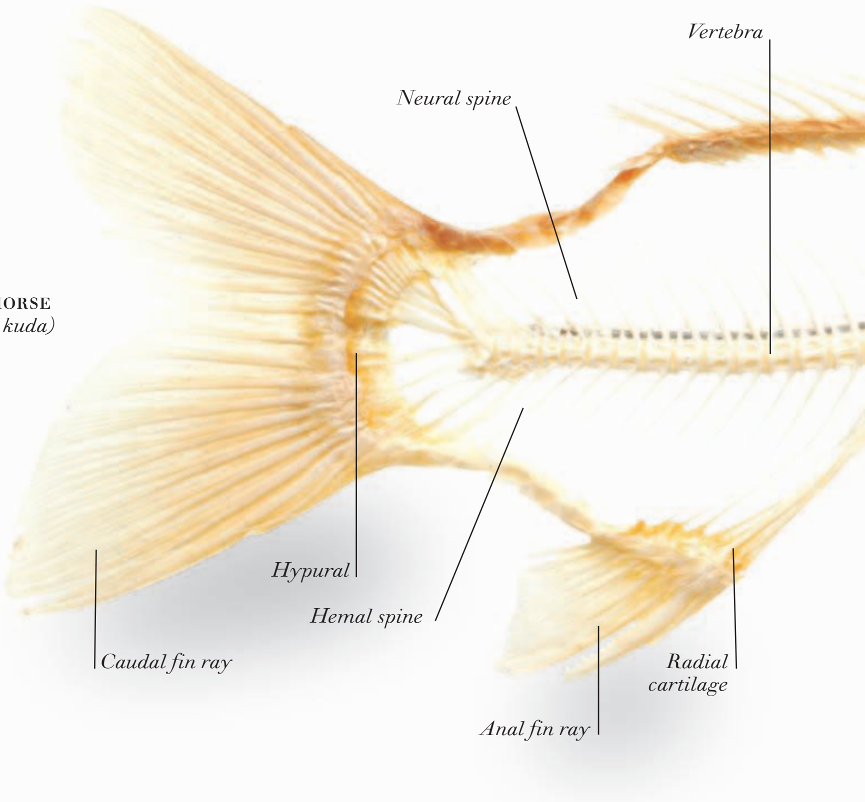
MANDARINFISH
(Synchiropus splendidus)

OCEANIC SEAHORSE
(Hippocampus kuda)



ANGLERFISH
(Caulophryne jordani)

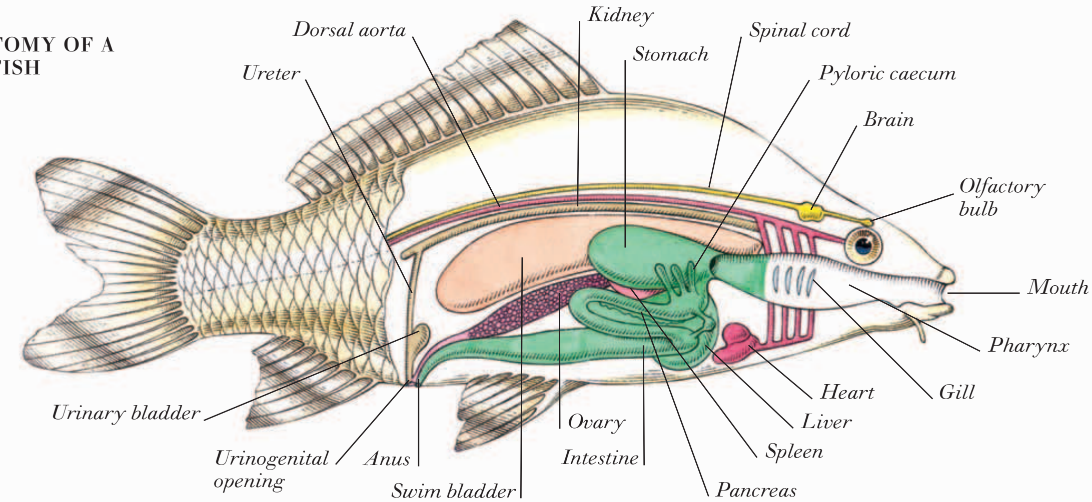
LIONFISH
(Pterois volitans)



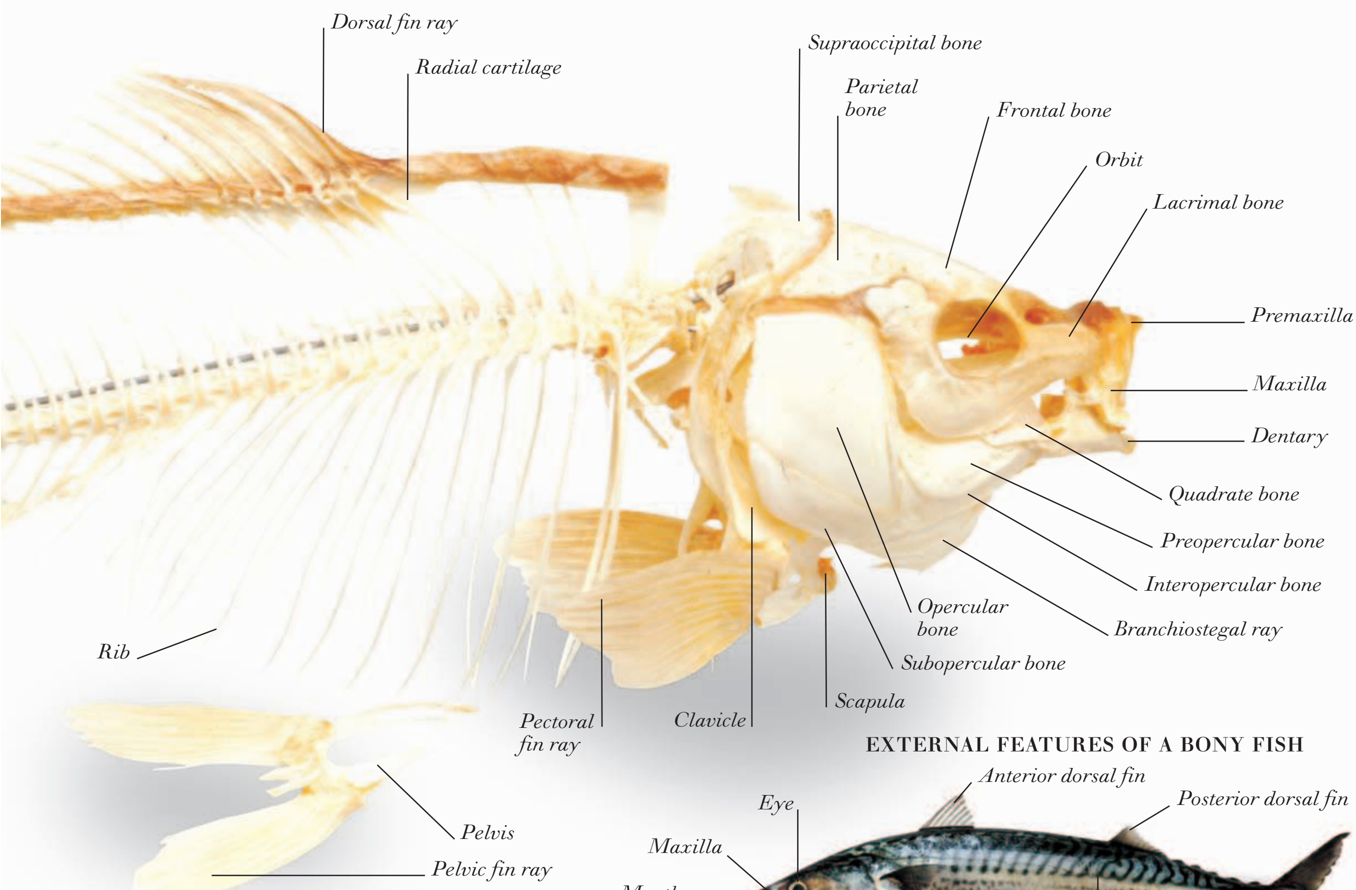
STURGEON
(Acipenser sturio)

SNOWFLAKE MORAY EEL
(Echidna nebulosa)

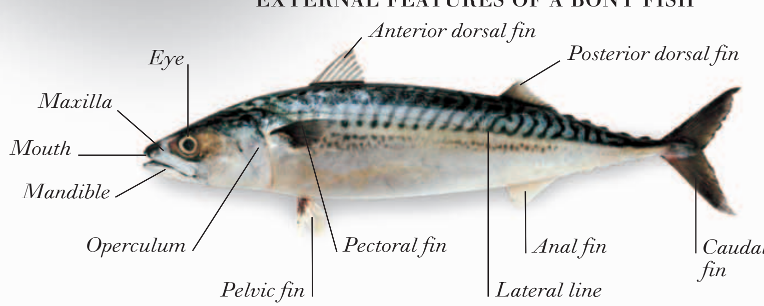
INTERNAL ANATOMY OF A FEMALE BONY FISH



SKELETON OF A BONY FISH



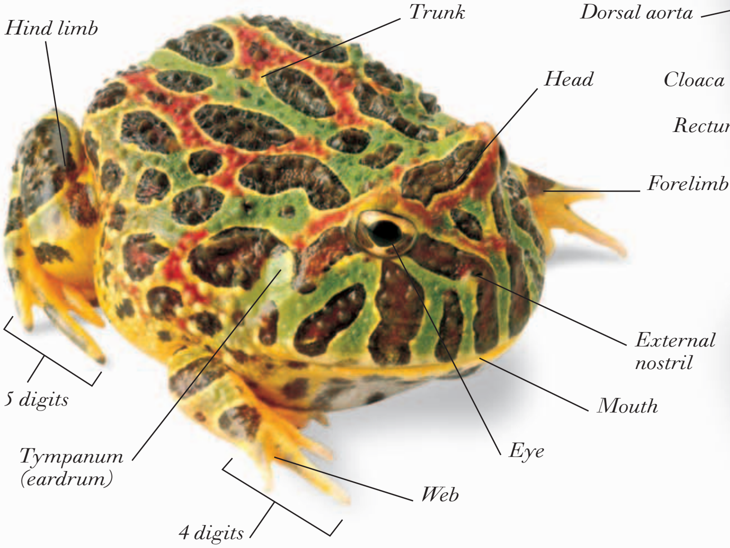
EXTERNAL FEATURES OF A BONY FISH



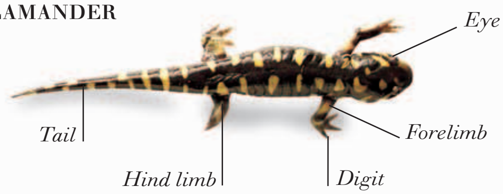
Amphibians

THE CLASS AMPHIBIA INCLUDES FROGS and toads (which make up the order Anura), and newts and salamanders (which make up the order Urodela). Amphibians typically have moist, scaleless, hairless skin; lungs; and are cold-blooded. They also undergo complete metamorphosis, from eggs laid in water through various water-living larval stages (such as tadpoles) to land-living adults. Typical features of adult frogs and toads include a squat body with no tail; long, powerful hind legs; and large, often bulging, eyes. Adult newts and salamanders typically have a long body with a well-developed tail; and relatively short, equal-sized legs. However, newts and salamanders show considerable variation; for example, in some species the adults have minute legs, external gills rather than lungs, and spend their entire lives in water.

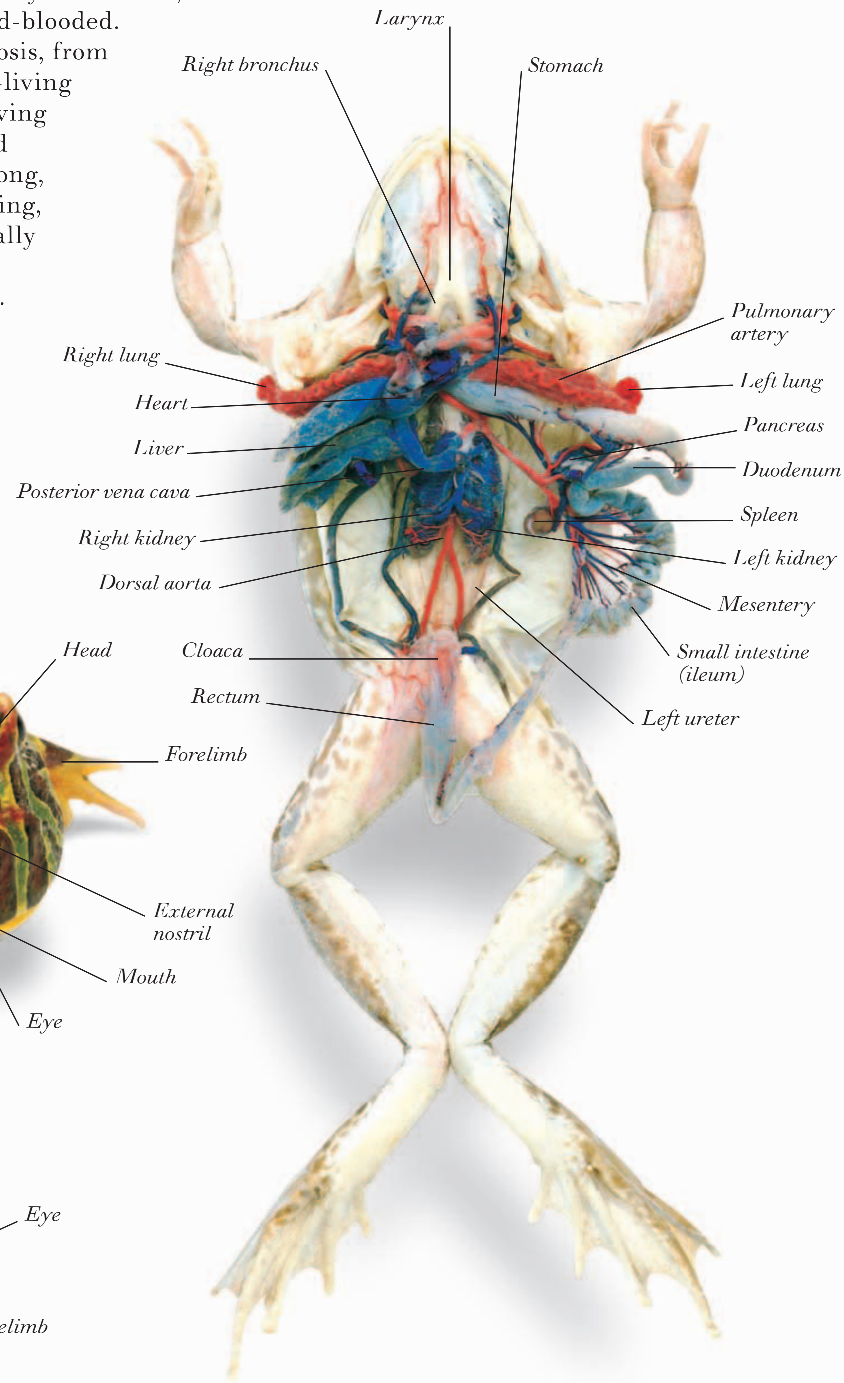
EXTERNAL FEATURES OF A FROG



EXTERNAL FEATURES OF A SALAMANDER



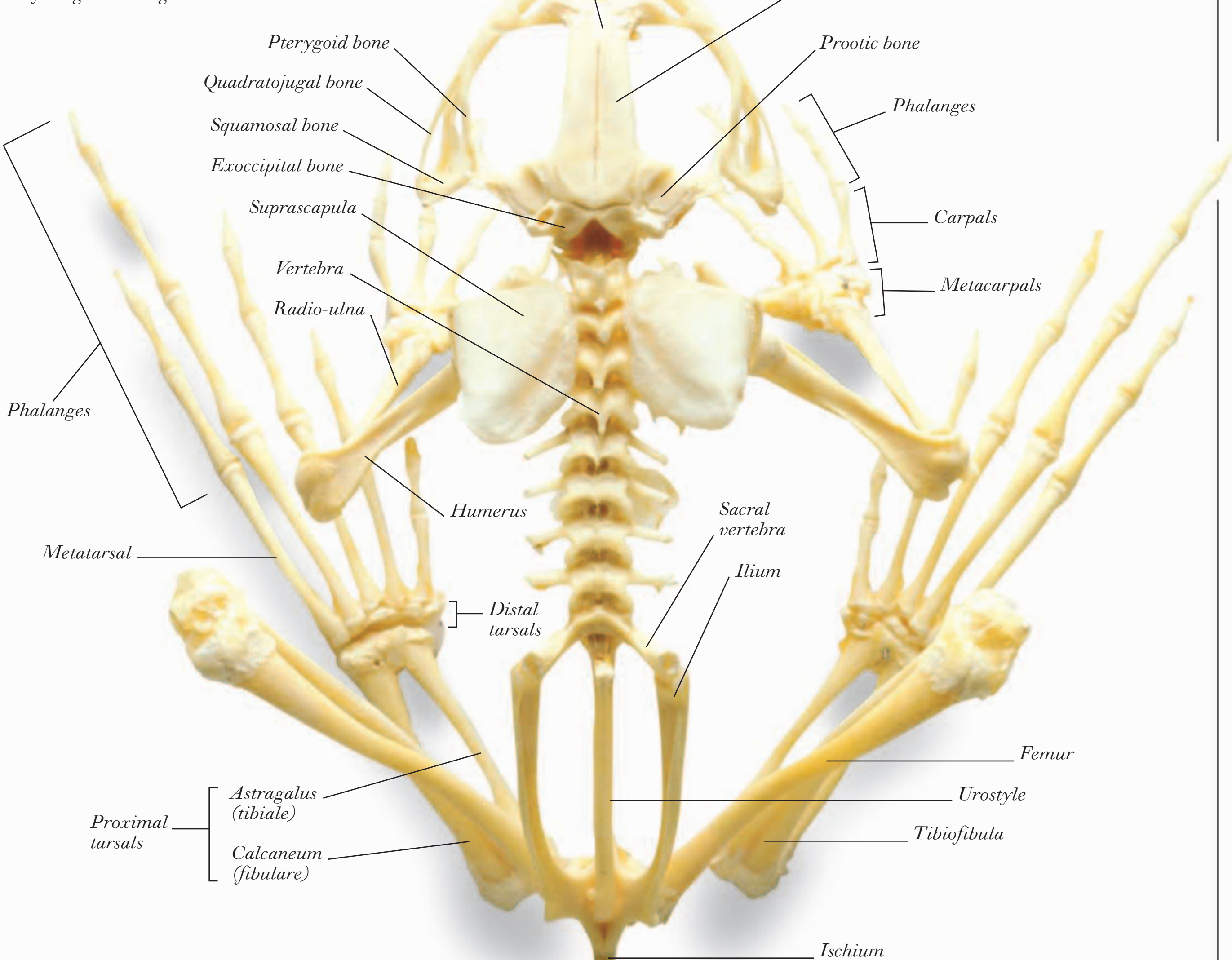
INTERNAL ANATOMY OF A FEMALE FROG



EGGS (SPAWN) YOUNG TADPOLES MATURE TADPOLE YOUNG FROG

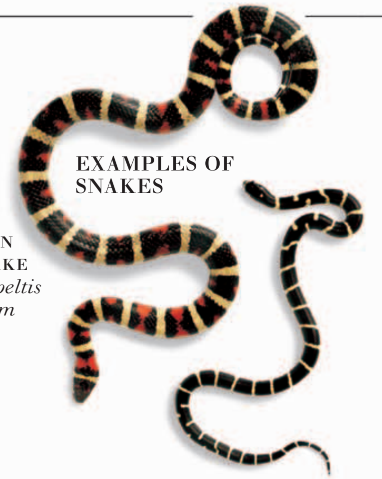
METAMORPHOSIS OF FROGS
Frogs undergo complete metamorphosis. Eggs (spawn) are laid in water and hatch into young tadpoles, which have a tail and external gills but no legs. As the tadpoles grow, the gills disappear, back legs develop, then front legs, and the tail shrinks. Eventually the tail disappears, resulting in a young adult frog.

SKELETON OF A FROG

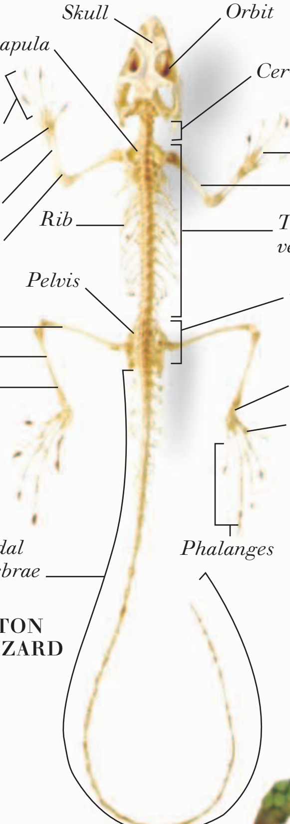


Lizards and snakes

LIZARDS AND SNAKES BELONG to the order Squamata, a division of the class Reptilia. Characteristic reptilian features include scaly skin, lungs, and cold-bloodedness. Most reptiles lay leathery-shelled eggs, although some hatch the eggs inside their bodies and give birth to live young. Lizards belong to the suborder Lacertilia. Typically, they have long tails, and shed their skin in several pieces. Many lizards can regenerate a tail if it is lost; some can change color; and some are limbless. Snakes make up the suborder Ophidia (also called Serpentes). All snakes have long, limbless bodies; can dislocate their lower jaw to swallow large prey; and have eyelids that are joined together to form a single transparent covering over the front of the eye. Most snakes shed their skin in a single piece. Constrictor snakes kill their prey by squeezing; venomous snakes poison their prey.



EXAMPLES OF SNAKES

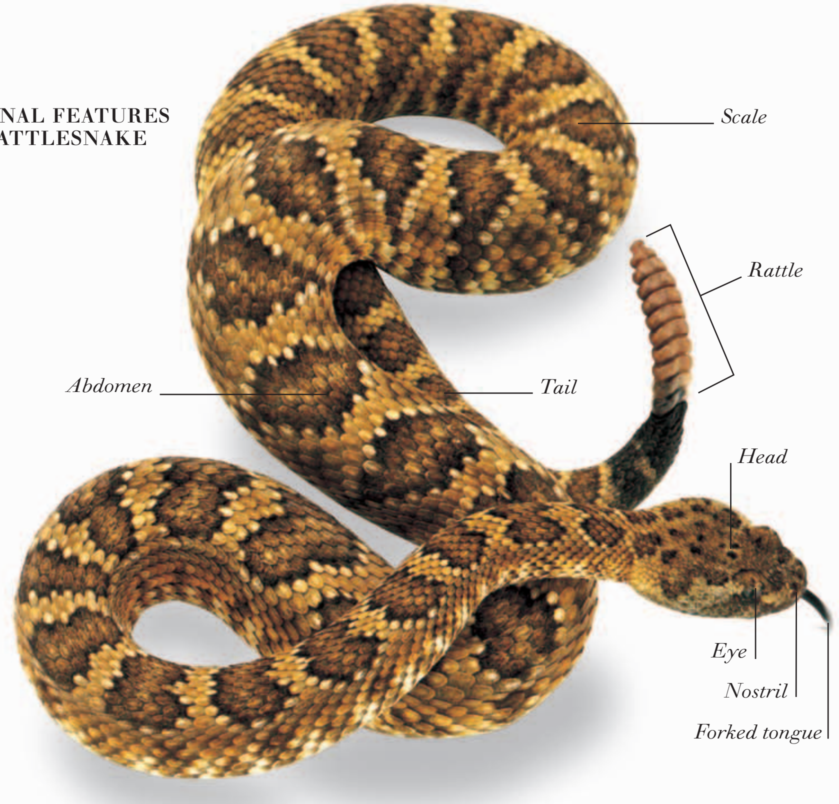


SKELETON OF A LIZARD

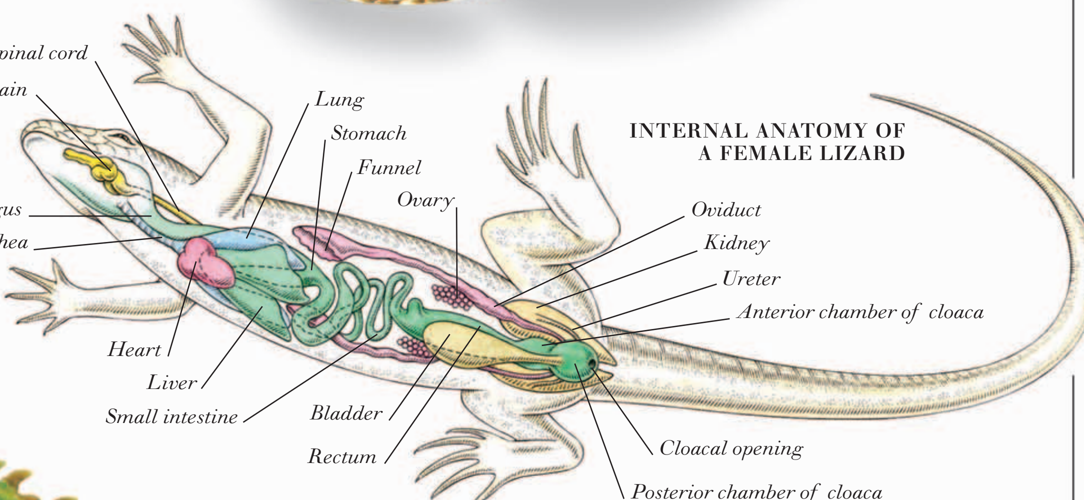
EXTERNAL FEATURES OF A LIZARD

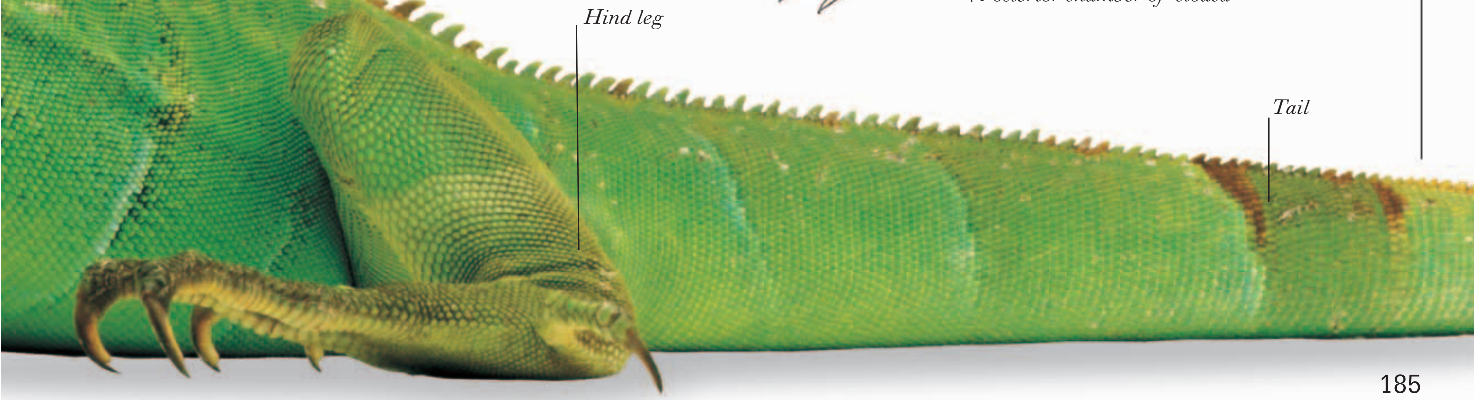
SKELETON OF A SNAKE

EXTERNAL FEATURES OF A RATTLESNAKE



INTERNAL ANATOMY OF A FEMALE LIZARD





Crocodilians and turtles

CROCODILIANS AND TURTLES BELONG to different orders in the class Reptilia. The order Crocodilia includes crocodiles, alligators, caimans, and gharials. Typically, crocodilians are carnivores (flesh-eaters), and have a long snout, sharp teeth for gripping prey, and hard, square scales. All crocodilians are adapted to living on land and in water: they have four strong legs for moving on land; a powerful tail for swimming; and their eyes and nostrils are high on the head so that they stay above water while the rest of the body is submerged. The order Chelonia includes marine turtles, terrapins (freshwater turtles), and tortoises (land turtles). Characteristically, chelonians have a short, broad body encased in a bony shell with an outer horny covering, into which the head and limbs can be withdrawn; and a horny beak instead of teeth.

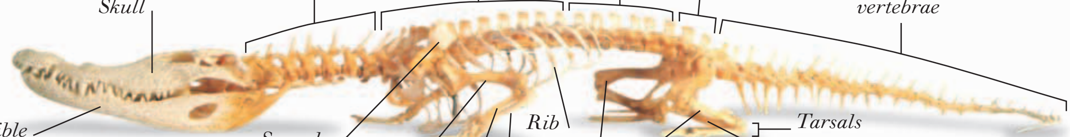
SKULLS OF CROCODILIANS

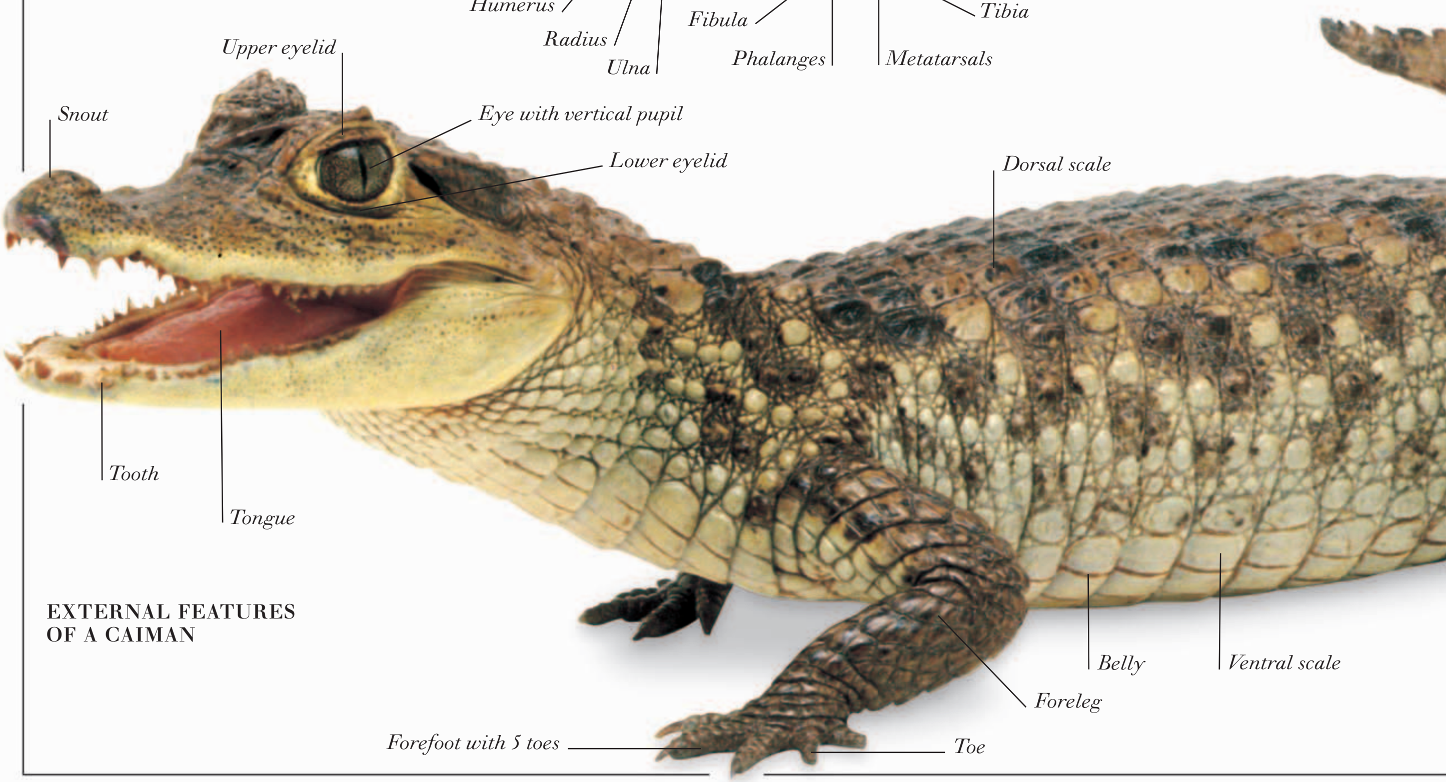
GHARIAL
(Gavialis gangeticus)

NILE CROCODILE
(Crocodylus niloticus)

AMERICAN ALLIGATOR
(Alligator mississippiensis)

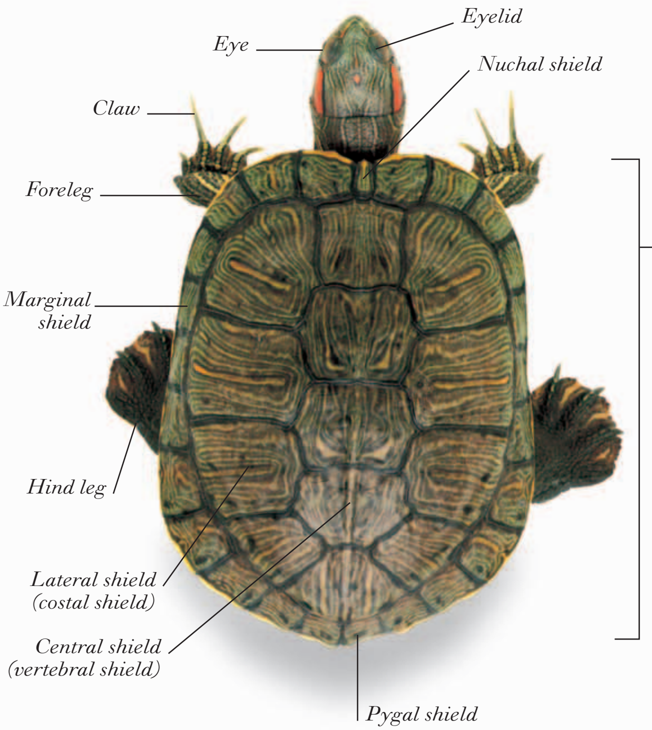
SKELETON OF A CROCODILE



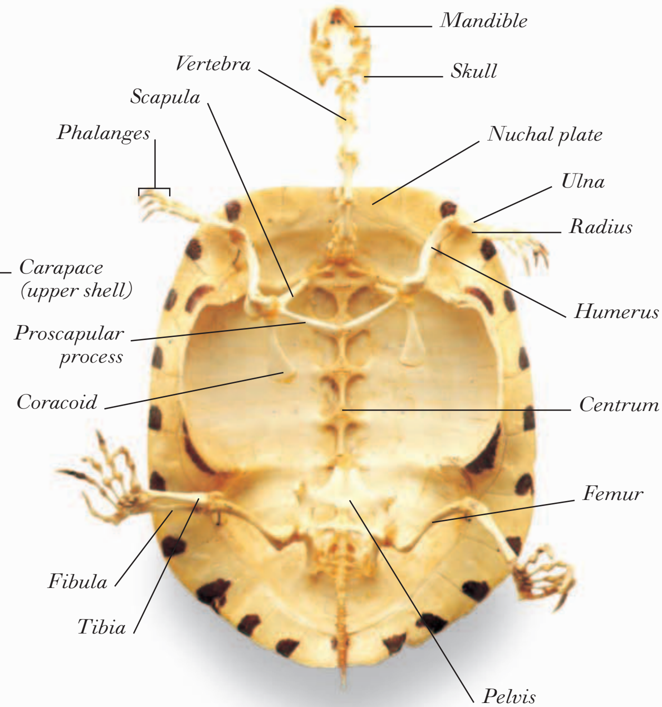


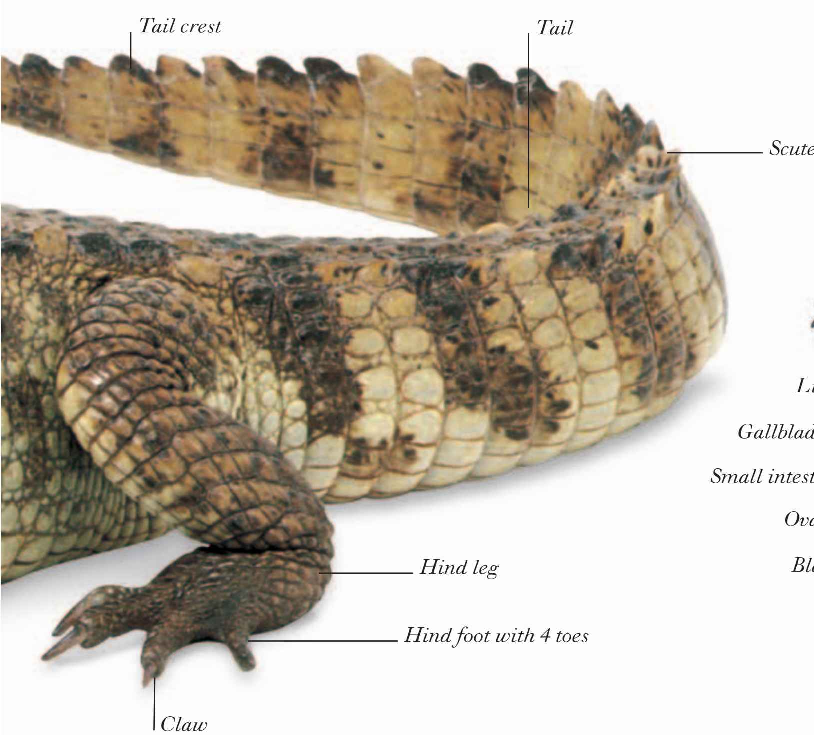
EXTERNAL FEATURES OF A CAIMAN

EXTERNAL FEATURES OF A TERRAPIN

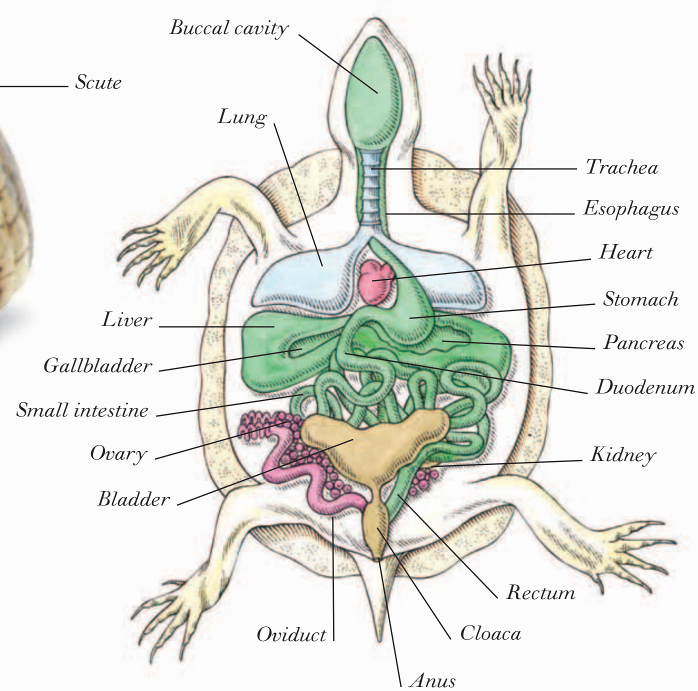


SKELETON OF A TURTLE





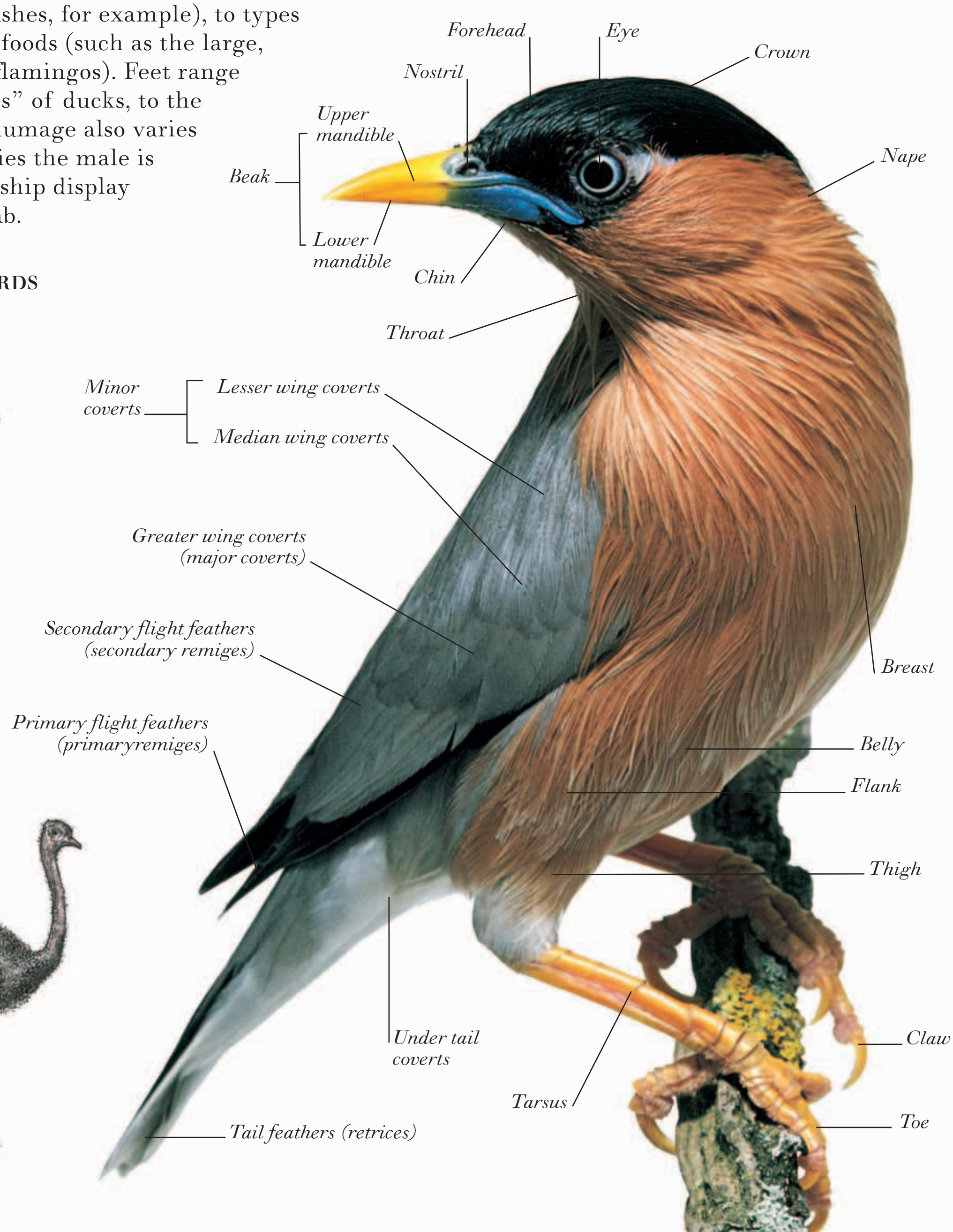
INTERNAL ANATOMY OF A FEMALE TORTOISE



Birds 1

BIRDS MAKE UP THE CLASS AVES. There are more than 9,000 species, almost all of which can fly (the only flightless birds are penguins, ostriches, rheas, cassowaries, and kiwis). The ability to fly is reflected in the typical bird features: forelimbs modified as wings; a streamlined body; and hollow bones to reduce weight. All birds lay hard-shelled eggs, which the parents incubate. Birds' beaks and feet vary according to diet and way of life. Beaks range from general-purpose types suitable for a mixed diet (those of thrushes, for example), to types specialized for particular foods (such as the large, curved, sieving beaks of flamingos). Feet range from the webbed "paddles" of ducks, to the talons of birds of prey. Plumage also varies widely, and in many species the male is brightly colored for courtship display whereas the female is drab.

EXTERNAL FEATURES OF A BIRD



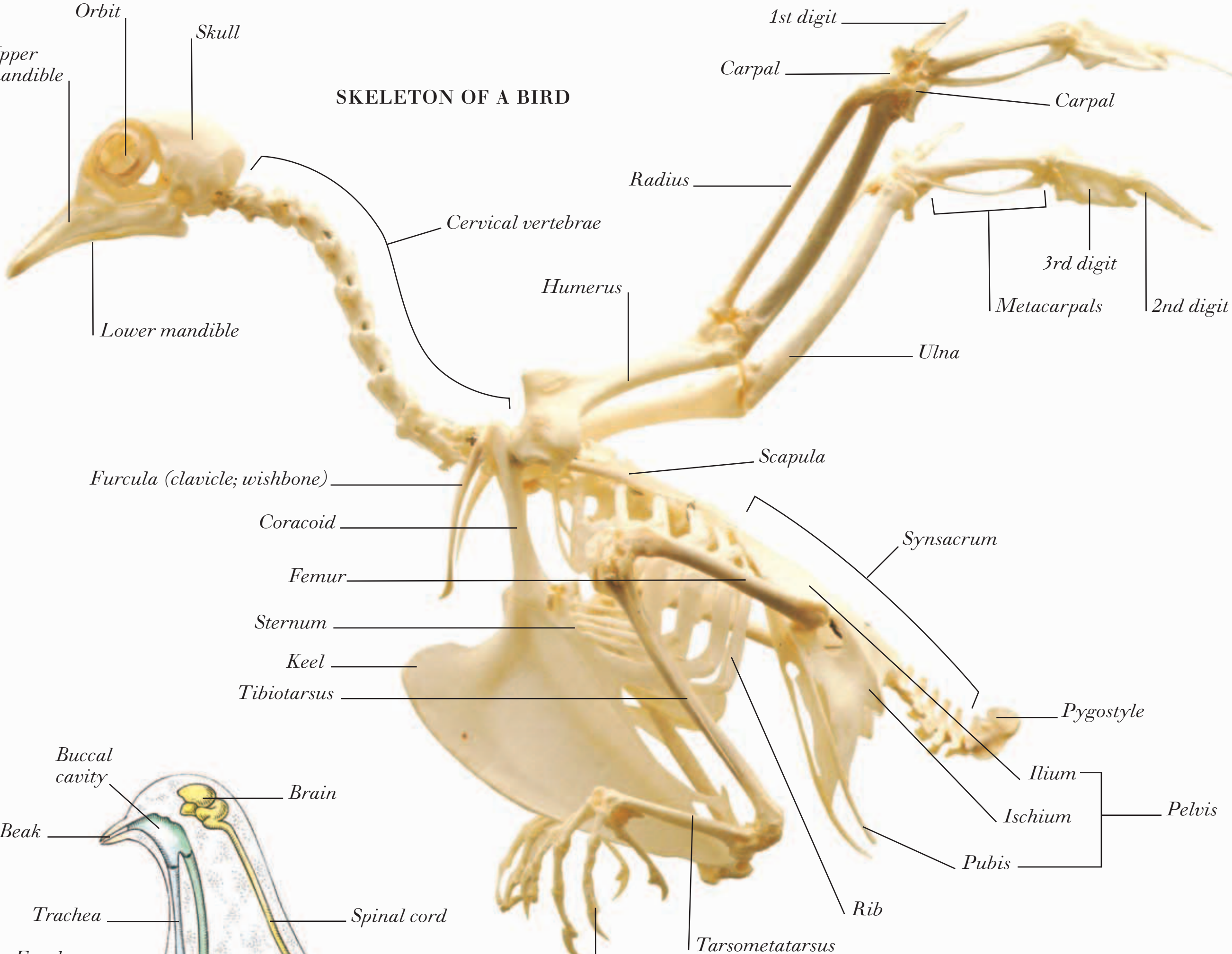
EXAMPLES OF BIRDS

MALE TUFTED DUCK
(Aythya fuligula)

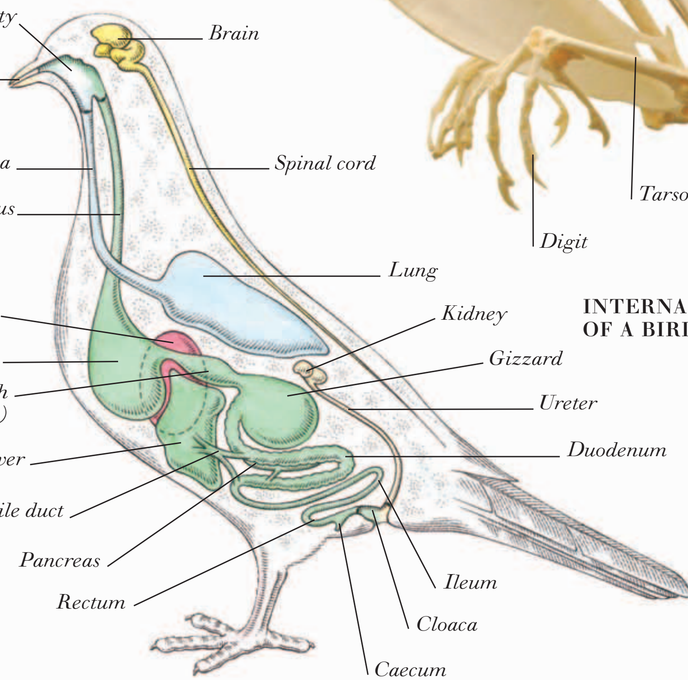
WHITE STORK
(Ciconia ciconia)

MALE OSTRICH
(Struthio camelus)

SKELETON OF A BIRD



INTERNAL ANATOMY OF A BIRD

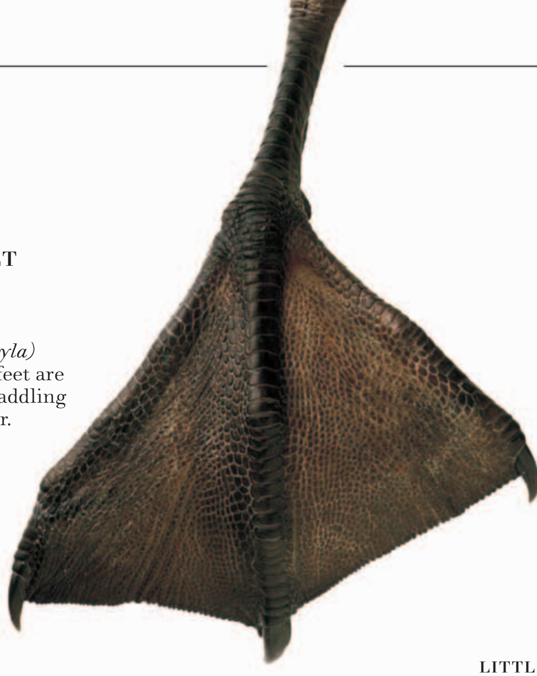


MALE KESTREL
(Falco tinnunculus)

COMMON BLACKHEADED GULL
(Larus ridibundus)

Birds 2

EXAMPLES OF BIRDS' FEET



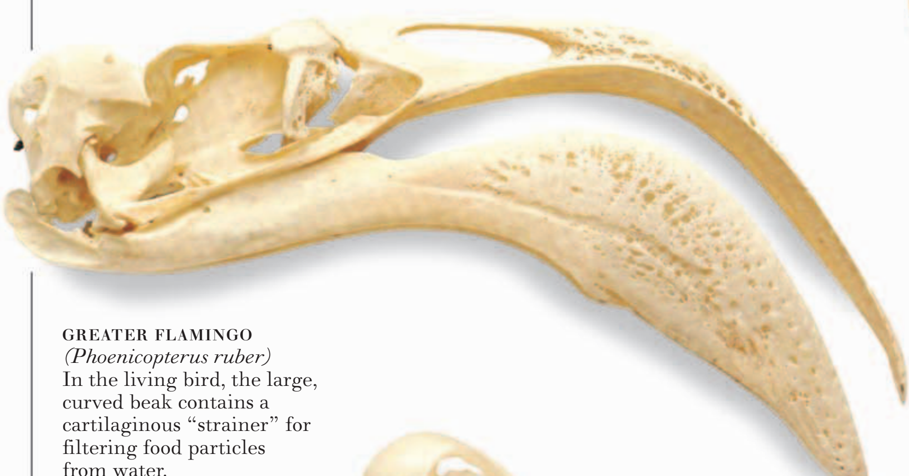
KITTIWAKE
(Rissa tridactyla)
The webbed feet are adapted for paddling through water.

LITTLE GREBE
(Tachybaptus ruficollis)
The lobed, flattened feet are adapted for swimming underwater.

TAWNY OWL
(Strix aluco)
The clawed feet are adapted for gripping prey.

EXAMPLES OF BIRDS' BEAKS

KING VULTURE
(Sarcorhamphus papa)
The hooked beak is adapted for pulling apart flesh.

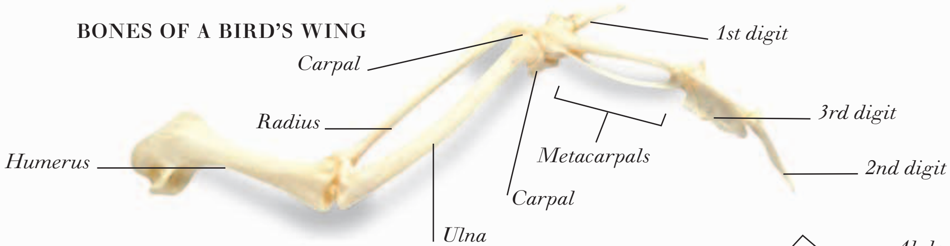


GREATER FLAMINGO
(Phoenicopterus ruber)
In the living bird, the large, curved beak contains a cartilaginous "strainer" for filtering food particles from water.

MISTLE THRUSH
(Turdus viscivorus)
The general-purpose beak is suitable for a wide range of animal and plant foods.

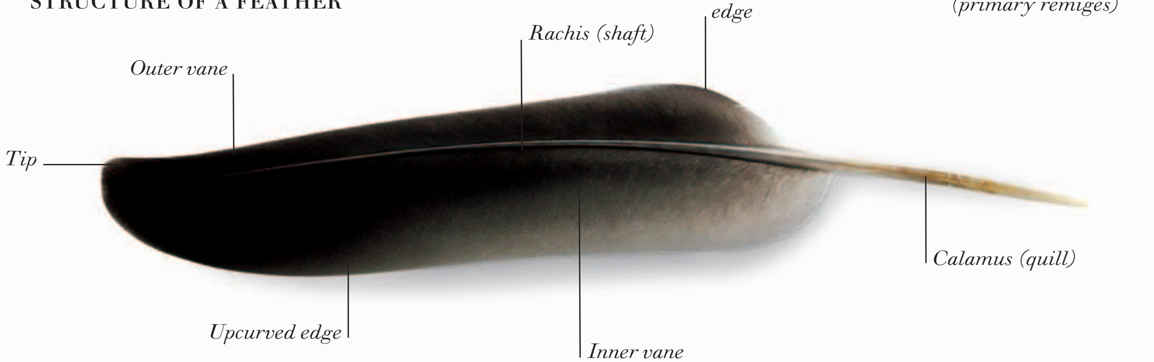
BLUE-AND-YELLOW MACAW
(Ara ararauna)
The broad, powerful, hooked beak is adapted for crushing seeds and eating fruit.

BONES OF A BIRD'S WING



FEATHERS OF A BIRD'S WING

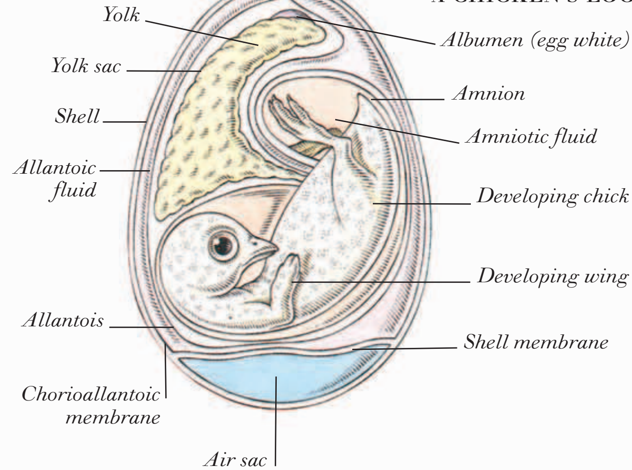
STRUCTURE OF A FEATHER



Eggs

AN EGG IS A SINGLE CELL, produced by the female, with the capacity to develop into a new individual. Development may take place inside the mother's body (as in most mammals) or outside, in which case the egg has a protective covering such as a shell. Egg yolk nourishes the growing young. Eggs developing inside the mother generally have little yolk, because the young are nourished from her body. Eggs developing outside may also have little yolk if they are produced by animals whose young go through a larval stage (such as a caterpillar) that feeds itself while developing into the adult form. The shelled eggs of birds and reptiles contain enough yolk to sustain the young until it hatches into a juvenile version of the adult.

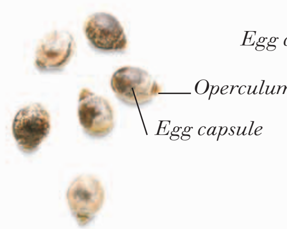
SECTION THROUGH A CHICKEN'S EGG



VARIETY OF EGGS

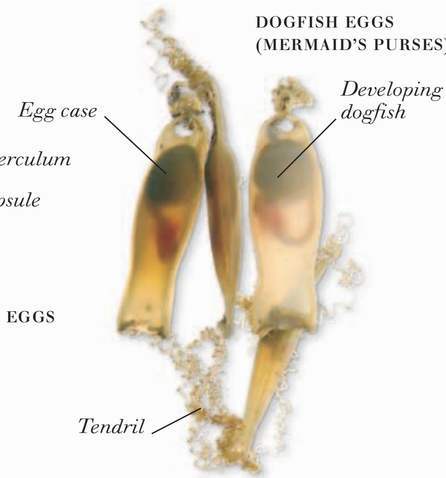
GIANT STICK INSECT EGGS

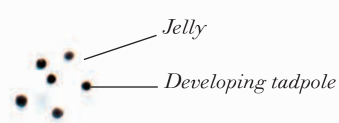
LEAF INSECT EGGS



INDIAN STICK INSECT EGGS

DOGFISH EGGS (MERMAID'S PURSES)

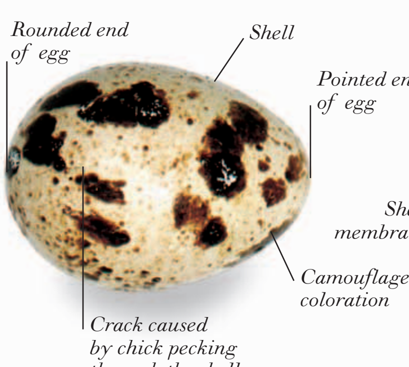




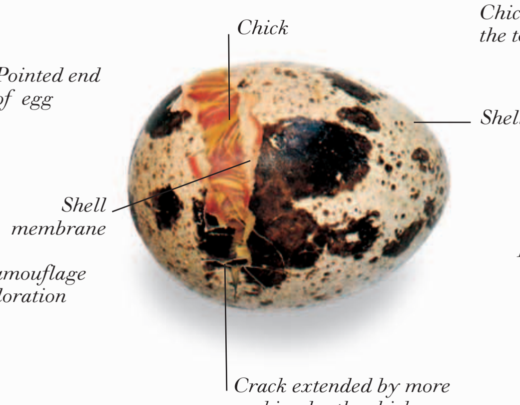
FROG EGGS (FROG SPAWN)

HATCHING OF A QUAIL'S EGG

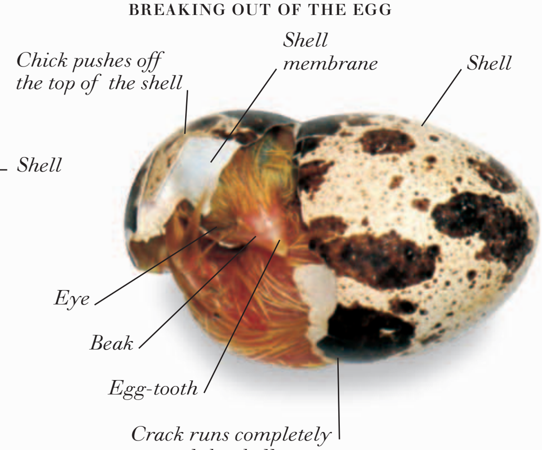
EGG AT THE POINT OF HATCHING



CUTTING THROUGH THE EGG



BREAKING OUT OF THE EGG



EXAMPLES OF BIRDS' EGGS

GREATER BLACKBACKED GULL
(Larus marinus)

BEE HUMMINGBIRD
(Calypte helenae)

OSTRICH
(Struthio camelus)

BALTIMORE ORIOLE
(Icterus galbula)

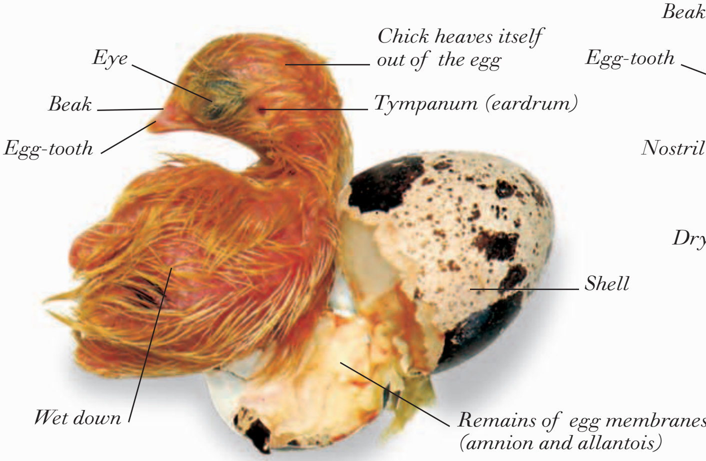
WILLOW GROUSE
(Lagopus lagopus)

COMMON TERN
(Sterna hirundo)

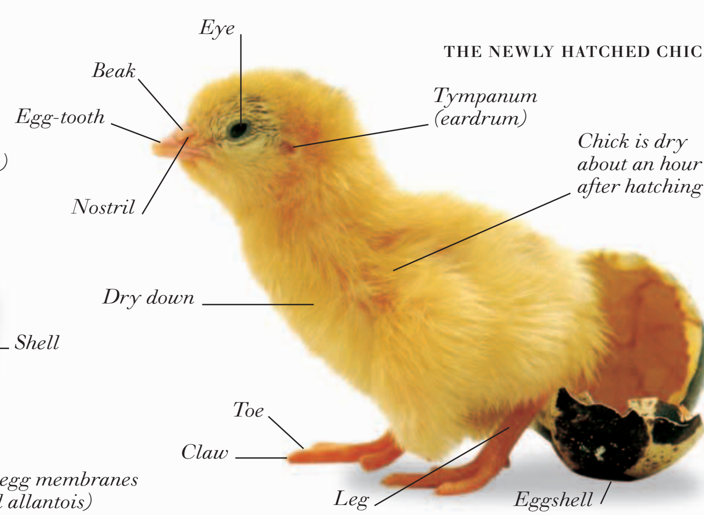
CARRION CROW
(Corvus corone)

CHAFFINCH
(Fringilla coelebs)

EMERGING FROM THE EGG



THE NEWLY HATCHED CHICK

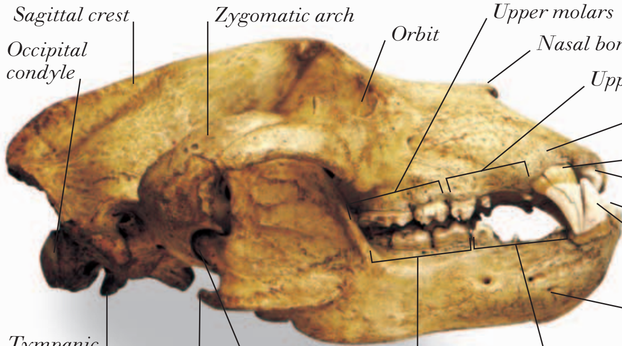


Carnivores

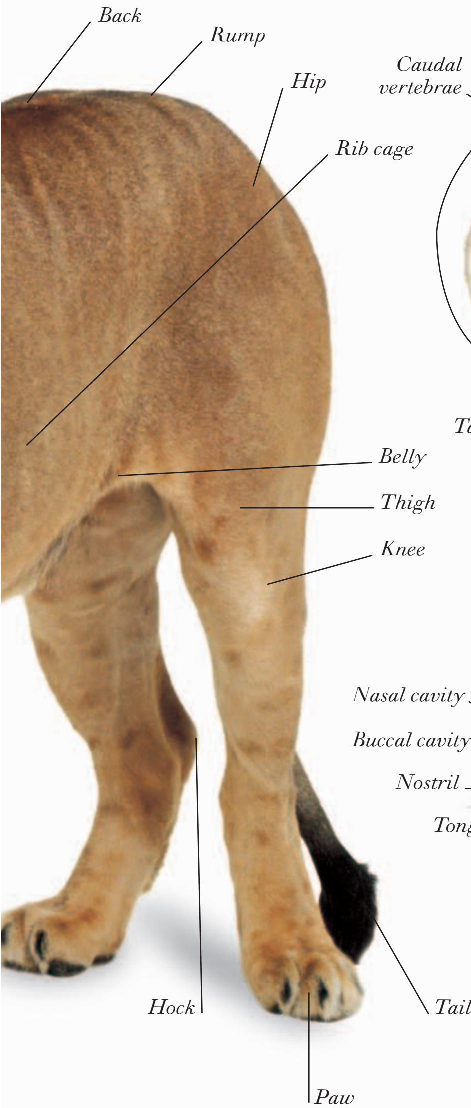
THE MAMMALIAN ORDER CARNIVORA includes cats, dogs, bears, raccoons, pandas, weasels, badgers, skunks, otters, civets, mongooses, and hyenas. The order's name is derived from the fact that most of its members are carnivores (flesh-eaters). Typical carnivore features therefore reflect a hunting life-style: speed and agility; sharp claws and well-developed canine teeth for holding and killing prey; carnassial teeth (cheek teeth) for cutting flesh; and forward-facing eyes for good distance judgment. However, some members of the order—bears, badgers, and foxes, for example—have a more mixed diet, and a few are entirely herbivorous (plant-eating), notably pandas. Such animals have no carnassial teeth and tend to be slower moving than pure flesh-eaters.

SKULL OF A LION

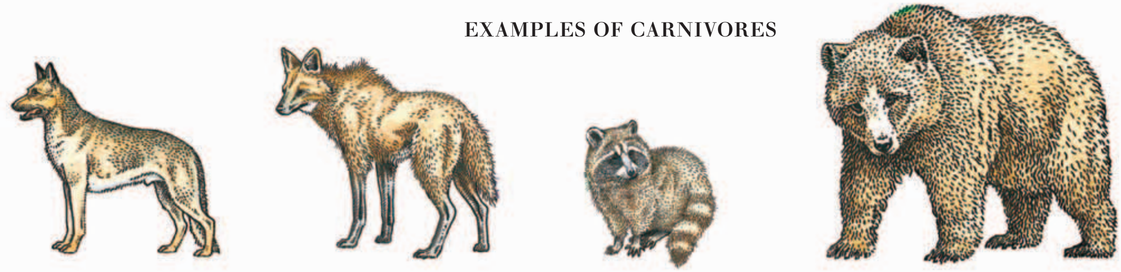
SKULL OF A BEAR



EXTERNAL FEATURES OF A MALE LION



EXAMPLES OF CARNIVORES



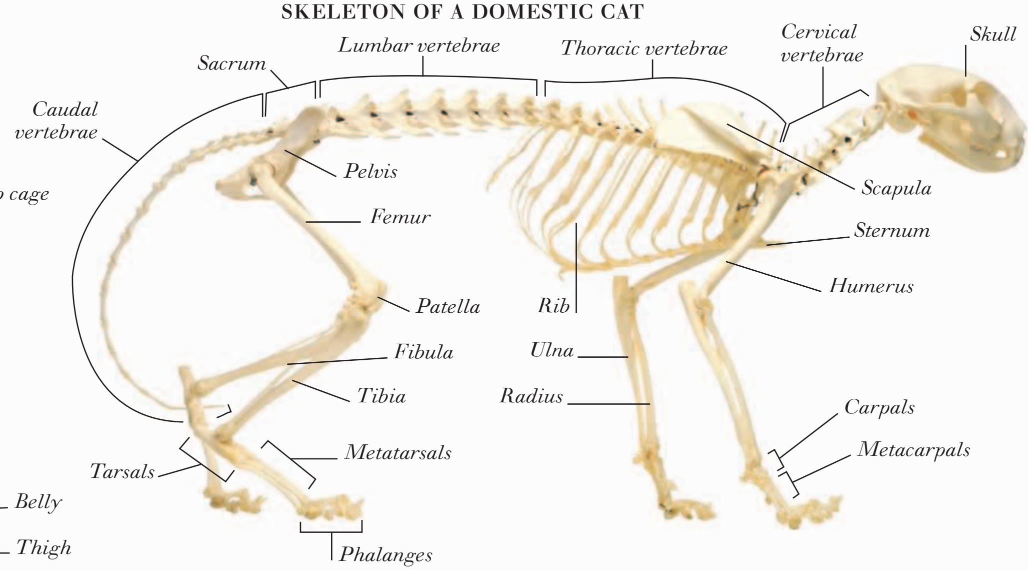
ALSATIAN DOG
(Canis familiaris)

MANED WOLF
(Chrysocyon brachyurus)

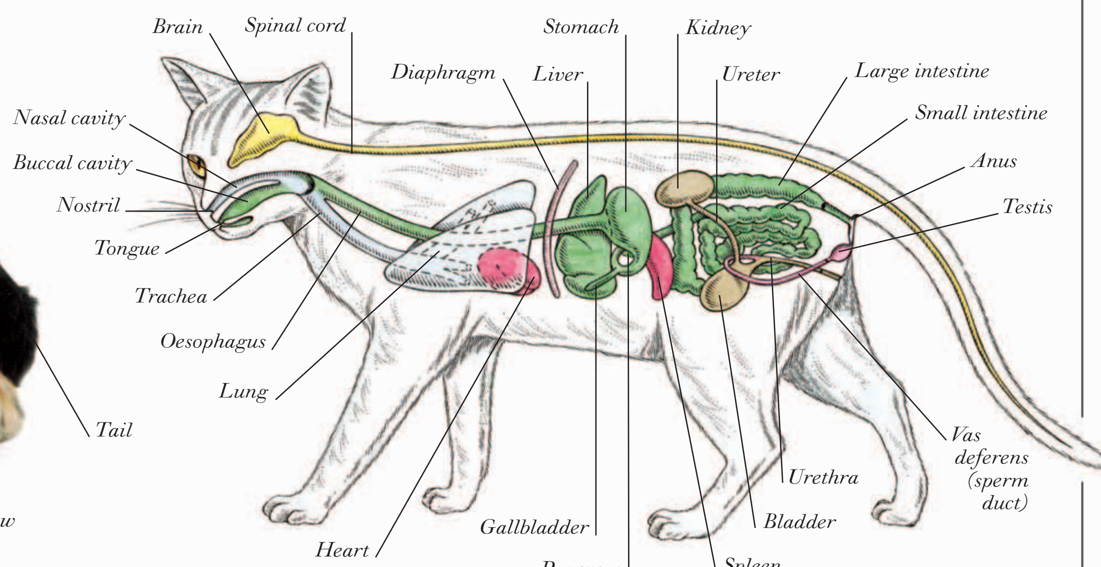
RACCOON
(Procyon lotor)

AMERICAN BLACK BEAR
(Ursus americanus)

SKELETON OF A DOMESTIC CAT



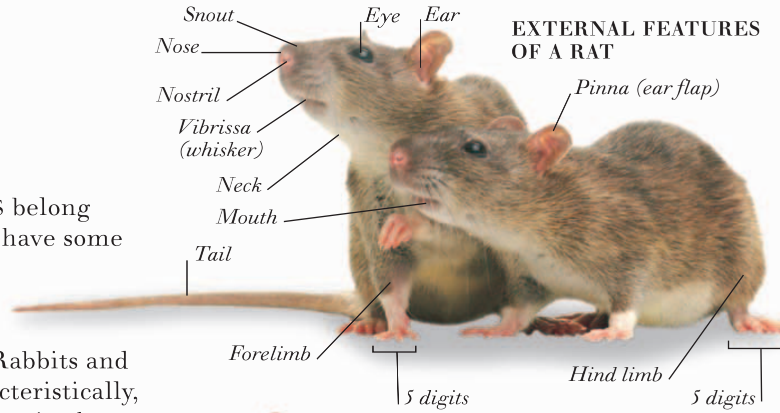
INTERNAL ANATOMY OF A MALE DOMESTIC CAT



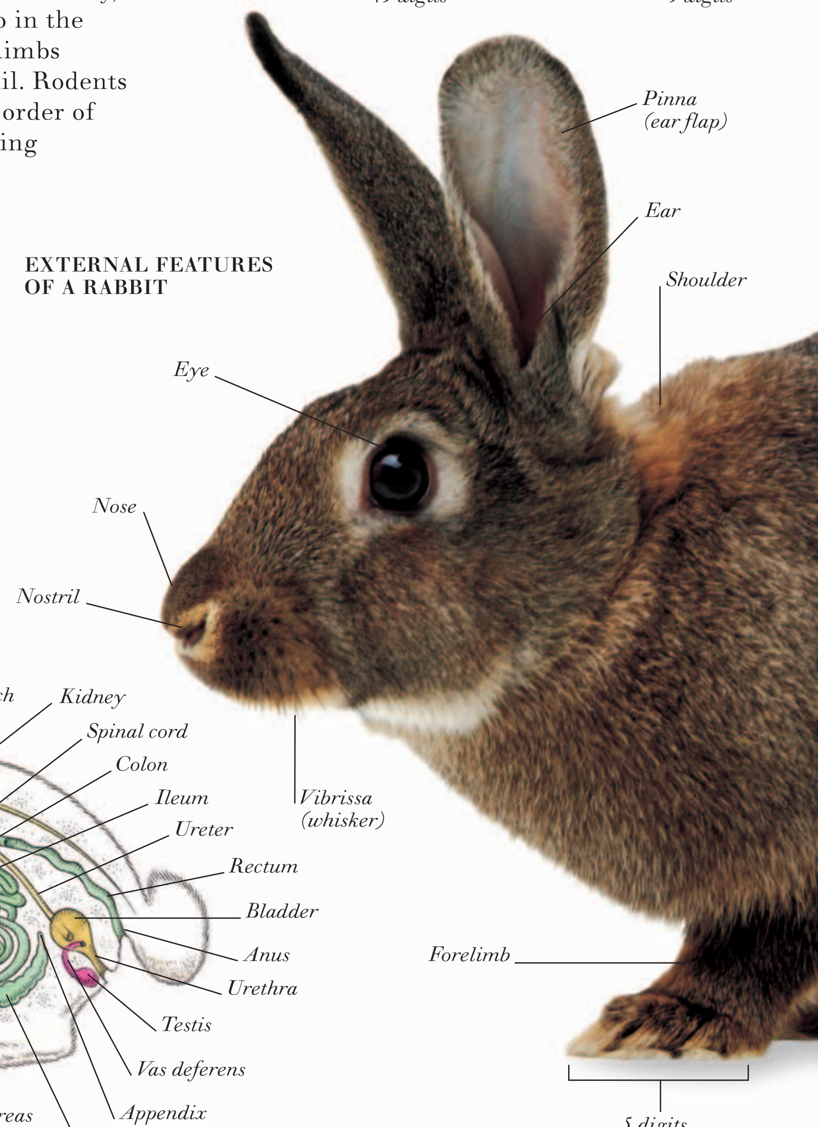
Rabbits and rodents

ALTHOUGH RABBITS AND RODENTS belong to different orders of mammals, they have some features in common. These features include chisel-shaped incisor teeth that grow continually, and eating their feces to extract more nutrients from their plant diet. Rabbits and hares belong to the order Lagomorpha. Characteristically, they have four incisors in the upper jaw and two in the lower jaw; powerful hind legs for jumping; forelimbs adapted for burrowing; long ears; and a small tail. Rodents make up the order Rodentia. This is the largest order of mammals, with more than 1,700 species, including squirrels, beavers, chipmunks, gophers, rats, mice, lemmings, gerbils, porcupines, cavies, and the capybara. Typical rodent features include two incisors in each jaw; short forelimbs for manipulating food; and cheek pouches for storing food.

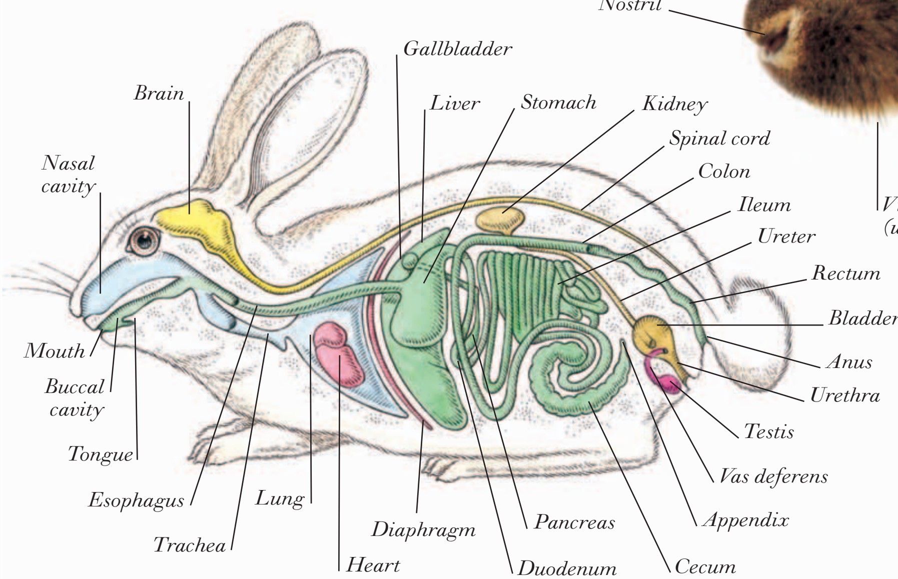
EXTERNAL FEATURES OF A RAT



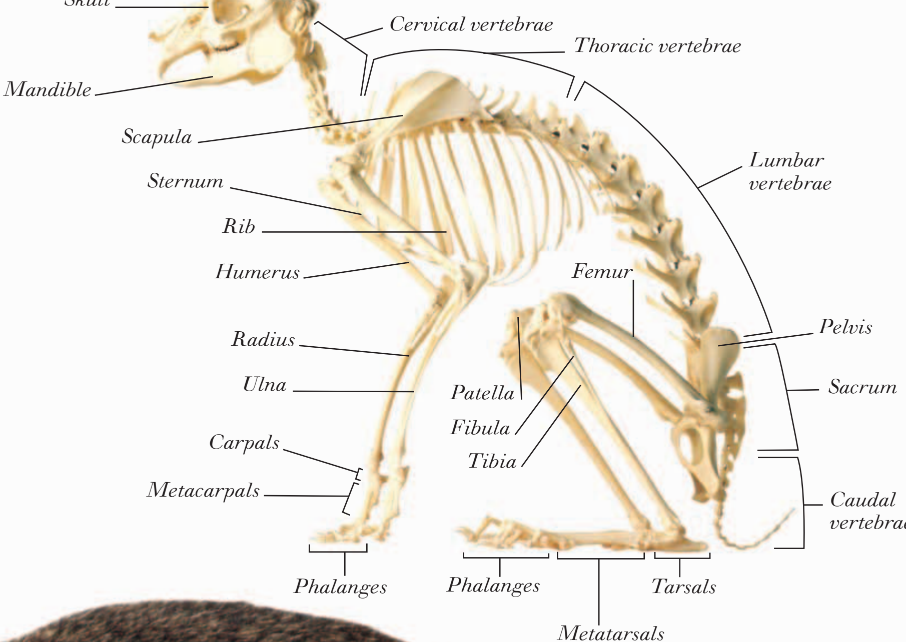
EXTERNAL FEATURES OF A RABBIT

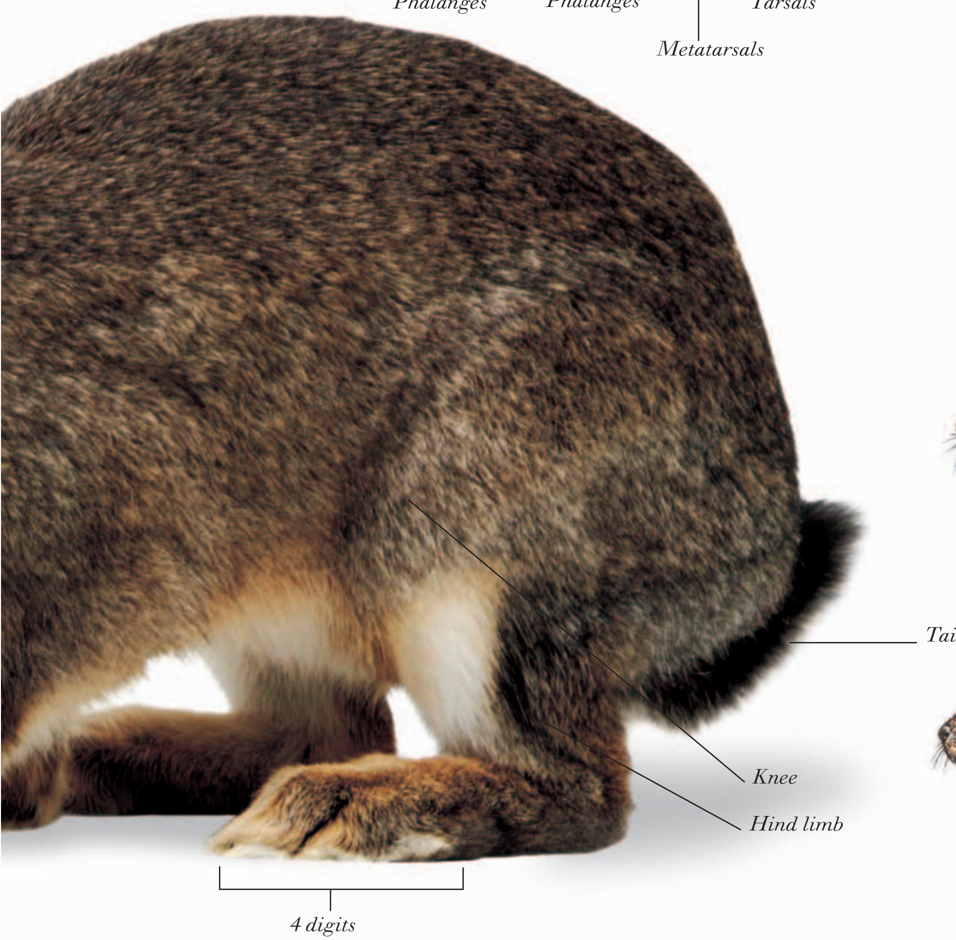


INTERNAL ANATOMY OF A MALE RABBIT



SKELETON OF A HARE





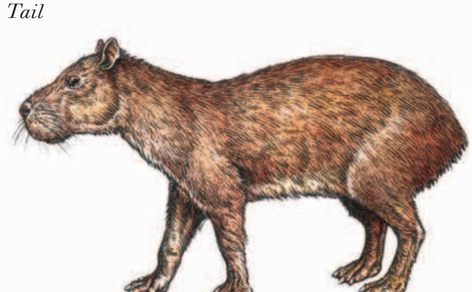
EXAMPLES OF RODENTS

GRAY SQUIRREL
(Sciuris carolinensis)

PLAINS VISCACHA
(Lagostomus maximus)

CRESTED PORCUPINE
(Hystrix africaeaustralis)

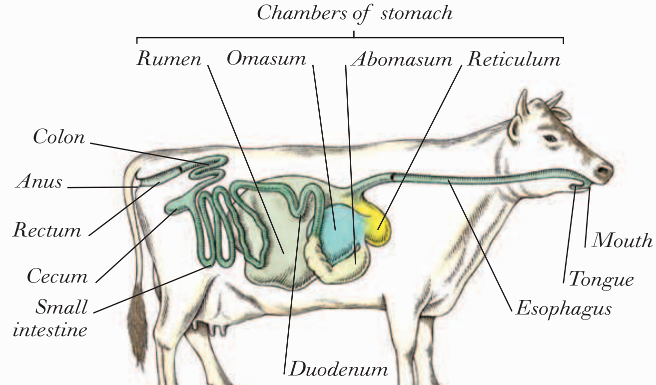
AMERICAN BEAVER
(Castor canadensis)



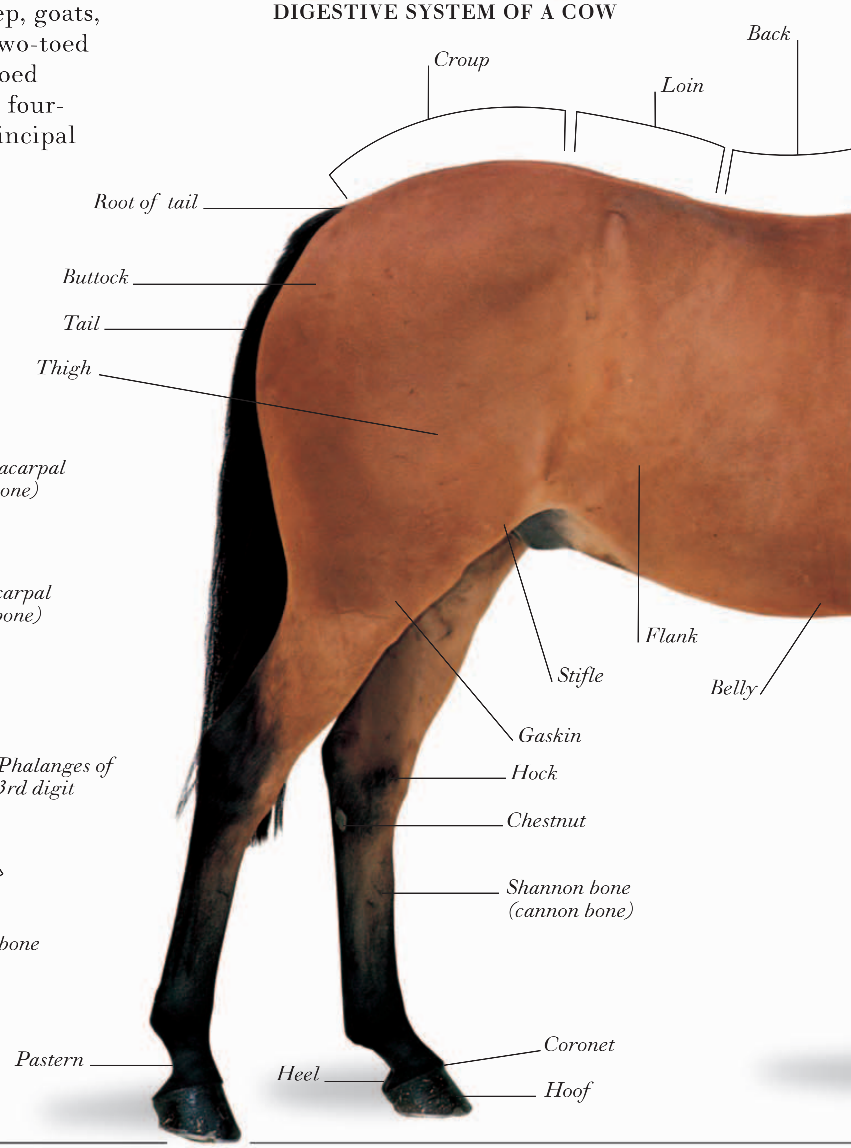
CAPYBARA
(Hydrochoerus hydrochaeris)

Ungulates

UNGULATES IS A GENERAL TERM FOR a large, varied group of mammals that includes horses, cattle, and their relatives. The ungulates are divided into two orders on the basis of the number of toes. Members of the order Perissodactyla (odd-toed ungulates) have one or three toes. Perissodactyls include horses, onagers, and zebras (all of which are one-toed), and rhinoceroses and tapirs (which are three-toed). Members of the order Artiodactyla (even-toed ungulates) have two or four toes. Most artiodactyls have two toes, which are typically encased in hooves to give the so-called cloven hoof. Two-toed, cloven-hoofed artiodactyls include cows and other cattle, sheep, goats, antelopes, deer, and giraffes. The other main two-toed artiodactyls are camels and llamas. Most two-toed artiodactyls are ruminants; that is, they have a four-chambered stomach and chew the cud. The principal four-toed artiodactyls are pigs, peccaries, and hippopotamuses.

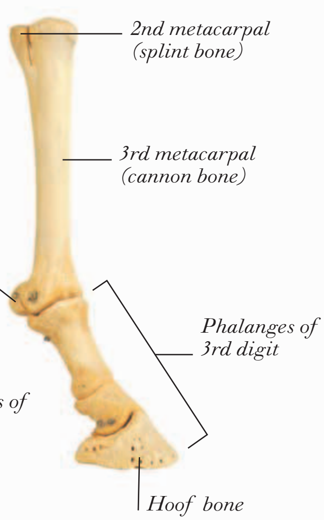


DIGESTIVE SYSTEM OF A COW

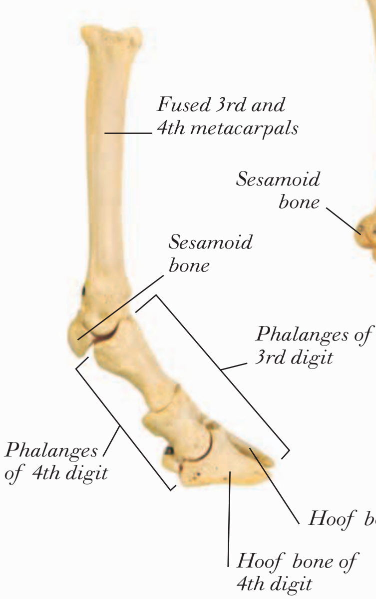


COMPARISON OF THE FRONT FEET OF A HORSE AND A COW

SKELETON OF THE LEFT FRONT FOOT OF A HORSE



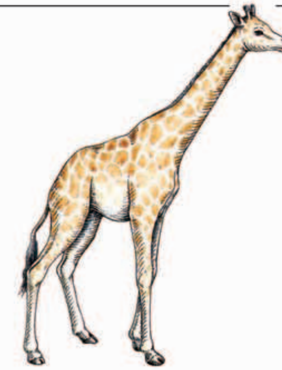
SKELETON OF THE RIGHT FRONT FOOT OF A COW



EXAMPLES OF UNGULATES

MALE RED DEER
(Cervus elephas)
An even-toed ungulate
(order Artiodactyla)

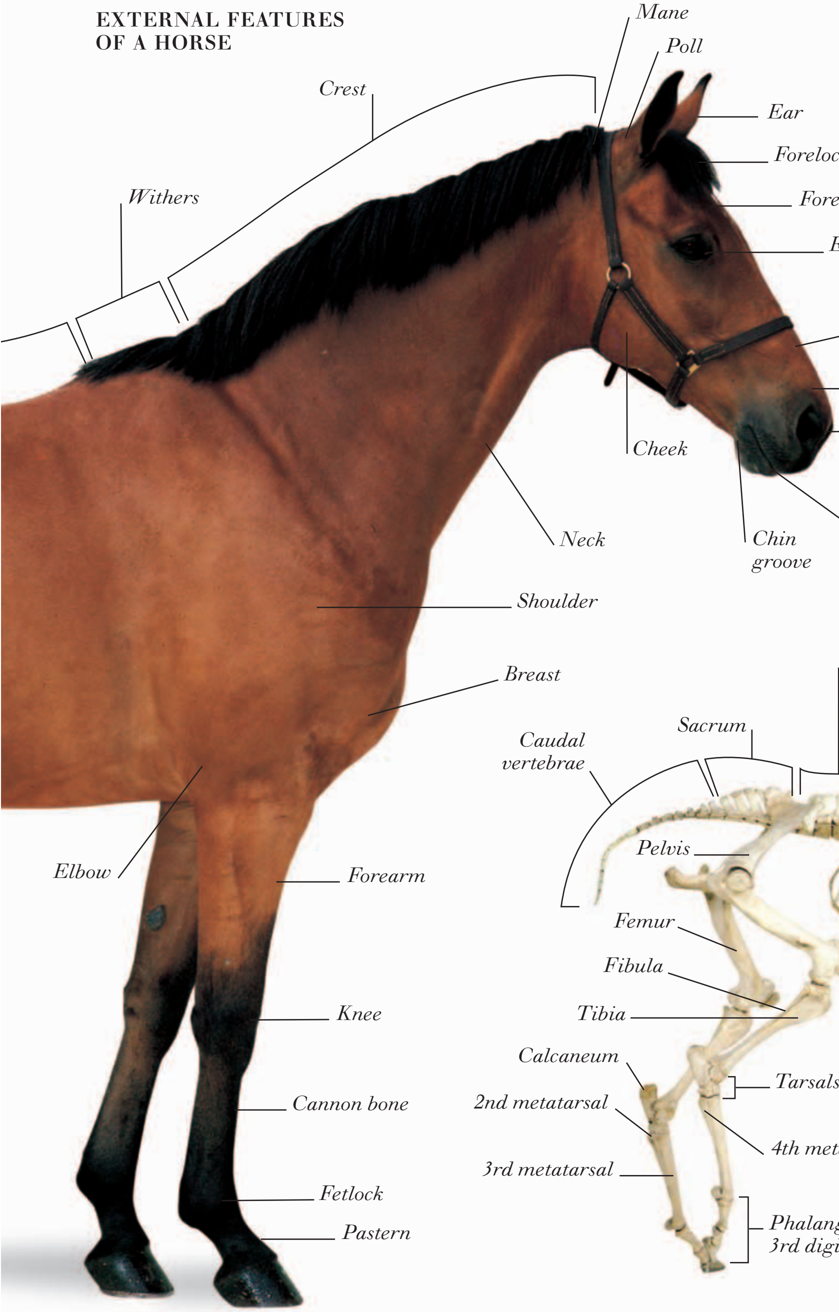
BACTRIAN CAMEL
(Camelus ferus)
An even-toed ungulate
(order Artiodactyla)



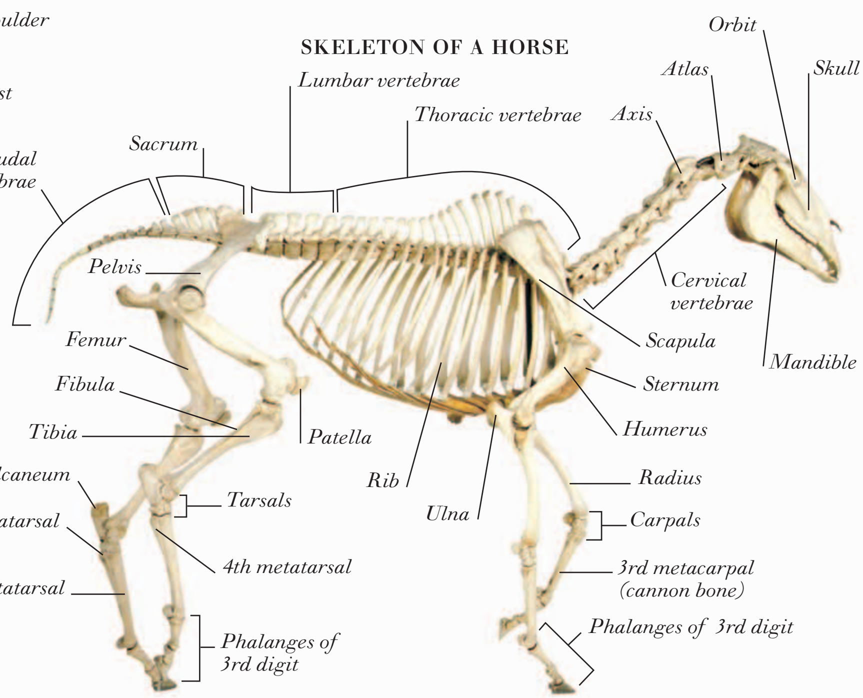
GIRAFFE
(Giraffa camelopardalis)
An even-toed ungulate
(order Artiodactyla)

BLACK RHINOCEROS
(Diceros bicornis)
An odd-toed ungulate
(order Perissodactyla)

EXTERNAL FEATURES OF A HORSE



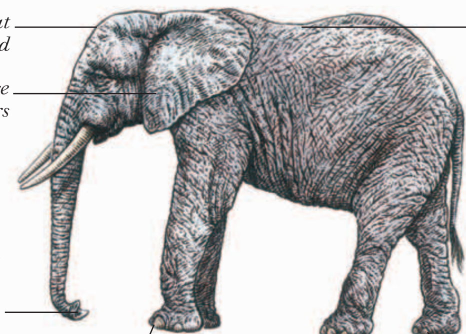
SKELETON OF A HORSE



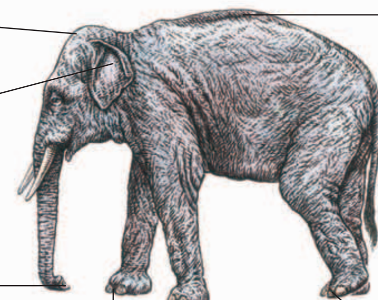
Elephants

THE TWO SPECIES OF elephant—African and Asian—are the only members of the mammalian order Proboscidea. The bigger African elephant is the largest land animal: a fully grown male may be up to 13 ft (4 m) tall and weigh nearly 8 tons (7 metric tons). A fully grown male Asian elephant may be 11 ft (3.3 m) tall and weigh 6 tons (5.4 metric tons). The trunk—an extension of the nose and upper lip—is the elephant's other most obvious feature. It is used for manipulating and lifting, feeding, drinking and spraying water, smelling, touching, and producing trumpeting sounds. Other characteristic features include a pair of tusks, used for defense and for crushing vegetation; thick, pillarlike legs and broad feet to support the massive body; and large ear flaps that act as radiators to keep the elephant cool.

DIFFERENCES BETWEEN AFRICAN AND ASIAN ELEPHANTS

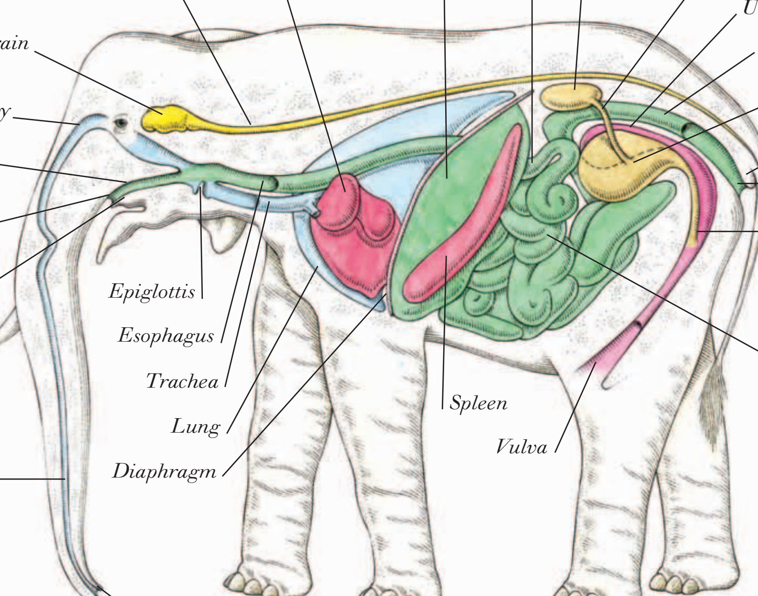


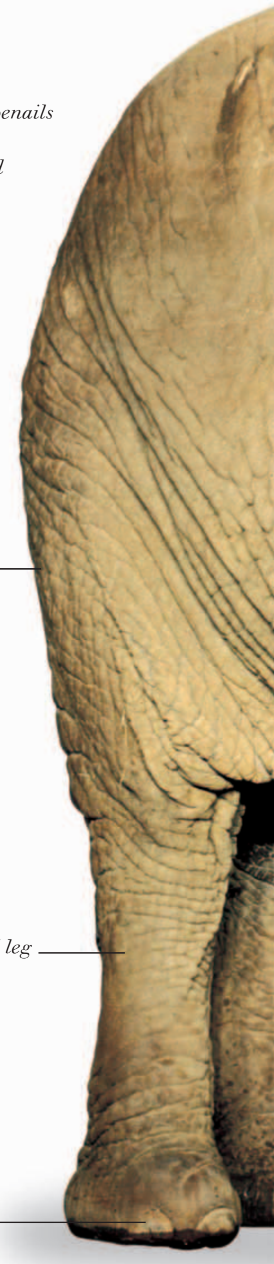
AFRICAN ELEPHANT
(Loxodonta africana)



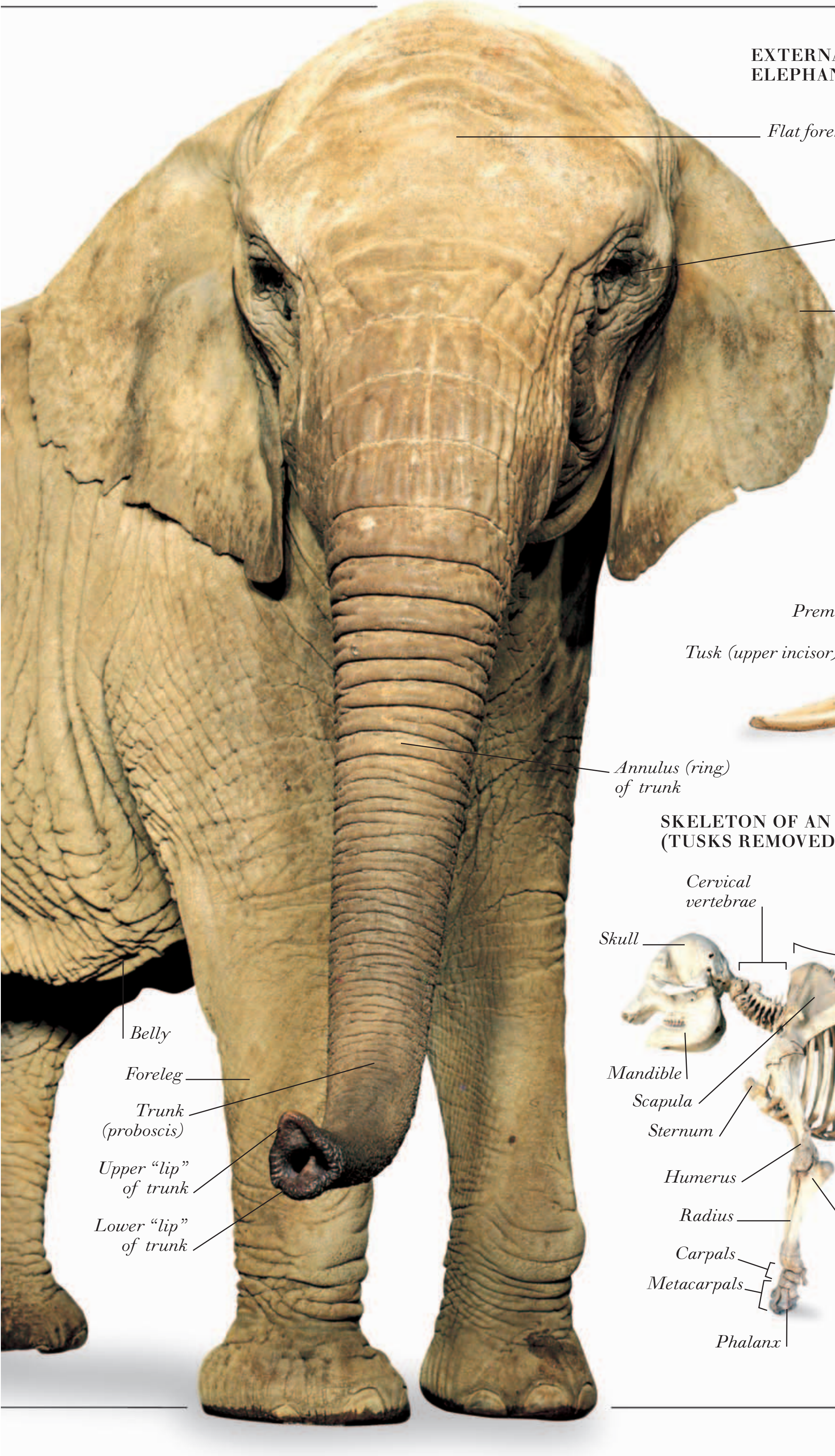
ASIAN ELEPHANT
(Elephas maximus)

INTERNAL ANATOMY OF A FEMALE ELEPHANT

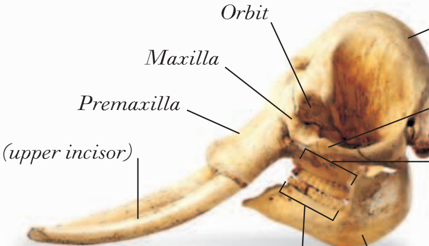




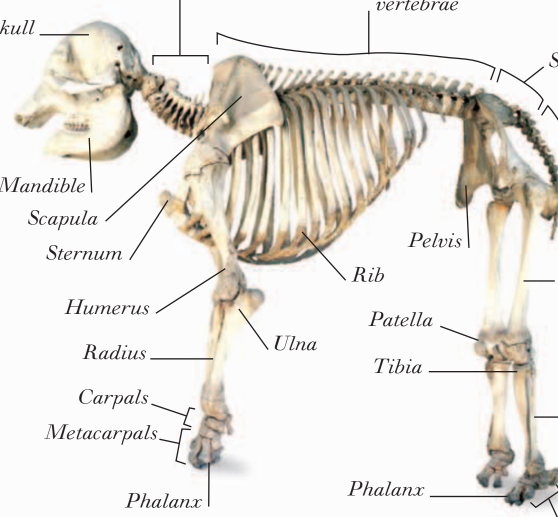
EXTERNAL FEATURES OF A FEMALE AFRICAN ELEPHANT (TUSKS REMOVED)



SKULL OF AN ASIAN ELEPHANT



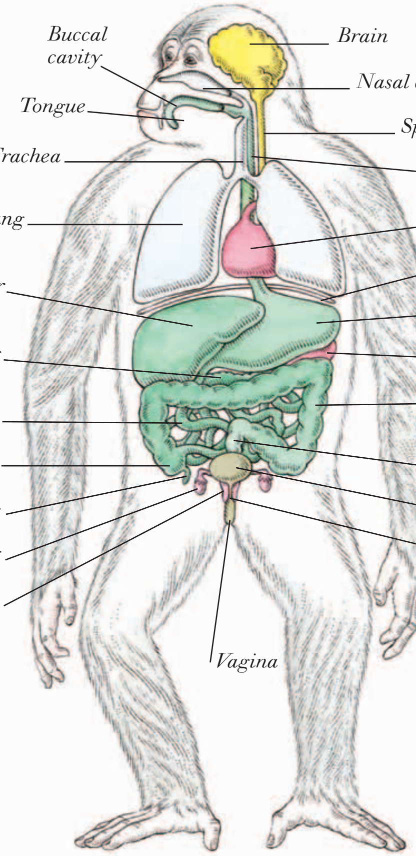
SKELETON OF AN AFRICAN ELEPHANT (TUSKS REMOVED)



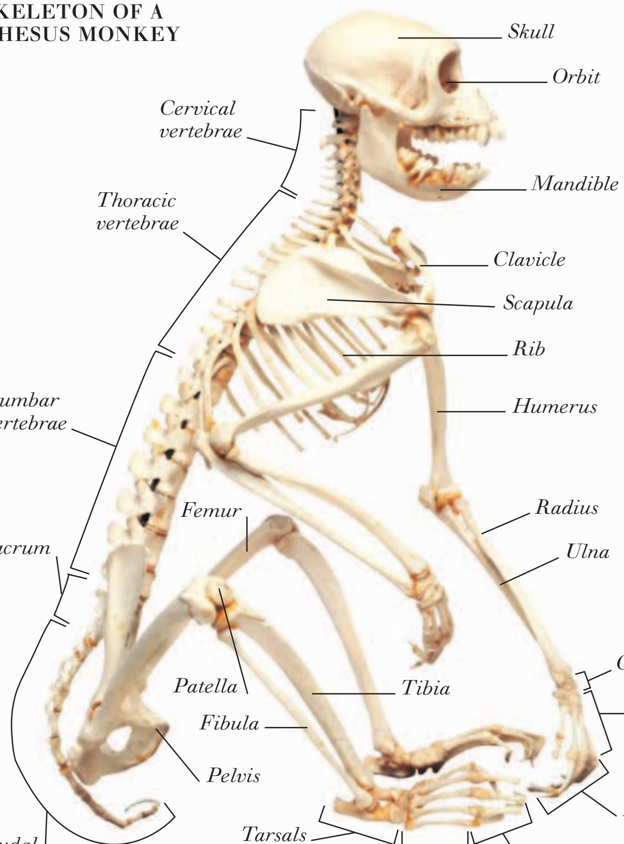
Primates

THE MAMMALIAN ORDER PRIMATES consists of monkeys, apes, and their relatives (including humans). There are two suborders of primates: Prosimii, the primitive primates, which include lemurs, tarsiers, and lorises; and Anthropoidea, the advanced primates, which include monkeys, apes, and humans. The anthropoids are divided into New World monkeys, Old World monkeys, and hominids. New World monkeys typically have wide-apart nostrils that open to the side; and long tails, which are prehensile (grasping) in some species. This group of monkeys lives in South America, and includes marmosets, tamarins, and howler monkeys. Old World monkeys typically have close-set nostrils that open forward or downward; and non-prehensile tails. This group of monkeys lives in Africa and Asia, and includes langurs, mandrills, macaques, and baboons. Hominids typically have large brains, and no tail. This group includes the apes—chimpanzees, gibbons, gorillas, and orangutans—and humans.

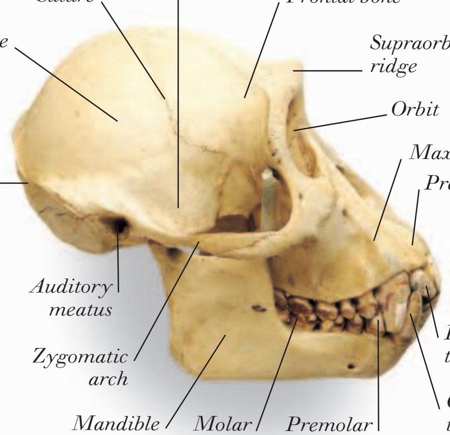
INTERNAL ANATOMY OF A FEMALE CHIMPANZEE



SKELETON OF A RHESUS MONKEY



SKULL OF A CHIMPANZEE



EXAMPLES OF PRIMATES

RING-TAILED LEMUR
(Lemur catta)
A prosimian

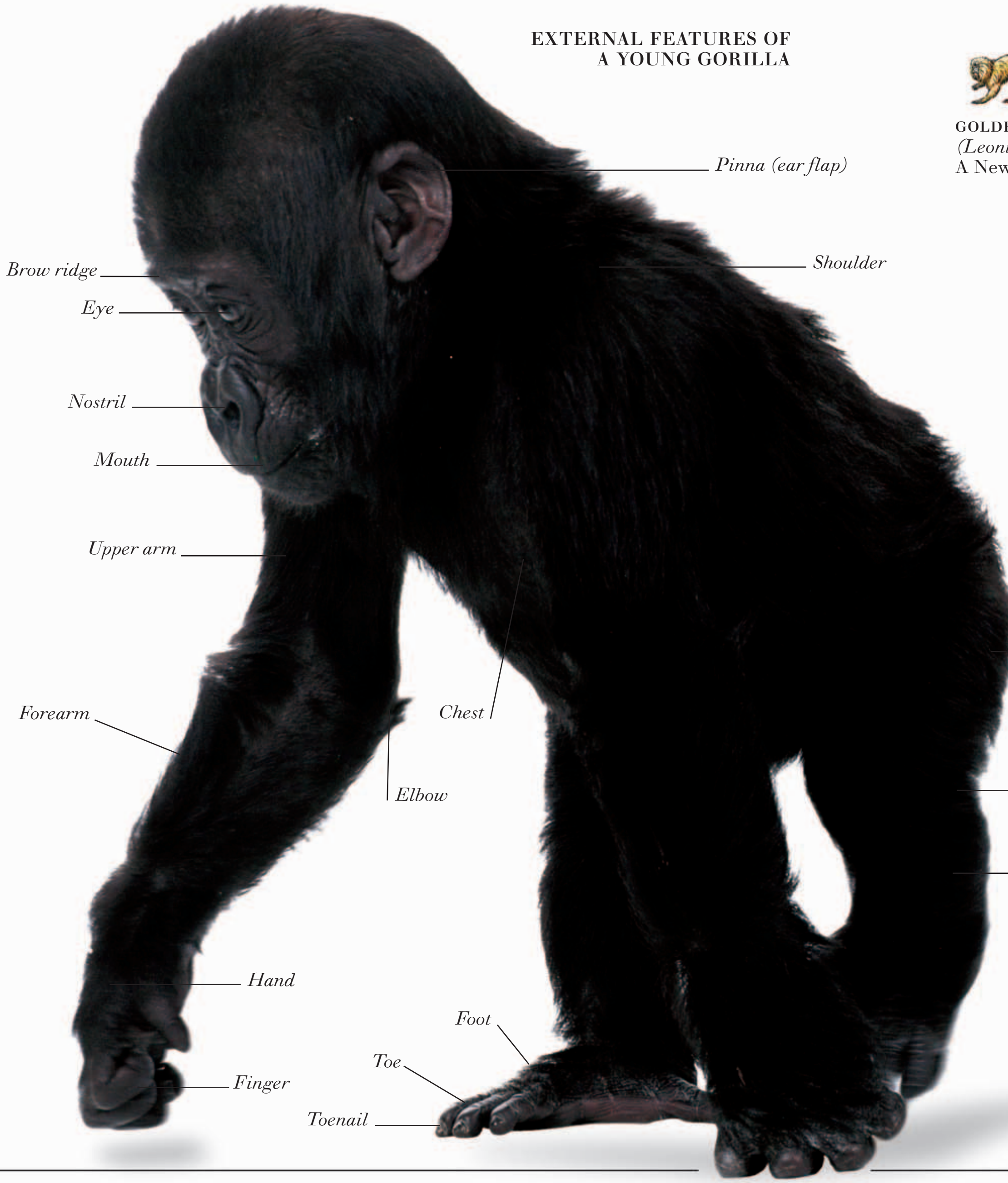
MALE RED HOWLER MONKEY
(Alouatta seniculus)
A New World monkey

MALE MANDRILL
(Mandrillus sphinx)
An Old World monkey

CHIMPANZEE
(Pan troglodytes)
An ape

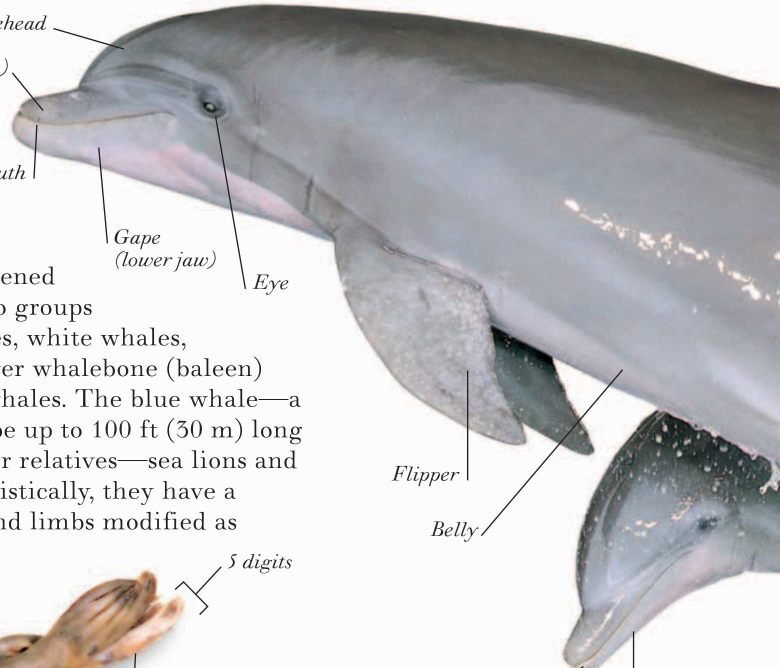
GOLDEN LION TAMARIN
(Leontopithecus rosalia)
A New World monkey

EXTERNAL FEATURES OF A YOUNG GORILLA



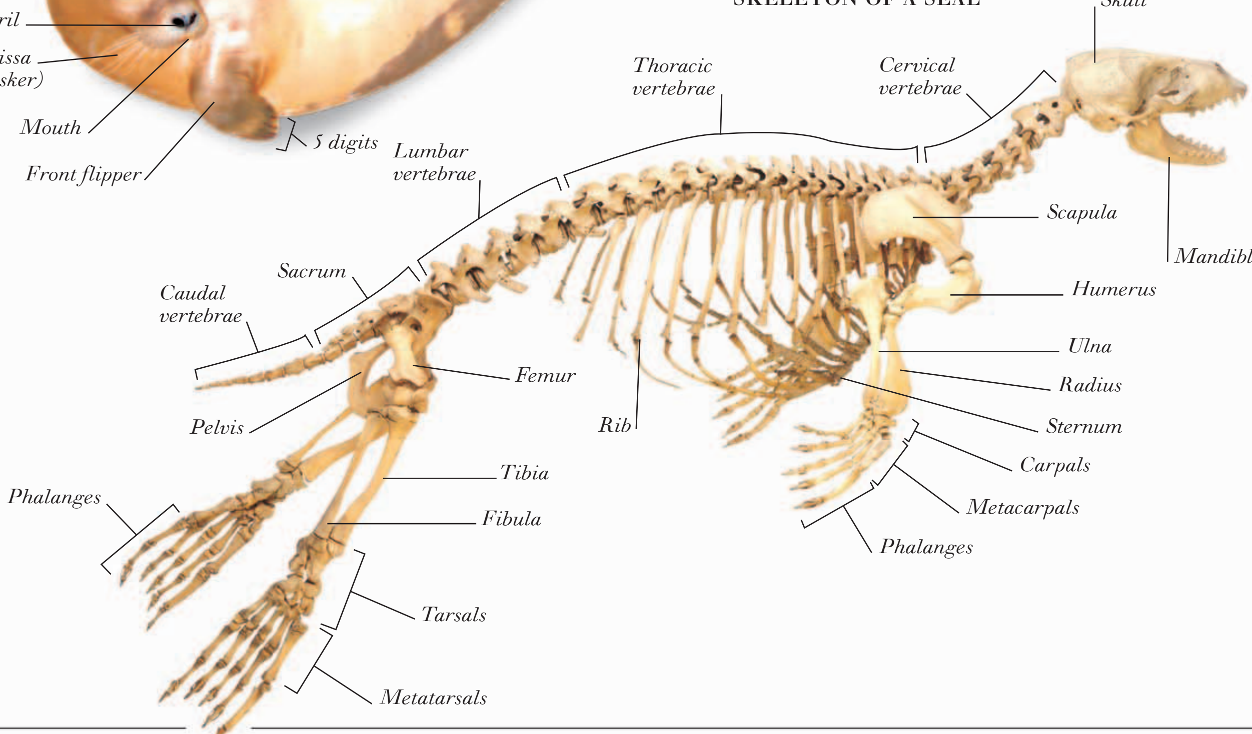
Dolphins, whales, and seals

DOLPHINS, WHALES, AND SEALS belong to two orders of mammal adapted to living in water. Dolphins and whales make up the order Cetacea. Typical cetacean features include a streamlined, fishlike shape; forelimbs in the form of flippers; no visible hind limbs; a horizontally flattened tail; and thick blubber under the skin. There are two groups of cetaceans: toothed whales, including sperm whales, white whales, beaked whales, dolphins, and porpoises; and the larger whalebone (baleen) whales, including rorquals, gray whales, and right whales. The blue whale—a rorqual—is the largest living animal: an adult may be up to 100 ft (30 m) long and weigh 145 tons (130 metric tons). Seals and their relatives—sea lions and walruses—make up the order Pinnipedia. Characteristically, they have a streamlined, torpedo-shaped body; forelimbs and hind limbs modified as flippers; thick blubber; and no external ears.



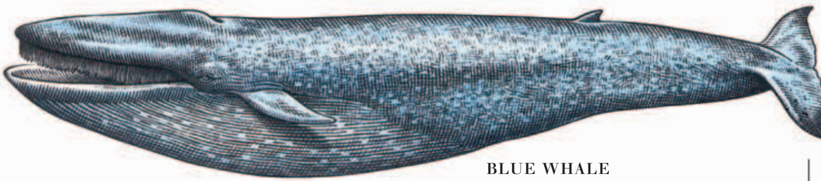
EXTERNAL FEATURES OF A SEAL

SKELETON OF A SEAL

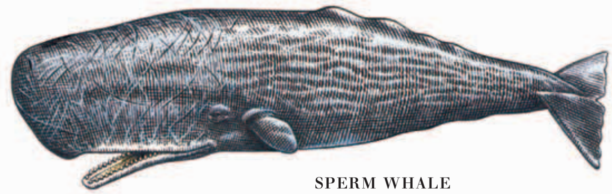


EXTERNAL FEATURES OF A DOLPHIN

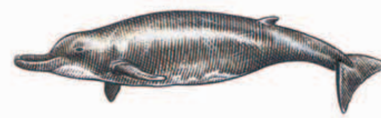
EXAMPLES OF CETACEANS



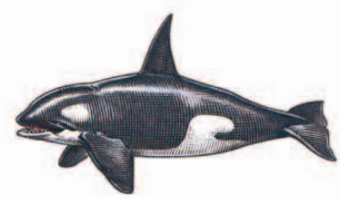
BLUE WHALE
(Balaenoptera musculus)



SPERM WHALE
(Physeter catodon)



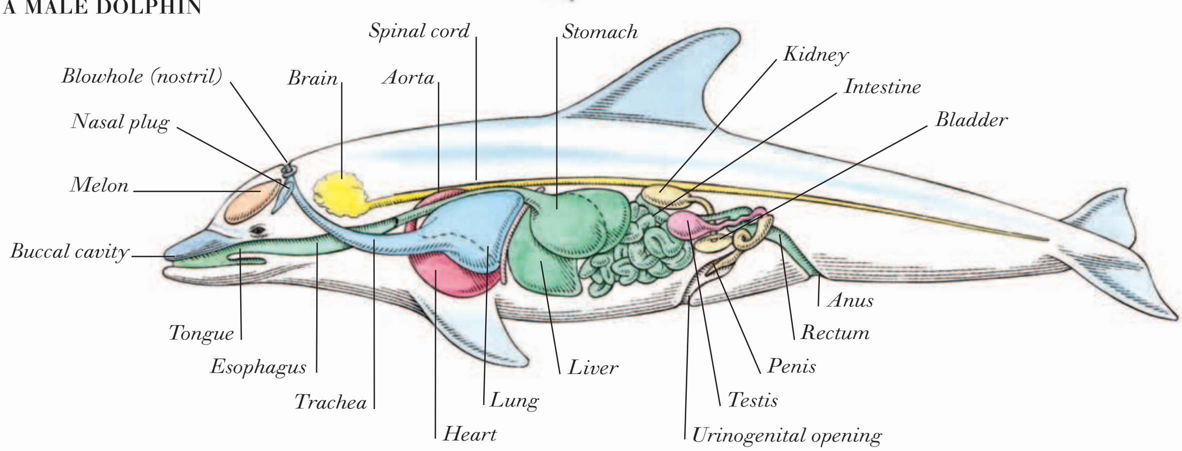
MALE BAIRD'S BEAKED WHALE
(Berardius bairdi)



MALE KILLER WHALE
(Orcinus orca)

MALE NARWHAL
(Monodon monoceros)

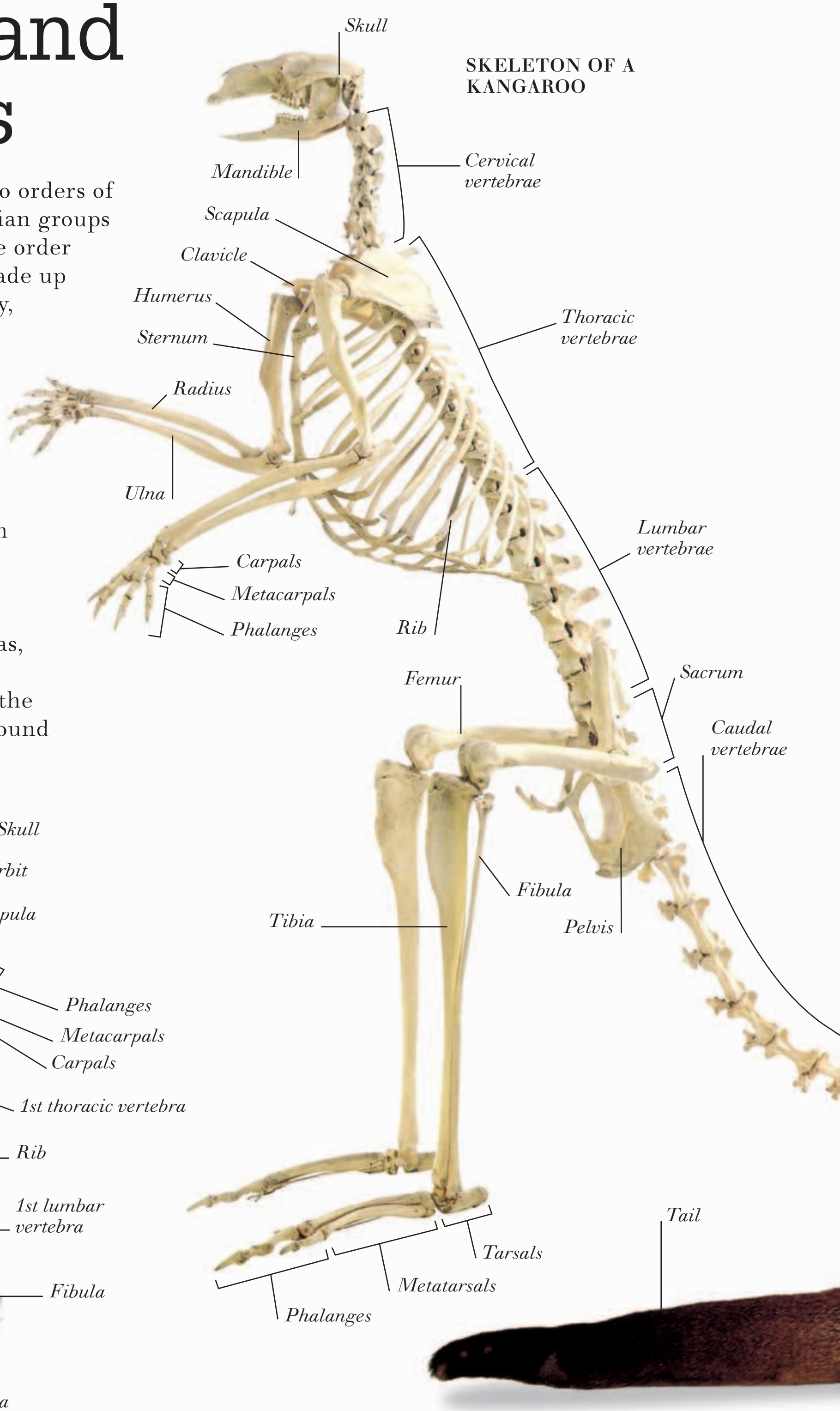
INTERNAL ANATOMY OF A MALE DOLPHIN



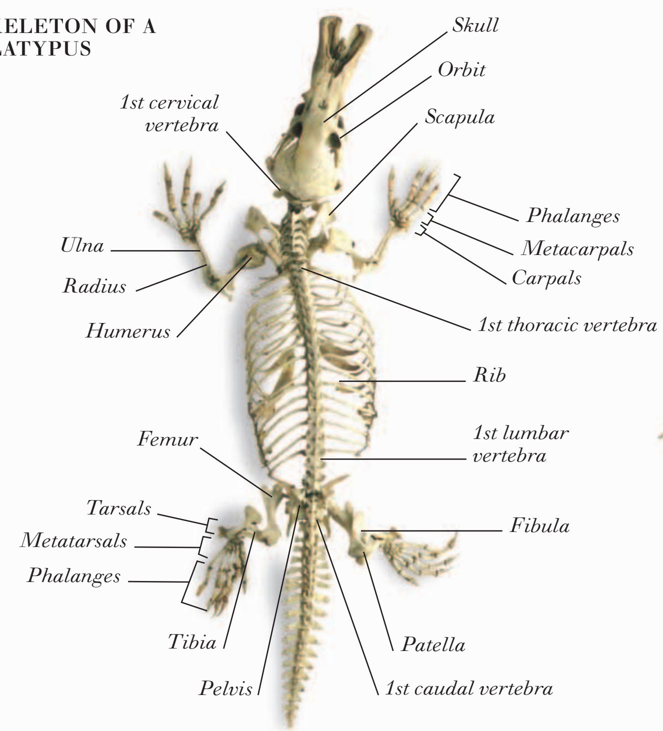
Marsupials and Monotremes

MARSUPIALS AND MONOTREMES are two orders of mammal that differ from other mammalian groups in the ways that their young develop. The order Marsupalia, the pouched mammals, is made up of kangaroos and their relatives. Typically, marsupials give birth to their young at a very early stage of development. The young then crawls to the mother's pouch (which is on the outside of her abdomen), where it attaches itself to a nipple and remains until fully developed. Most marsupials live in Australia, although the opossums—which are classified as marsupials despite not having a pouch—live in the Americas. The order Monotremata is made up of the platypus and its relatives (the echidnas, or spiny anteaters). The monotremes are primitive mammals that lay eggs, which the mother incubates. The monotremes are found only in Australia and New Guinea.

SKELETON OF A KANGAROO



SKELETON OF A PLATYPUS



EXAMPLES OF MARSUPIALS AND MONOTREMES

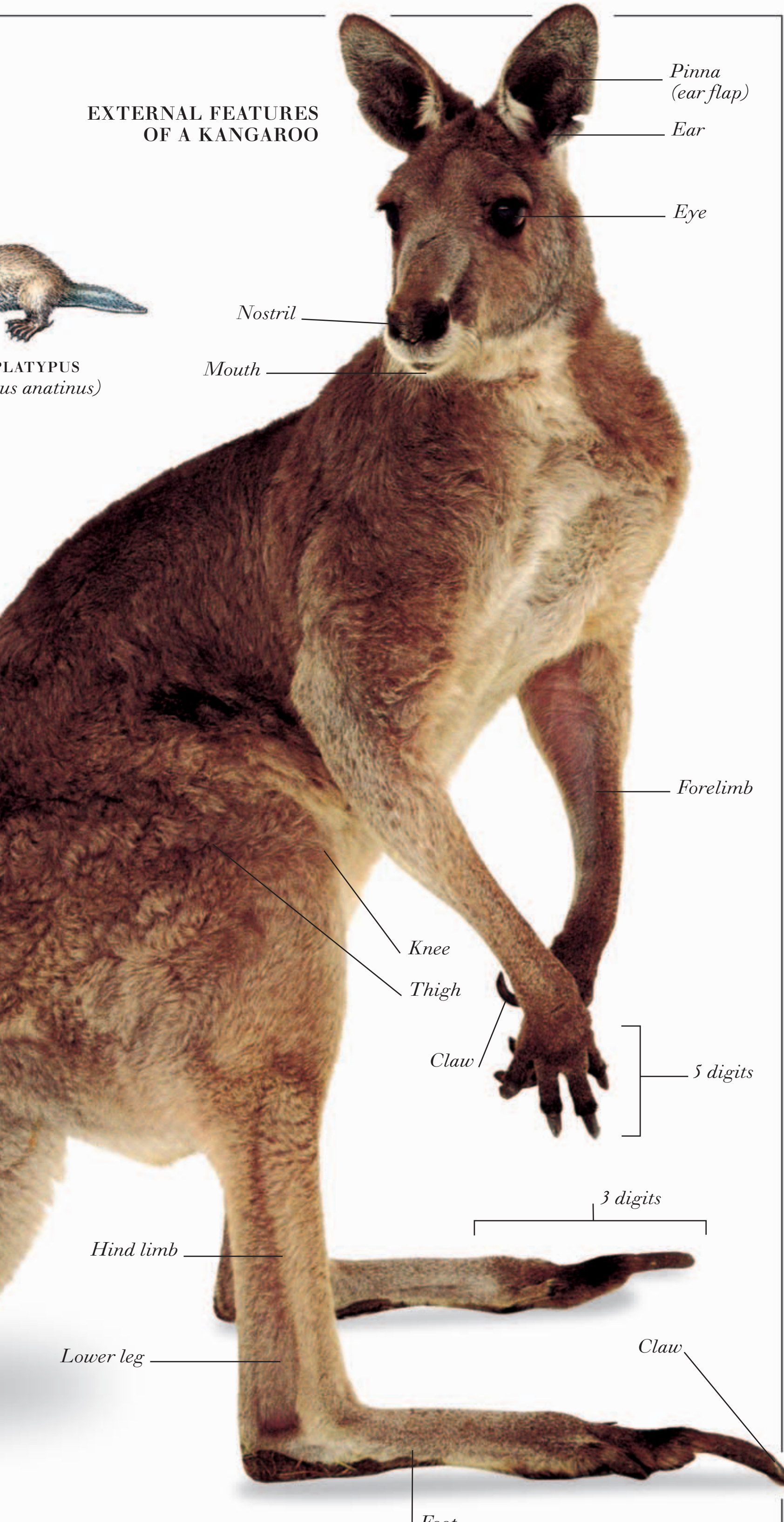
KOALA
(Phascolarctos cinereus)
A marsupial

DUCK-BILLED PLATYPUS
(Ornithorhynchus anatinus)
A monotreme

TASMANIAN DEVIL
(Sarcophilus harrisii)
A marsupial

VIRGINIA OPOSSUM
(Didelphis virginiana)
A marsupial

EXTERNAL FEATURES OF A KANGAROO



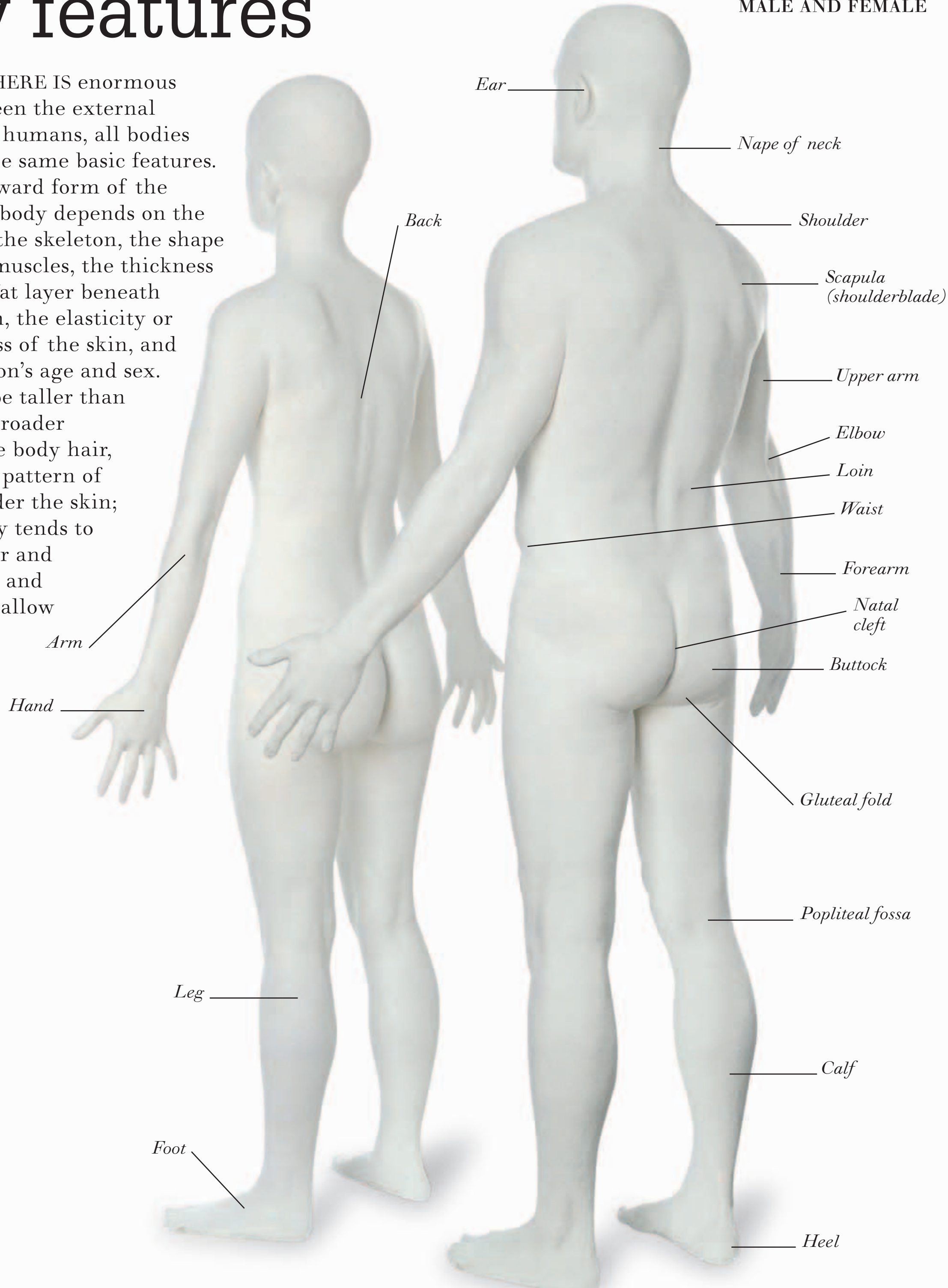
The Human Body

Body features

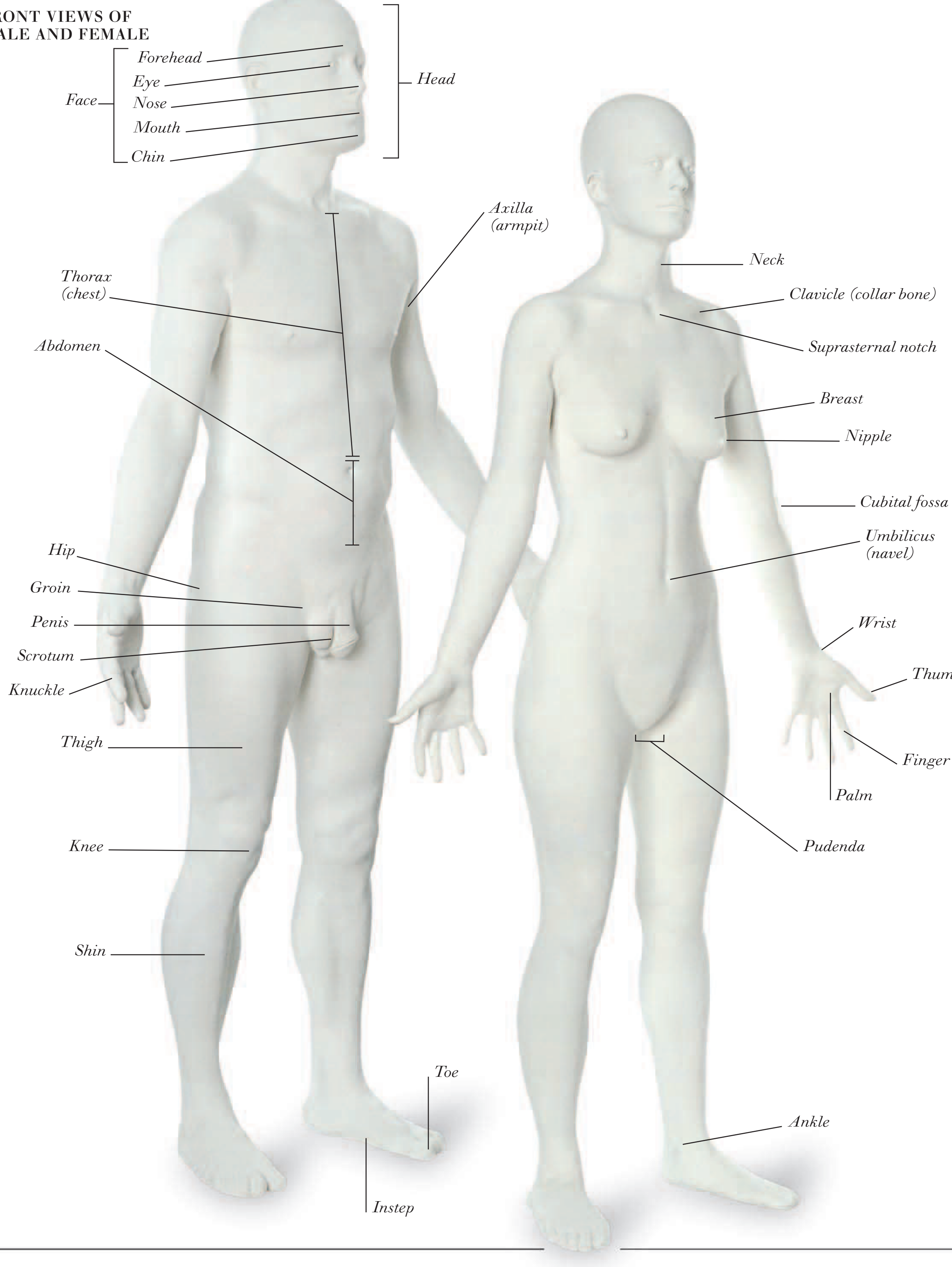
ALTHOUGH THERE IS enormous variation between the external appearances of humans, all bodies contain the same basic features.

The outward form of the human body depends on the size of the skeleton, the shape of the muscles, the thickness of the fat layer beneath the skin, the elasticity or sagginess of the skin, and the person's age and sex. Males tend to be taller than females, with broader shoulders, more body hair, and a different pattern of fat deposits under the skin; the female body tends to be less muscular and has a shallower and wider pelvis to allow for childbirth.

BACK VIEWS OF MALE AND FEMALE



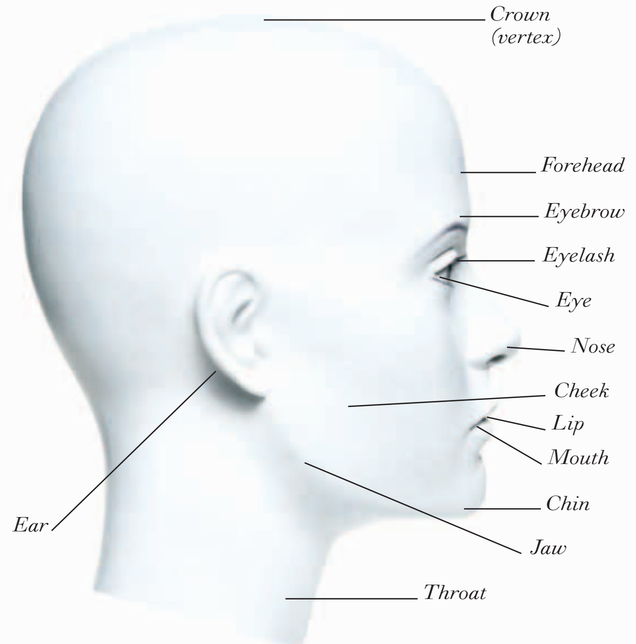
FRONT VIEWS OF MALE AND FEMALE



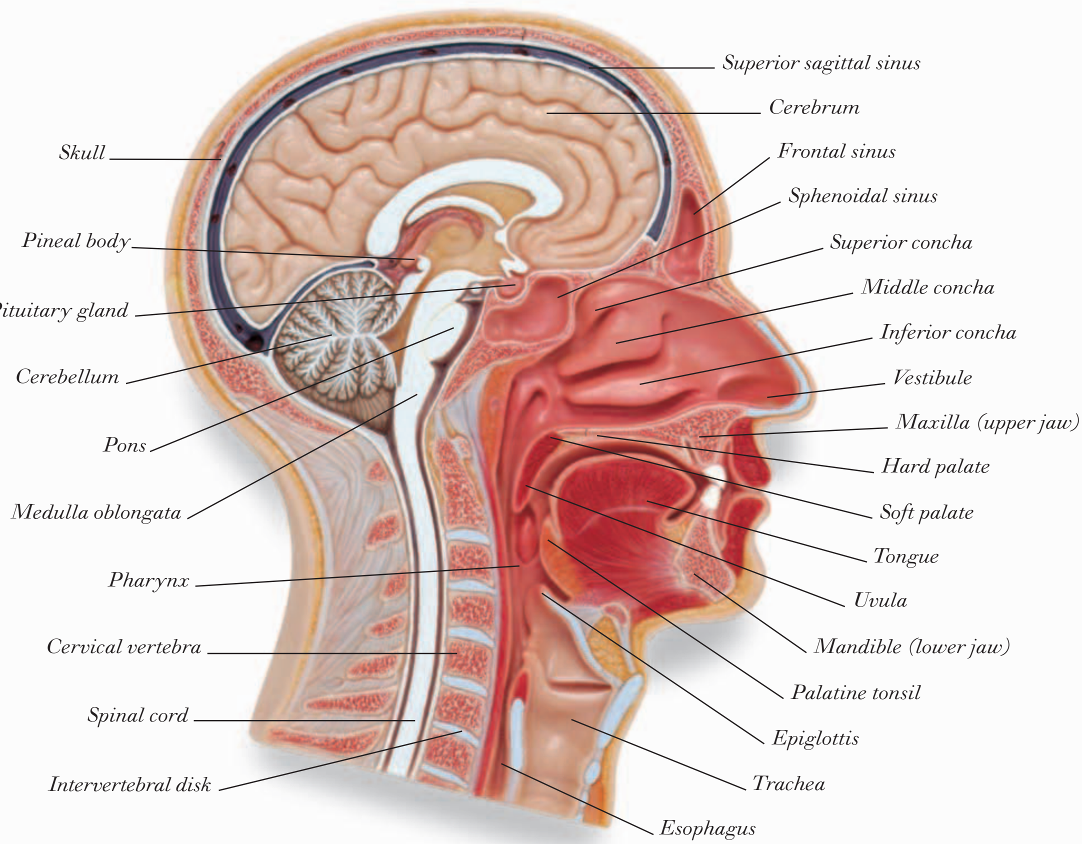
Head

IN A NEWBORN BABY, the head accounts for one-quarter of the total body length; by adulthood, the proportion has reduced to one-eighth. Contained in the head are the body's main sense organs: eyes, ears, olfactory nerves that detect smells, and the taste buds of the tongue. Signals from these organs pass to the body's great coordination center: the brain, housed in the protective, bony dome of the skull. Hair on the head insulates against heat loss, and adult males also grow thick facial hair. The face has three important openings: two nostrils through which air passes, and the mouth, which takes in nourishment and helps form speech. Although all heads are basically similar, differences in the size, shape, and color of features produce an infinite variety of appearances.

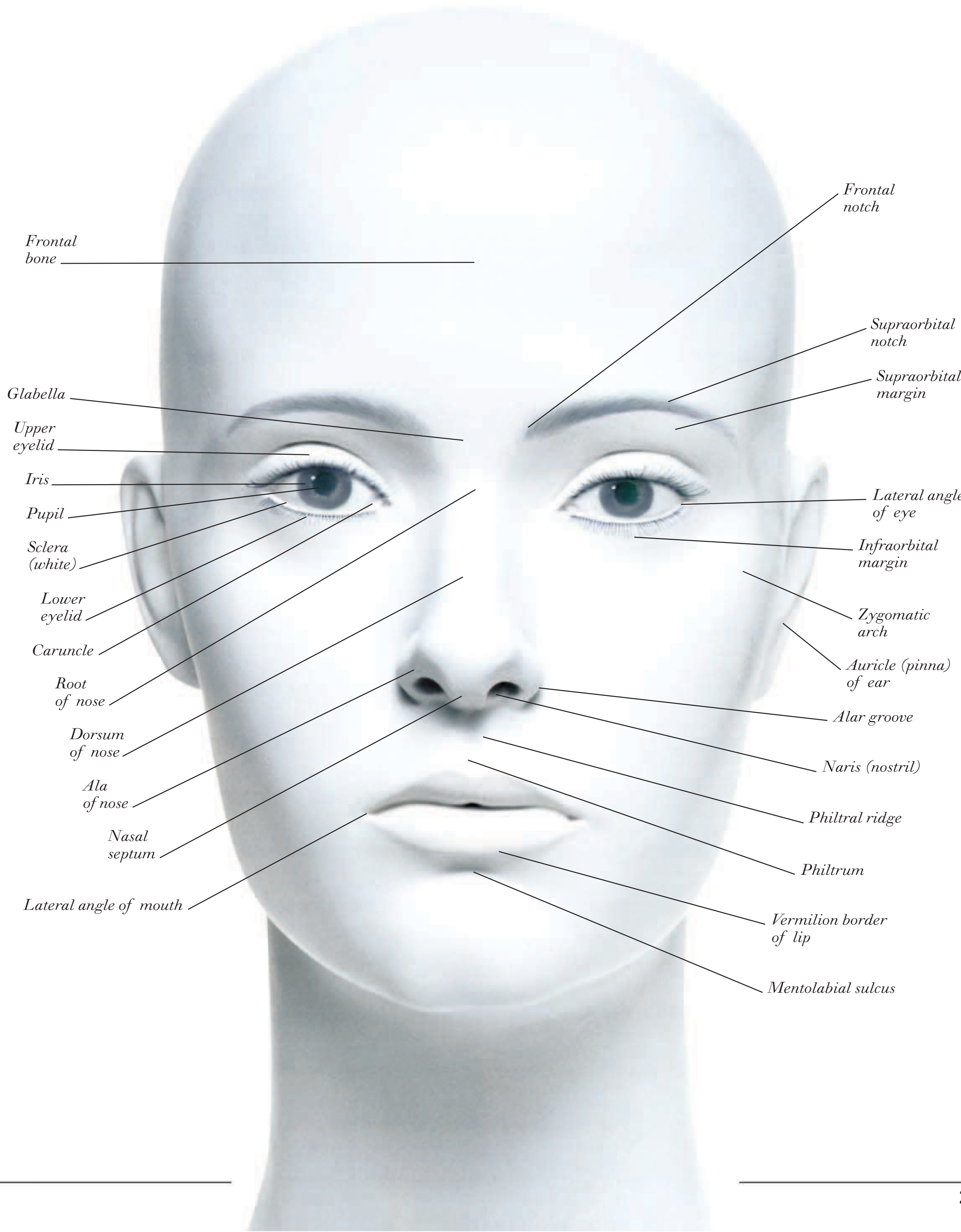
SIDE VIEW OF EXTERNAL FEATURES OF HEAD



SECTION THROUGH HEAD



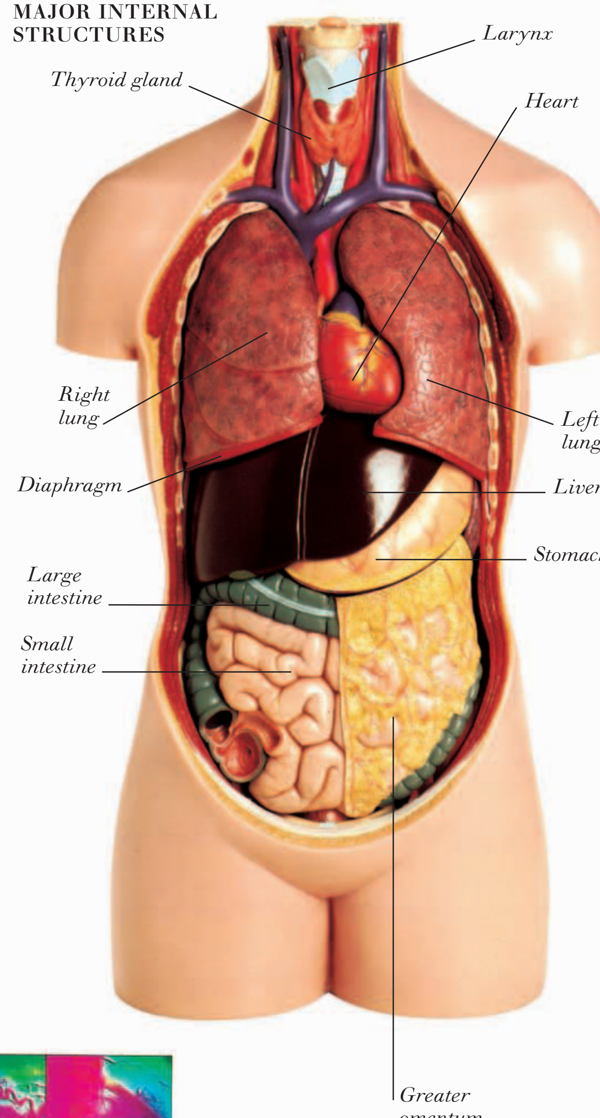
FRONT VIEW OF EXTERNAL FEATURES OF HEAD



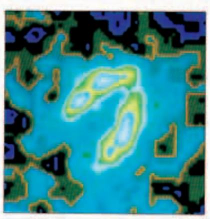
Body organs

ALL THE VITAL BODY ORGANS except for the brain are enclosed within the trunk or torso (the body apart from the head and limbs). The trunk contains two large cavities separated by a muscular sheet called the diaphragm. The upper cavity, known as the thorax or chest cavity, contains the heart and lungs. The lower cavity, called the abdominal cavity, contains the stomach, intestines, liver, and pancreas, which all play a role in digesting food. Also within the trunk are the kidneys and bladder, which are part of the urinary system, and the reproductive organs, which hold the seeds of new human life. Modern imaging techniques, such as contrast X-rays and different types of scans, make it possible to see and study body organs without the need to cut through their protective coverings of skin, fat, muscle, and bone.

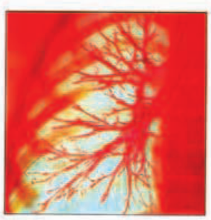
MAJOR INTERNAL STRUCTURES



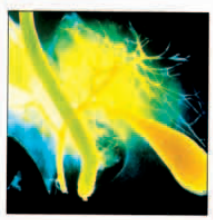
IMAGING THE BODY



SCINTIGRAM OF HEART CHAMBERS



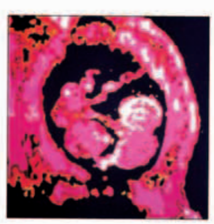
ANGIOGRAM OF RIGHT LUNG



CONTRAST X-RAY OF GALLBLADDER

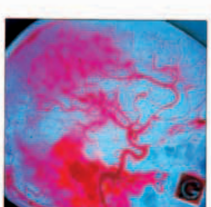
SCINTIGRAM OF NERVOUS SYSTEM

DOUBLE CONTRAST X-RAY OF COLON



ULTRASOUND SCAN OF TWINS IN UTERUS

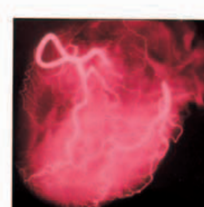
ANGIOGRAM OF KIDNEYS



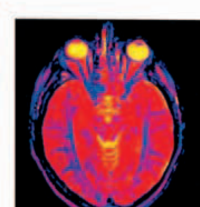
ANGIOGRAM OF ARTERIES OF HEAD

CT SCAN THROUGH FEMALE CHEST

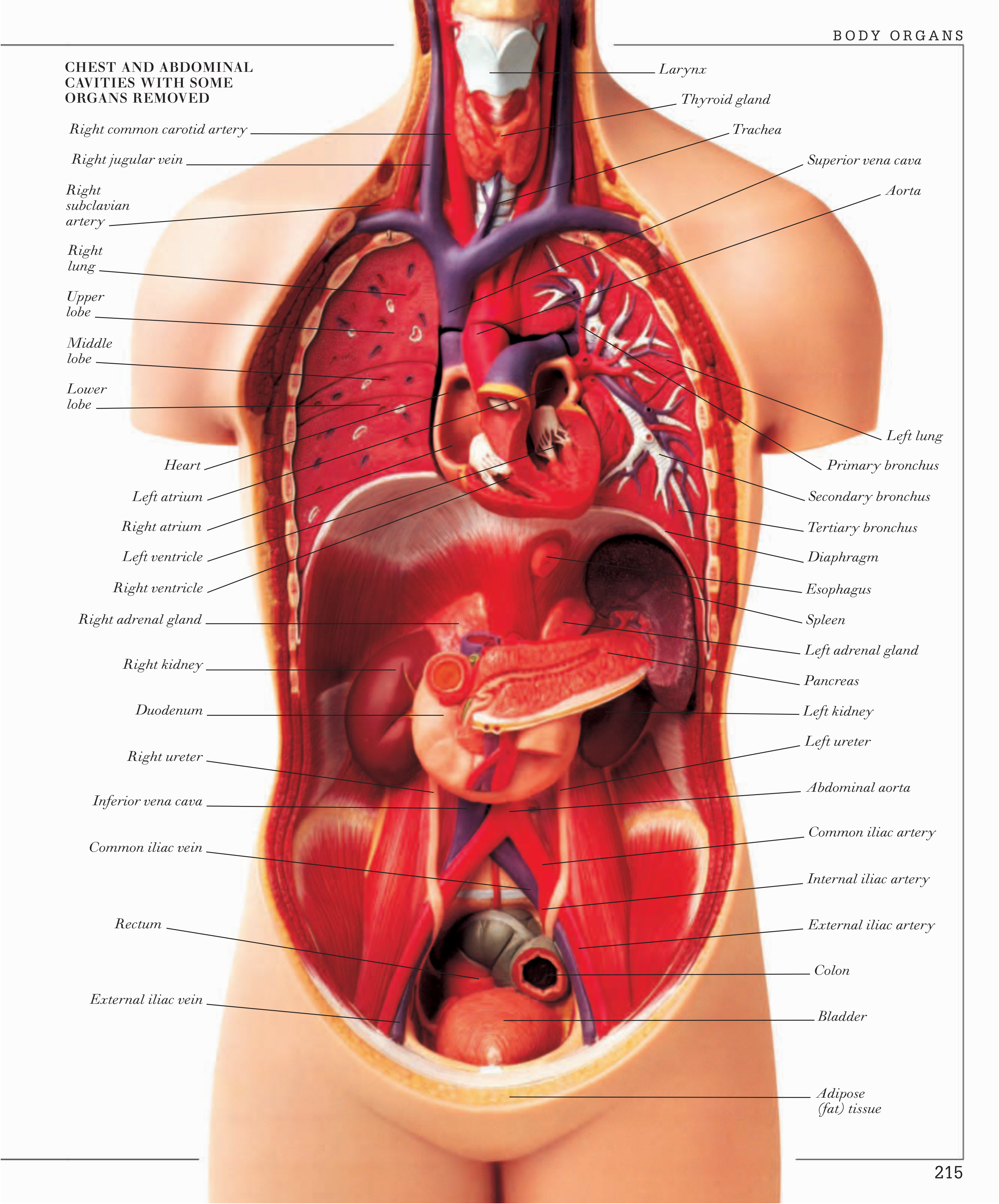
THERMOGRAM OF CHEST REGION



ANGIOGRAM OF ARTERIES OF HEART

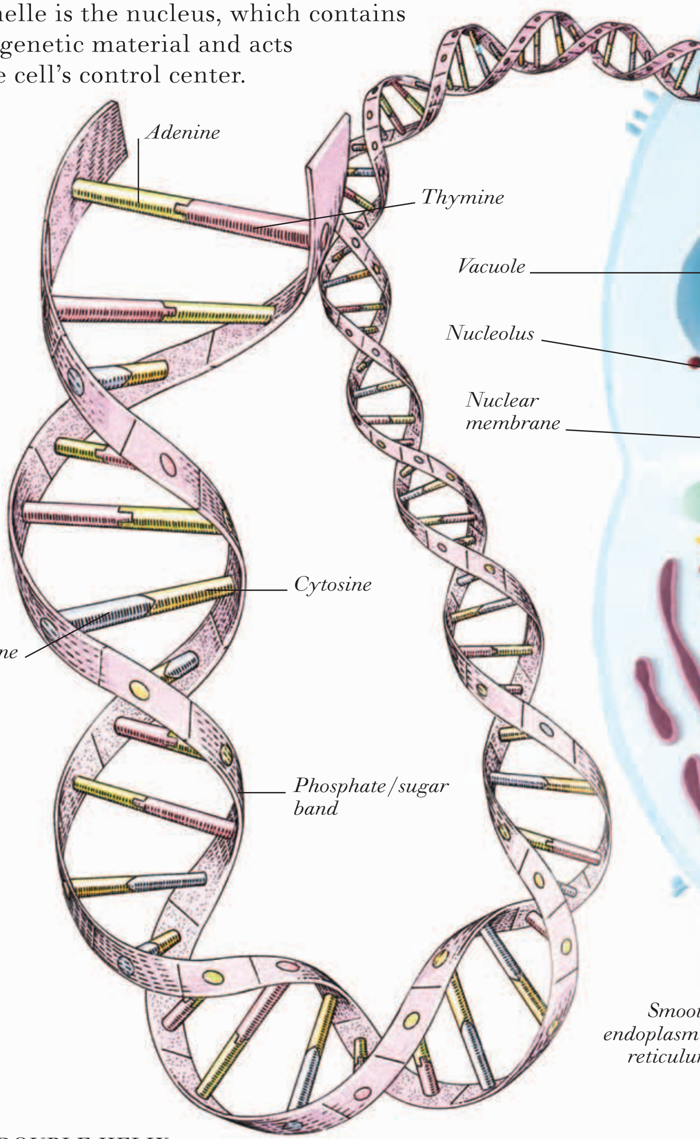


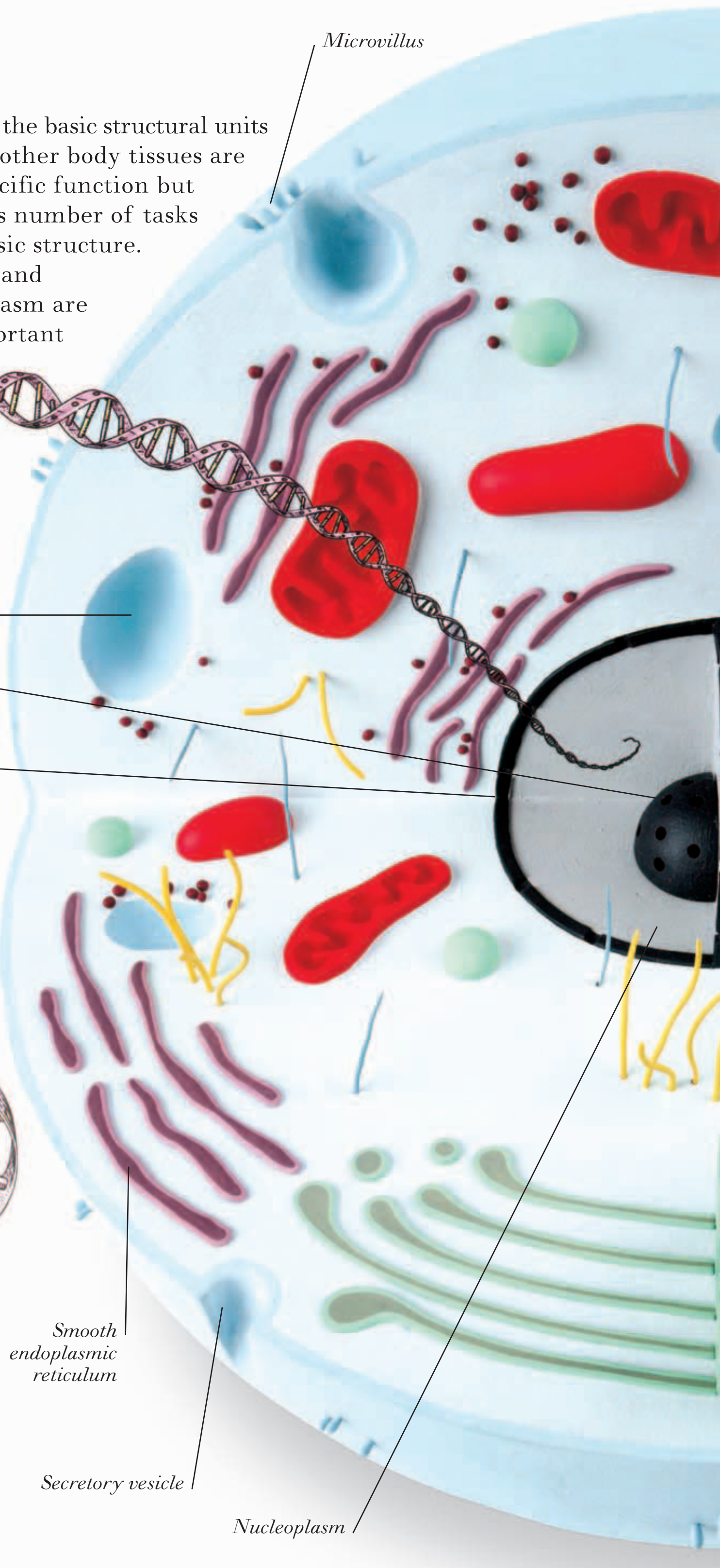
MRI SCAN THROUGH HEAD AT EYE LEVEL


CHEST AND ABDOMINAL CAVITIES WITH SOME ORGANS REMOVED
Larynx
Thyroid gland
Right common carotid artery
Trachea
Right jugular vein
Superior vena cava
Right subclavian artery
Aorta
Right lung
Upper lobe
Middle lobe
Lower lobe
Left lung
Heart
Primary bronchus
Left atrium
Secondary bronchus
Right atrium
Tertiary bronchus
Left ventricle
Diaphragm
Right ventricle
Esophagus
Spleen
Right adrenal gland
Left adrenal gland
Right kidney
Pancreas
Duodenum
Left kidney
Left ureter
Right ureter
Abdominal aorta
Inferior vena cava
Common iliac artery
Common iliac vein
Internal iliac artery
Rectum
External iliac artery
Colon
External iliac vein
Bladder
Adipose (fat) tissue

Body cells

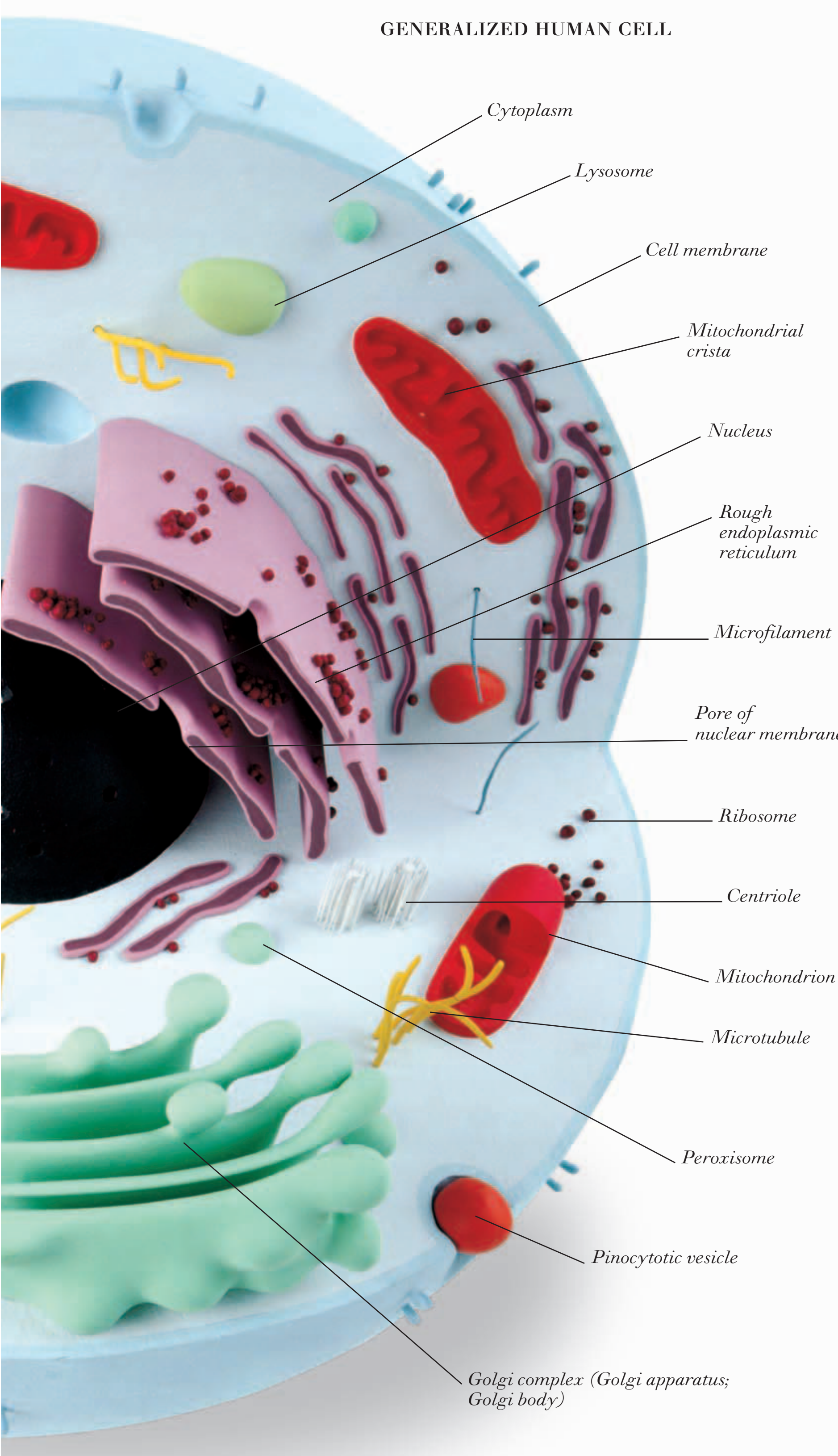
EVERYONE IS MADE UP OF BILLIONS OF CELLS, which are the basic structural units of the body. Bones, muscles, nerves, skin, blood, and all other body tissues are formed from different types of cells. Each cell has a specific function but works with other types of cells to perform the enormous number of tasks needed to sustain life. Most body cells have a similar basic structure. Each cell has an outer layer (called the cell membrane) and contains a fluid material (cytoplasm). Within the cytoplasm are many specialized structures (organelles). The most important organelle is the nucleus, which contains vital genetic material and acts as the cell's control center.



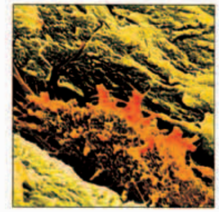


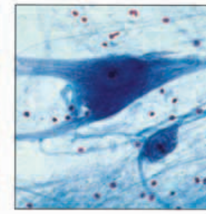
THE DOUBLE HELIX
Diagrammatic representation of DNA, which is structured like a spiral ladder. DNA contains all the vital genetic information and instruction codes necessary for the maintenance and continuation of life.

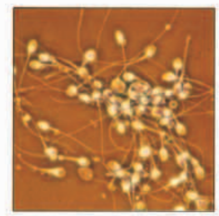
GENERALIZED HUMAN CELL

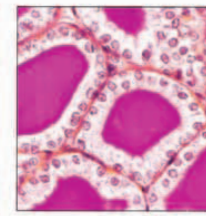


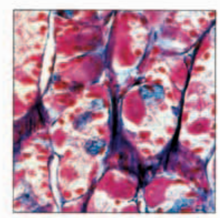
TYPES OF CELLS

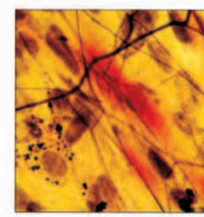

BONE-FORMING CELL

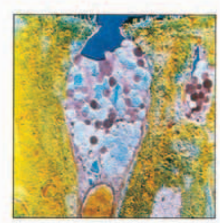

NERVE CELLS IN SPINAL CORD

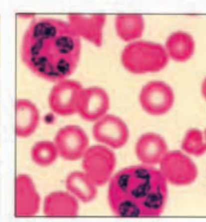

SPERM CELLS IN SEMEN

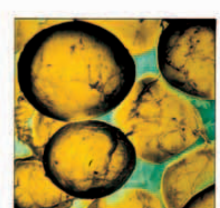

SECRETORY THYROID GLAND CELLS

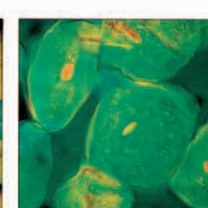

ACID-SECRETING STOMACH CELLS


CONNECTIVE TISSUE CELLS


MUCUS-SECRETING DUODENAL CELLS

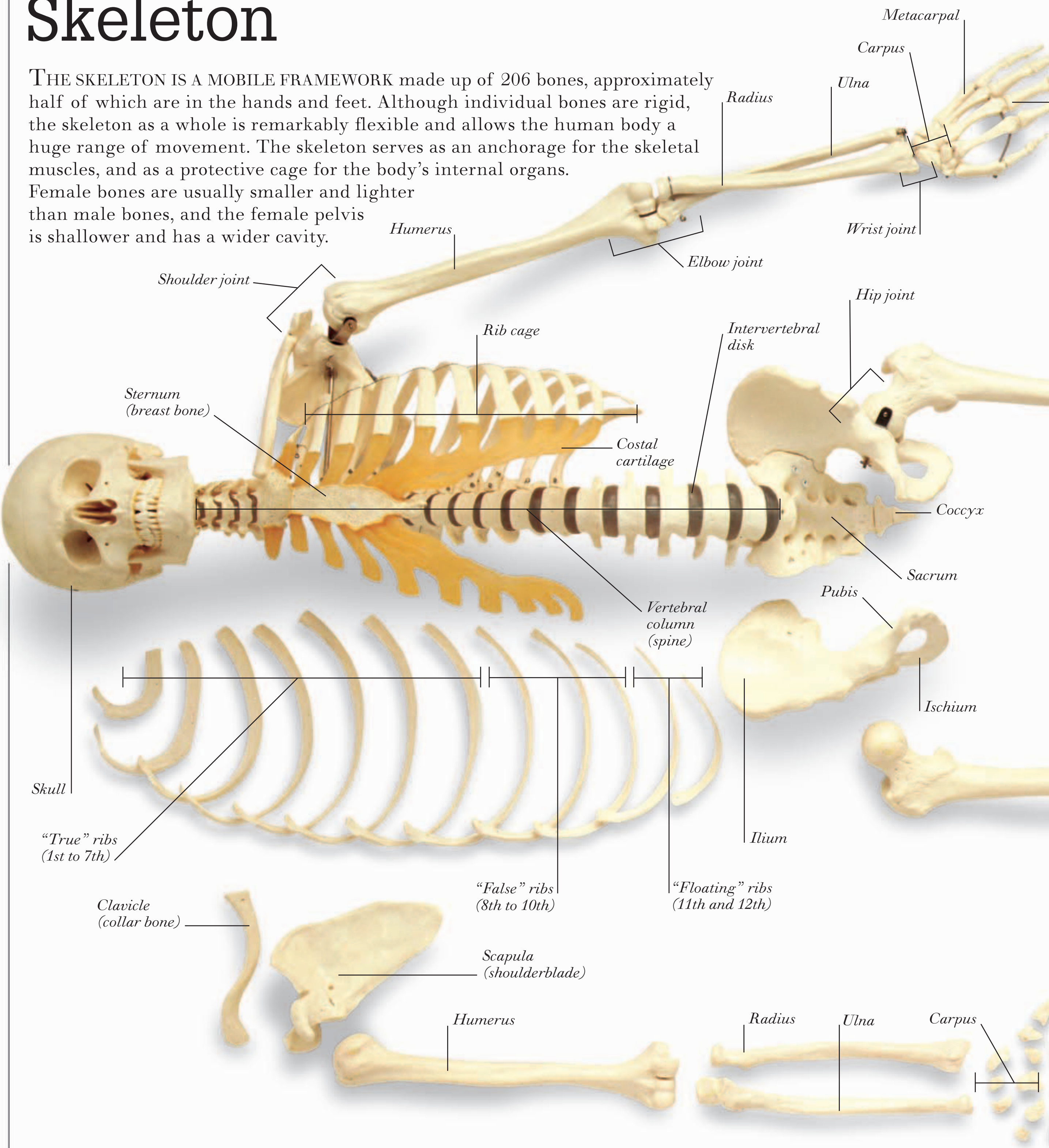

RED AND TWO WHITE BLOOD CELLS


FAT CELLS IN ADIPOSE TISSUE


EPITHELIAL CELLS IN CHEEK

Skeleton

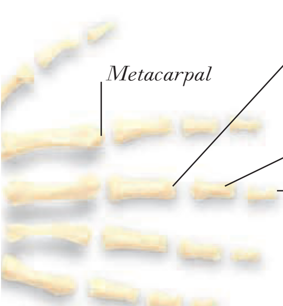
THE SKELETON IS A MOBILE FRAMEWORK made up of 206 bones, approximately half of which are in the hands and feet. Although individual bones are rigid, the skeleton as a whole is remarkably flexible and allows the human body a huge range of movement. The skeleton serves as an anchorage for the skeletal muscles, and as a protective cage for the body's internal organs. Female bones are usually smaller and lighter than male bones, and the female pelvis is shallower and has a wider cavity.



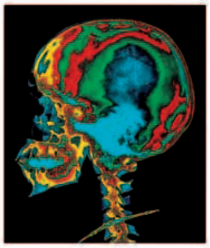

Distal phalanx
Middle phalanx
Proximal phalanx


Femur
Patella
Tibia
Fibula
Tarsus
Proximal phalanx
Middle phalanx
Distal phalanx
Knee joint
Ankle joint
Metatarsal


Patella
Distal phalanx
Middle phalanx
Proximal phalanx
Femur
Tibia
Fibula
Tarsus
Metatarsal

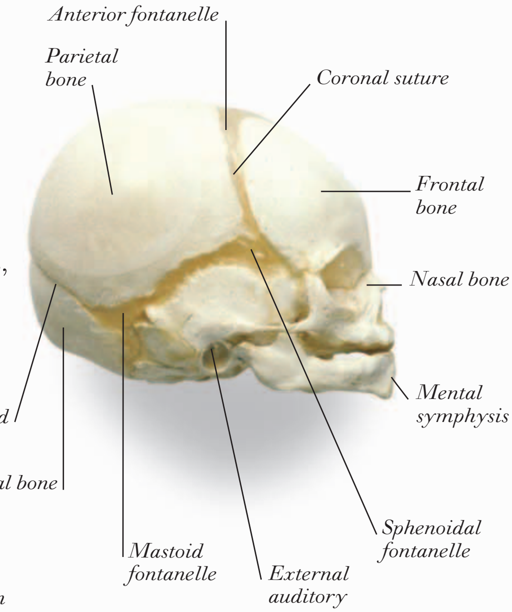

Proximal phalanx
Metacarpal
Middle phalanx
Distal phalanx

Skull

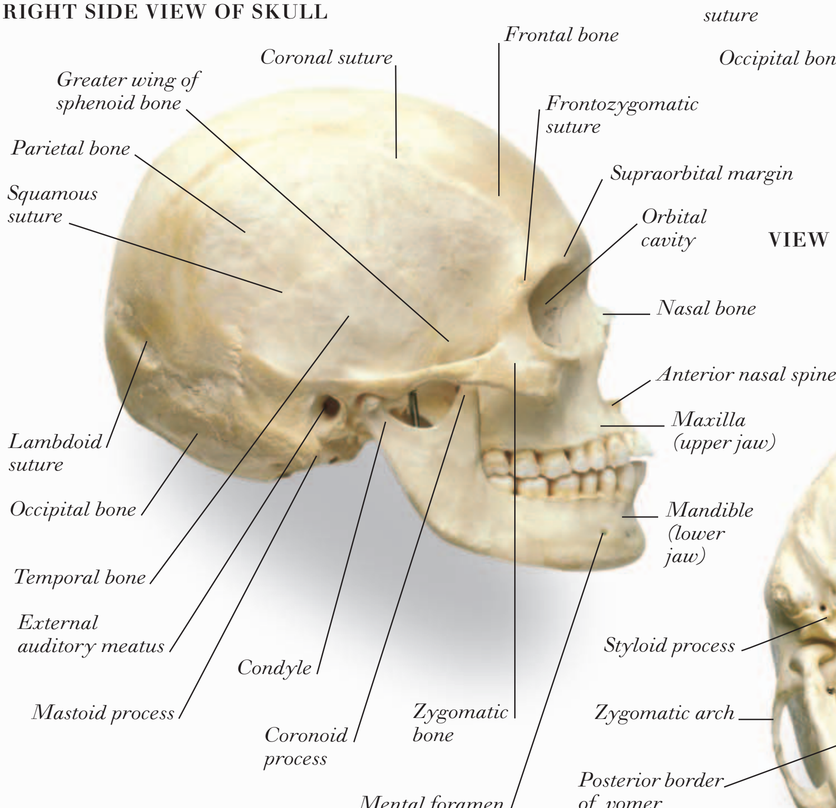


THE SKULL is the most complicated bony structure of the body but every feature serves a purpose. Internally, the main hollow chamber of the skull has three levels that support the brain, with every bump and hollow corresponding to the shape of the brain. Underneath and toward the back of the skull is a large round hole, the foramen magnum, through which the spinal cord passes. To the front of this are many smaller openings through which nerves, arteries, and veins pass to and from the brain. The roof of the skull is formed from four thin, curved bones that are firmly fixed together from the age of about two years. At the front of the skull are the two orbits, which contain the eyeballs, and a central hole for the airway of the nose. The jaw bone hinges on either side at ear level.

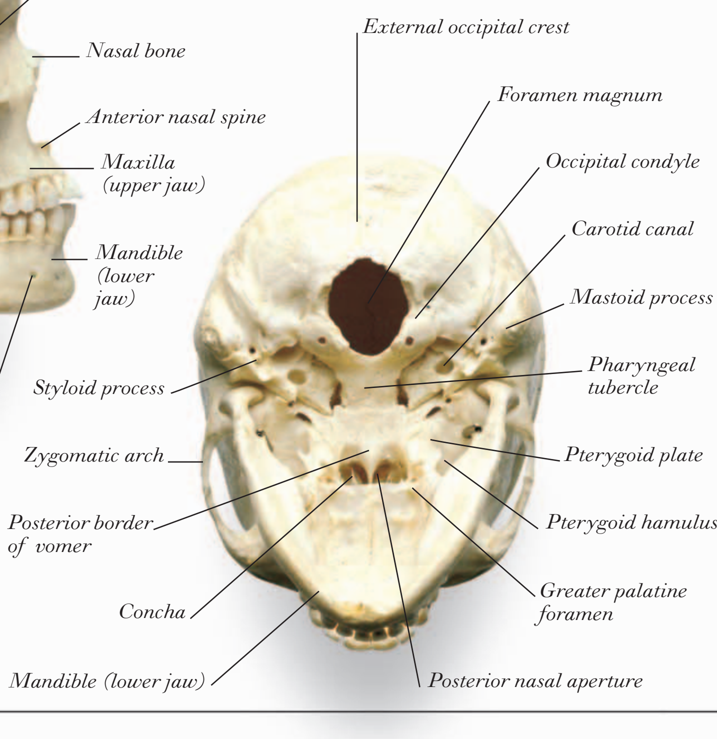
RIGHT SIDE VIEW OF A FETAL SKULL



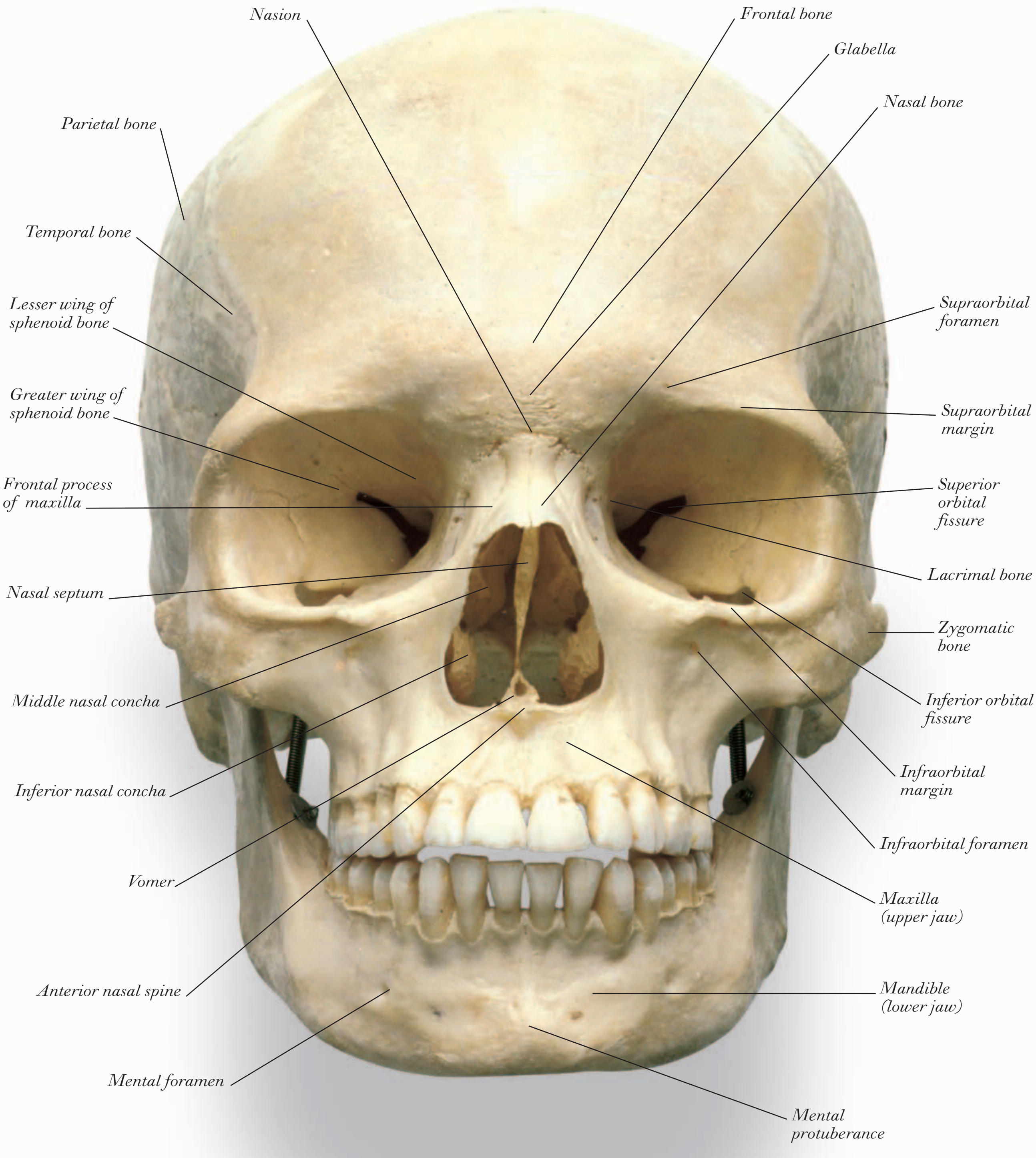
RIGHT SIDE VIEW OF SKULL



VIEW OF SKULL FROM BELOW



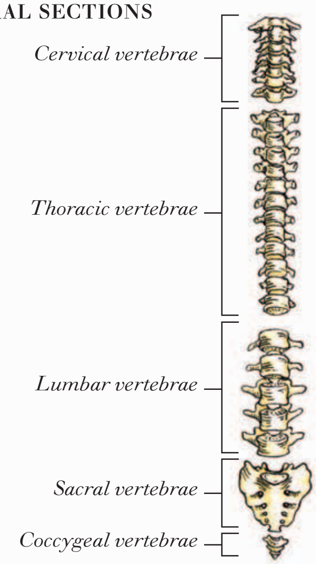
FRONT VIEW OF SKULL



Spine

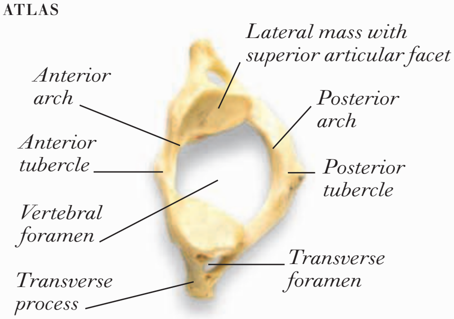
THE SPINE (OR VERTEBRAL COLUMN) has two main functions: it serves as a protective surrounding for the delicate spinal cord and forms the supporting back bone of the skeleton. The spine consists of 24 separate differently shaped bones (vertebrae) with a curved, triangular bone (the sacrum) at the bottom. The sacrum is made up of fused vertebrae; at its lower end is a small tail-like structure made up of tiny bones collectively called the coccyx. Between each pair of vertebrae is a disk of cartilage that cushions the bones during movement. The top two vertebrae differ in appearance from the others and work as a pair: the first, called the atlas, rotates around a stout vertical peg on the second, the axis. This arrangement allows the skull to move freely up and down, and from side to side.

SPINE DIVIDED INTO VERTEBRAL SECTIONS

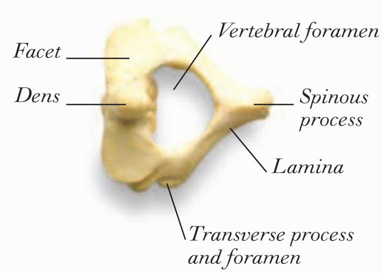


TYPES OF VERTEBRAE (VIEWED FROM ABOVE)

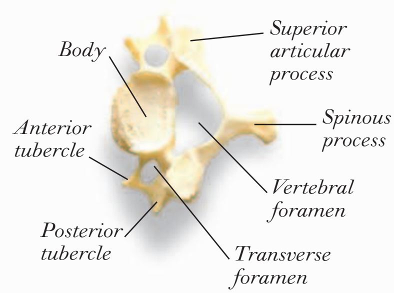
ATLAS



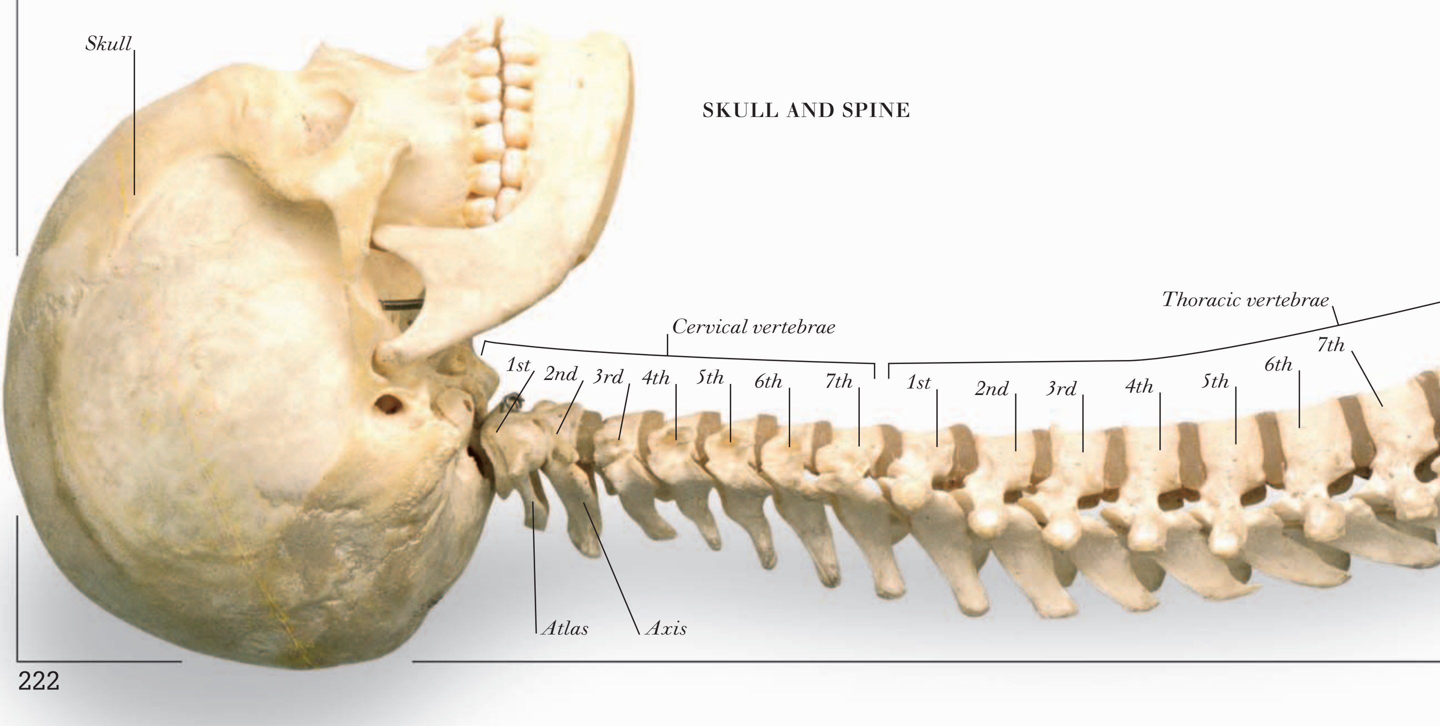
AXIS



CERVICAL VERTEBRA



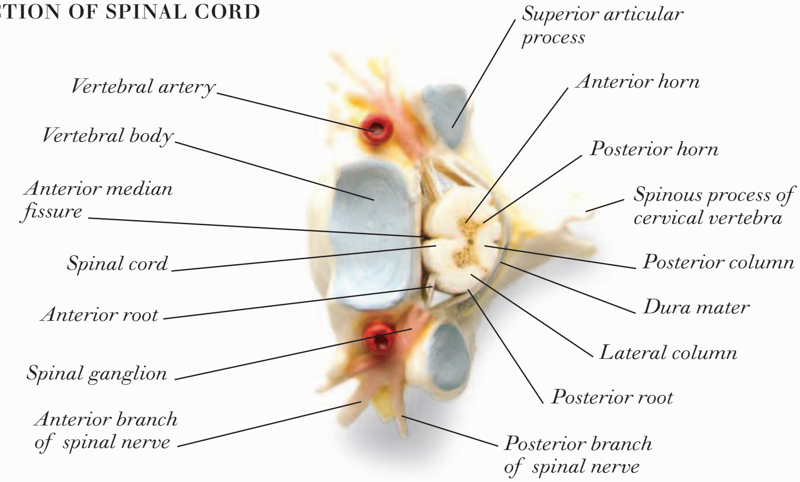
SKULL AND SPINE



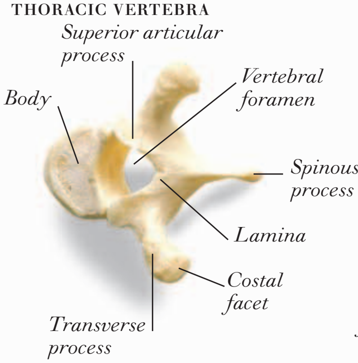
RIGHT SIDE

BACK

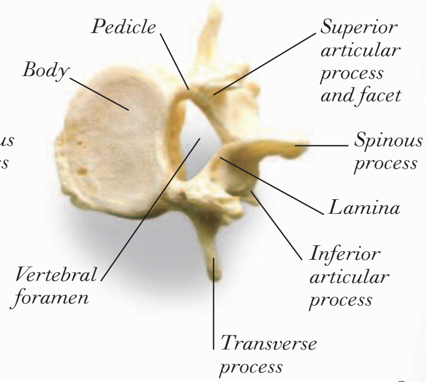
CERVICAL VERTEBRA AND SECTION OF SPINAL CORD



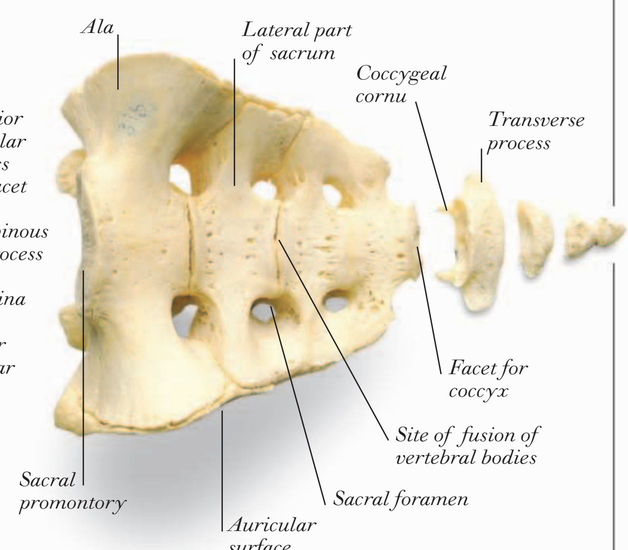
THORACIC VERTEBRA

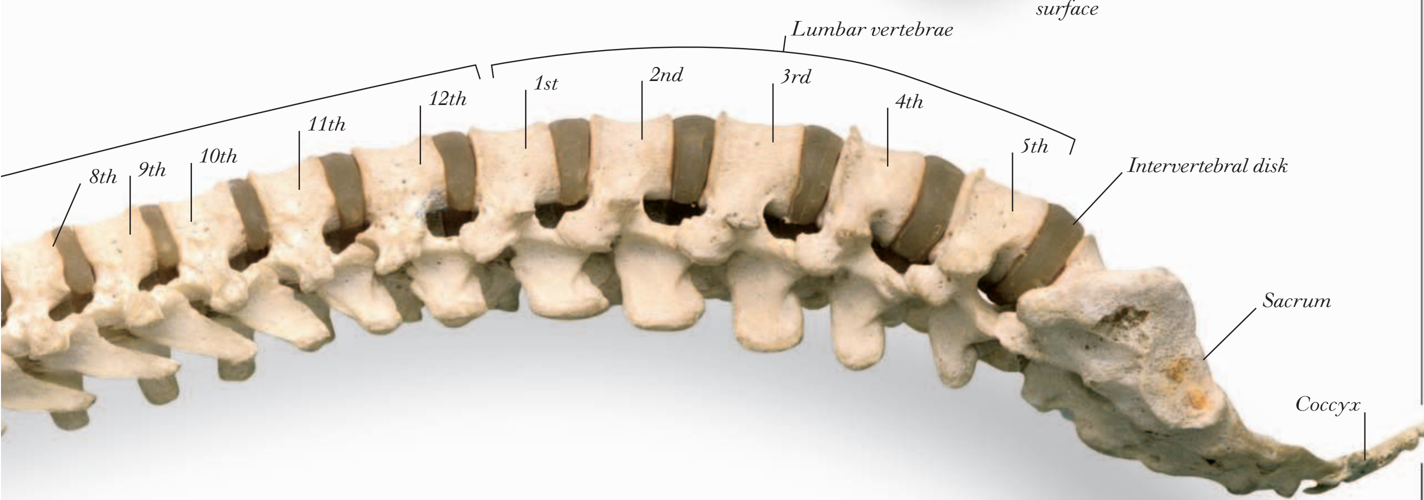


LUMBAR VERTEBRA



SACRUM **COCCYX**

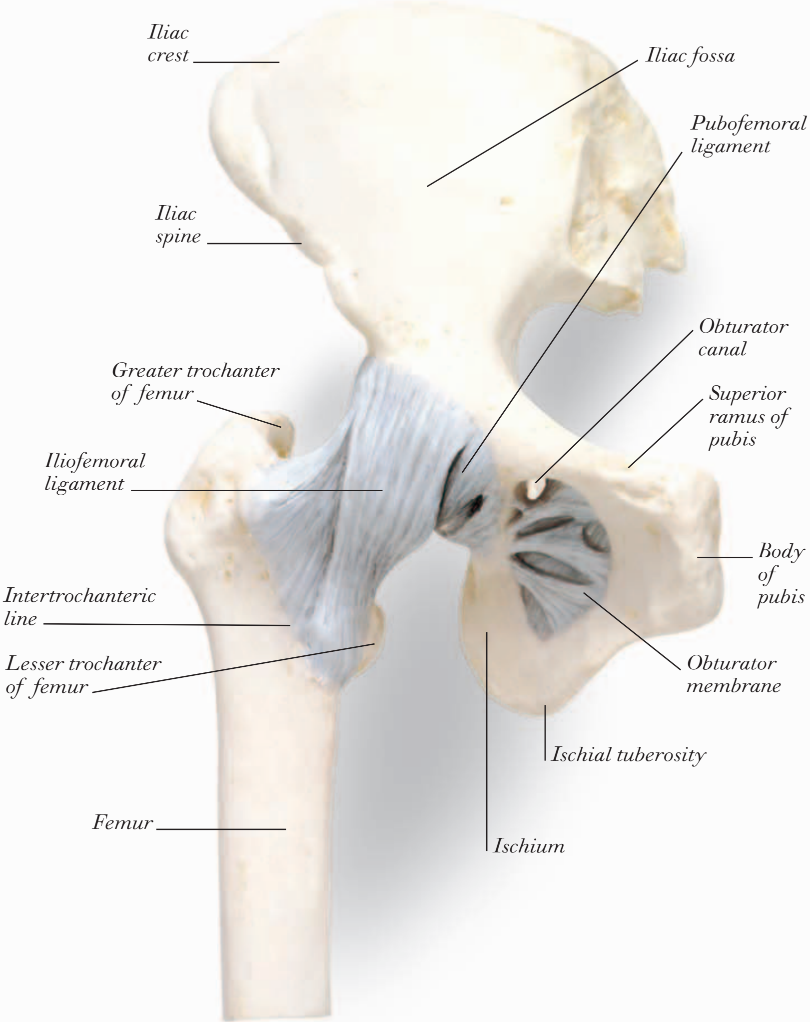




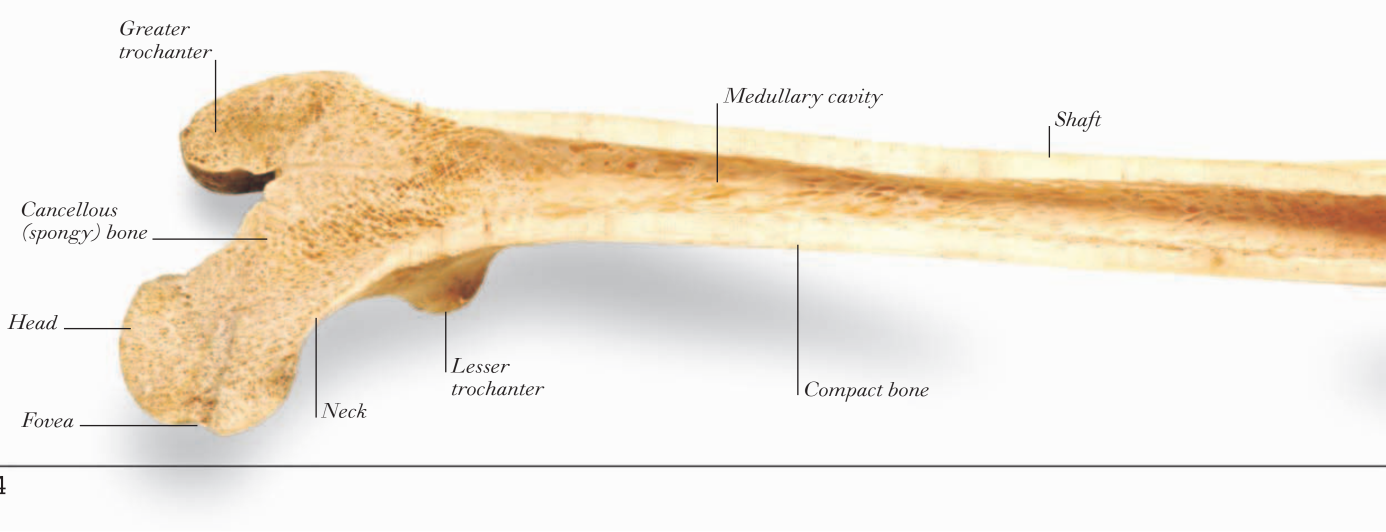
Bones and joints

BONES FORM the body's hard, strong skeletal framework. Each bone has a hard, compact exterior surrounding a spongy, lighter interior. The long bones of the arms and legs, such as the femur (thigh bone), have a central cavity containing bone marrow. Bones are composed chiefly of calcium, phosphorus, and a fibrous substance known as collagen. Bones meet at joints, which are of several different types. For example, the hip is a ball-and-socket joint that allows the femur a wide range of movement, whereas finger joints are simple hinge joints that allow only bending and straightening. Joints are held in place by bands of tissue called ligaments. Movement of joints is facilitated by the smooth hyaline cartilage that covers the bone ends and by the synovial membrane that lines and lubricates the joint.

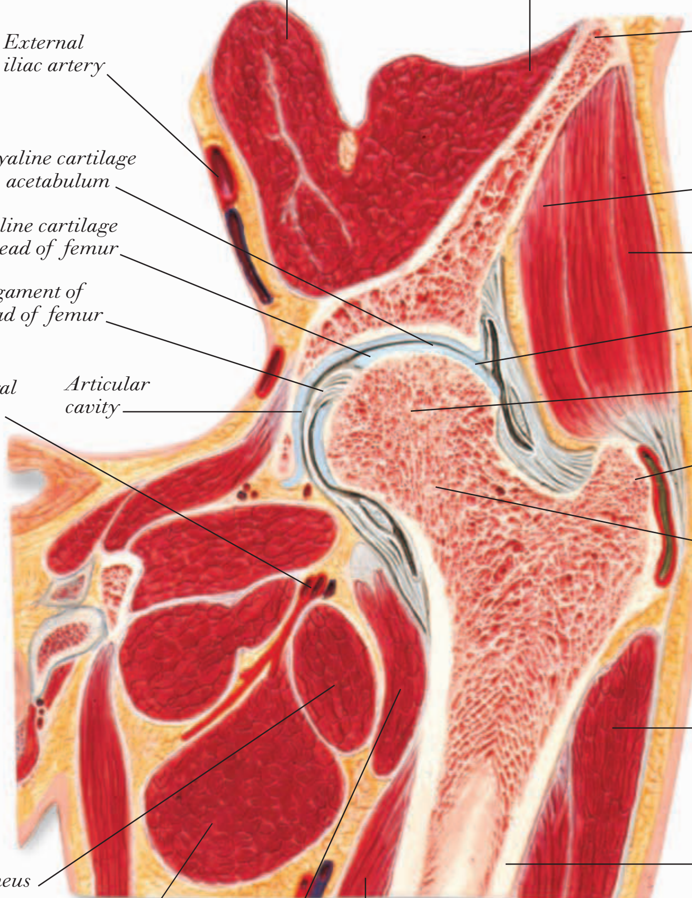
LIGAMENTS SURROUNDING HIP JOINT



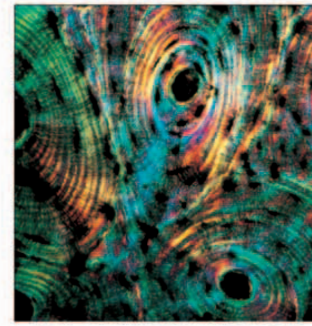
SECTION THROUGH LEFT FEMUR



SECTION THROUGH HIP JOINT

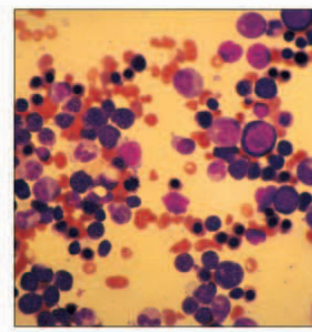


SECTION OF COMPACT BONE

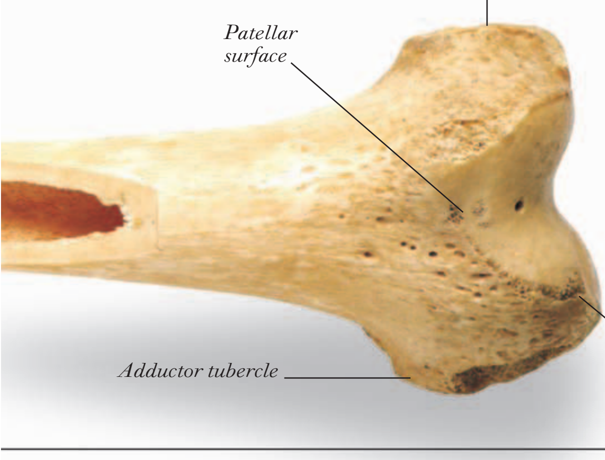


Parallel rows of concentric bony layers make up this strong material.

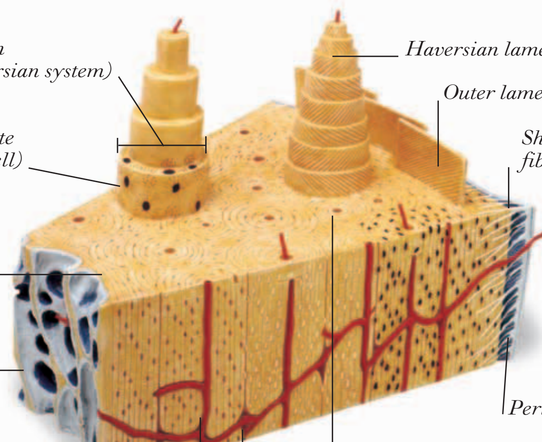
BONE MARROW SMEAR



Composed mainly of red and white blood cells, marrow fills the cavities of bones.



SECTION THROUGH LONG BONE

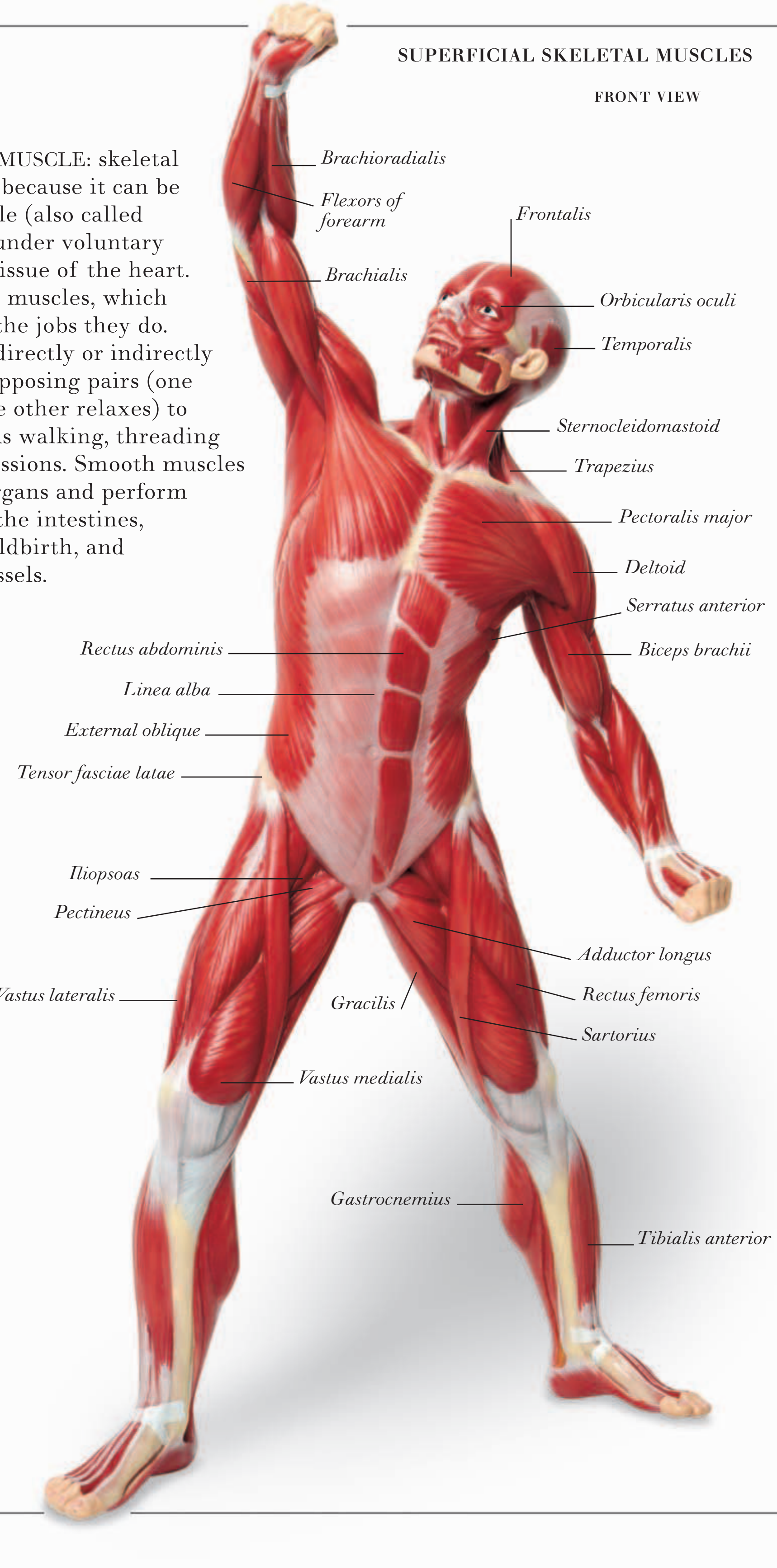


Muscles 1

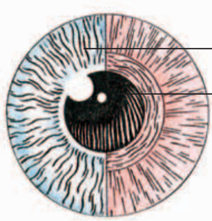
THERE ARE THREE MAIN TYPES OF MUSCLE: skeletal muscle (also called voluntary muscle because it can be consciously controlled); smooth muscle (also called involuntary muscle because it is not under voluntary control); and the specialized muscle tissue of the heart. Humans have more than 600 skeletal muscles, which differ in size and shape according to the jobs they do. Skeletal muscles are attached either directly or indirectly (via tendons) to bones, and work in opposing pairs (one muscle in the pair contracts while the other relaxes) to produce body movements as diverse as walking, threading a needle, and an array of facial expressions. Smooth muscles occur in the walls of internal body organs and perform actions such as forcing food through the intestines, contracting the uterus (womb) in childbirth, and pumping blood through the blood vessels.

SUPERFICIAL SKELETAL MUSCLES

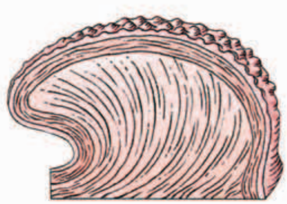
FRONT VIEW



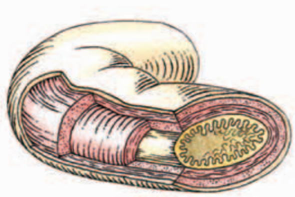
SOME OTHER MUSCLES IN THE BODY



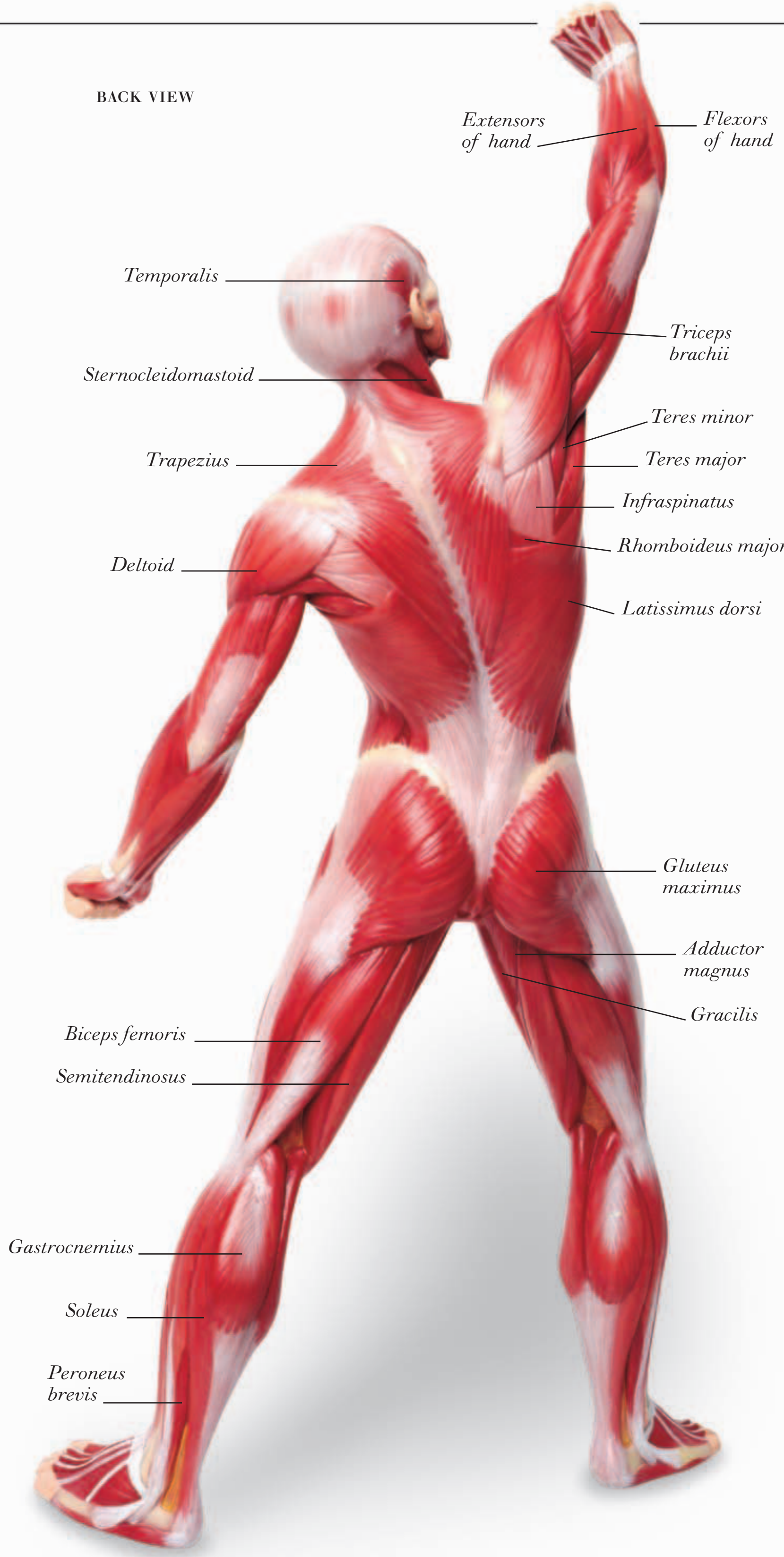
IRIS
The muscle fibers contract and dilate (expand) to alter pupil size.



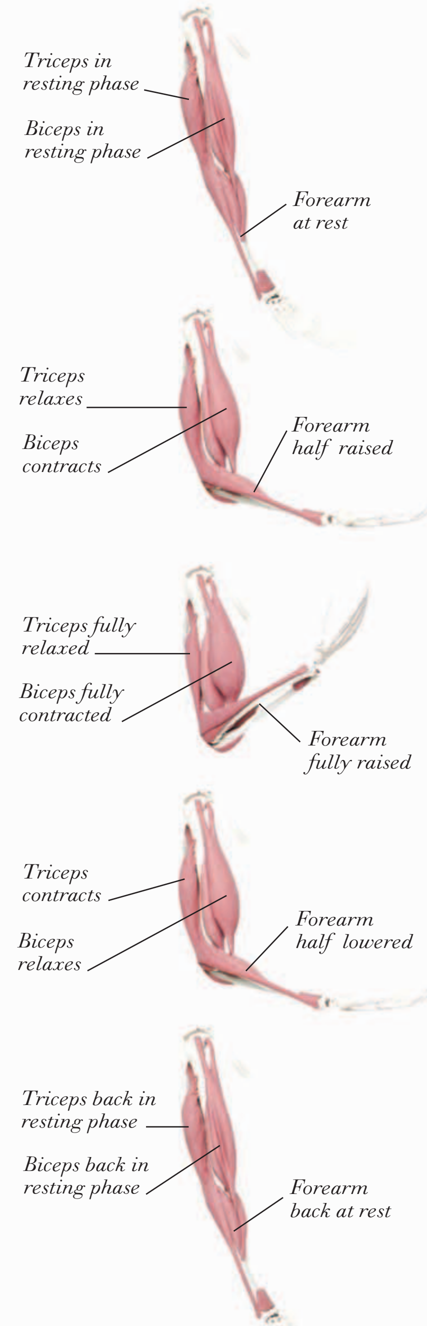
TONGUE
Interlacing layers of muscle allow great mobility.



ILEUM
Opposing muscle layers transport semidigested food.

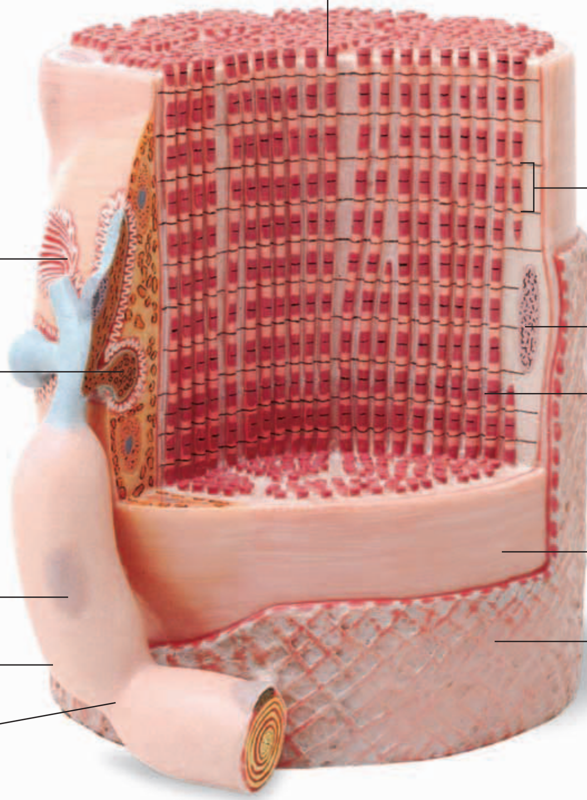


MOVEMENT OF THE FOREARM
Controlled movement of the limbs relies on coordinated relaxation and contraction of opposing muscles. To raise the forearm, the biceps (two-rooted muscle) contracts and shortens while the triceps (three-rooted muscle) relaxes; the reverse occurs when the forearm is lowered.

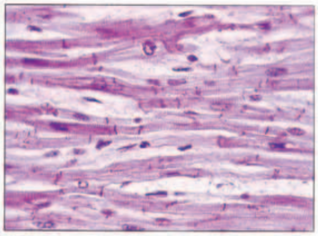


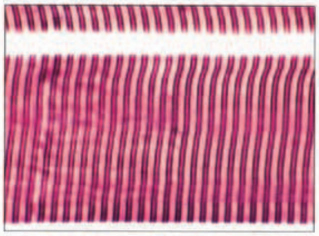
Muscles 2

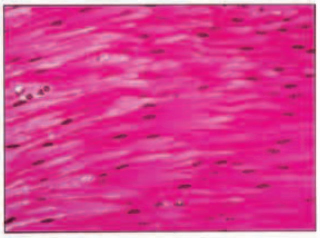
SKELETAL MUSCLE FIBER



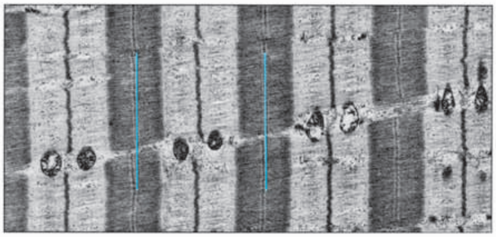
TYPES OF MUSCLE

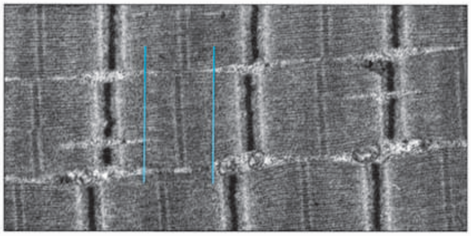

CARDIAC MUSCLE


SKELETAL MUSCLE


SMOOTH MUSCLE

CONTRACTION OF SKELETAL MUSCLE


RELAXED STATE


CONTRACTED STATE

MUSCLES OF FACIAL EXPRESSION

A single expression is the result of movement of many muscles; the main muscles of expression are shown in action below.


FRONTALIS

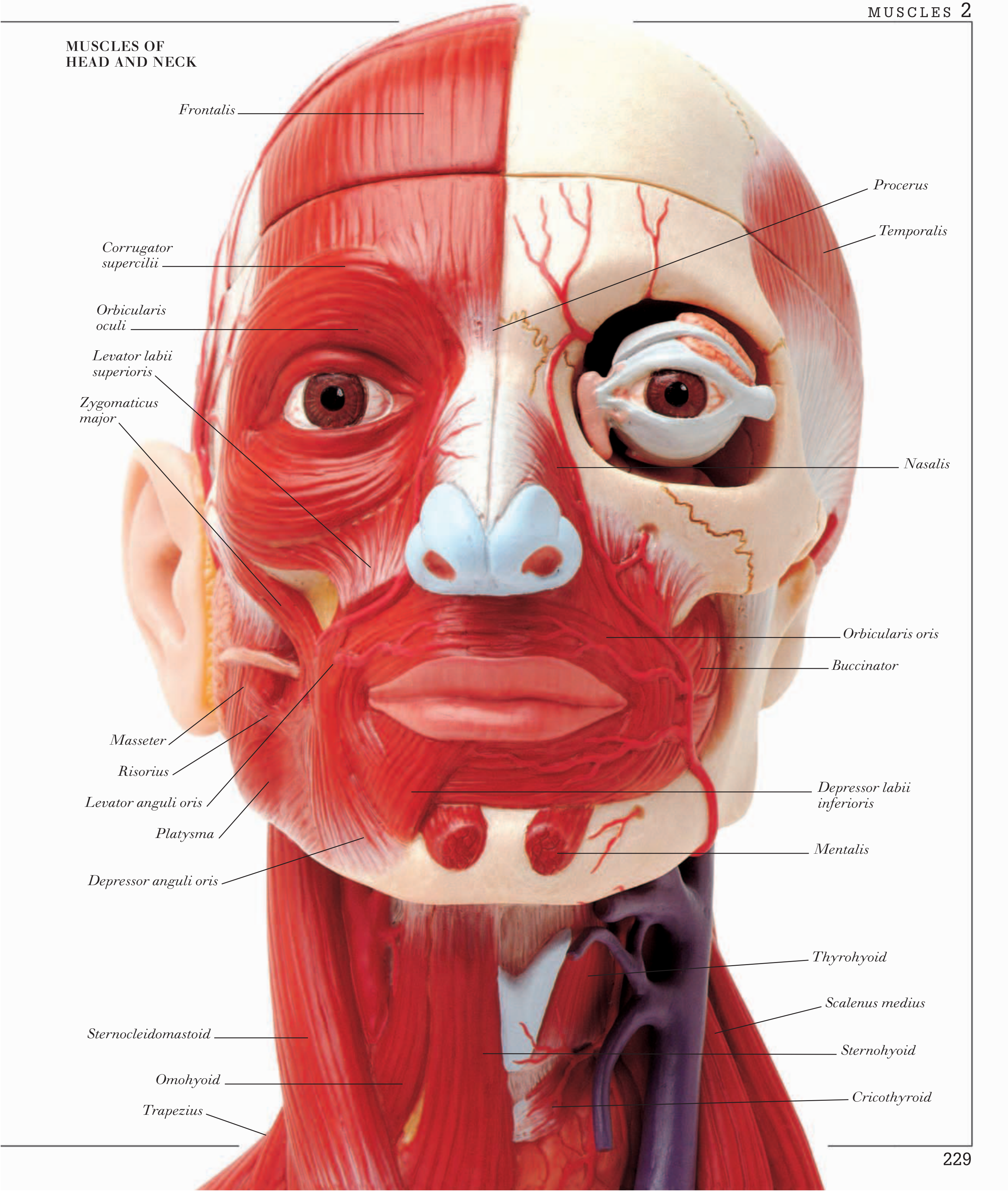

CORRUGATOR SUPERCILII


ORBICULARIS ORIS


ZYGOMATICUS MAJOR


DEPRESSOR ANGULI ORIS

MUSCLES OF HEAD AND NECK



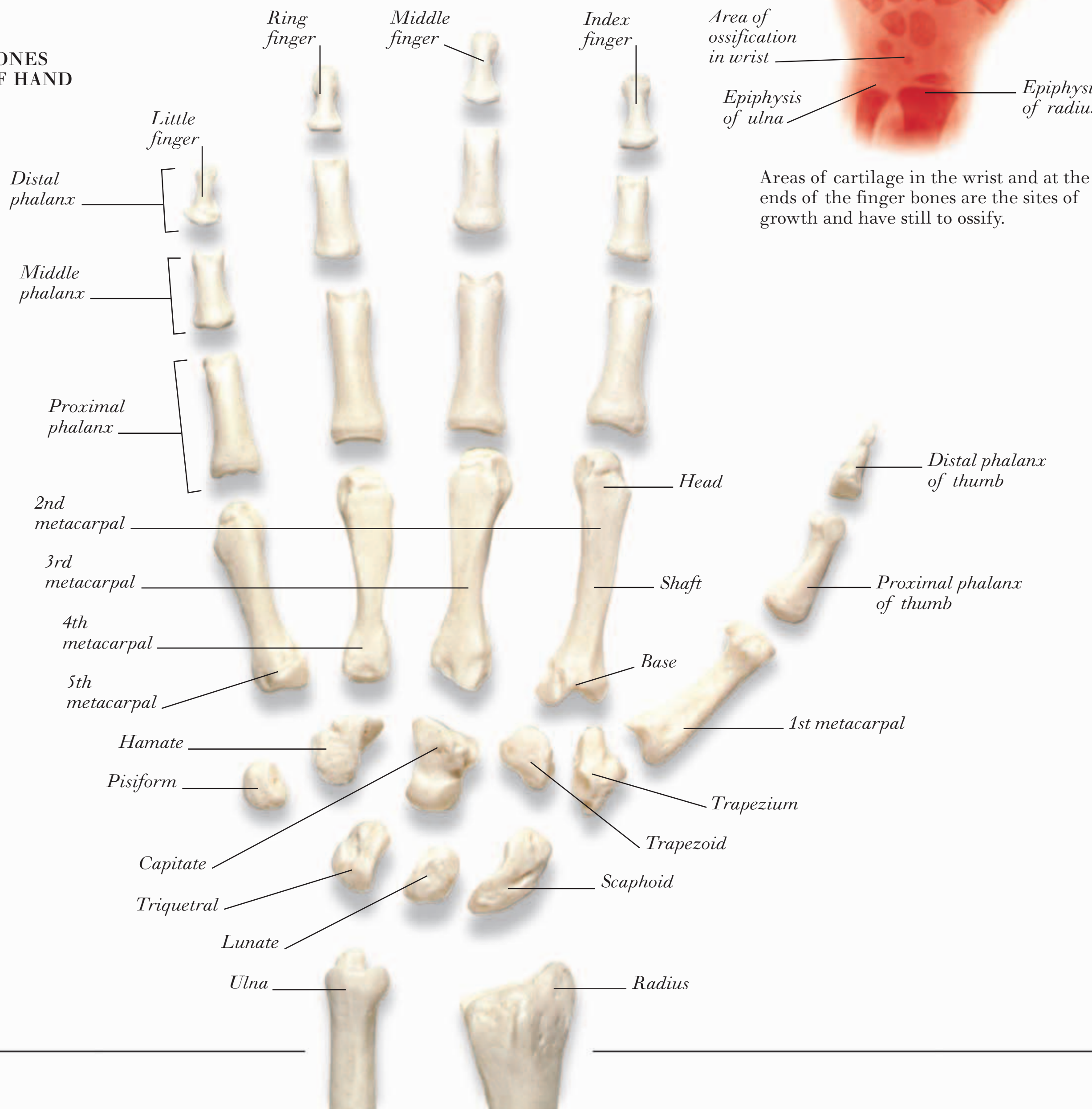
Hands

THE HUMAN HAND is an extremely versatile tool, capable of delicate manipulation as well as powerful gripping actions. The arrangement of its 27 small bones, moved by 37 skeletal muscles that are connected to the bones by tendons, allows a wide range of movements. Our ability to bring the tips of our thumbs and fingers together, combined with the extraordinary sensitivity of our fingertips due to their rich supply of nerve endings, makes our hands uniquely dextrous.

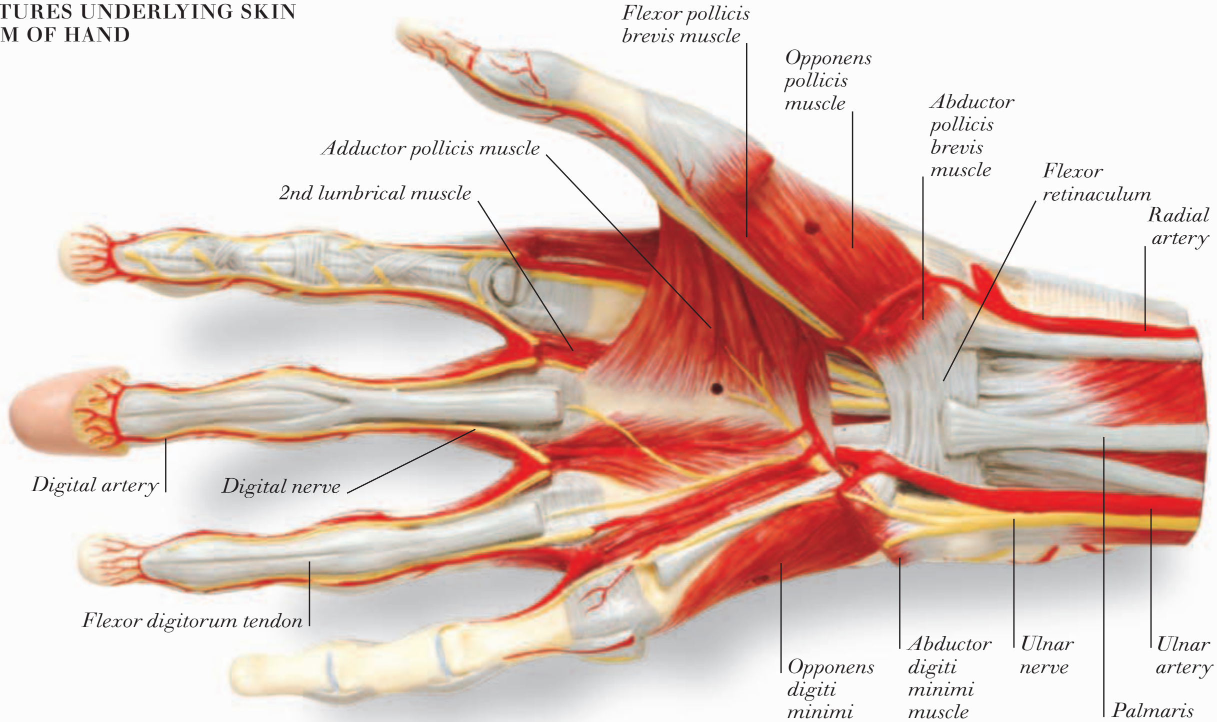
X-RAY OF LEFT HAND OF A YOUNG CHILD

Areas of cartilage in the wrist and at the ends of the finger bones are the sites of growth and have still to ossify.

BONES OF HAND



STRUCTURES UNDERLYING SKIN OF PALM OF HAND

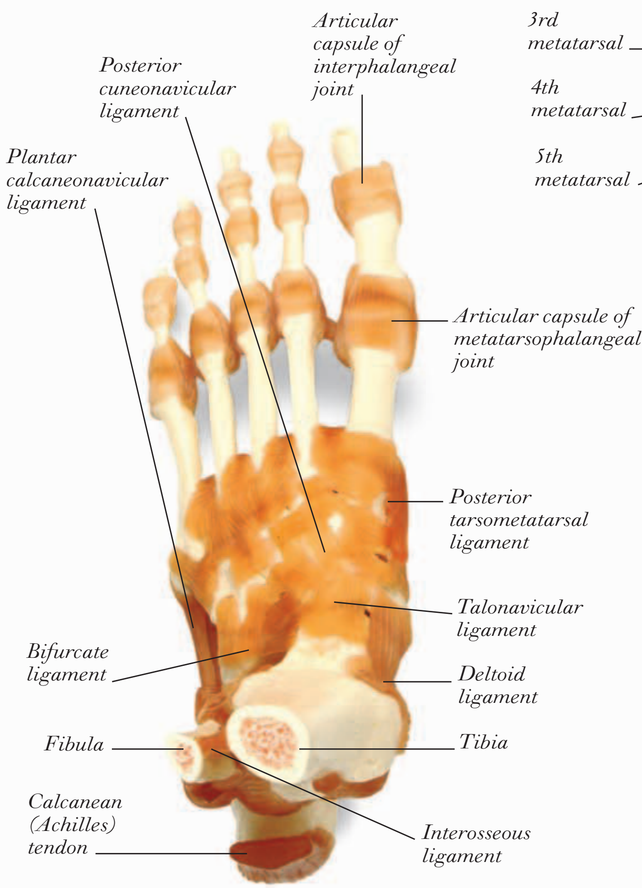


EXTERNAL FEATURES OF BACK OF HAND

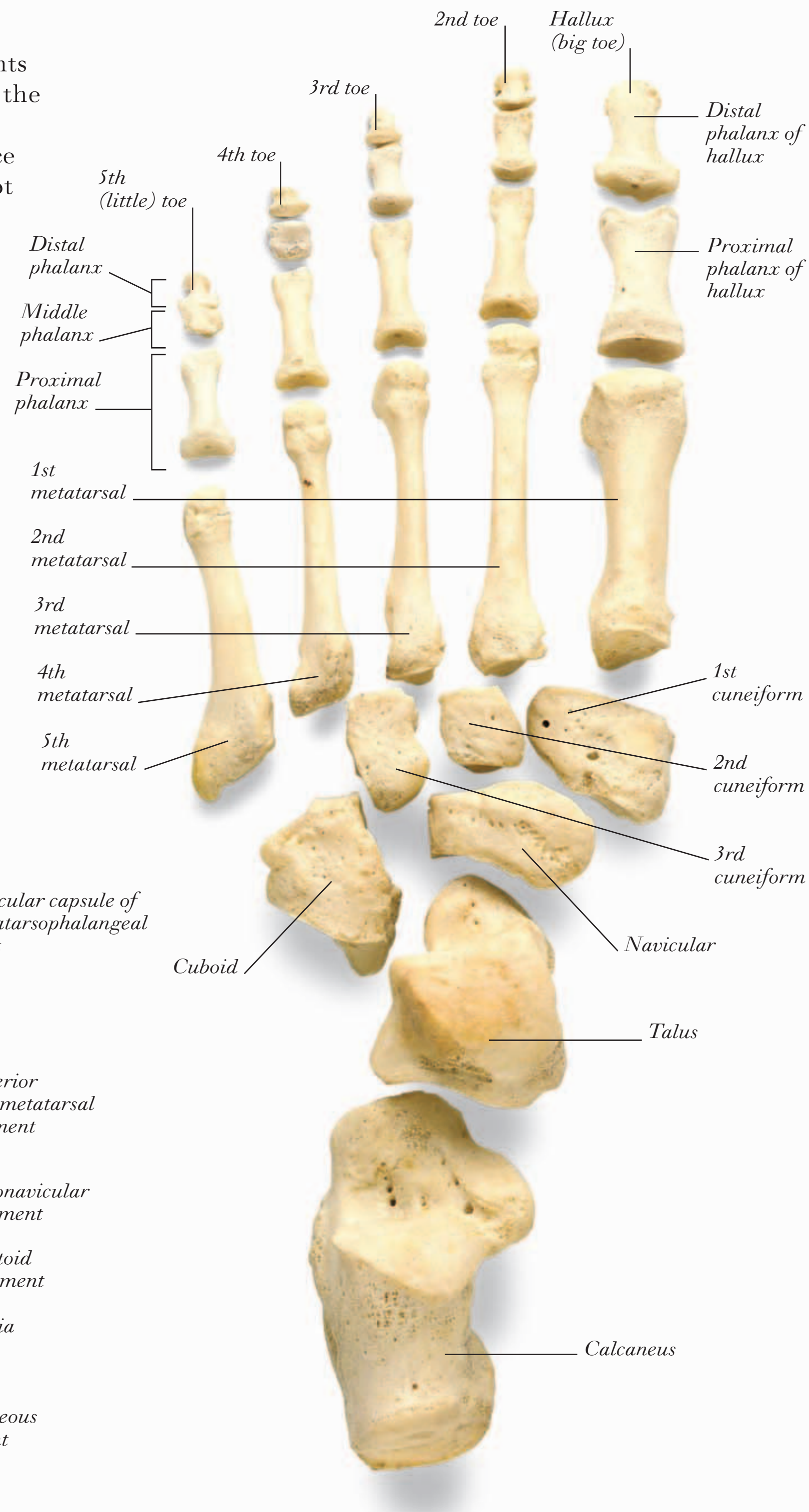
Feet

THE FEET AND TOES are essential elements in body movement. They bear and propel the weight of the body during walking and running, and also help to maintain balance during changes of body position. Each foot has 26 bones, more than 100 ligaments, and 33 muscles, some of which are attached to the lower leg. The heel pad and the arch of the foot act as shock absorbers, providing a cushion against the jolts that occur with every step.

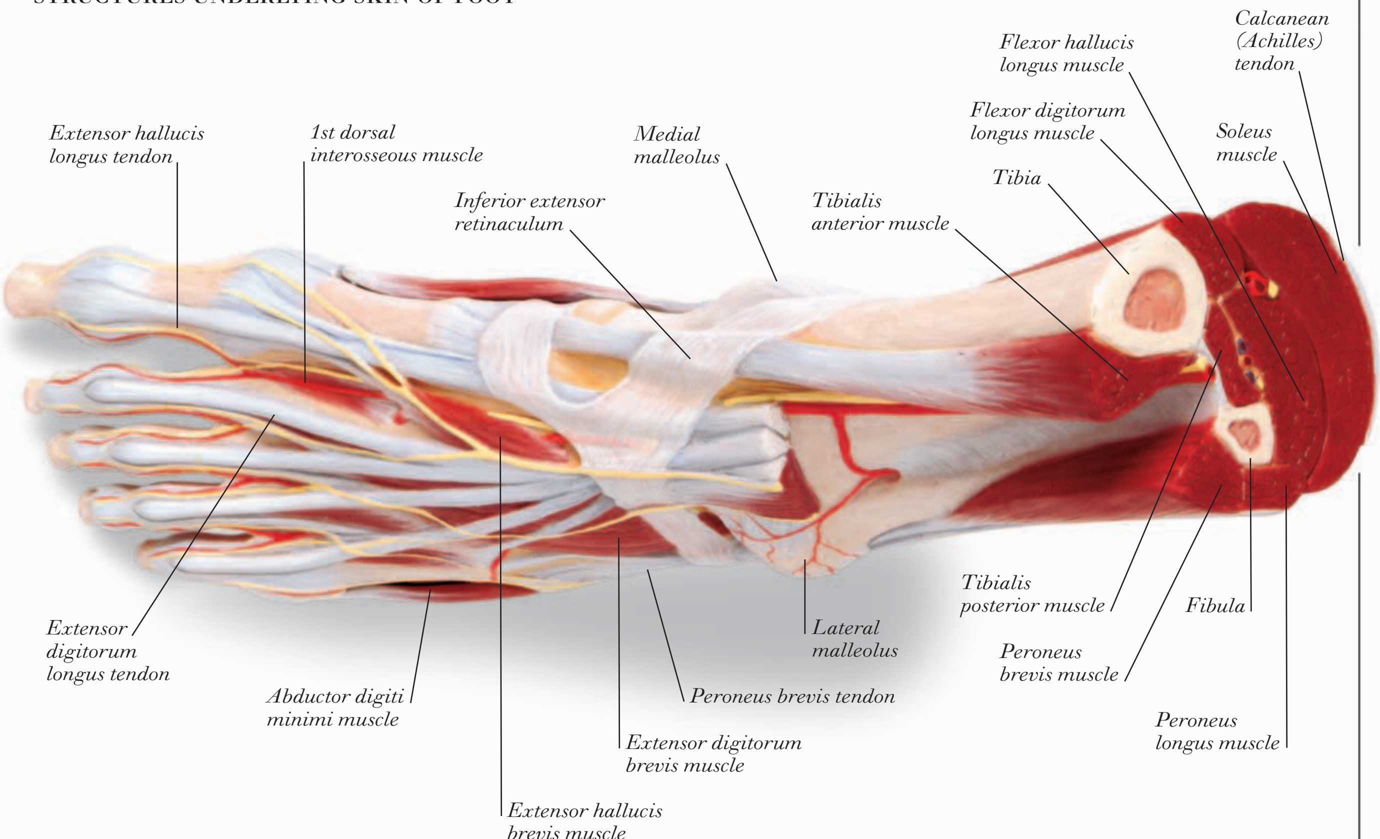
LIGAMENTS OF FOOT



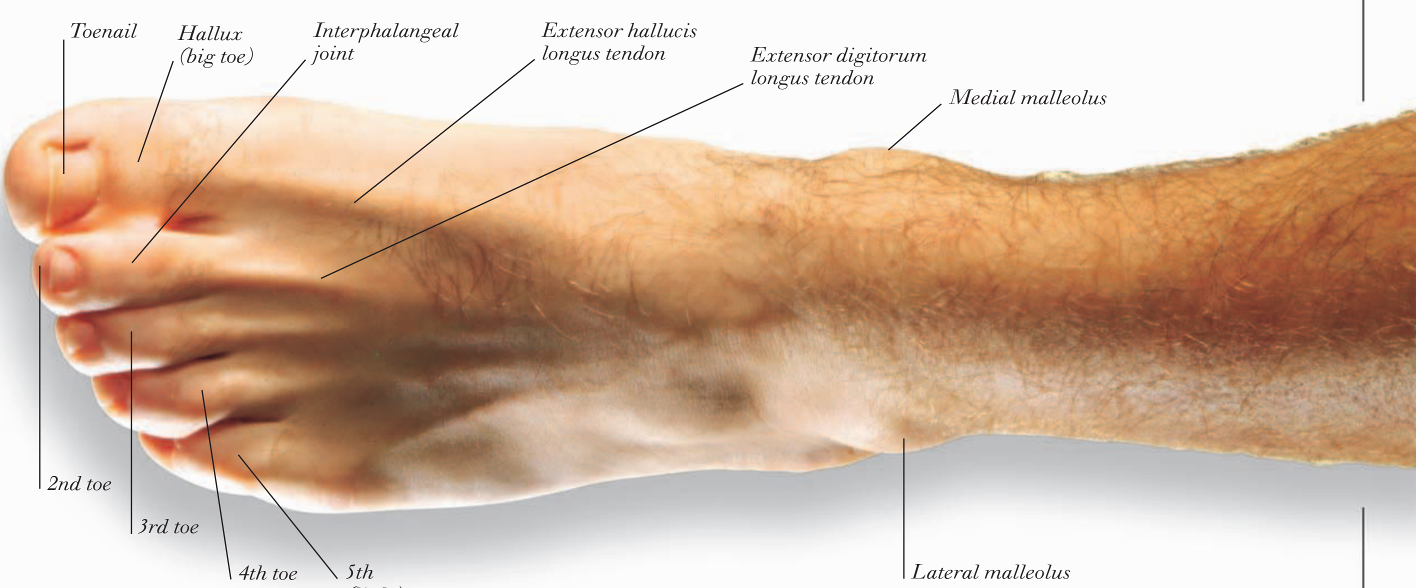
BONES OF FOOT



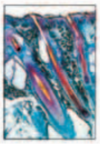
STRUCTURES UNDERLYING SKIN OF FOOT



EXTERNAL FEATURES OF FOOT

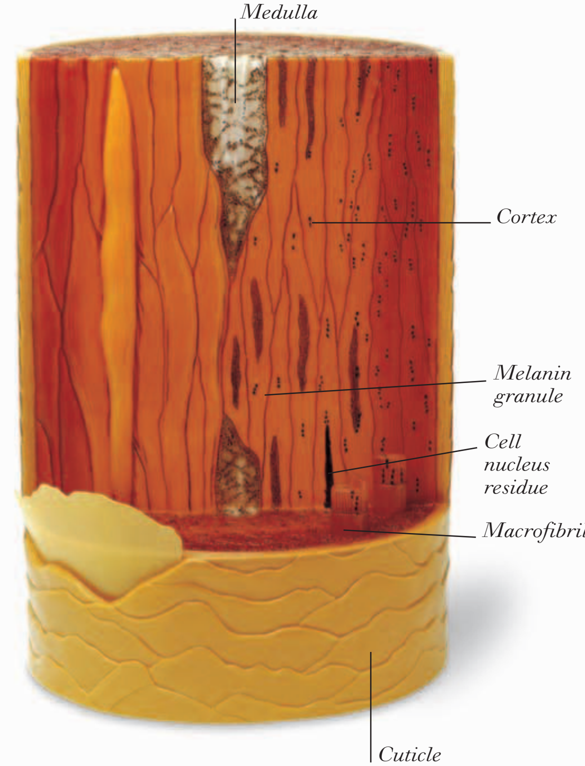


Skin and hair

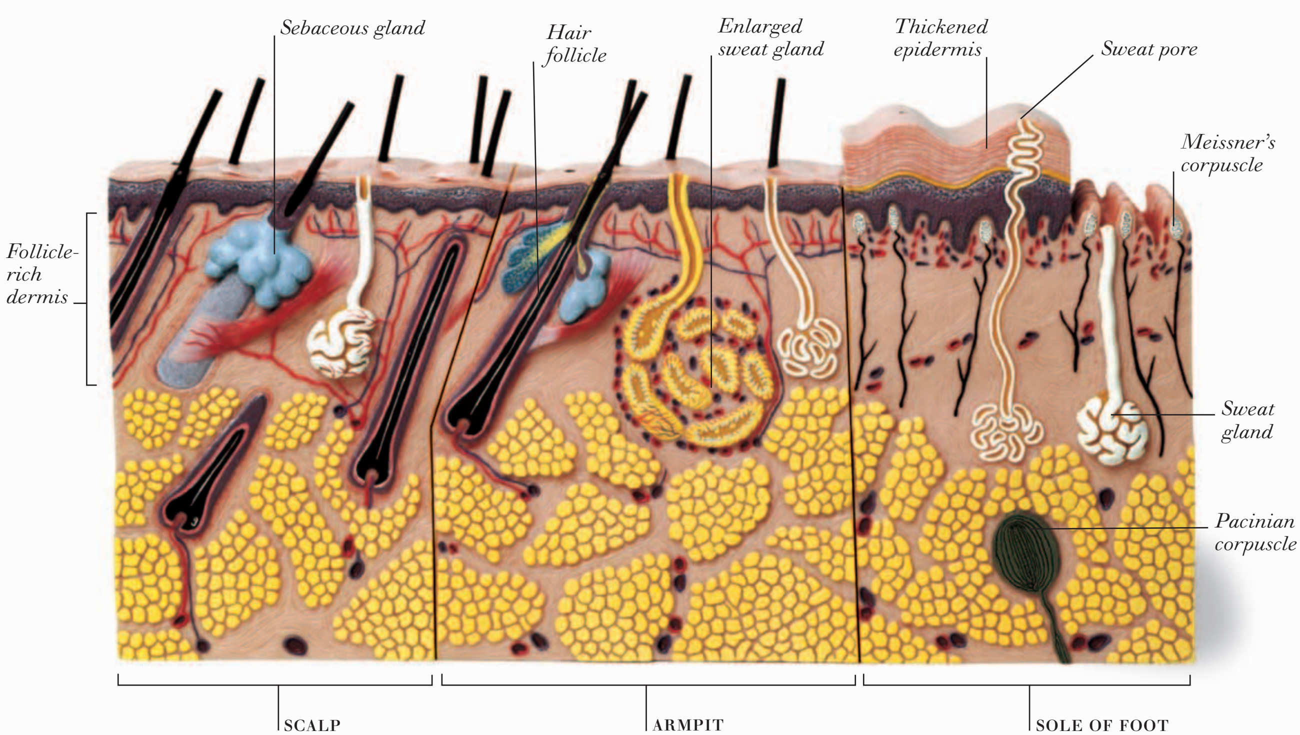


SKIN IS THE BODY'S LARGEST ORGAN, a waterproof barrier that protects the internal organs against infection, injury, and harmful sun rays. The skin is also an important sensory organ and helps to control body temperature. The outer layer of the skin, known as the epidermis, is coated with keratin, a tough, horny protein that is also the chief constituent of hair and nails. Dead cells are shed from the skin's surface and are replaced by new cells from the base of the epidermis, the region that also produces the skin pigment, melanin. The dermis contains most of the skin's living structures, and includes nerve endings, blood vessels, elastic fibers, sweat glands that cool the skin, and sebaceous glands that produce oil to keep the skin supple. Beneath the dermis lies the subcutaneous tissue (hypodermis), which is rich in fat and blood vessels. Hair shafts grow from hair follicles situated in the dermis and subcutaneous tissue. Hair grows on every part of the skin apart from the palms of the hands and soles of the feet.

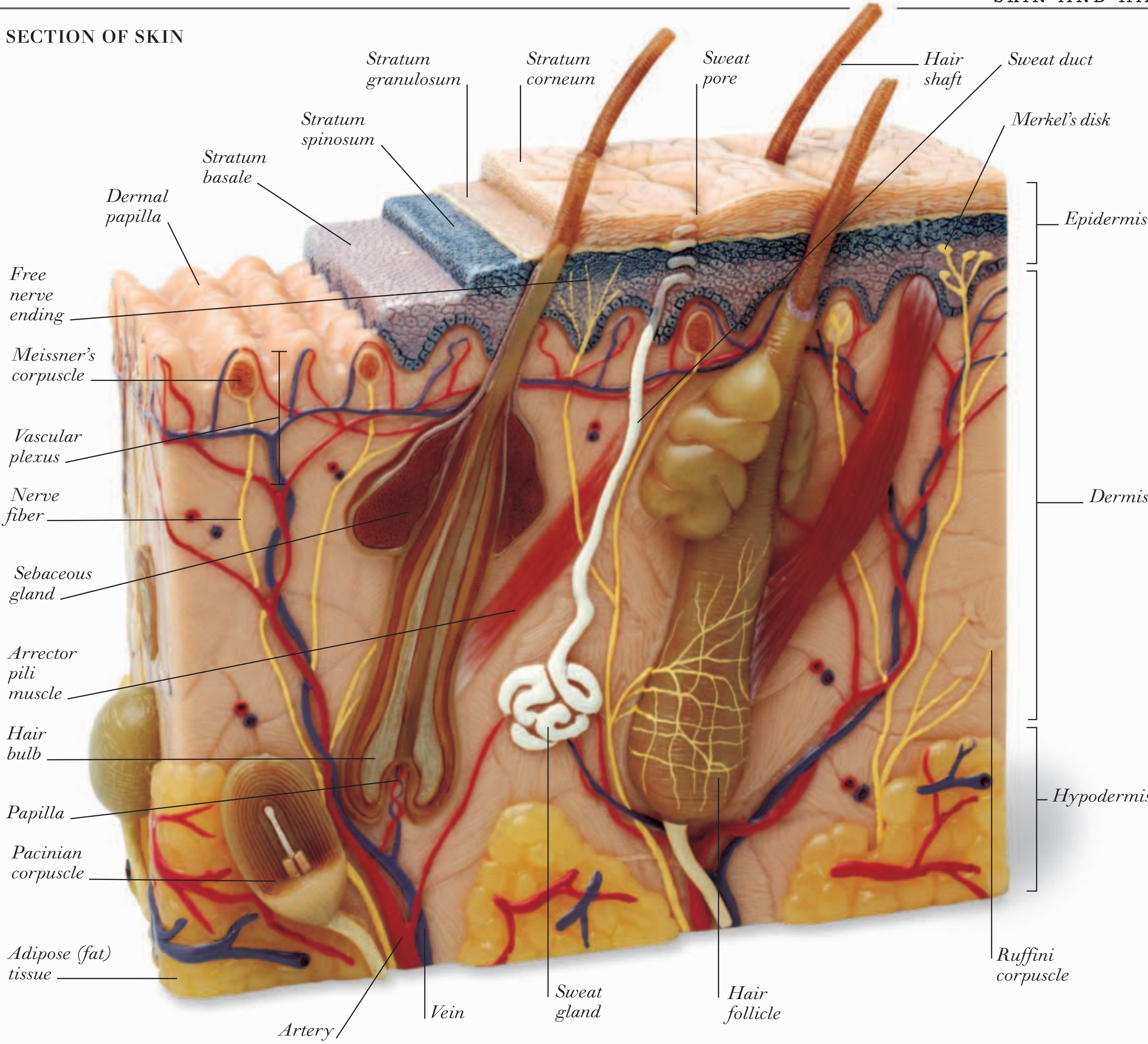
SECTION OF HAIR



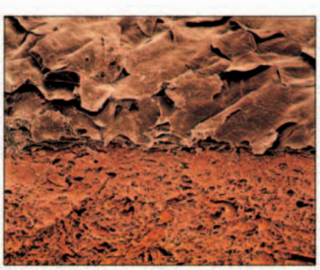
SECTIONS OF DIFFERENT TYPES OF SKIN



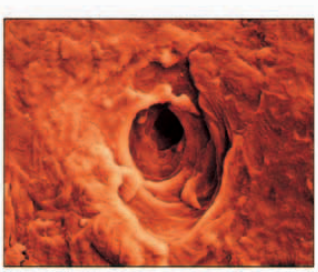
SECTION OF SKIN



PHOTOMICROGRAPHS OF SKIN AND HAIR

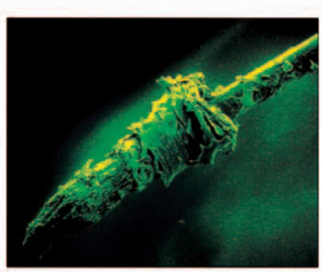


SECTION OF SKIN
The flaky cells at the skin's surface are shed continuously.



SWEAT PORE
This allows loss of fluid as part of temperature control.

SKIN HAIR
Two hairs pushing through the outer layer of skin.

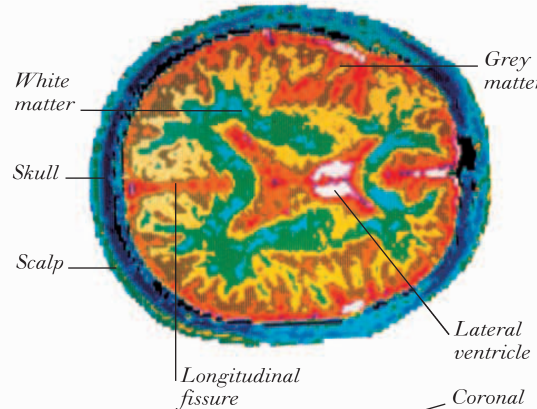


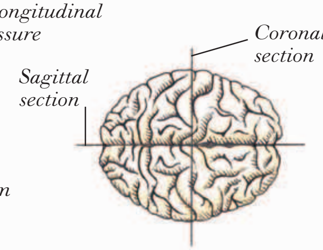
HEAD HAIR
The root and part of the shaft of a hair from the scalp.

Brain

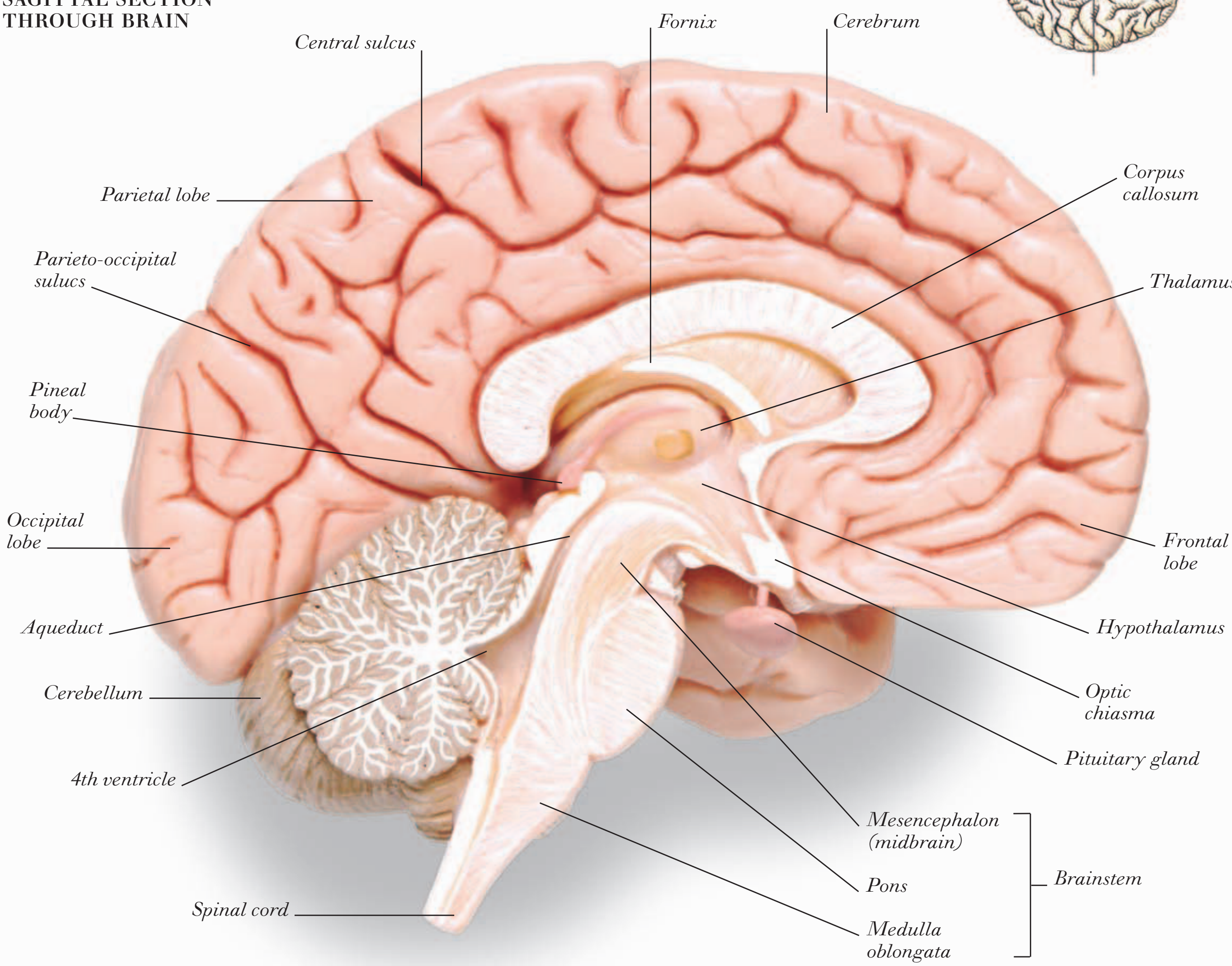
THE BRAIN IS THE MAJOR ORGAN of the central nervous system and the control center for all the body's voluntary and involuntary activities. It is also responsible for the complexities of thought, memory, emotion, and language. In adults, this complex organ is a mere 3 lb (1.4 kg) in weight, containing over 10 billion nerve cells. Three distinct regions can easily be seen—the brainstem, the cerebellum, and the large cerebrum. The brainstem controls vital body functions, such as breathing and digestion. The cerebellum's main functions are the maintenance of posture and the coordination of body movements. The cerebrum, which consists of the right and left cerebral hemispheres joined by the corpus callosum, is the site of most conscious and intelligent activities.

MRI SCAN OF TRANSVERSE SECTION THROUGH BRAIN

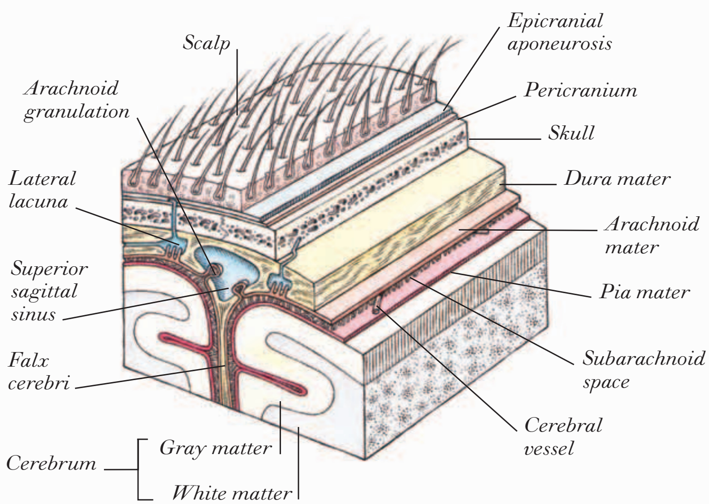




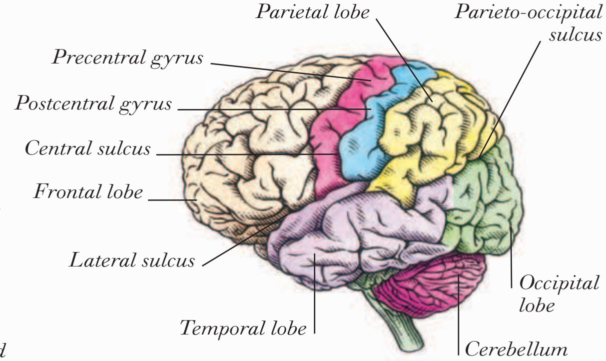
SAGITTAL SECTION THROUGH BRAIN



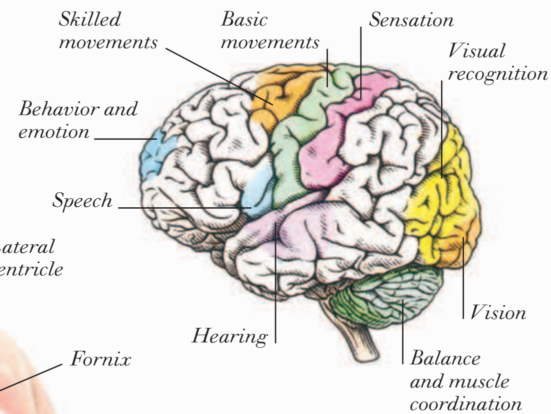
SECTION THROUGH SKULL AND BRAIN



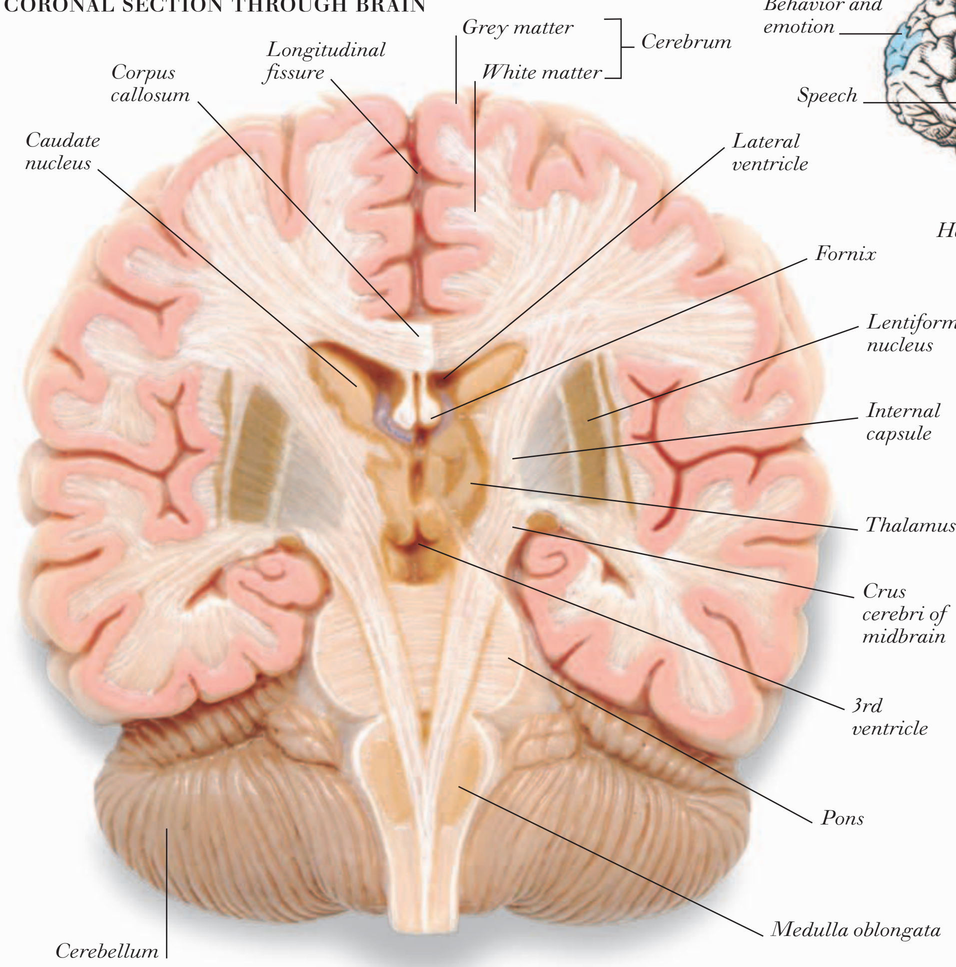
EXTERNAL ANATOMY OF BRAIN



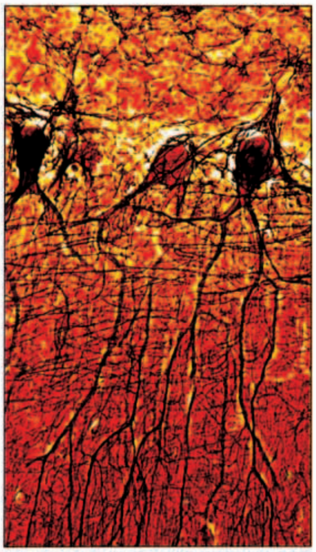
SPECIFIC ROLES OF AREAS OF CEREBRUM



CORONAL SECTION THROUGH BRAIN

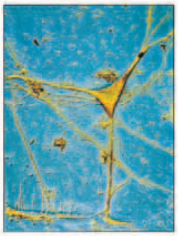


NERVE CELLS IN BRAIN



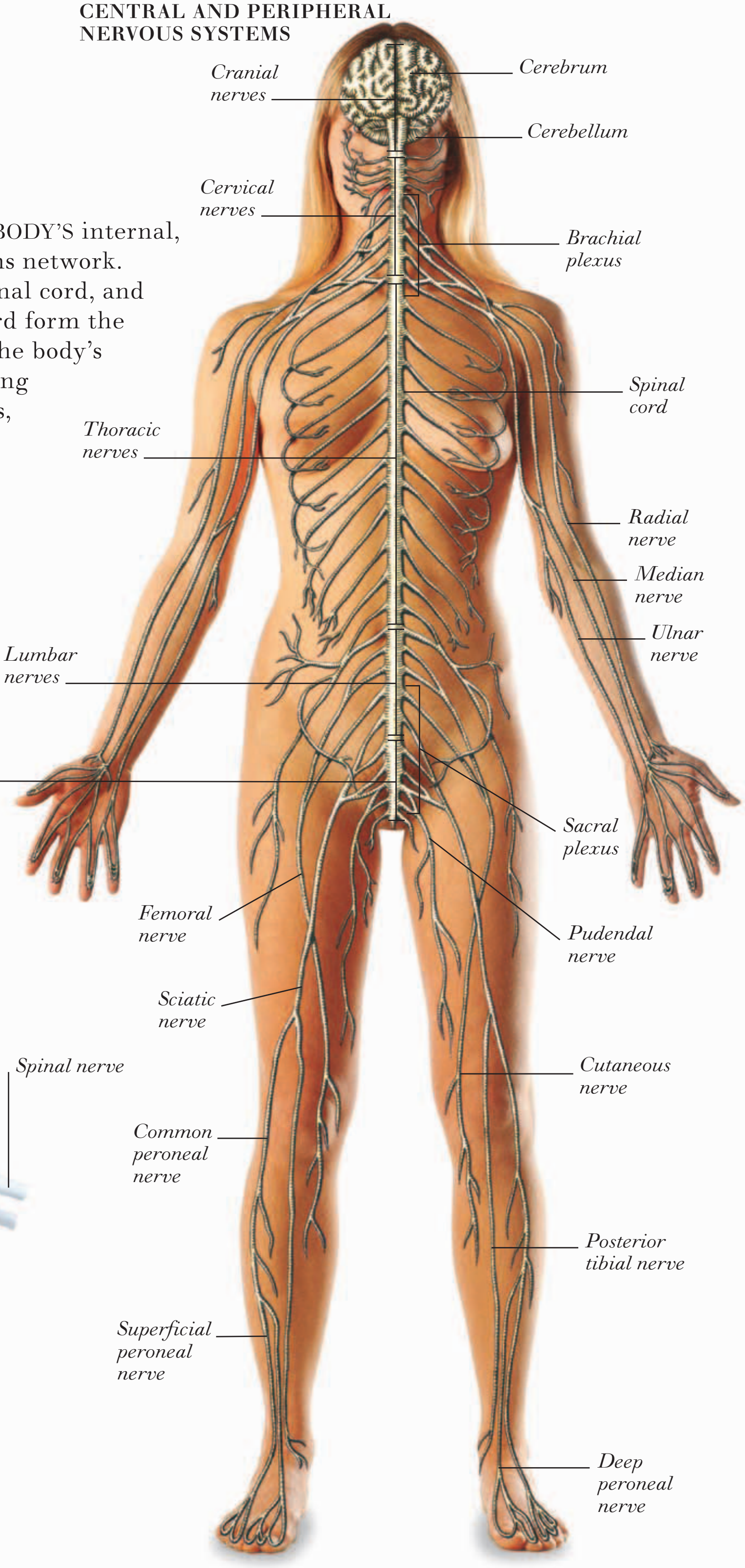
The dark cells are Purkinje's cells, which are among the largest nerve cells in the body.

Nervous system

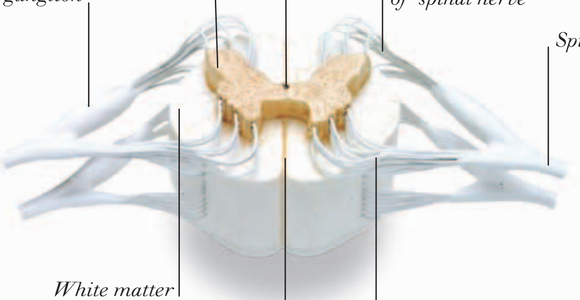


THE NERVOUS SYSTEM IS THE BODY'S internal, electrochemical, communications network. Its main parts are the brain, spinal cord, and nerves. The brain and spinal cord form the central nervous system (CNS), the body's chief controlling and coordinating centers. Billions of long neurons, many grouped as nerves, make up the peripheral nervous system, transmitting nerve impulses between the CNS and other regions of the body. Each neuron has three parts: a cell body, branching dendrites that receive chemical signals from other neurons, and a tubelike axon that conveys these signals as electrical impulses.

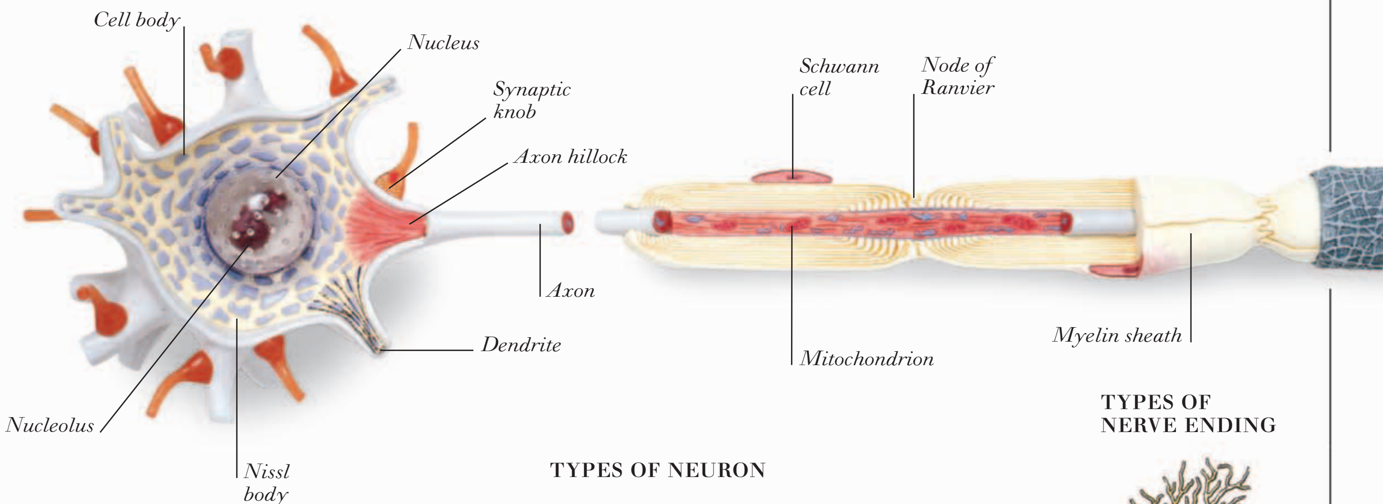
CENTRAL AND PERIPHERAL NERVOUS SYSTEMS



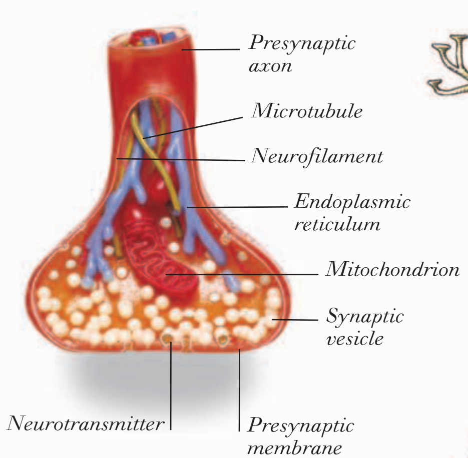
SECTION THROUGH SPINAL CORD



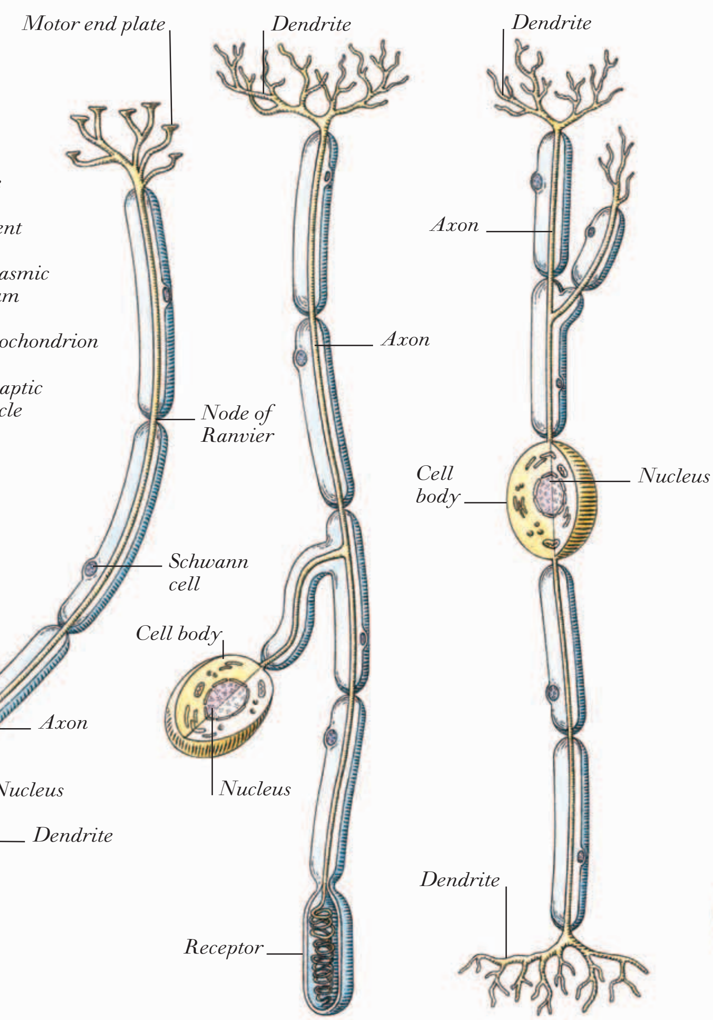
STRUCTURE OF A MOTOR NEURON

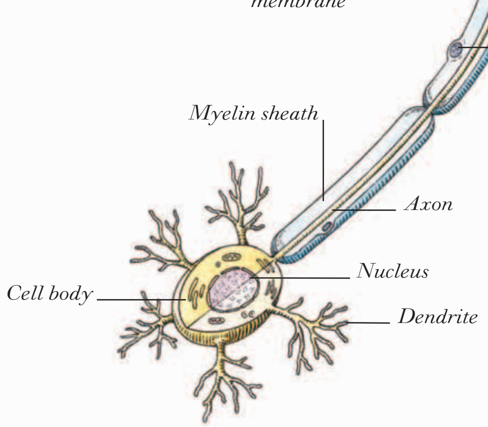


STRUCTURE OF A SYNAPTIC KNOB

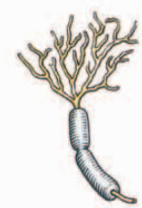


TYPES OF NEURON





TYPES OF NERVE ENDING



FREE NERVE ENDING

MEISSNER'S CORPUSCLE

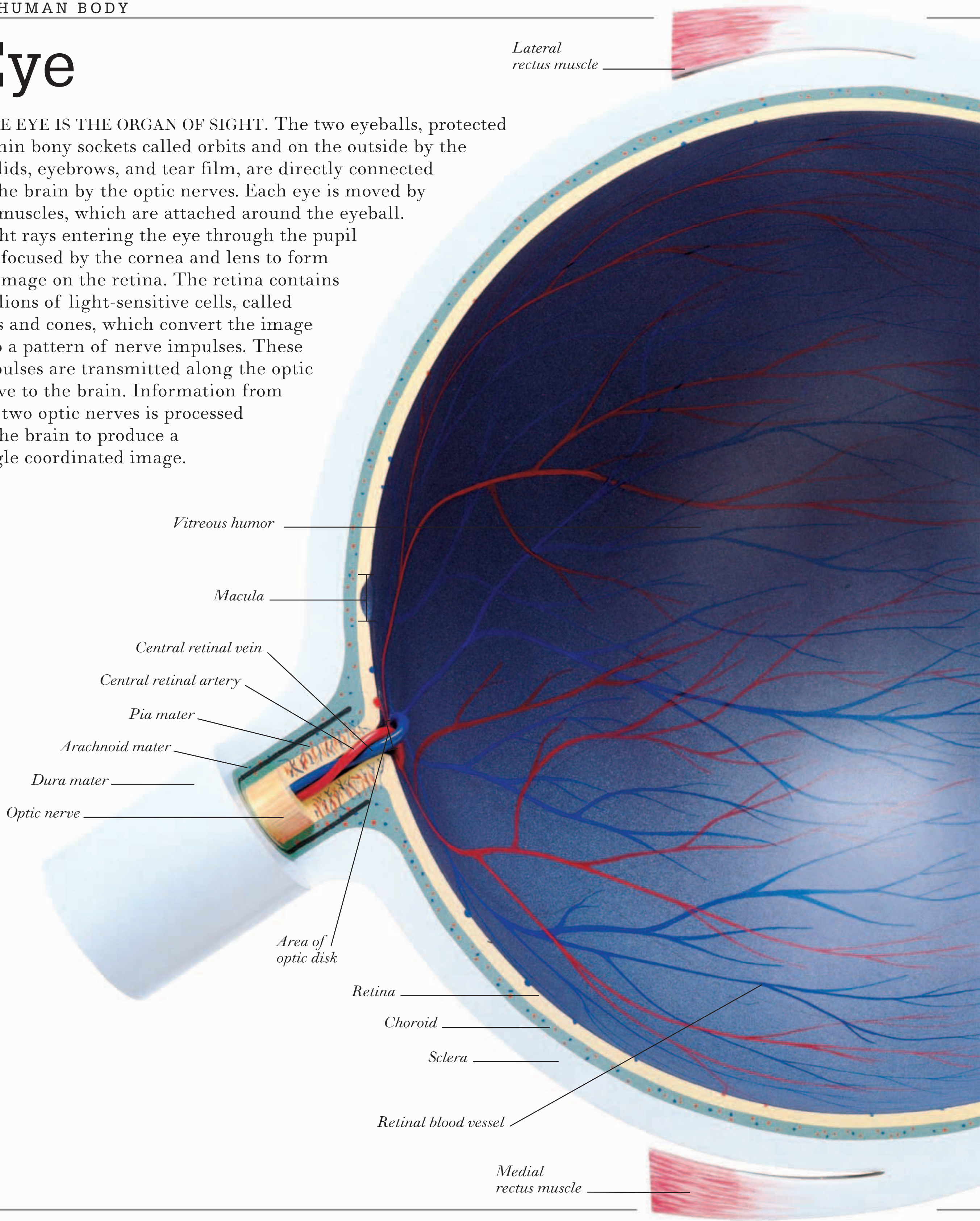
MERKEL'S DISK

RUFFINI CORPUSCLE

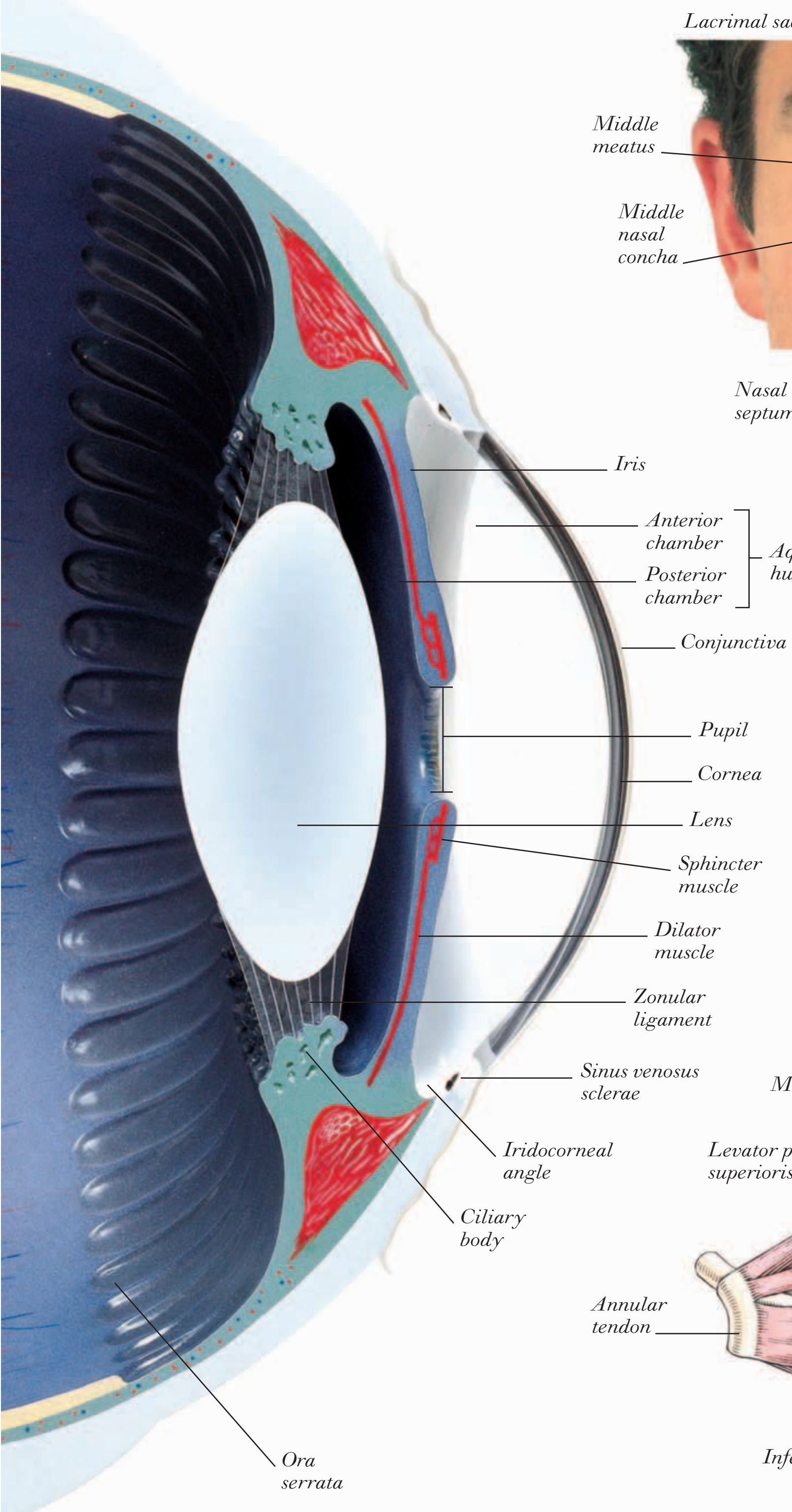
PACINIAN CORPUSCLE

Eye

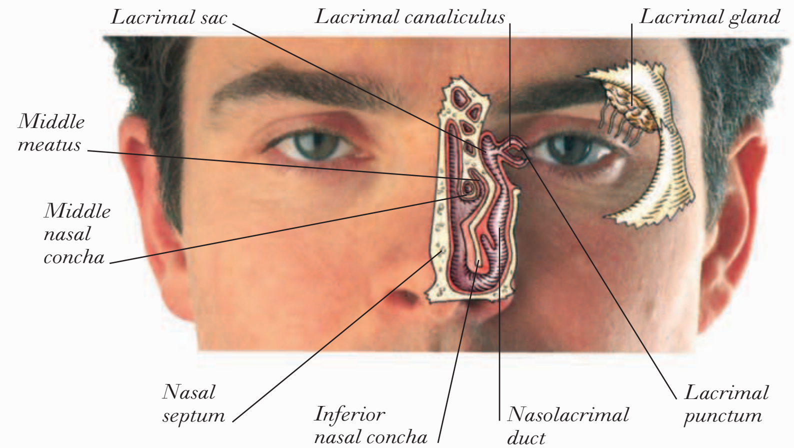
THE EYE IS THE ORGAN OF SIGHT. The two eyeballs, protected within bony sockets called orbits and on the outside by the eyelids, eyebrows, and tear film, are directly connected to the brain by the optic nerves. Each eye is moved by six muscles, which are attached around the eyeball. Light rays entering the eye through the pupil are focused by the cornea and lens to form an image on the retina. The retina contains millions of light-sensitive cells, called rods and cones, which convert the image into a pattern of nerve impulses. These impulses are transmitted along the optic nerve to the brain. Information from the two optic nerves is processed in the brain to produce a single coordinated image.



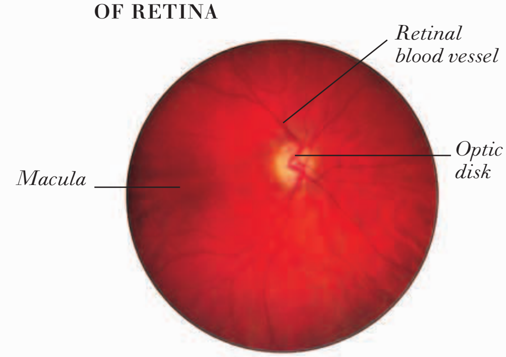
SECTION THROUGH LEFT EYE



LACRIMAL (TEAR-PRODUCING) APPARATUS

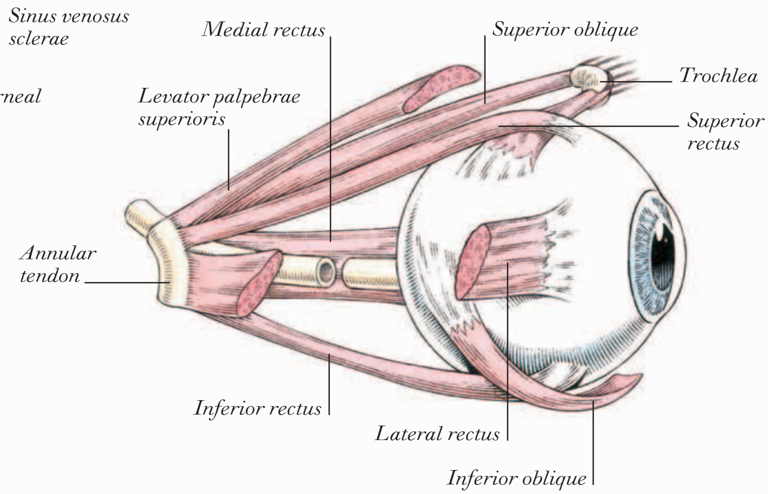


OPHTHALMOSCOPIC VIEW OF RETINA



The blind spot, where the optic nerve leaves the eye, can be clearly seen as a light circular area toward the center of the image.

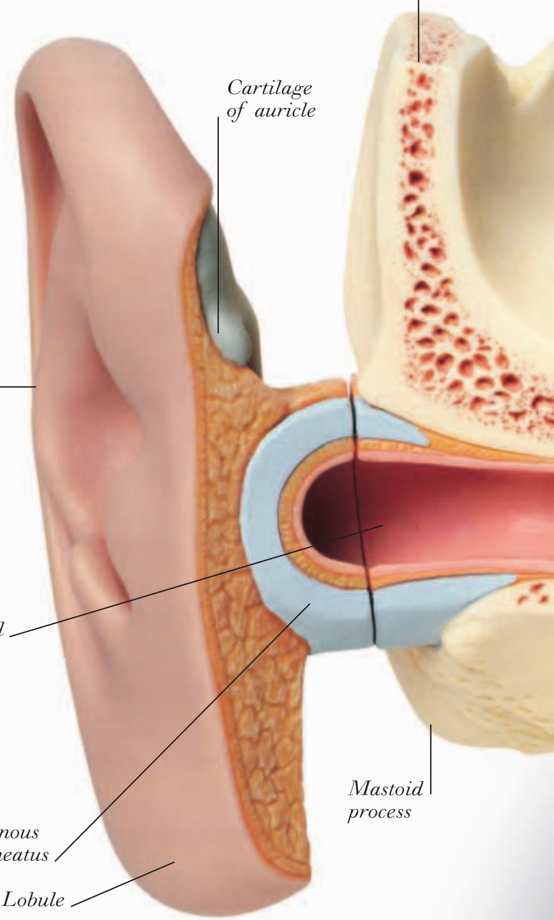
MUSCLES SURROUNDING RIGHT EYE



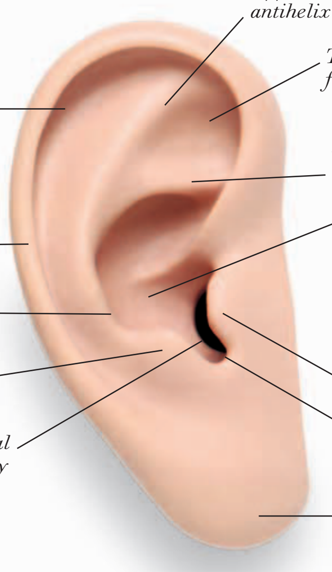
Ear

THE EAR IS THE ORGAN OF HEARING AND BALANCE. The outer ear consists of a flap called the auricle or pinna and the auditory canal. The main functional parts-the middle and inner ears-are enclosed within the skull. The middle ear consists of three tiny bones, known as auditory ossicles, and the eustachian tube, which links the ear to the back of the nose. The inner ear consists of the spiral-shaped cochlea, and also the semicircular canals and the vestibule, which are the organs of balance. Sound waves entering the ear travel through the auditory canal to the tympanic membrane (eardrum), where they are converted to vibrations that are transmitted via the ossicles to the cochlea. Here, the vibrations are converted by millions of microscopic hairs into electrical nerve signals to be interpreted by the brain.

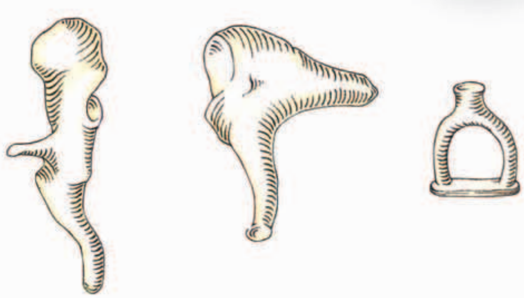
STRUCTURE OF EAR



RIGHT AURICLE (PINNA)



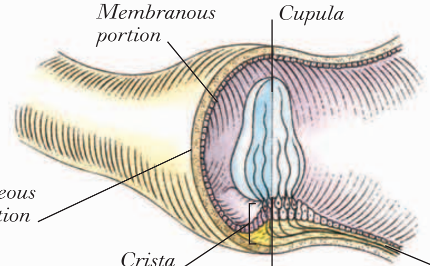
OSSICLES OF MIDDLE EAR

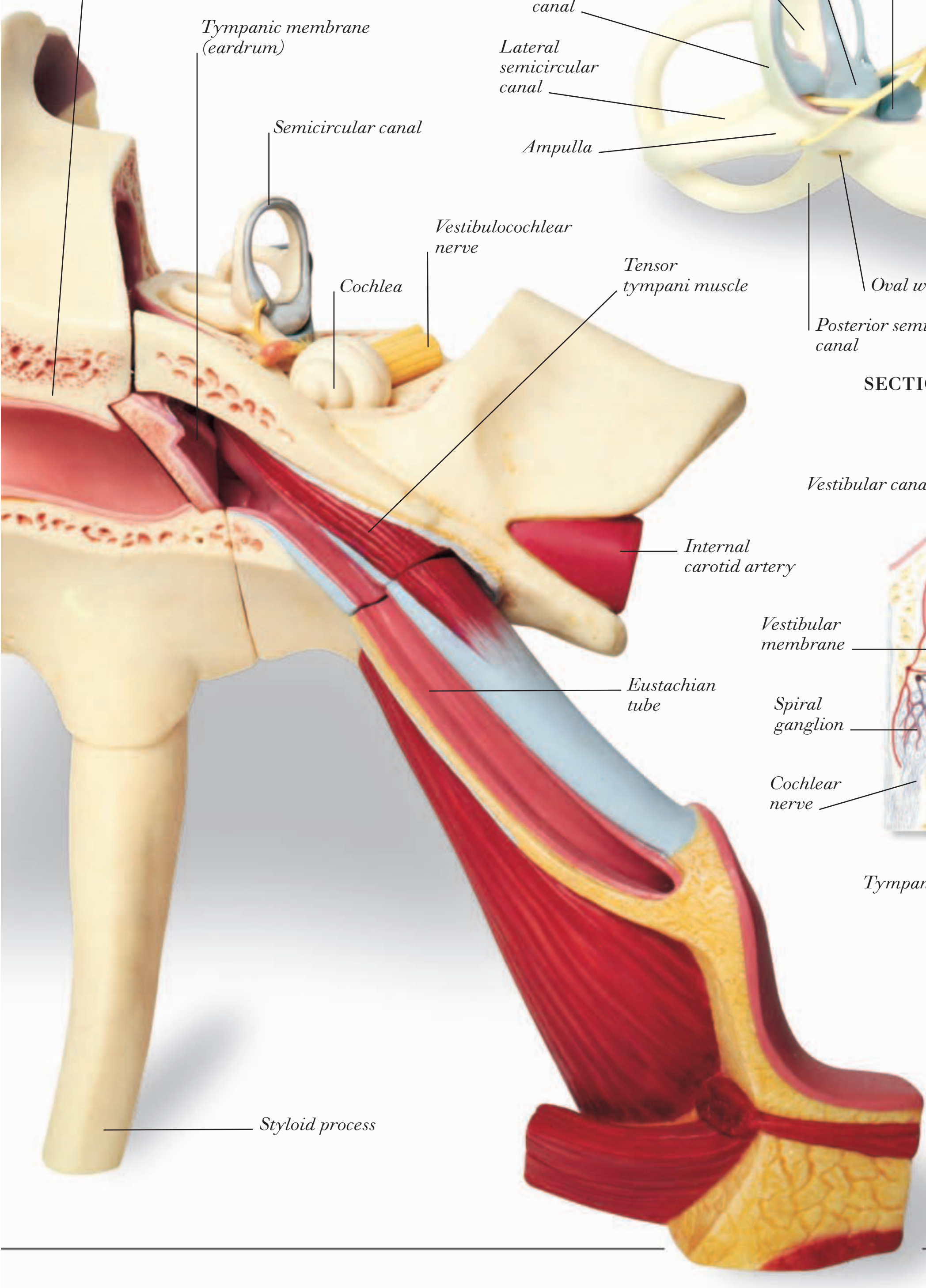


MALLEUS (HAMMER) INCUS (ANVIL) STAPES (STIRRUP)

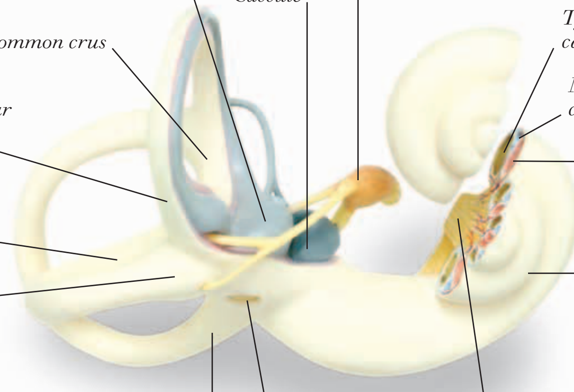
These three tiny bones connect to form a bridge between the tympanic membrane and the oval window. With a system of membranes they convey sound vibrations to the inner ear.

INTERNAL STRUCTURE OF AMPULLA

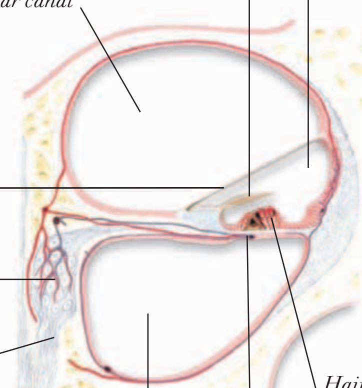




LABYRINTH



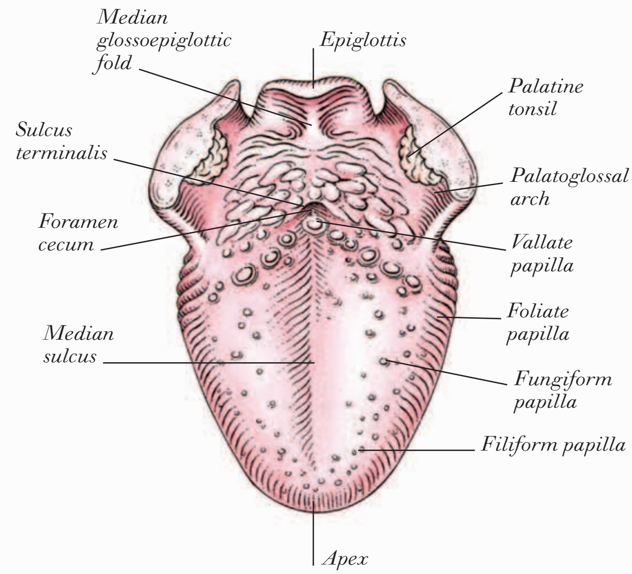
SECTION THROUGH COCHLEA



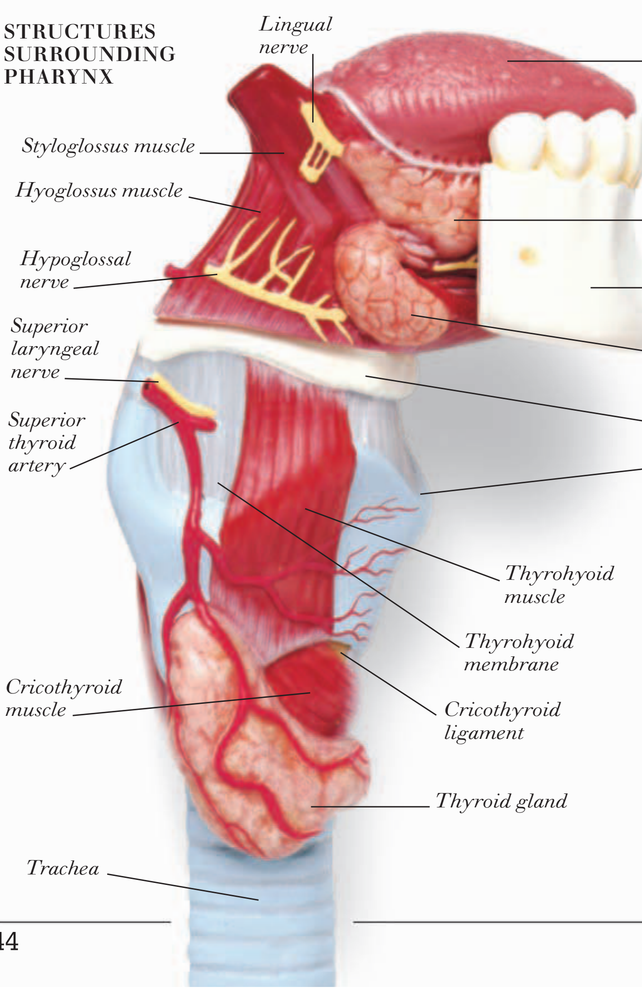
Nose, mouth, and throat

WITH EVERY BREATH, air passes through the nasal cavity down the pharynx (throat), larynx ("voice box"), and trachea (windpipe) to the lungs. The nasal cavity warms and moistens air, and the tiny layers in its lining protect the airway against damage by foreign bodies. During swallowing, the tongue moves up and back, the larynx rises, the epiglottis closes off the entrance to the trachea, and the soft palate separates the nasal cavity from the pharynx. Saliva, secreted from three pairs of salivary glands, lubricates food to make swallowing easier; it also begins the chemical breakdown of food, and helps to produce taste. The senses of taste and smell are closely linked. Both depend on the detection of dissolved molecules by sensory receptors in the olfactory nerve endings of the nose and in the taste buds of the tongue.

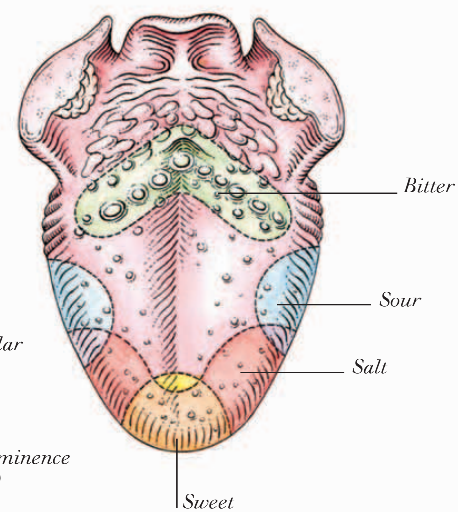
STRUCTURE OF TONGUE



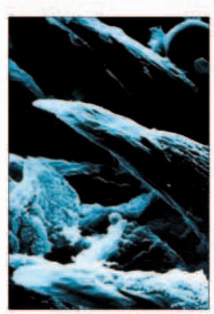
STRUCTURES SURROUNDING PHARYNX

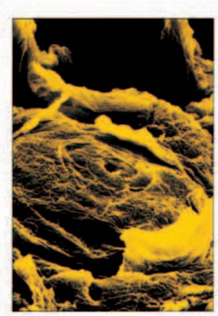


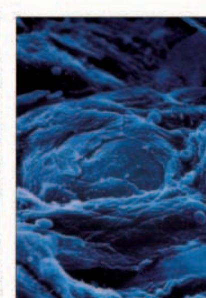
TASTE AREAS ON TONGUE



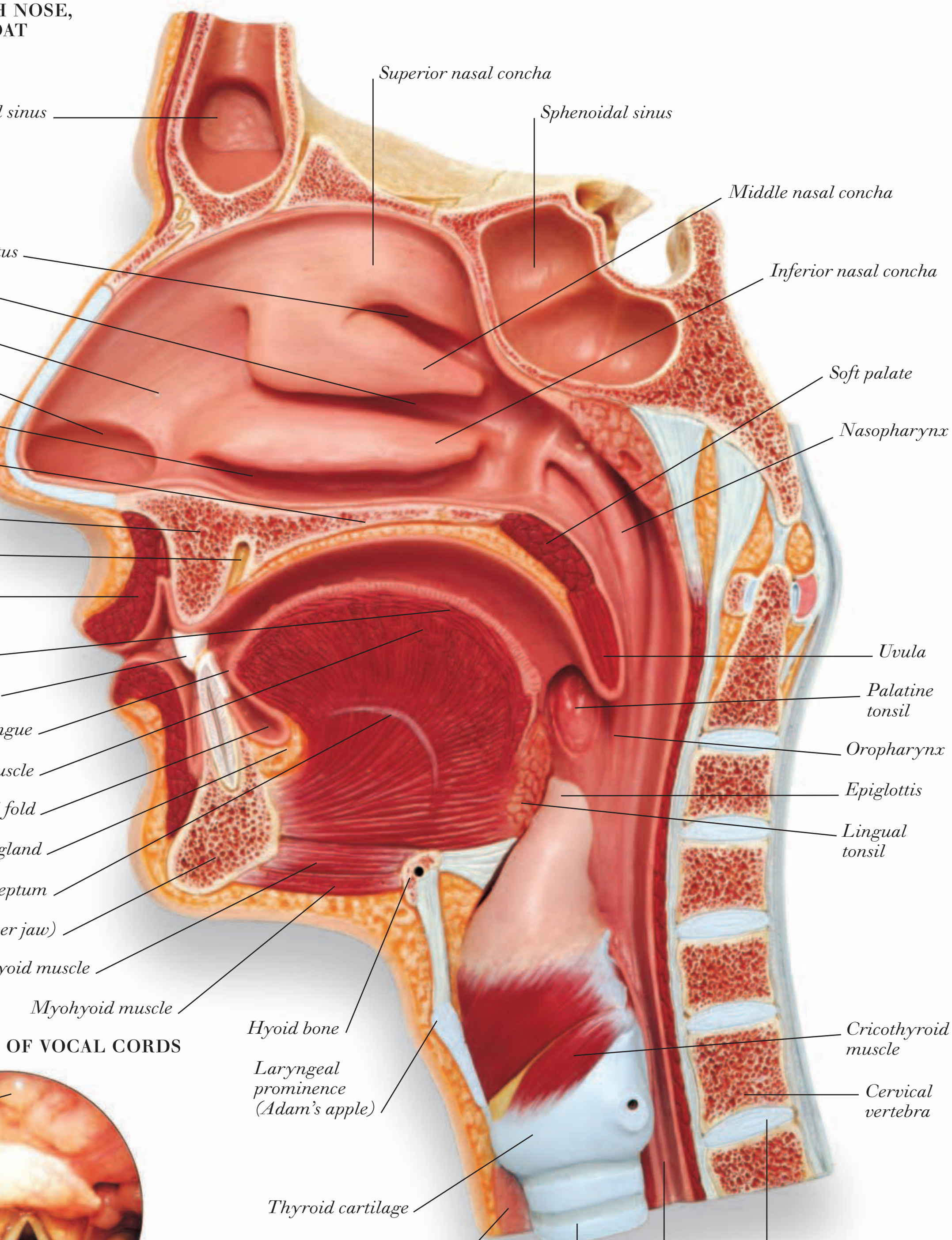
TYPES OF PAPILLAE


FILIFORM PAPILLAE

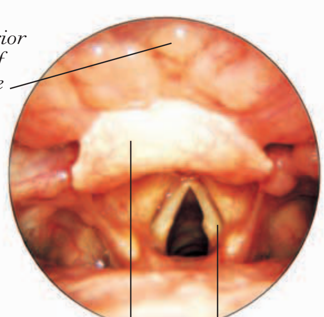

FUNGIFORM PAPILLAE


VALLATE PAPILLAE

SECTION THROUGH NOSE, MOUTH, AND THROAT



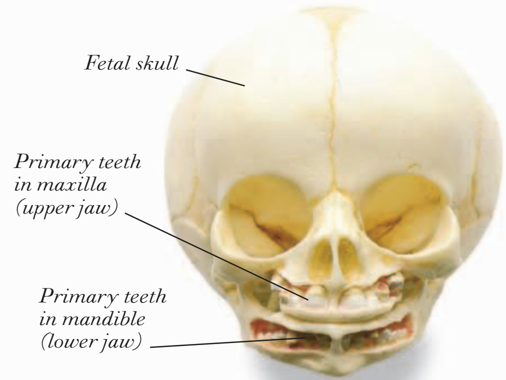
ENDOSCOPIC VIEW OF VOCAL CORDS



Teeth

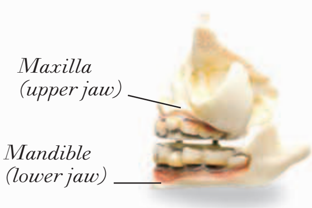
THE 20 PRIMARY TEETH (also called deciduous or baby teeth) usually begin to erupt when a baby is about six months old. They start to be replaced by the permanent teeth when the child is about six years old. By the age of 20, most adults have a full set of 32 teeth although the third molars (commonly called wisdom teeth) may never erupt. While teeth help people to speak clearly and give shape to the face, their main function is the chewing of food. Incisors and canines shear and tear the food into pieces; premolars and molars crush and grind it further. Although tooth enamel is the hardest substance in the body, it tends to be eroded and destroyed by acid produced in the mouth during the breakdown of food.

DEVELOPMENT OF TEETH IN A FETUS



FETAL JAWS
By the sixth week of embryonic development areas of thickening occur in each jaw; these areas give rise to tooth buds. By the time the fetus is six months old, enamel has formed on the tooth buds.

DEVELOPMENT OF JAW AND TEETH



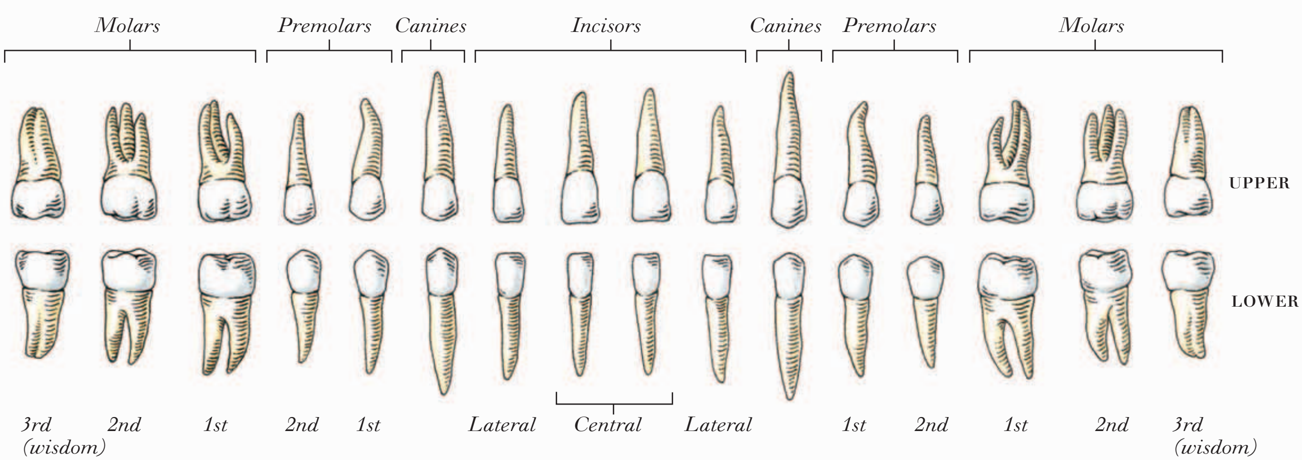
A NEWBORN BABY'S JAWS
The primary teeth can be seen developing in the jaw bones; they begin to erupt around the age of six months.

A FIVE-YEAR-OLD CHILD'S TEETH
There is a full set of 20 erupted primary teeth; the permanent teeth can be seen developing in the upper and lower jaws.

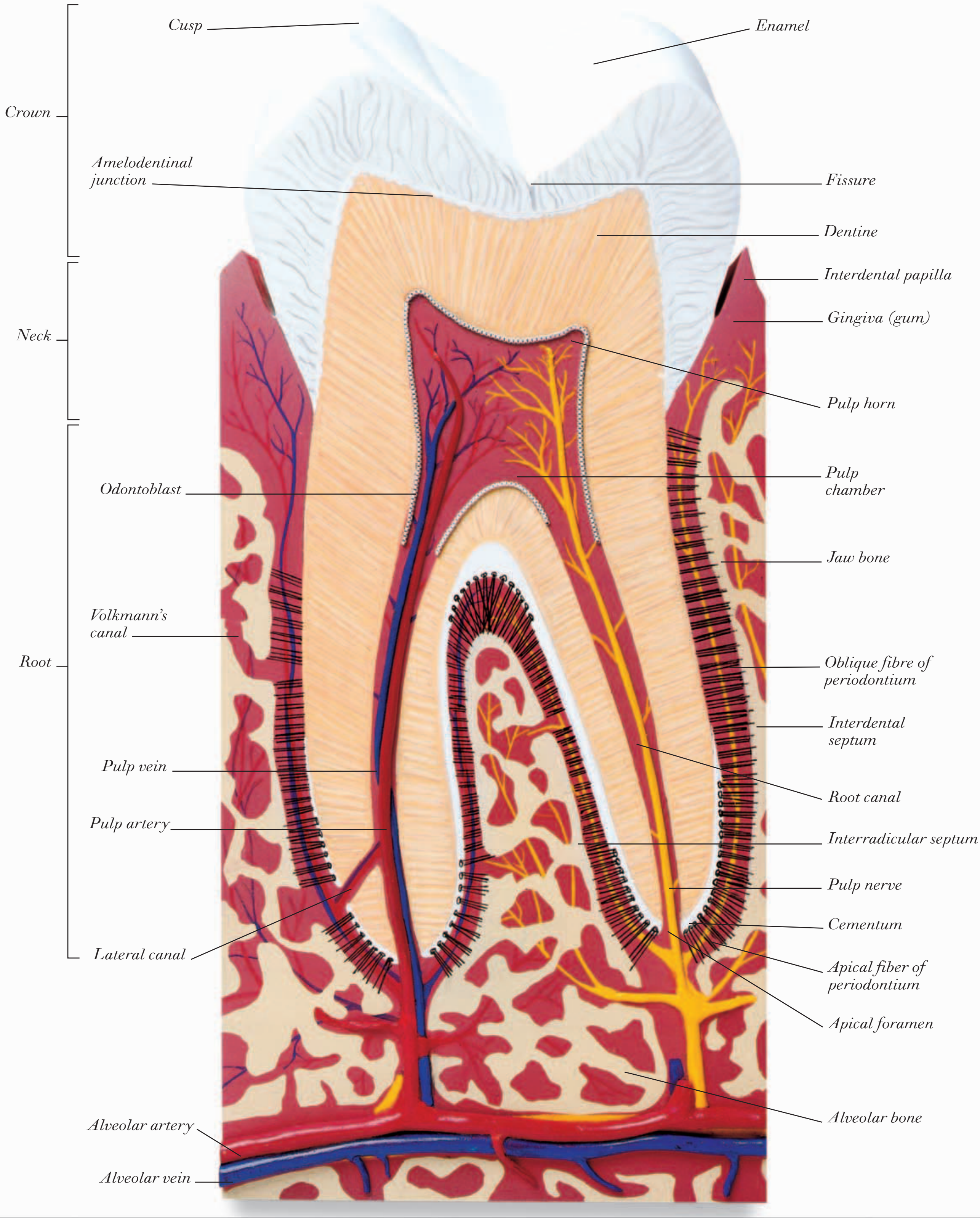
A NINE-YEAR-OLD CHILD'S TEETH
Most of the teeth are primary teeth but the permanent incisors and first molars have now emerged.

AN ADULT'S TEETH
By the age of 20, the full set of 32 permanent teeth (including the wisdom teeth) should be in position.

THE PERMANENT TEETH

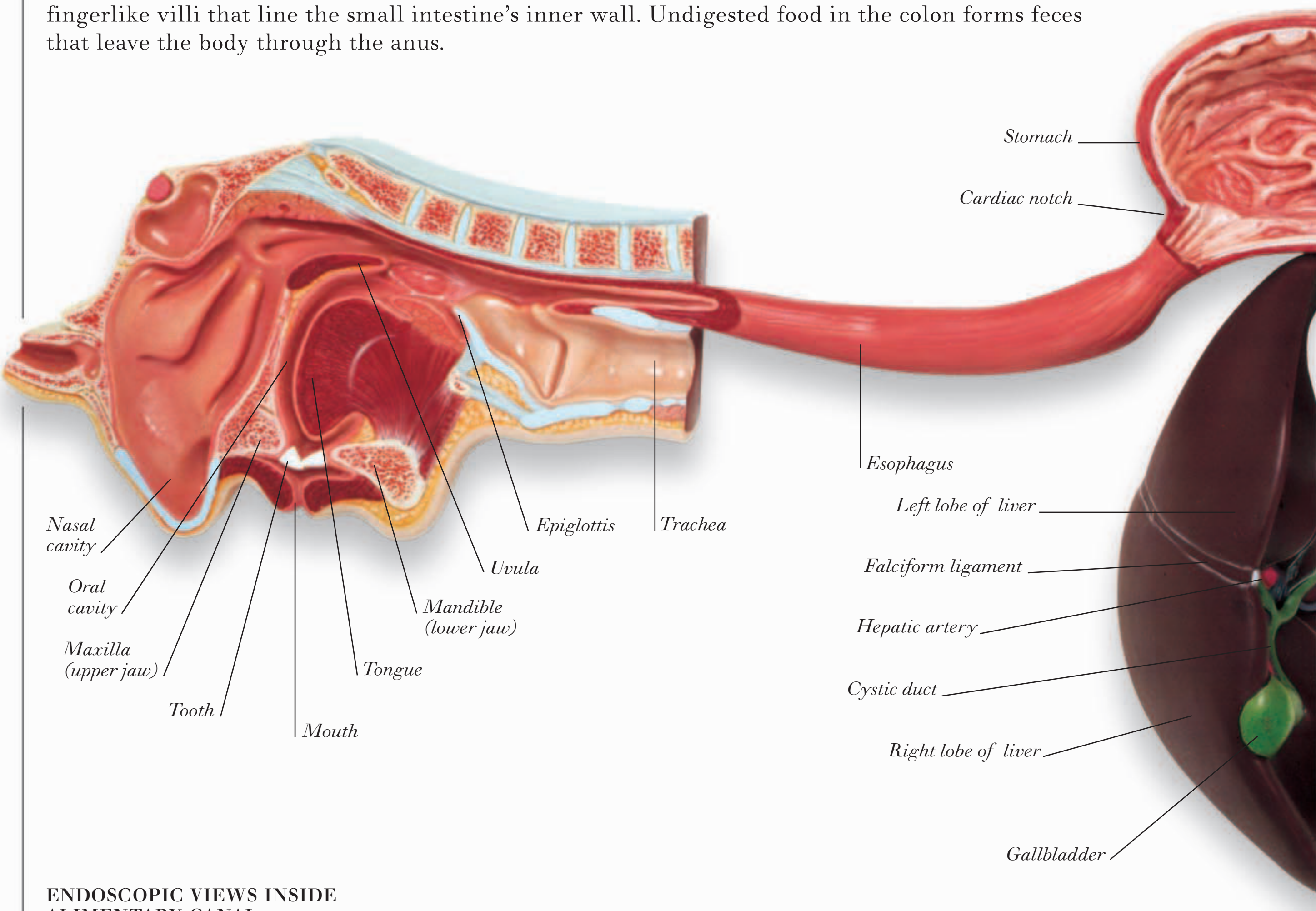


STRUCTURE OF A TOOTH



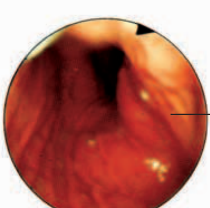
Digestive system

THE DIGESTIVE SYSTEM BREAKS DOWN FOOD into particles so tiny that blood can take nourishment to all parts of the body. The system's main part is a 30 ft (9 m) tube from mouth to rectum; muscles in this alimentary canal force food along. Chewed food first travels through the esophagus to the stomach, which churns and liquidizes food before it passes through the duodenum, jejunum, and ileum—the three parts of the long, convoluted small intestine. Here, digestive juices from the gallbladder and pancreas break down food particles; many filter out into the blood through tiny fingerlike villi that line the small intestine's inner wall. Undigested food in the colon forms feces that leave the body through the anus.

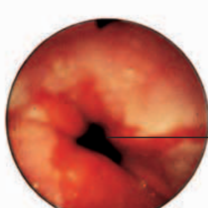


ENDOSCOPIC VIEWS INSIDE ALIMENTARY CANAL

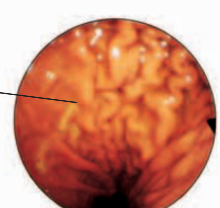
ESOPHAGUS



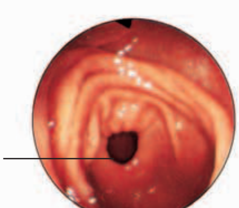
STOMACH ENTRANCE



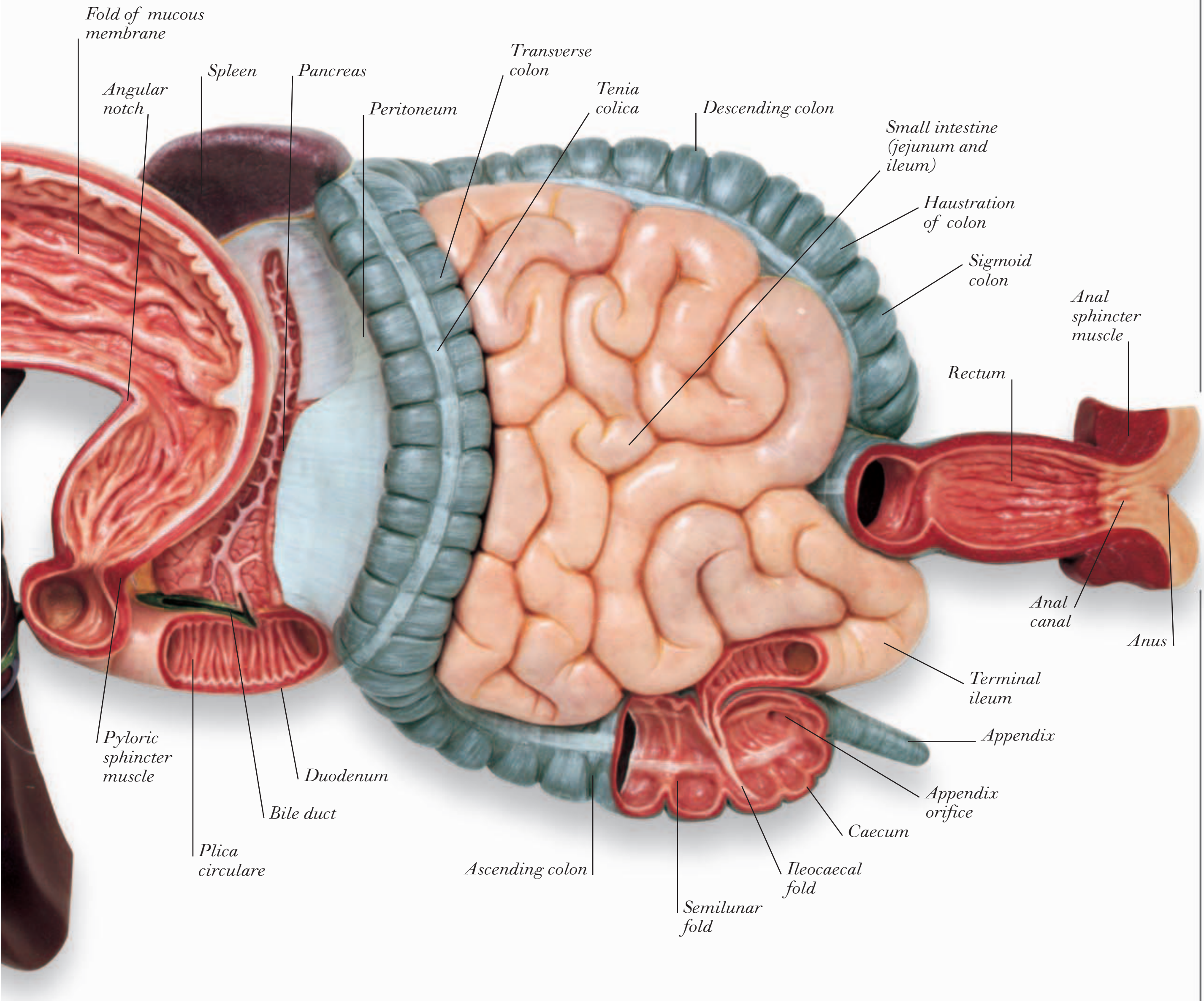
STOMACH

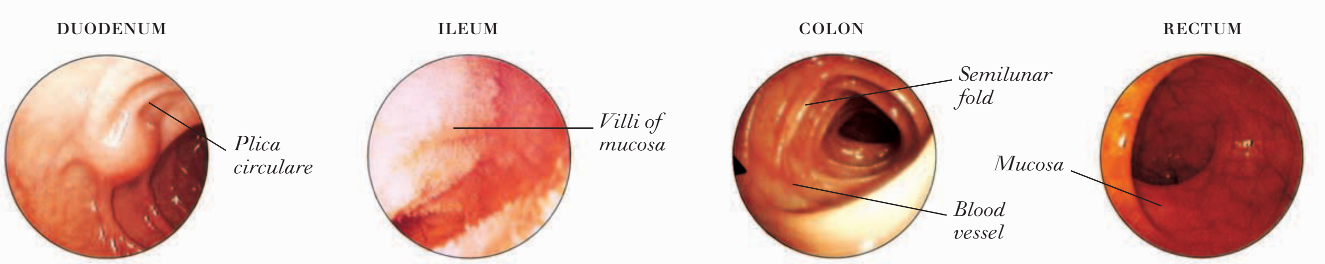


STOMACH EXIT

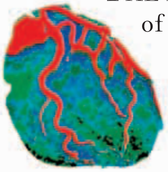


ALIMENTARY CANAL



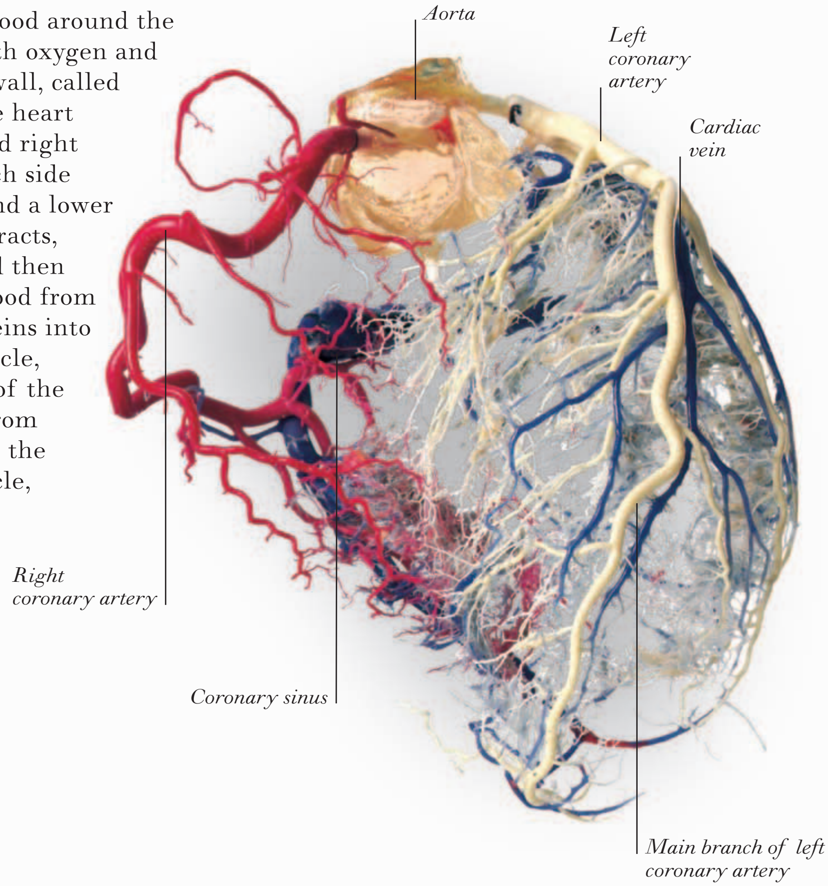


Heart

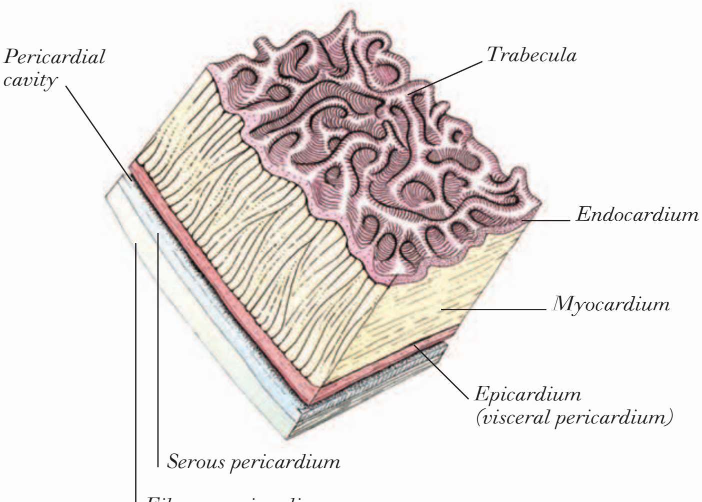


THE HEART IS A HOLLOW MUSCLE in the middle of the chest that pumps blood around the body, supplying cells with oxygen and nutrients. A muscular wall, called the septum, divides the heart lengthwise into left and right sides. A valve divides each side into two chambers: an upper atrium and a lower ventricle. When the heart muscle contracts, it squeezes blood through the atria and then through the ventricles. Oxygenated blood from the lungs flows from the pulmonary veins into the left atrium, through the left ventricle, and then out via the aorta to all parts of the body. Deoxygenated blood returning from the body flows from the vena cava into the right atrium, through the right ventricle, and then out via the pulmonary artery to the lungs for reoxygenation. At rest the heart beats between 60 and 80 times a minute; during exercise or at times of stress or excitement the rate may increase to 200 beats a minute.

ARTERIES AND VEINS SURROUNDING HEART

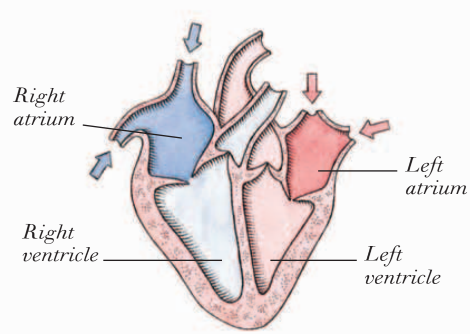


SECTION THROUGH HEART WALL



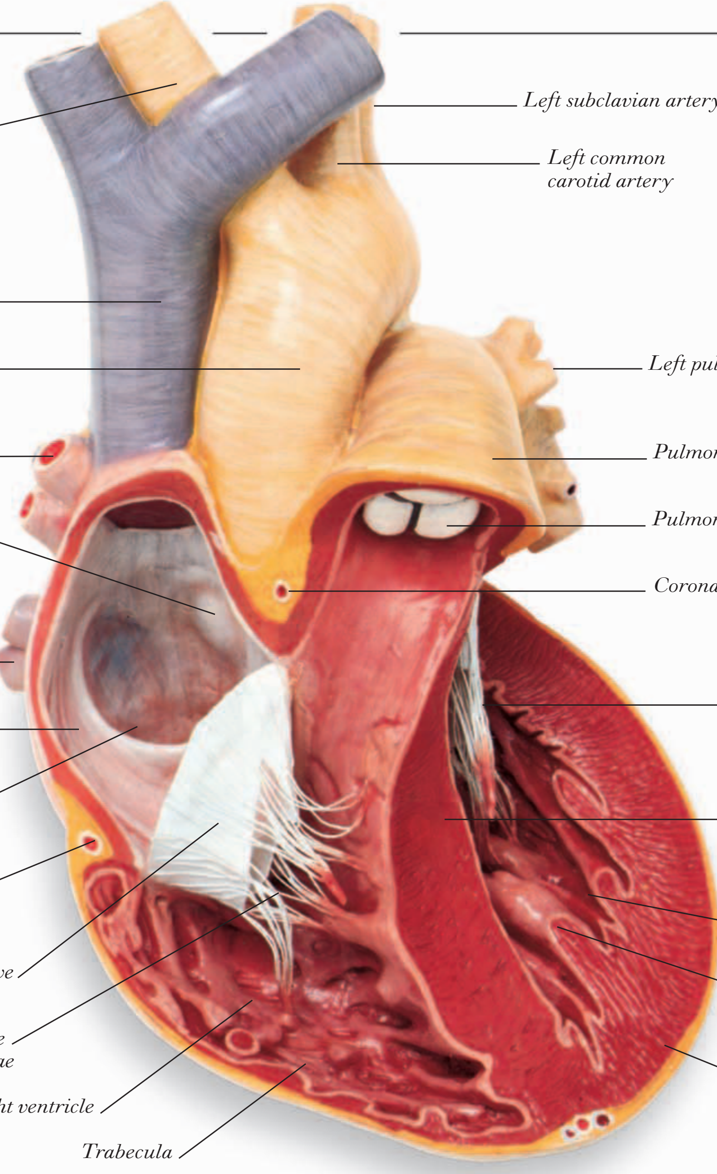
HEARTBEAT SEQUENCE

ATRIAL DIASTOLE

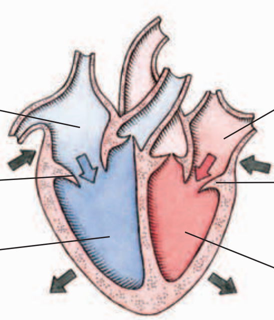


Deoxygenated blood enters the right atrium while the left atrium receives oxygenated blood.

STRUCTURE OF HEART

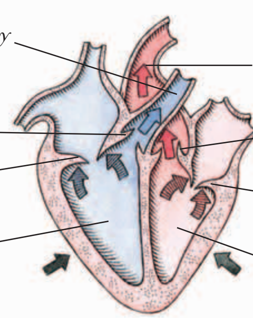


ATRIAL SYSTOLE (VENTRICULAR DIASTOLE)



Left and right atria contract, forcing blood into the relaxed ventricles.

VENTRICULAR SYSTOLE

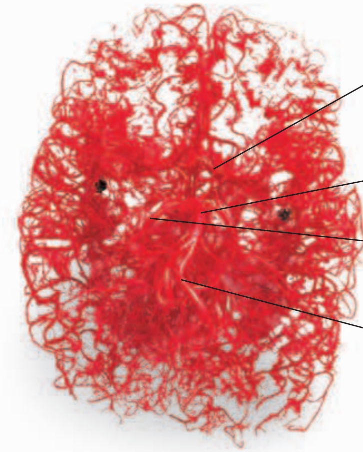


Ventricles contract and force blood to the lungs for oxygenation and via the aorta to the rest of the body.

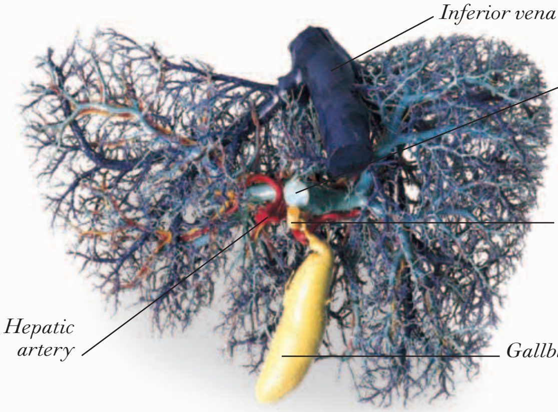
Circulatory system

THE CIRCULATORY SYSTEM consists of the heart and blood vessels, which together maintain a continuous flow of blood around the body. The heart pumps oxygen-rich blood from the lungs to all parts of the body through a network of tubes called arteries, and smaller branches called arterioles. Blood returns to the heart via small vessels called venules, which lead in turn into larger tubes called veins. Arterioles and venules are linked by a network of tiny vessels called capillaries, where the exchange of oxygen and carbon dioxide between blood and body cells takes place. Blood has four main components: red blood cells, white blood cells, platelets, and liquid plasma.

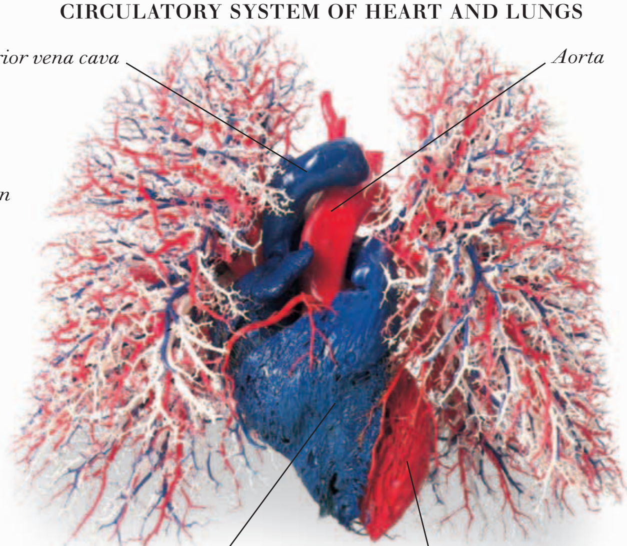
ARTERIAL SYSTEM OF BRAIN



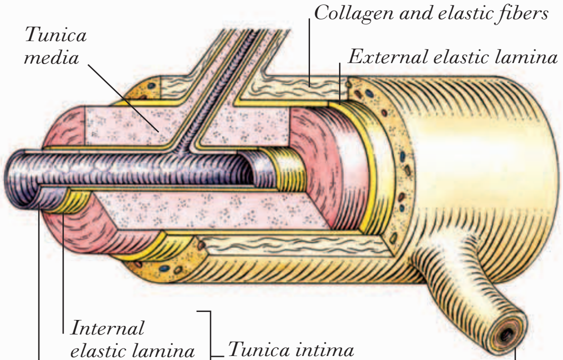
CIRCULATORY SYSTEM OF LIVER



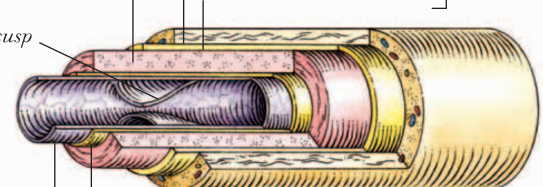
CIRCULATORY SYSTEM OF HEART AND LUNGS



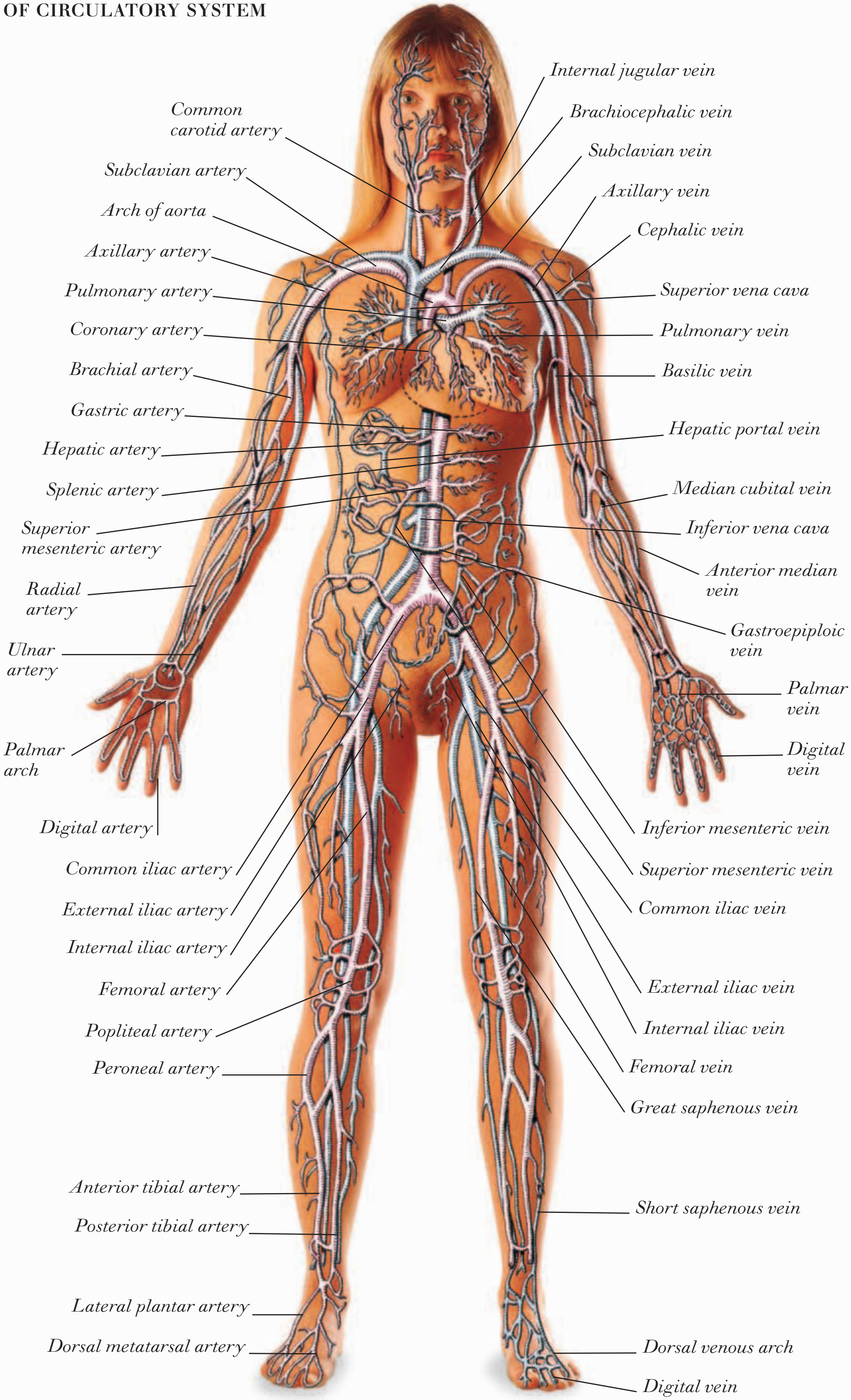
SECTION OF MAIN ARTERY



SECTION OF MAIN VEIN

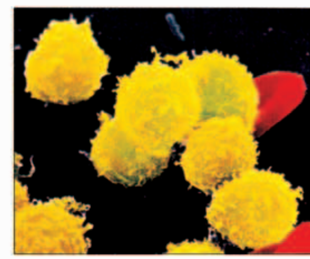


PRINCIPAL ARTERIES AND VEINS OF CIRCULATORY SYSTEM



TYPES OF BLOOD CELLS

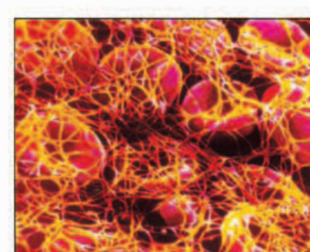
RED BLOOD CELLS
These cells are biconcave in shape to maximize their oxygen-carrying capacity.



WHITE BLOOD CELLS
Lymphocytes are the smallest white blood cells; they form antibodies against disease.

PLATELETS
Tiny cells that are activated whenever blood clotting or repair to vessels is necessary.

BLOOD CLOTTING

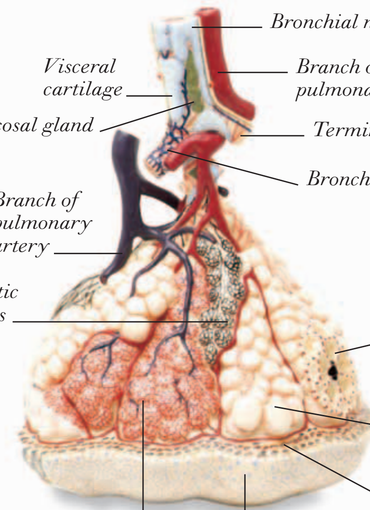


Filaments of fibrin enmesh red blood cells as part of the process of blood clotting.

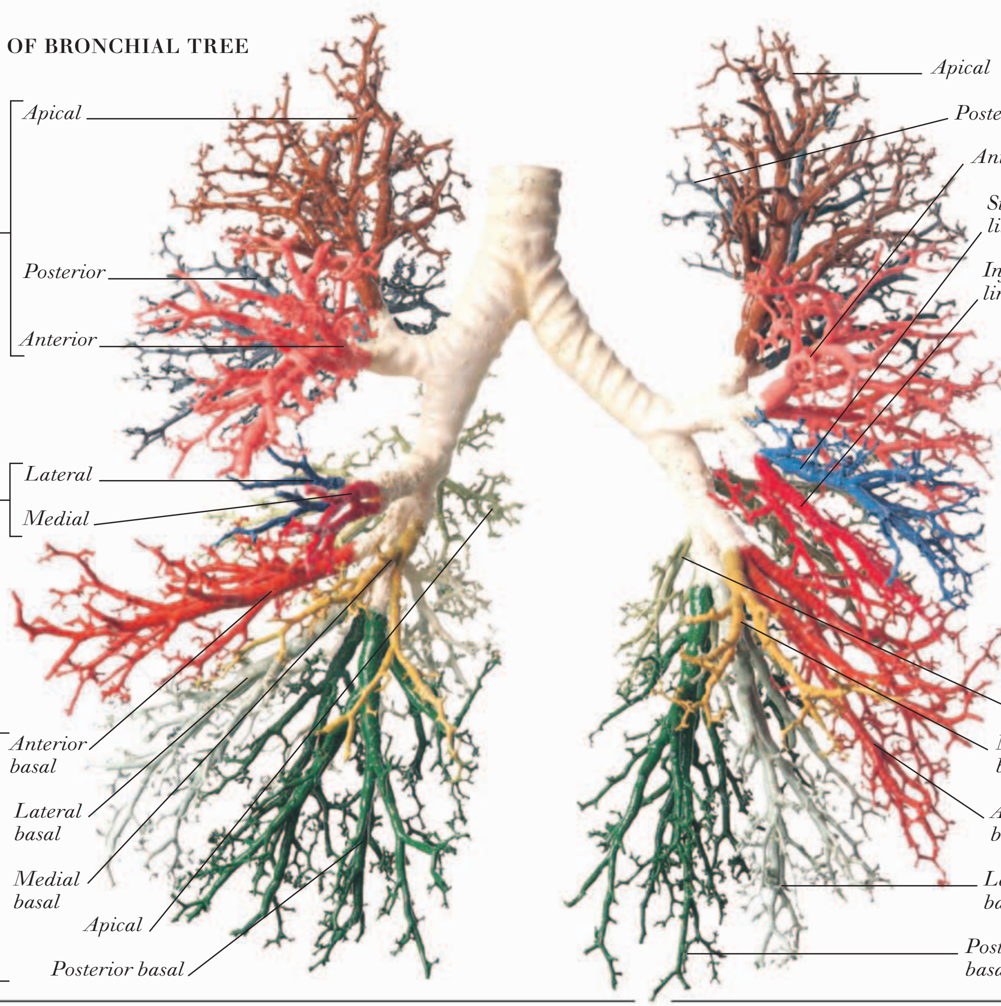
Respiratory system

THE RESPIRATORY SYSTEM supplies the oxygen needed by body cells and carries off their carbon dioxide waste. Inhaled air passes via the trachea (windpipe) through two narrower tubes, the bronchi, to the lungs. Each lung comprises many fine, branching tubes called bronchioles that end in tiny clustered chambers called alveoli. Gases cross the thin alveolar walls to and from a network of tiny blood vessels. Intercostal (rib) muscles and the muscular diaphragm below the lungs operate the lungs like bellows, drawing air in and forcing it out at regular intervals.

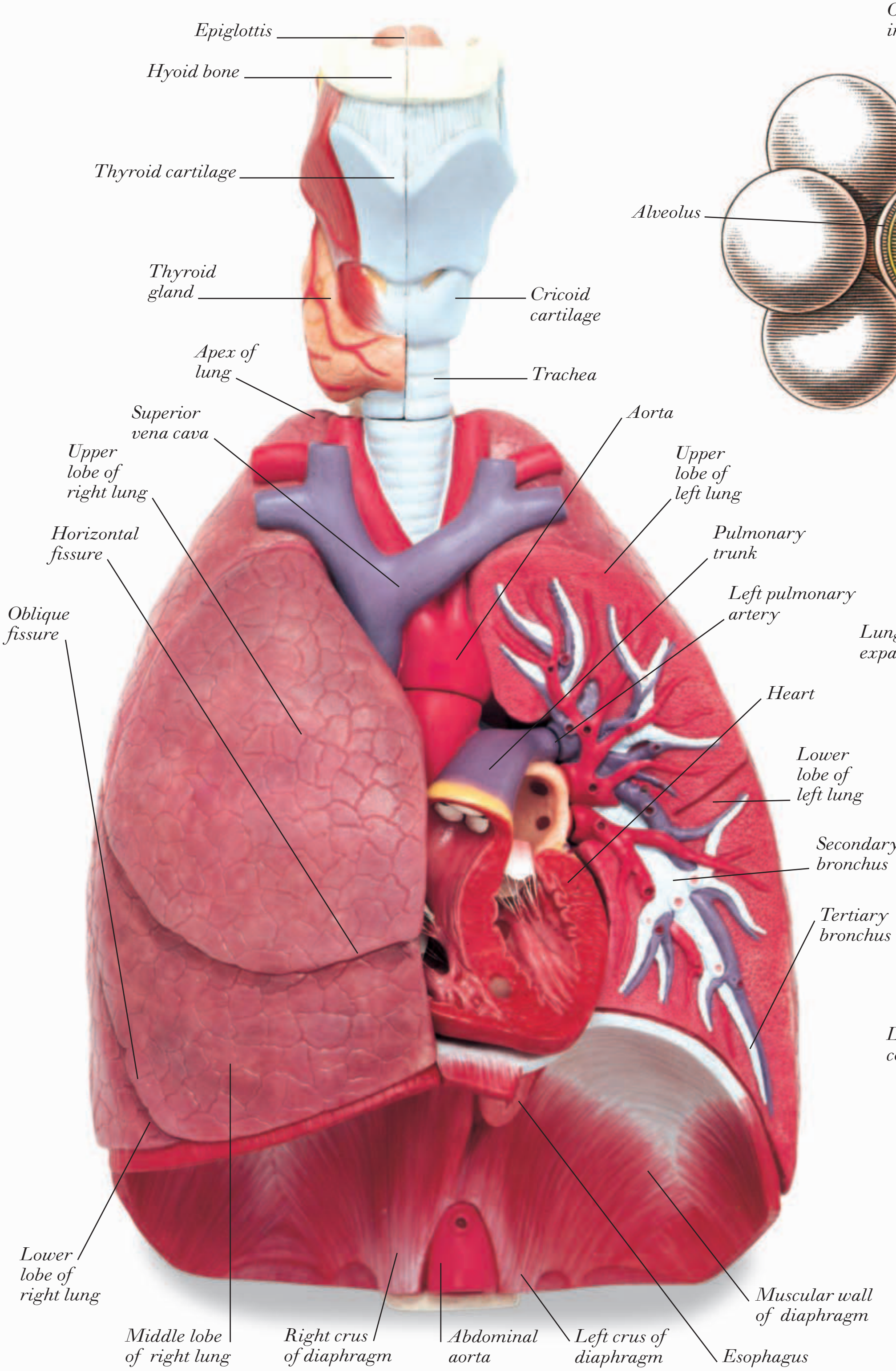
BRONCHIOLE AND ALVEOLI



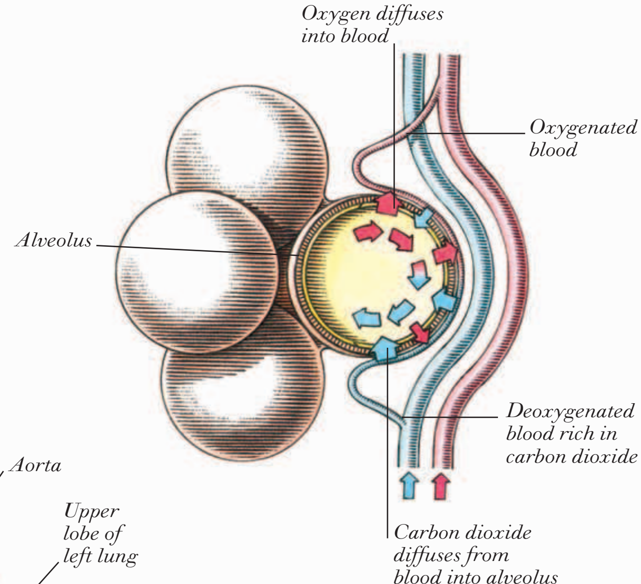
SEGMENTS OF BRONCHIAL TREE



STRUCTURES OF THORACIC CAVITY

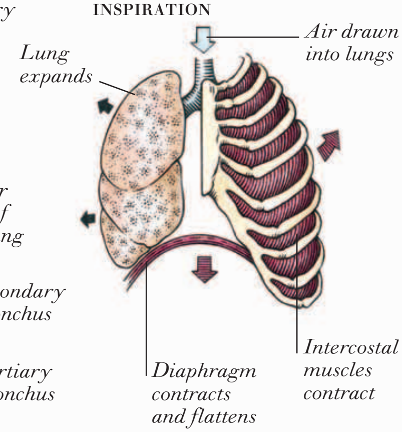


GASEOUS EXCHANGE IN ALVEOLUS

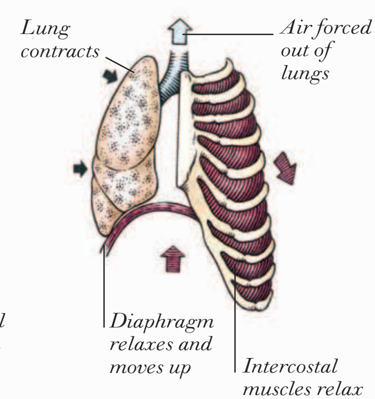


MECHANISM OF RESPIRATION

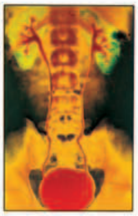
INSPIRATION



EXPIRATION

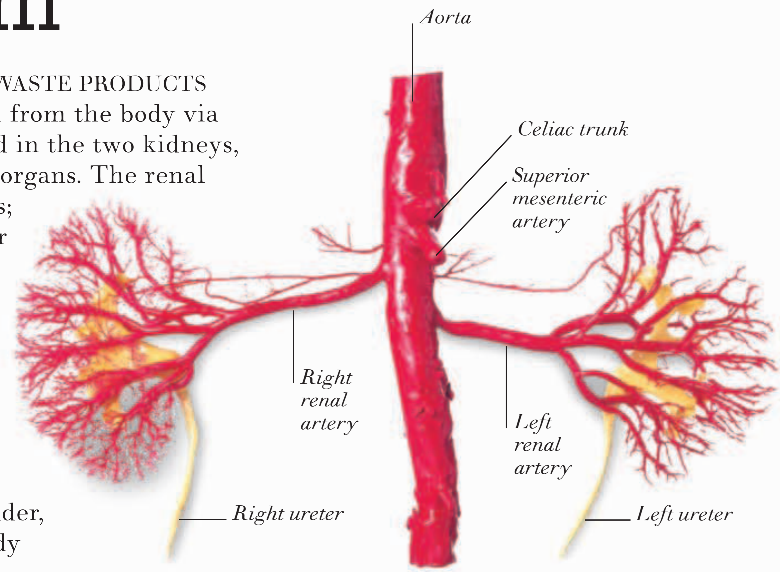


Urinary system

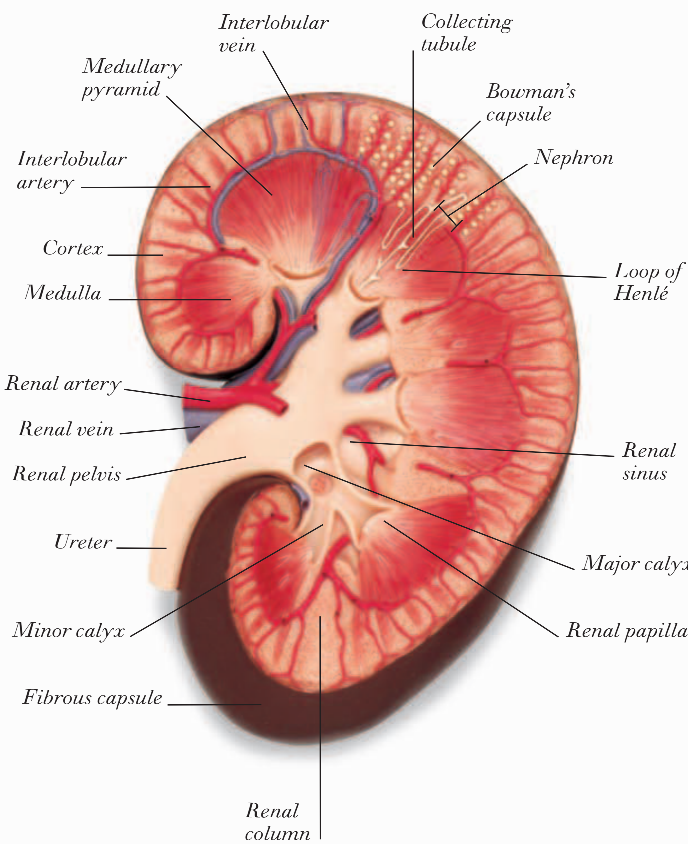


THE URINARY SYSTEM FILTERS WASTE PRODUCTS from the blood and removes them from the body via a system of tubes. Blood is filtered in the two kidneys, which are fist-sized, bean-shaped organs. The renal arteries carry blood to the kidneys; the renal veins remove blood after filtering. Each kidney contains about one million tiny units called nephrons. Each nephron is made up of a tubule and a filtering unit called a glomerulus, which consists of a collection of tiny blood vessels surrounded by the hollow Bowman's capsule. The filtering process produces a watery fluid that leaves the kidney as urine. The urine is carried via two tubes called ureters to the bladder, where it is stored until its release from the body through another tube called the urethra.

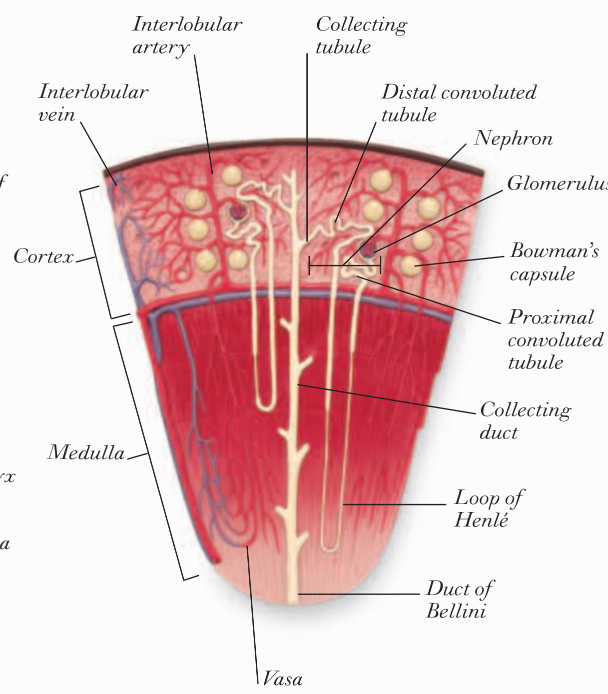
ARTERIAL SYSTEM OF KIDNEYS



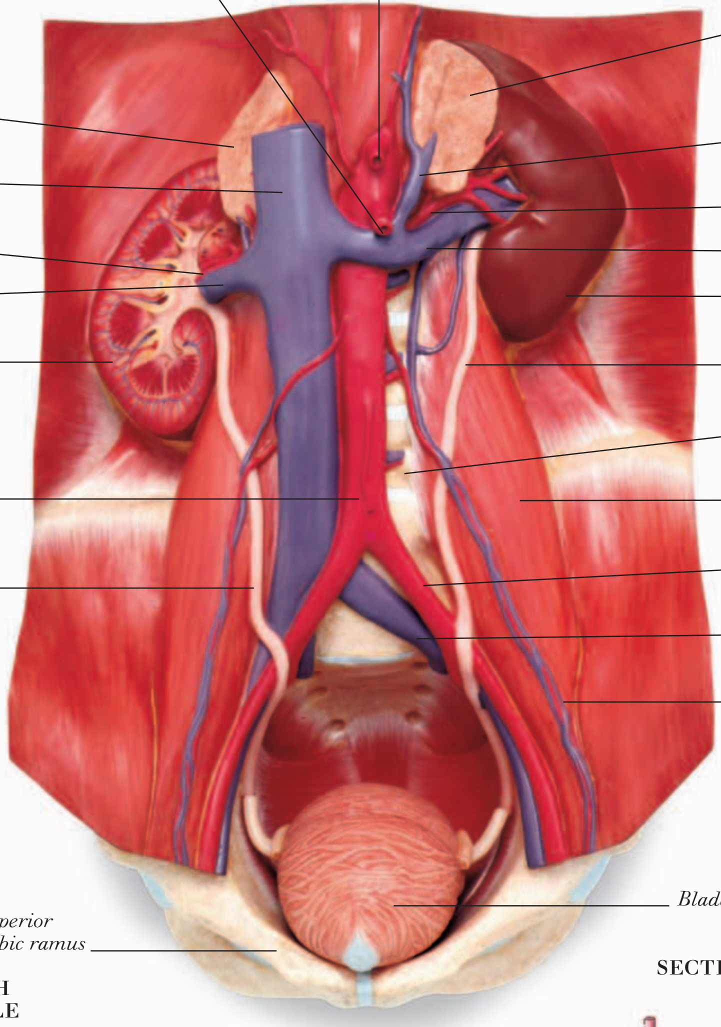
SECTION THROUGH LEFT KIDNEY



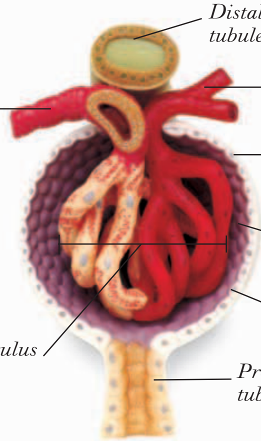
SECTION OF KIDNEY



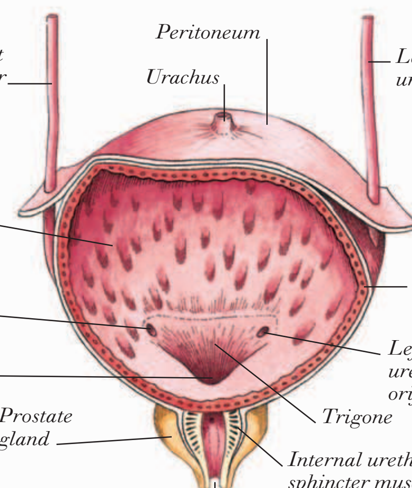
MALE URINARY TRACT



SECTION THROUGH BOWMAN'S CAPSULE



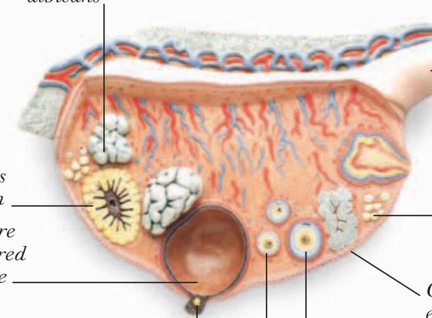
SECTION THROUGH MALE BLADDER



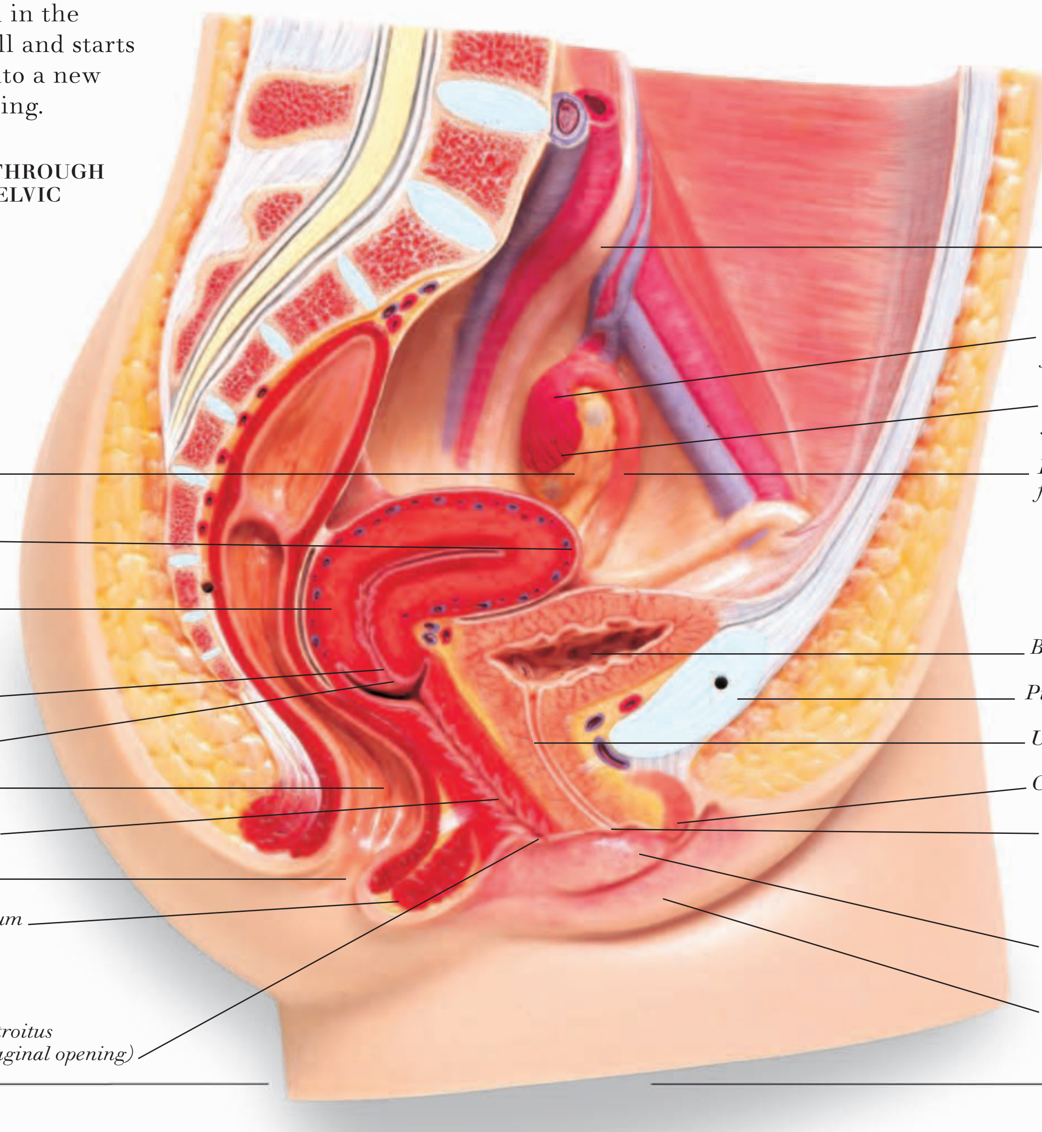
Reproductive system

SEX ORGANS LOCATED IN THE PELVIS create new human lives. Each month a ripe egg is released from one of the female's ovaries into a fallopian tube leading to the uterus (womb), a muscular pear-sized organ. A male produces minute tadpolelike sperm in two oval glands called testes. When the male is ready to release sperm into the female's vagina, many millions pass into his urethra and leave his body through the fleshy penis. The sperm travel up through the vagina into the uterus and fallopian tubes, and one sperm may enter and fertilize an egg. The fertilized egg becomes embedded in the uterus wall and starts to grow into a new human being.

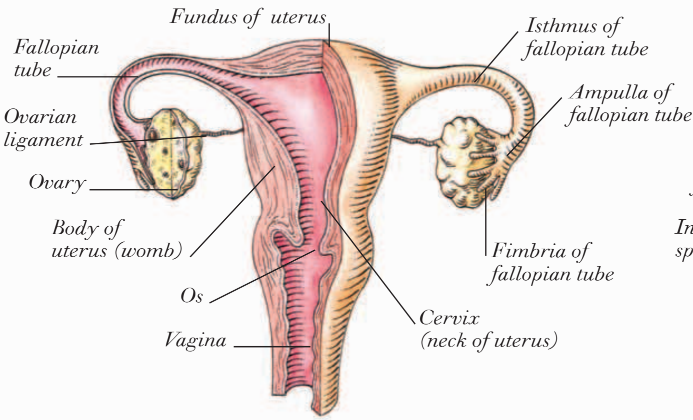
SECTION THROUGH OVARY



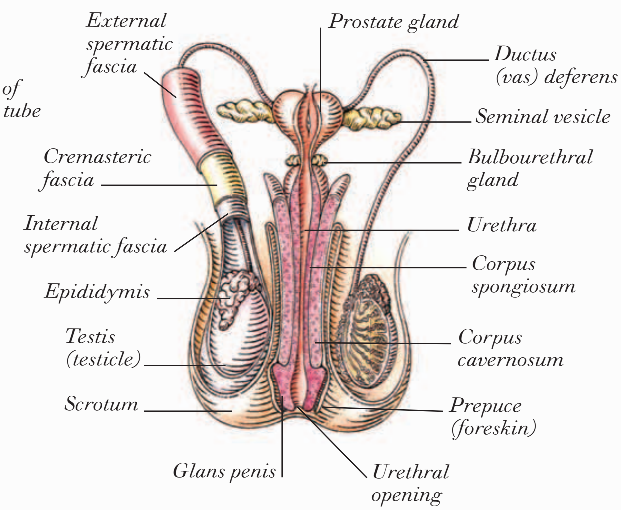
SECTION THROUGH FEMALE PELVIC REGION



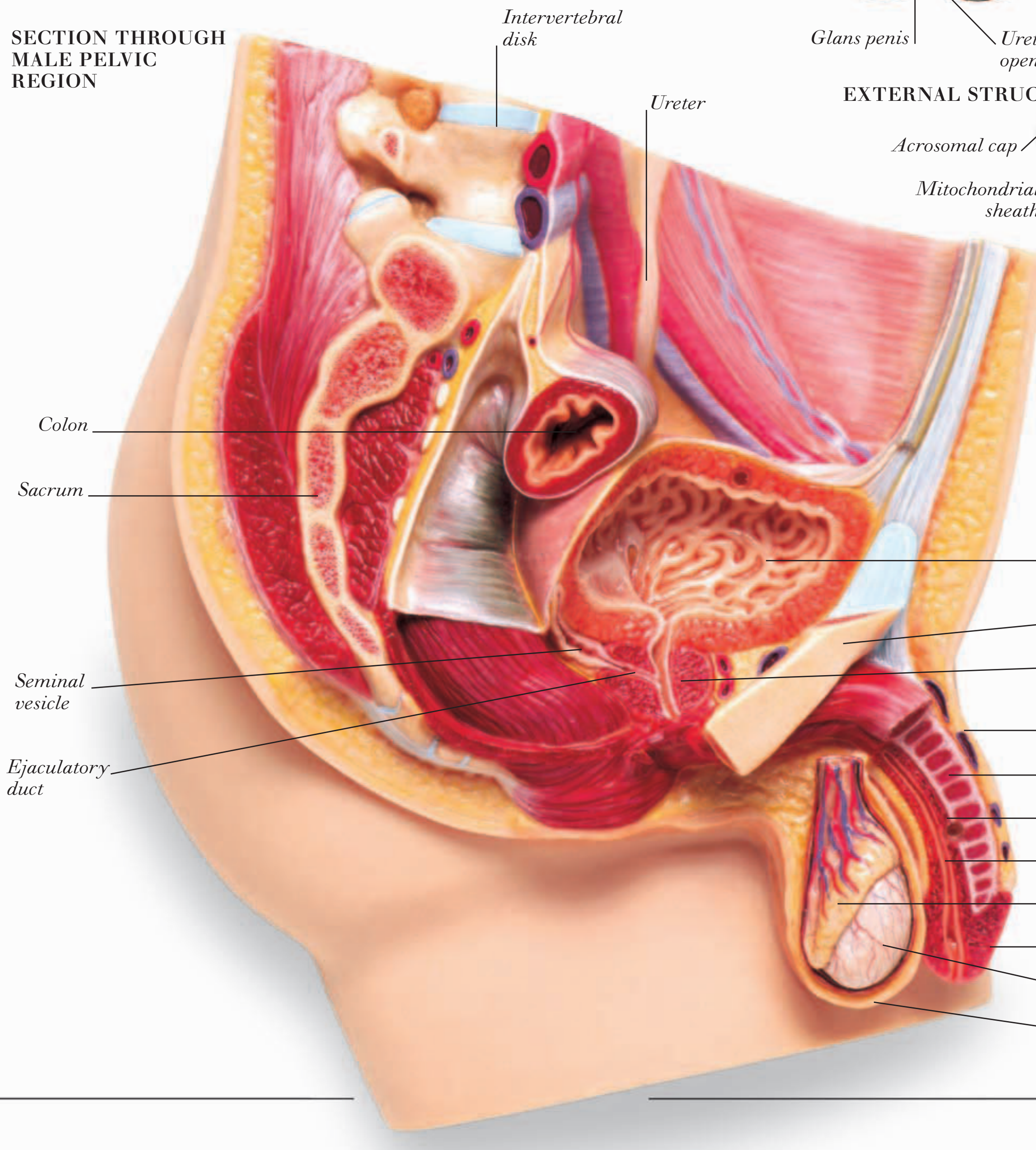
FEMALE REPRODUCTIVE ORGANS



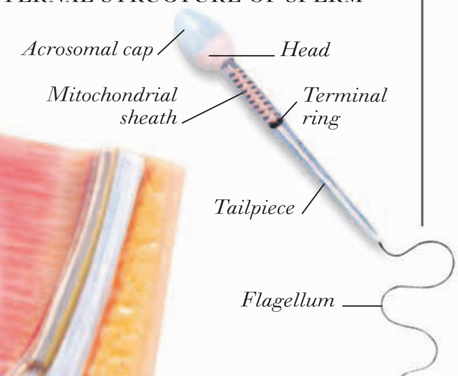
MALE REPRODUCTIVE ORGANS



SECTION THROUGH MALE PELVIC REGION



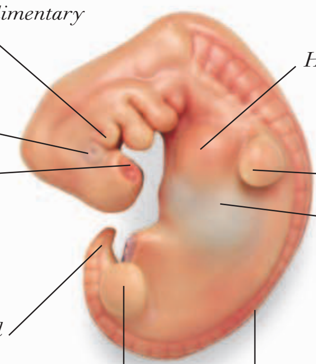
EXTERNAL STRUCTURE OF SPERM



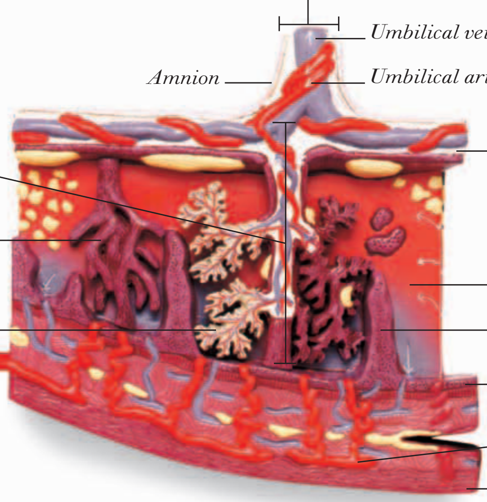
Development of a baby

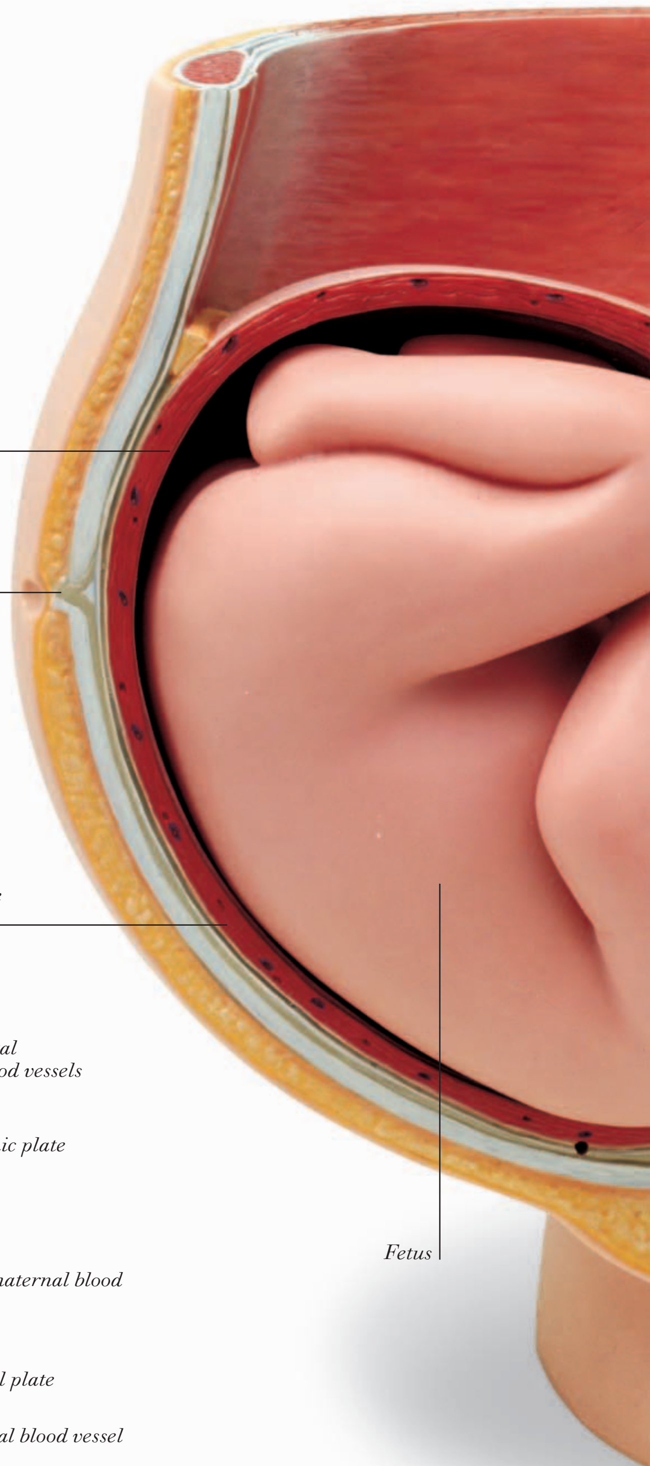
A FERTILIZED EGG IS NOURISHED AND PROTECTED as it develops into an embryo and then a fetus during the 40 weeks of pregnancy. The placenta, a mass of blood vessels implanted in the uterus lining, delivers nourishment and oxygen, and removes waste through the umbilical cord. Meanwhile, the fetus lies snugly in its amniotic sac, a bag of fluid that protects it against any sudden jolts. In the last weeks of the pregnancy, the rapidly growing fetus turns head-down: a baby ready to be born.

EMBRYO AT FIVE WEEKS

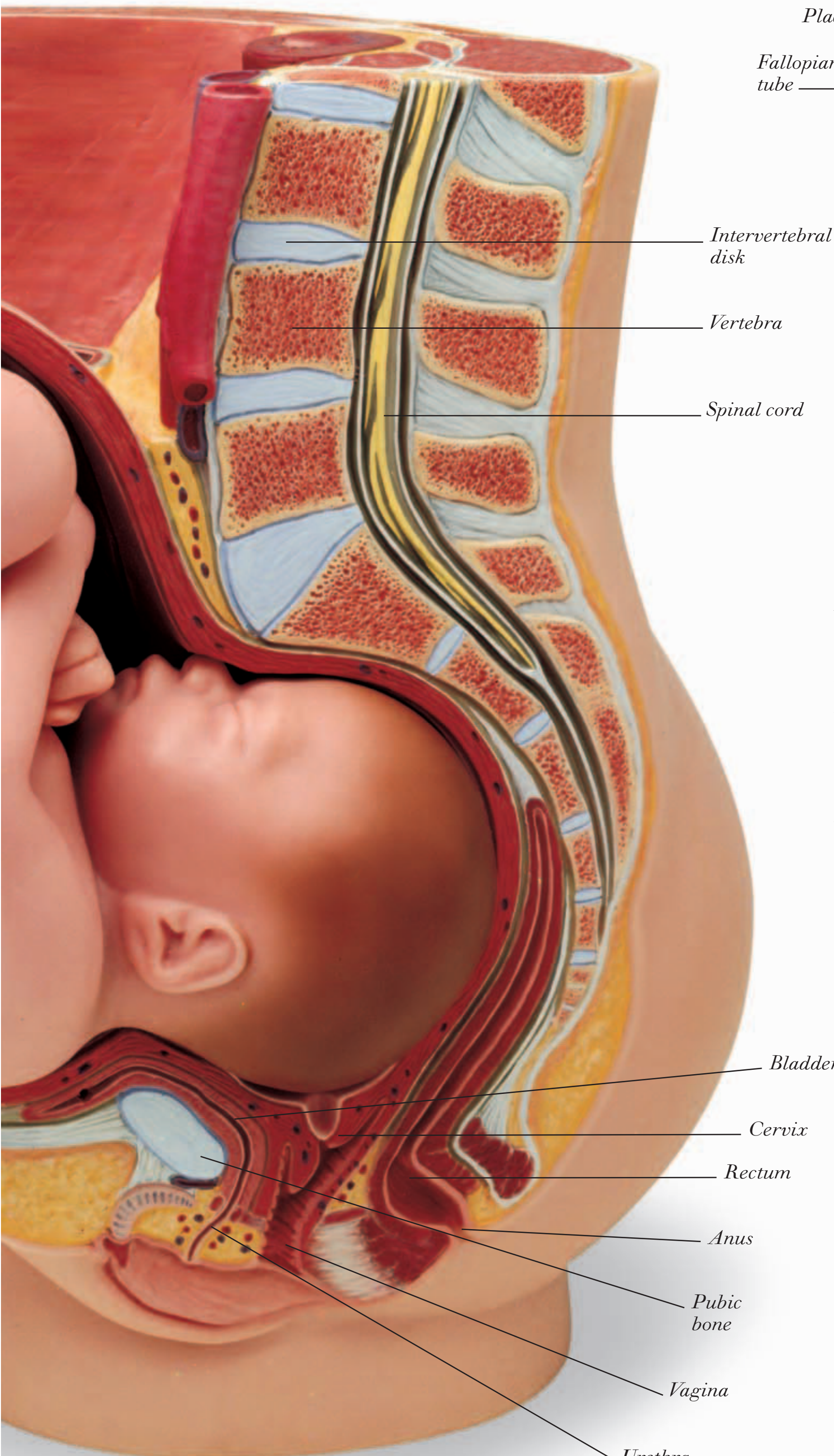


SECTION THROUGH PLACENTA

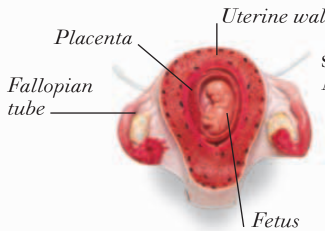




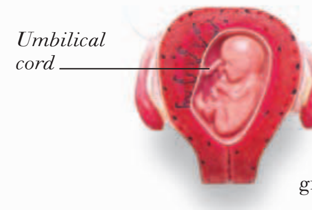
SECTION THROUGH PELVIS IN NINTH MONTH OF PREGNANCY



THE DEVELOPING FETUS

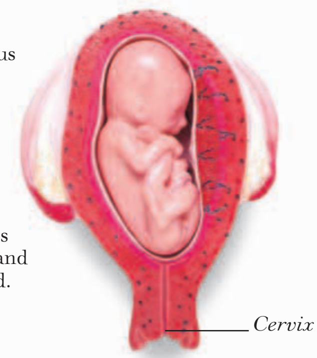


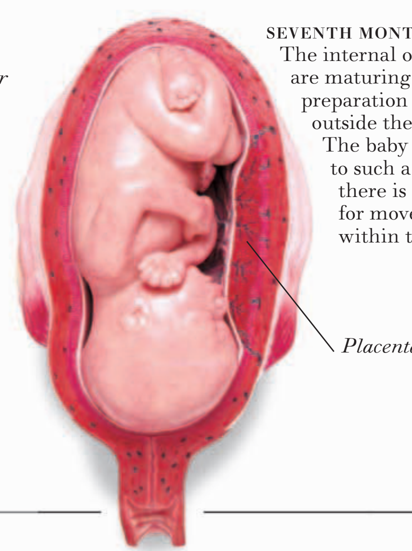
SECOND MONTH
All the internal organs have developed by this stage.



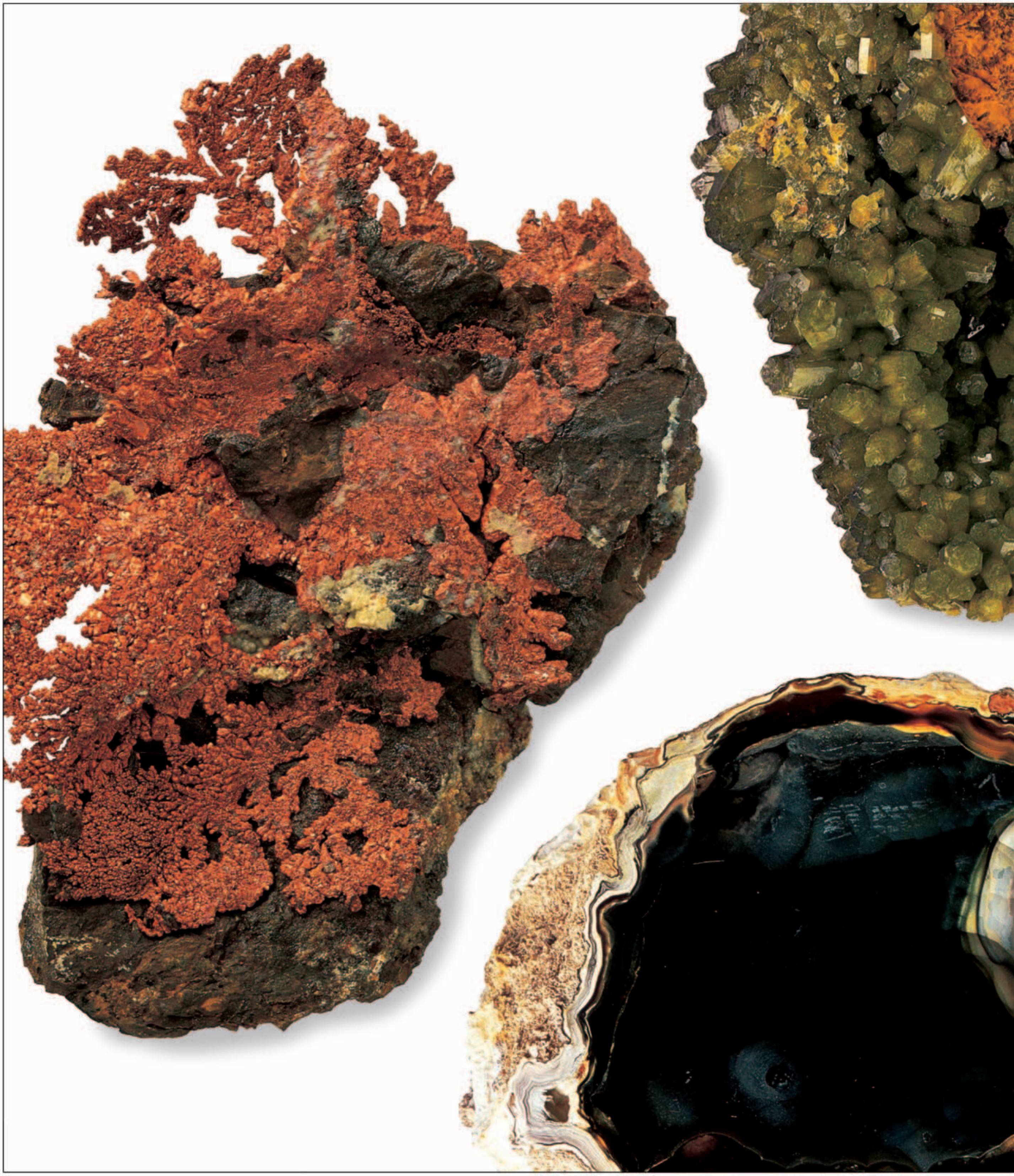
THIRD MONTH
The fetus is fully formed and now begins a period of rapid growth.

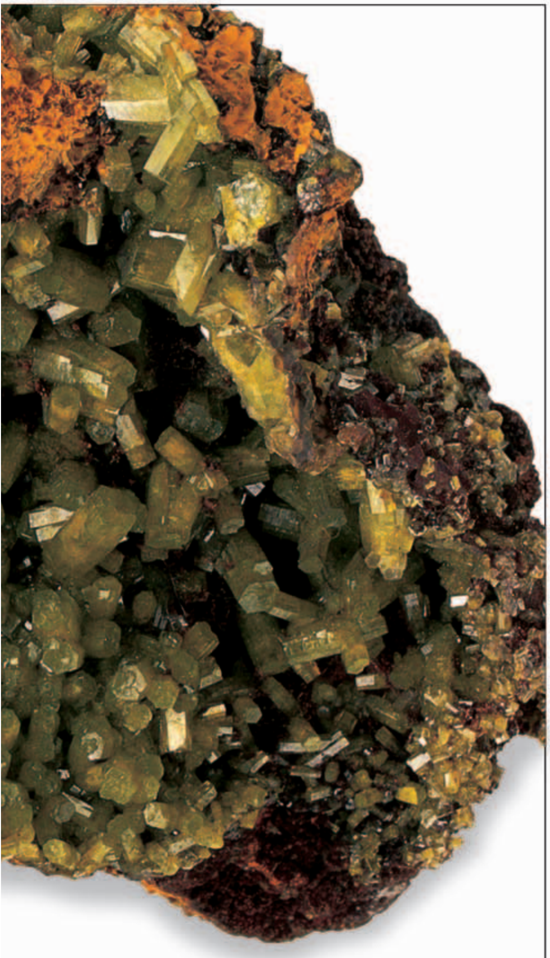
FIFTH MONTH
Although the fetus is here in breech (bottom down) position, it will probably turn by 180° before birth. By the fifth month the baby is moving actively and responds to sound.



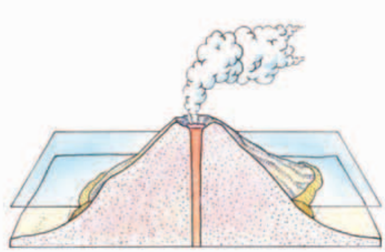


SEVENTH MONTH
The internal organs are maturing in preparation for life outside the uterus. The baby has grown to such a size that there is less room for movement within the uterus.





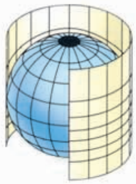
Geology, Geography, and Meteorology



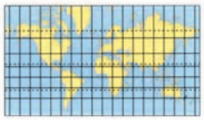
Earth's physical features

MOST OF THE EARTH'S SURFACE (about 70 percent) is covered with water. The largest single body of water, the Pacific Ocean, alone covers about 30 percent of the surface. Most of the land is distributed as seven continents; these are (from largest to smallest) Asia, Africa, North America, South America, Antarctica, Europe, and Australasia. The physical features of the land are remarkably varied. Among the most notable are mountain ranges, rivers, and deserts. The largest mountain ranges—the Himalayas in Asia and the Andes in South America—extend for thousands of miles. The Himalayas include the world's highest mountain, Mount Everest (29,029 ft/8,848 m). The longest rivers are the Nile River in Africa (4,160 miles/6,695 km) and the Amazon River in South America (4,000 miles/ 6,437 km). Deserts cover about 20 percent of the total land area. The largest is the Sahara, which covers nearly a third of Africa. The Earth's surface features can be represented in various ways. Only a globe can correctly represent areas, shapes, sizes, and directions, because there is always distortion when a spherical surface—the Earth's, for example—is projected on to the flat surface of a map. Each map projection is therefore a compromise; it shows some features accurately but distorts others. Even satellite mapping does not produce completely accurate maps, although they can show physical features with great clarity.

EXAMPLES OF MAP PROJECTIONS

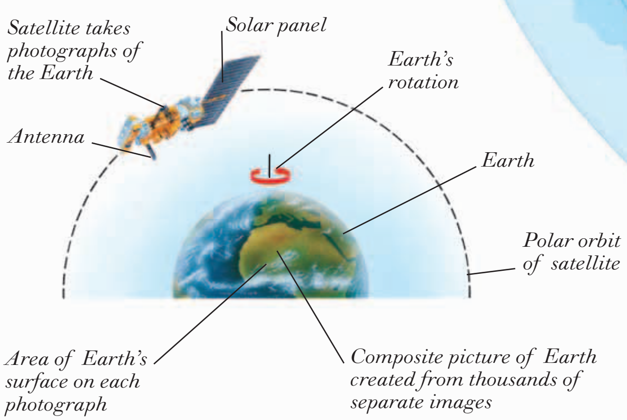


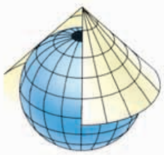
CYLINDRICAL PROJECTION



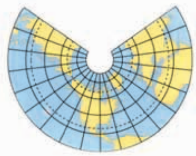
CYLINDRICAL-PROJECTION MAP

SATELLITE MAPPING OF THE EARTH

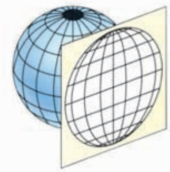




CONICAL PROJECTION

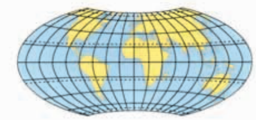


CONICAL-PROJECTION MAP



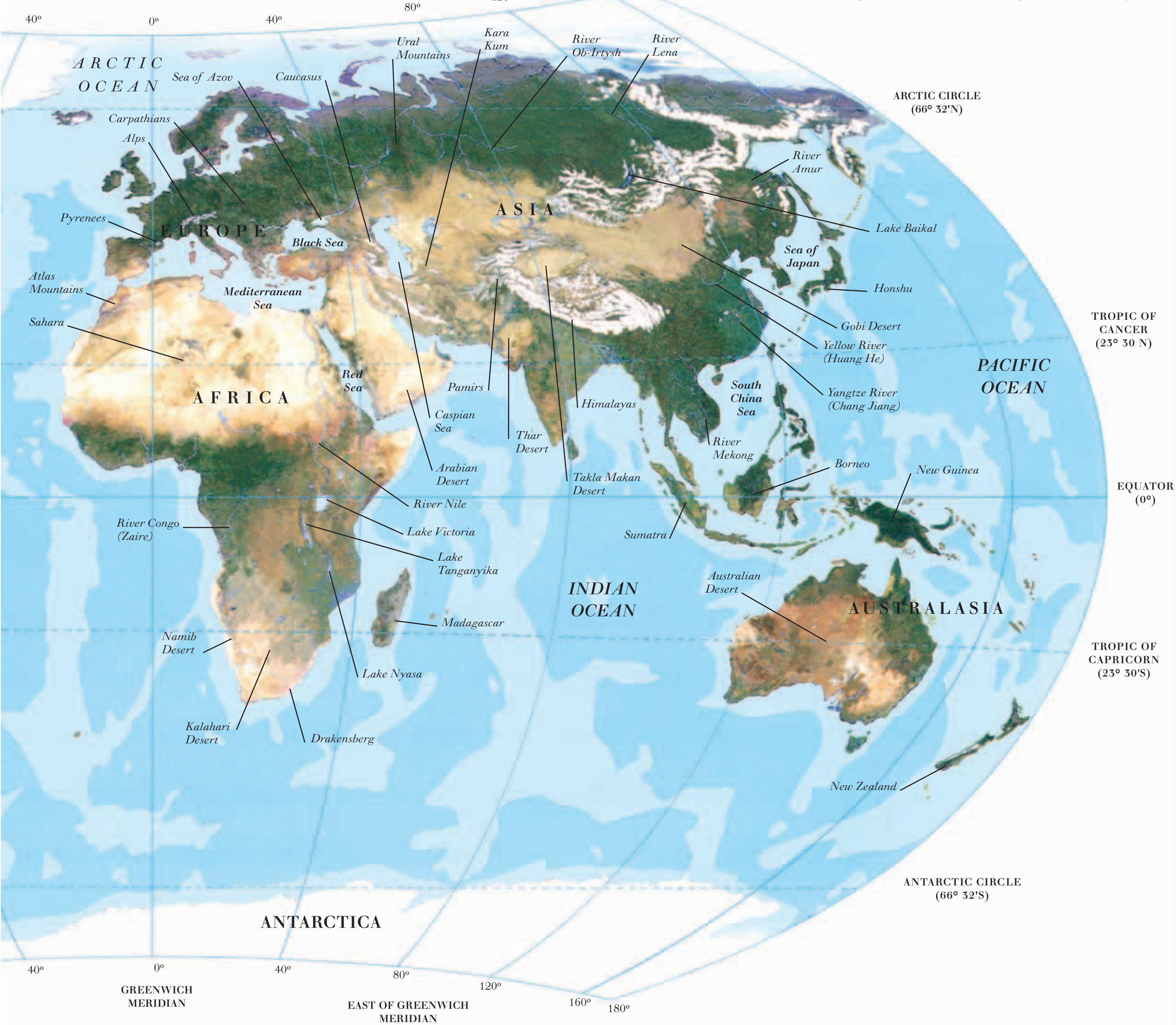
AZIMUTHAL PROJECTION

AZIMUTHAL-PROJECTION MAP

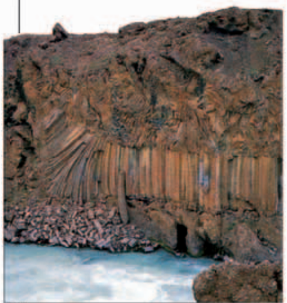


MODIFIED AZIMUTHAL-PROJECTION MAP

SATELLITE MAP OF THE EARTH



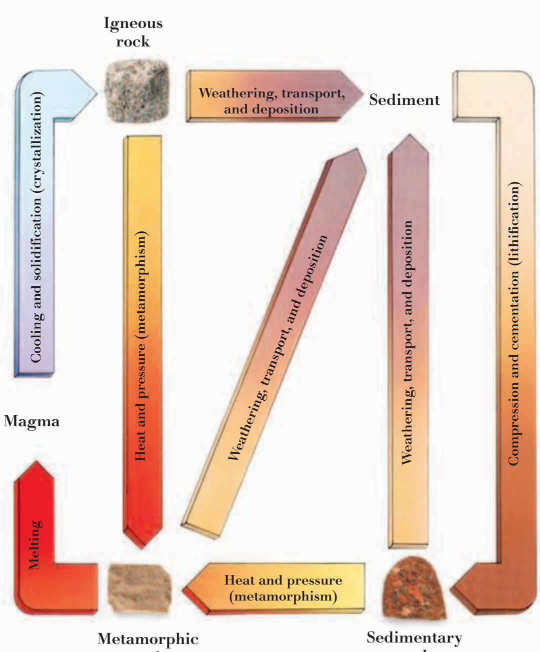
The rock cycle



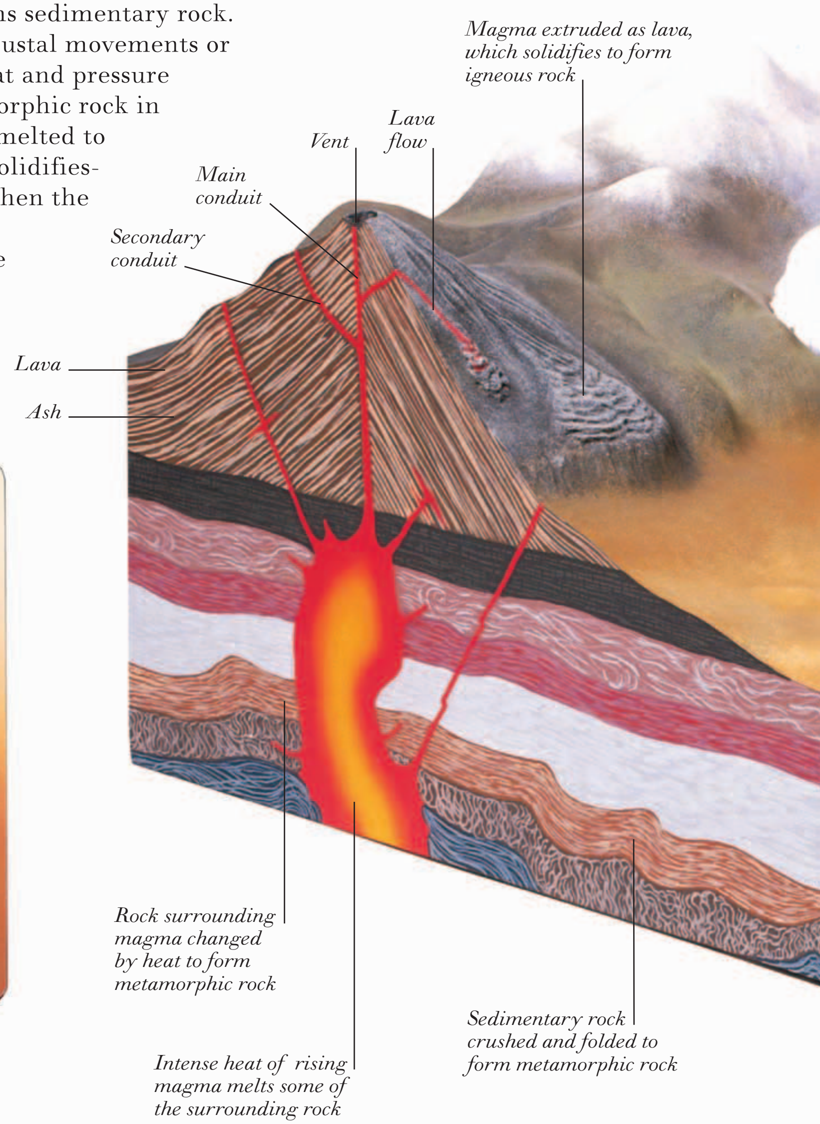
HEXAGONAL BASALT COLUMNS, ICELAND

THE ROCK CYCLE IS A CONTINUOUS PROCESS through which old rocks are transformed into new ones. Rocks can be divided into three main groups: igneous, sedimentary, and metamorphic. Igneous rocks are formed when magma (molten rock) from the Earth's interior cools and solidifies (see pp. 274-275). Sedimentary rocks are formed when sediment (rock particles, for example) becomes compressed and cemented together in a process known as lithification (see pp. 276-277). Metamorphic rocks are formed when igneous, sedimentary, or other metamorphic rocks are changed by heat or pressure (see pp. 274-275). Rocks are added to the Earth's surface by crustal movements and volcanic activity. Once exposed on the surface, the rocks are broken down into rock particles by weathering (see pp. 282-283). The particles are then transported by glaciers, rivers, and wind, and deposited as sediment in lakes, deltas, deserts, and on the ocean floor. Some of this sediment undergoes lithification and forms sedimentary rock. This rock may be thrust back to the surface by crustal movements or forced deeper into the Earth's interior, where heat and pressure transform it into metamorphic rock. The metamorphic rock in turn may be pushed up to the surface or may be melted to form magma. Eventually, the magma cools and solidifies-below or on the surface-forming igneous rock. When the sedimentary, igneous, and metamorphic rocks are exposed once more on the Earth's surface, the cycle begins again.

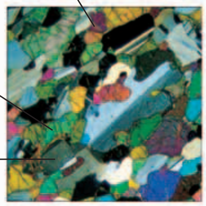
THE ROCK CYCLE



STAGES IN THE ROCK CYCLE



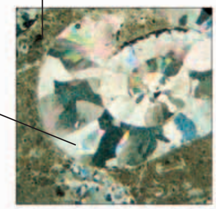
IGNEOUS ROCK



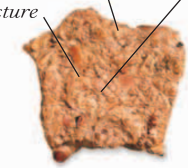
PHOTOMICROGRAPH OF GABBRO

PIECE OF GABBRO

SEDIMENTARY ROCK

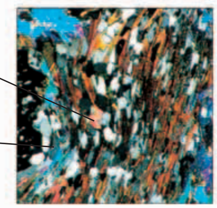


PHOTOMICROGRAPH OF SHELLY LIMESTONE



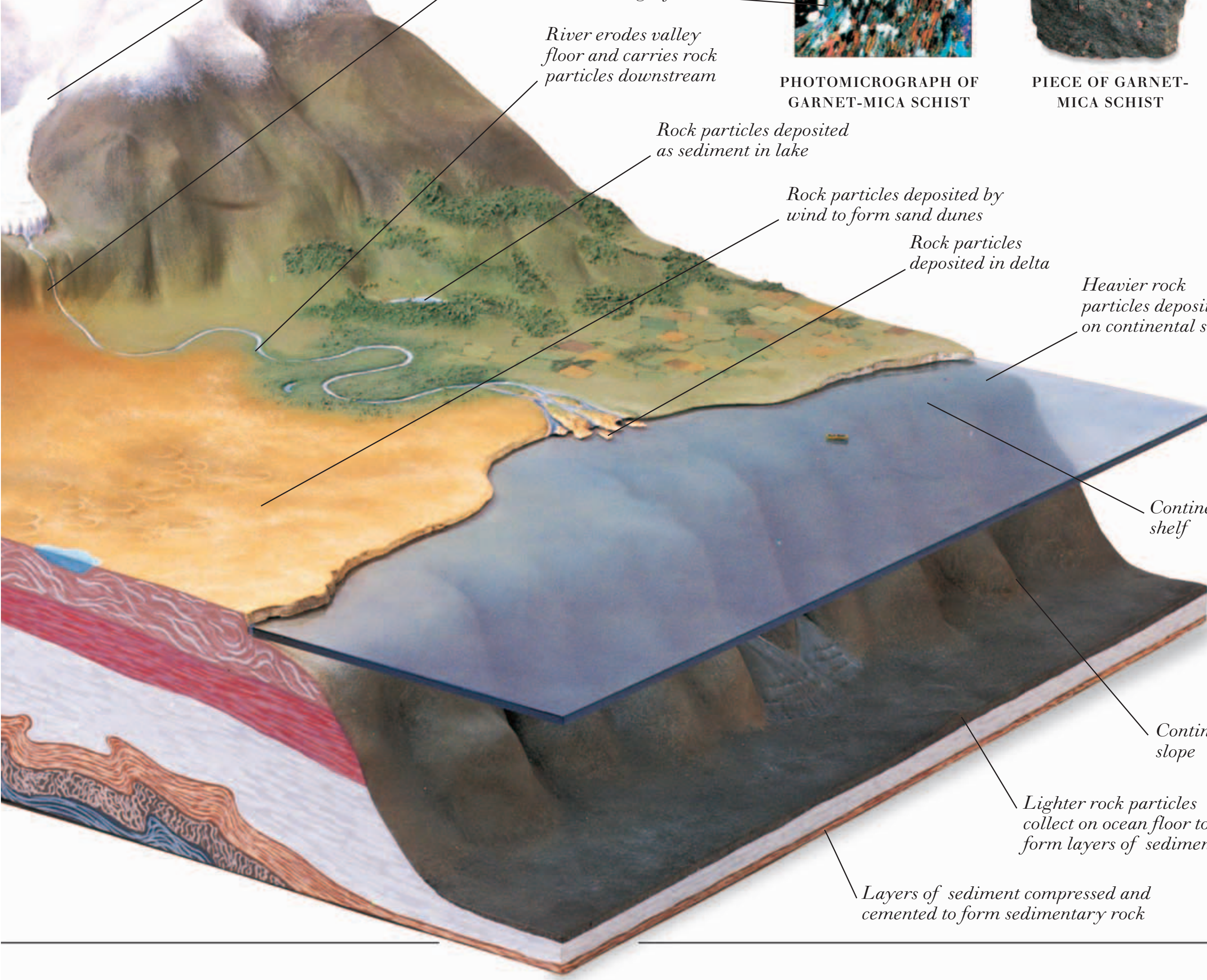
PIECE OF SHELLY LIMESTONE

METAMORPHIC ROCK



PHOTOMICROGRAPH OF GARNET-MICA SCHIST

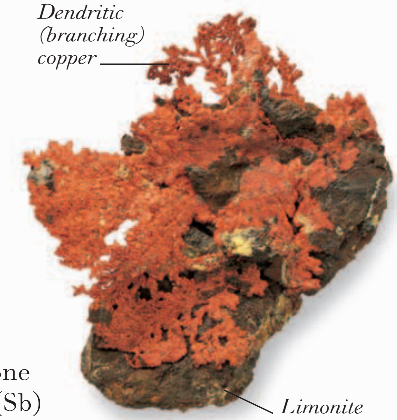
PIECE OF GARNET-MICA SCHIST



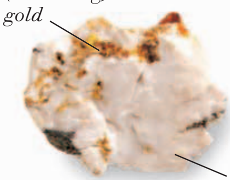
Minerals

A MINERAL IS A NATURALLY OCCURRING SUBSTANCE that has a characteristic chemical composition and specific physical properties, such as habit and streak (see pp. 270-271). A rock, by comparison, is an aggregate of minerals and need not have a specific chemical composition. Minerals are made up of elements (substances that cannot be broken down chemically into simpler substances), each of which can be represented by a chemical symbol. Minerals can be divided into two main groups: native elements and compounds. Native elements are made up of a pure element. Examples include gold (chemical symbol Au), silver (Ag), copper (Cu), and carbon (C); carbon occurs as a native element in two forms, diamond and graphite. Compounds are combinations of two or more elements. For example, sulfides are compounds of sulfur (S) and one or more other elements, such as lead (Pb) in the mineral galena, or antimony (Sb) in the mineral stibnite.

NATIVE ELEMENTS



COPPER
(Cu)



GOLD
(Au)

DIAMOND
(C)

GRAPHITE
(C)

SULFIDES

GALENA
(PbS)

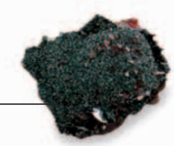
STIBNITE
(Sb_2S_3)

PYRITES
(FeS_2)

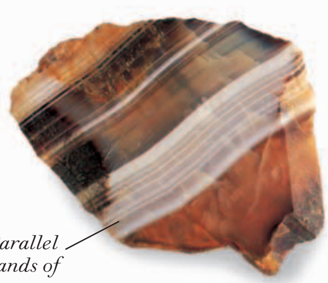
OXIDES/HYDROXIDES

SMOKY QUARTZ
(SiO_2)

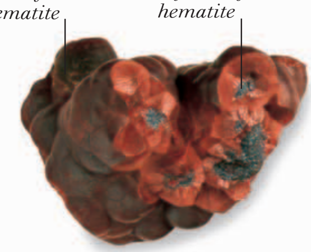
BAUXITE
($FeO(OH)$ and $Al_2O_3.2H_2O$)



SPECULAR HEMATITE
(Fe_2O_3)



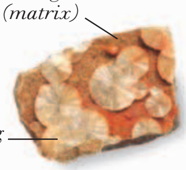
ONYX
(SiO_2)



KIDNEY ORE HEMATITE
(Fe_2O_3)

PHOSPHATES

PYROMORPHITE
$(Pb_5(PO_4)_3Cl)$



WAVELLITE
$(Al_3(PO_4)_2(OH,F)_3.5H_2O)$

CARBONATES

CERUSSITE
$(PbCO_3)$

CALCITE
$(CaCO_3)$

SULFATES

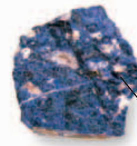
CYANOTRICHITE
$(Cu_4Al_2(SO_4)(OH)_{12}.2H_2O)$

DAISY GYPSUM
$(CaSO_4.2H_2O)$

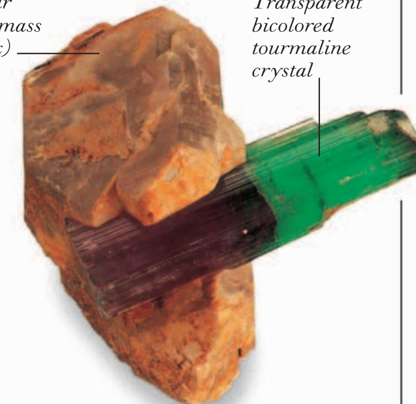
MOLYBDATE

WULFENITE
$(PbMoO_4)$

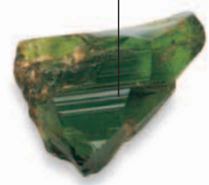
SILICATES



SODALITE
$(Na_8Al_6Si_6O_{24}Cl_2)$



TOURMALINE
$(Na(Mg,Fe,Li,Mn,Al)_3Al_6(BO_3)_3Si_6.O_{18}(OH,F)_4)$



OLIVINE
$(Fe_2SiO_4 - Mg_2SiO_4)$

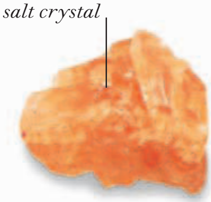
EPIDOTE
$(Ca_2(Al,Fe)_3(SiO_4)_3(OH))$

MUSCOVITE
$(KAl_2(Si_3Al)O_{10}(OH,F)_2)$

ORTHOCLASE
$(KAlSi_3O_8)$

HALIDES

GREEN FLUORITE
(CaF_2)

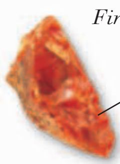


ORANGE HALITE (ROCK SALT)
$(NaCl)$

Mineral features

MINERALS CAN BE IDENTIFIED BY STUDYING features such as fracture, cleavage, crystal system, habit, hardness, color, and streak. Minerals can break in different ways. If a mineral breaks in an irregular way, leaving rough surfaces, it possesses fracture. If a mineral breaks along well-defined planes of weakness, it possesses cleavage. Specific minerals have distinctive patterns of cleavage; for example, mica cleaves along one plane. Most minerals form crystals, which can be categorized into crystal systems according to their symmetry and number of faces. Within each system, several different but related forms of crystal are possible; for example, a cubic crystal can have six, eight, or 12 sides. A mineral's habit is the typical form taken by an aggregate of its crystals. Examples of habit include botryoidal (like a bunch of grapes) and massive (no definite form). The relative hardness of a mineral may be assessed by testing its resistance to scratching. This property is usually measured using Mohs scale, which increases in hardness from 1 (talc) to 10 (diamond). The color of a mineral is not a dependable guide to its identity as some minerals have a range of colors. Streak (the color the powdered mineral makes when rubbed across an unglazed tile) is a more reliable indicator.

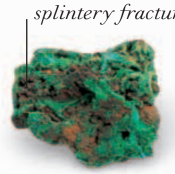
FRACTURE



CONCHOIDAL FRACTURE

HACKLY FRACTURE

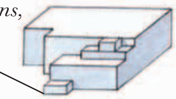
UNEVEN FRACTURE



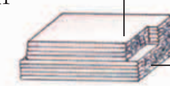
SPLINTERY FRACTURE

CLEAVAGE

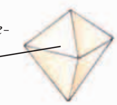
CLEAVAGE ALONG ONE PLANE



CLEAVAGE ALONG THREE PLANES



CLEAVAGE ALONG TWO PLANES



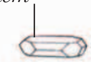
CLEAVAGE ALONG FOUR PLANES

CRYSTAL SYSTEMS

CUBIC SYSTEM

TETRAGONAL SYSTEM

HEXAGONAL/TRIGONAL SYSTEM



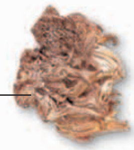
ORTHORHOMBIC SYSTEM

MONOCLINIC SYSTEM

TRICLINIC SYSTEM

HABIT

PRISMATIC HABIT

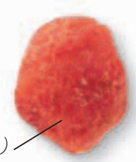


TWISTED WIRE HABIT

TABULAR HABIT

FIBROUS HABIT

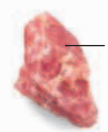
BOTRYOIDAL HABIT



MASSIVE HABIT

STREAK

COLOR



ROSE, PINK

WHITE-GRAY

ORANGE

BEIGE, TRANSPARENT

MOHS SCALE OF HARDNESS

TALC	GYPSUM	CALCITE	FLUORITE	APATITE	ORTHOCLASE	QUARTZ	TOPAZ	CORUNDUM	DIAMOND
1	2	3	4	5	6	7	8	9	10

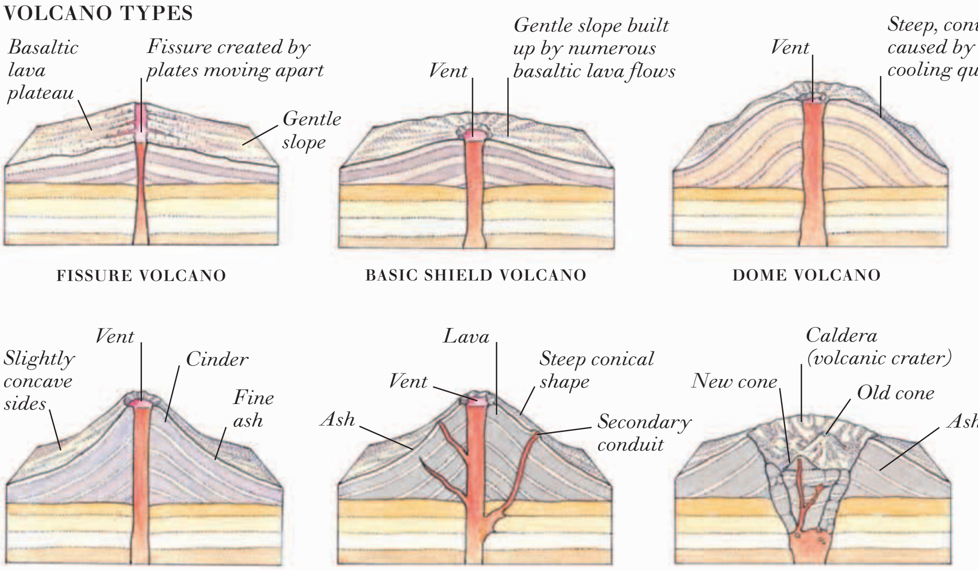
Volcanoes

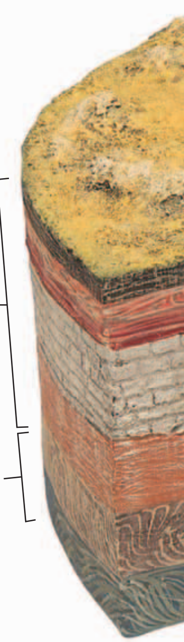
PAHOEHOE (ROPY LAVA)

VOLCANOES ARE VENTS OR FISSURES in the Earth's crust through which magma (molten rock that originates from deep beneath the crust) is forced on to the surface as lava. They occur most commonly along the boundaries of crustal plates; most volcanoes lie in a belt called the "Ring of Fire," which runs along the edge of the Pacific Ocean. Volcanoes can be classified according to the violence and frequency of their eruptions. Nonexplosive volcanic eruptions generally occur where crustal plates pull apart. These eruptions produce runny basaltic lava that spreads quickly over a wide area to form relatively flat cones. The most violent eruptions take place where plates collide. Such eruptions produce thick rhyolitic lava and may also blast out clouds of dust and pyroclasts (lava fragments). The lava does not flow far before cooling and therefore builds up steep-sided, conical volcanoes. Some volcanoes produce lava and ash eruptions, which build up composite volcanic cones. Volcanoes that erupt frequently are described as active; those that erupt rarely are termed dormant; and those that have stopped erupting altogether are termed extinct. As well as the volcanoes themselves, other features associated with volcanic regions include geysers, hot mineral springs, solfataras, fumaroles, and bubbling mud pools.

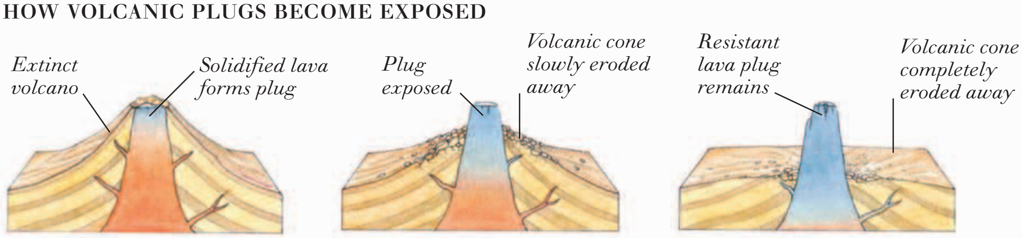
HORU GEYSER, NEW ZEALAND

VOLCANO TYPES





HOW VOLCANIC PLUGS BECOME EXPOSED



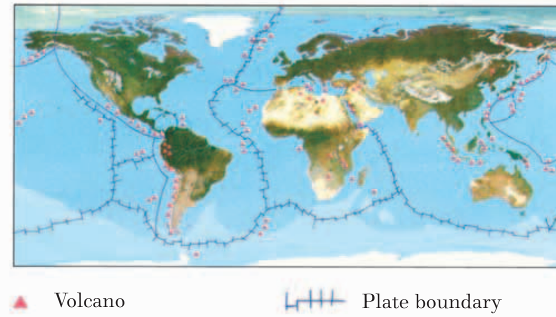
LAPILLI (LAVA FRAGMENTS)

TYPES OF LAVA

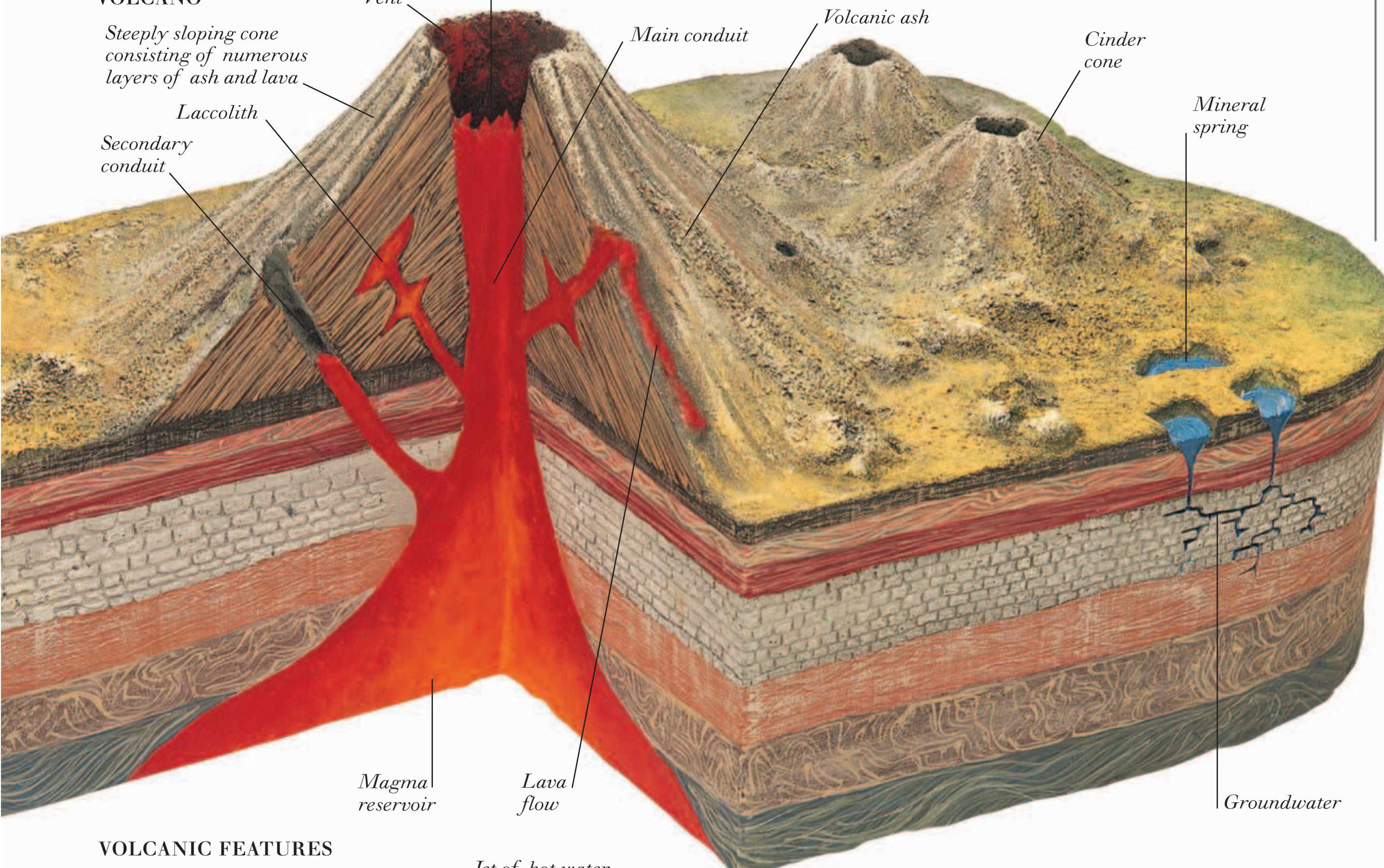
AA (BLOCKY LAVA)

REMELTED LAVA

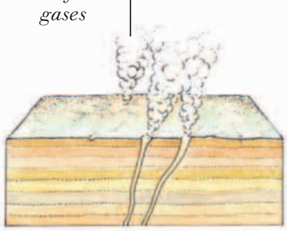
LOCATION OF VOLCANOES



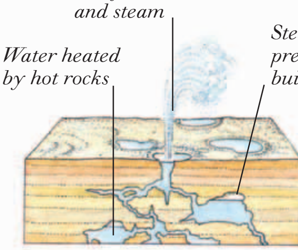
STRUCTURE OF A VOLCANO



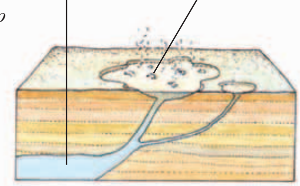
VOLCANIC FEATURES



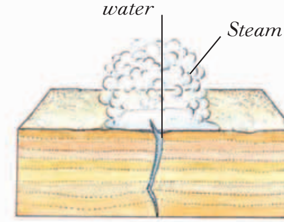
SOLFATARA



GEYSER



MUD POOL

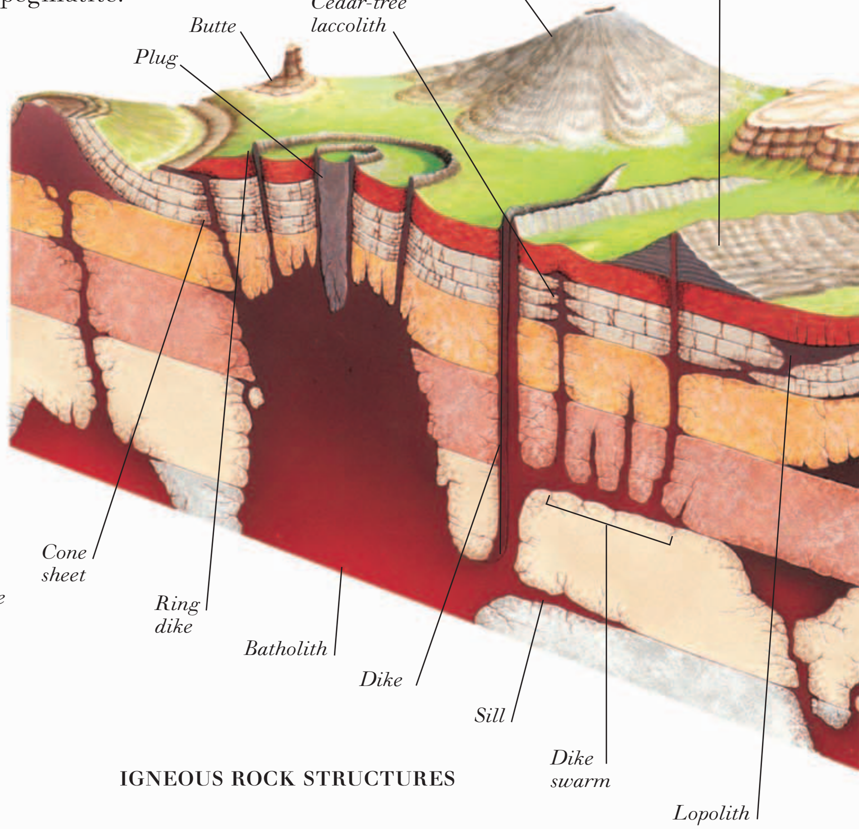


FUMAROLE

Igneous and metamorphic rocks

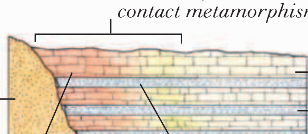
BASALT COLUMNS

IGNEOUS ROCKS ARE FORMED WHEN MAGMA (molten rock that originates from deep beneath the Earth's crust) cools and solidifies. There are two main types of igneous rock: intrusive and extrusive. Intrusive rocks are formed deep underground where magma is forced into cracks or between rock layers to form structures such as sills, dikes, and batholiths. The magma cools slowly to form coarse-grained rocks such as gabbro and pegmatite. Extrusive rocks are formed above the Earth's surface from lava (magma that has been ejected in a volcanic eruption). The molten lava cools quickly, producing fine-grained rocks such as rhyolite and basalt. Metamorphic rocks are those that have been altered by intense heat (contact metamorphism) or extreme pressure (regional metamorphism). Contact metamorphism occurs when rocks are changed by heat from, for example, an igneous intrusion or lava flow. Regional metamorphism occurs when rock is crushed in the middle of a folding mountain range. Metamorphic rocks can be formed from igneous rocks, sedimentary rocks, or even from other metamorphic rocks.

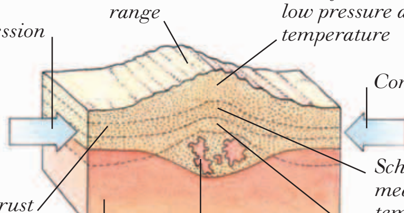


IGNEOUS ROCK STRUCTURES

CONTACT METAMORPHISM

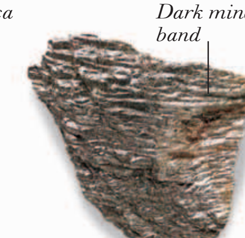


REGIONAL METAMORPHISM



EXAMPLES OF METAMORPHIC ROCKS

GNEISS



FOLDED SCHIST

SKARN

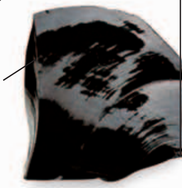
EXAMPLES OF EXTRUSIVE IGNEOUS ROCKS

RHYOLITE

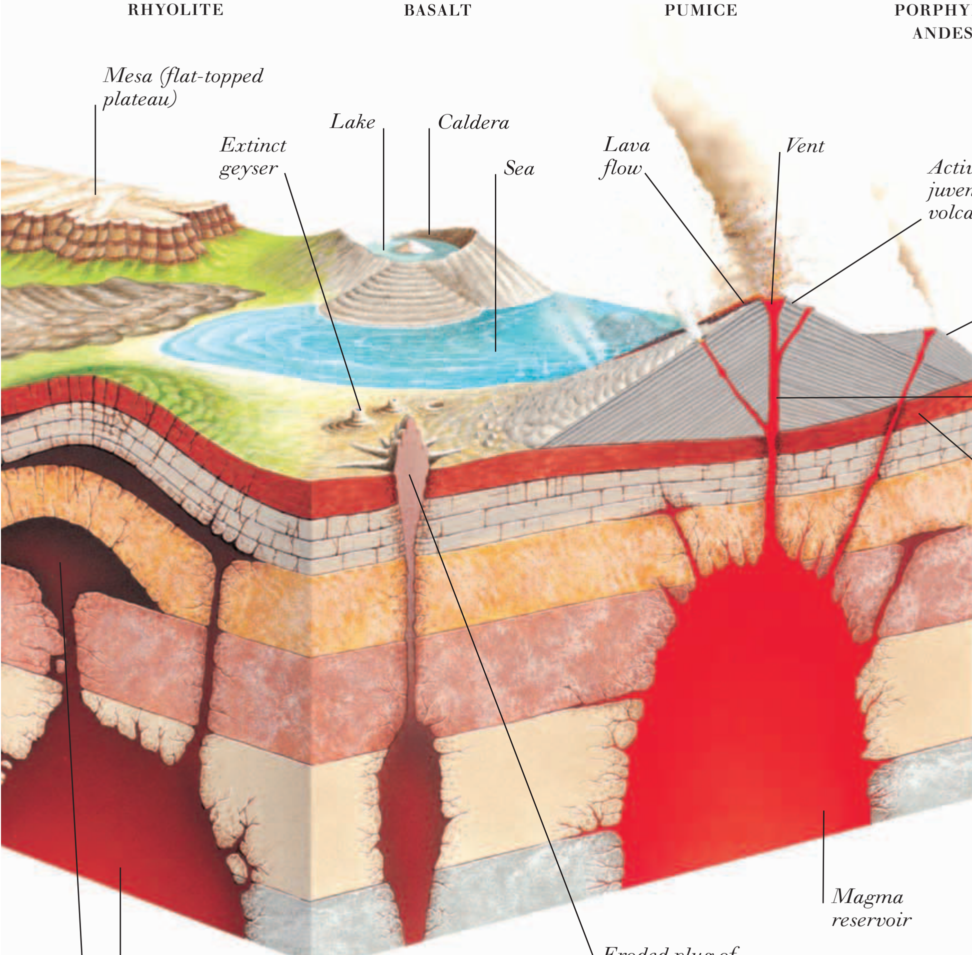
BASALT

PUMICE

PORPHYRITIC ANDESITE



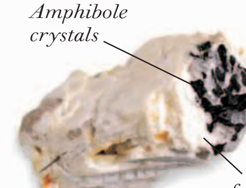
OBSIDIAN



EXAMPLES OF INTRUSIVE IGNEOUS ROCKS

KIMBERLITE

OLIVINE GABBRO



FELDSPAR PEGMATITE

SLATE WITH PYRITES

CHIASTOLITE HORNFELS

GREEN MARBLE

HALLEFLINTA

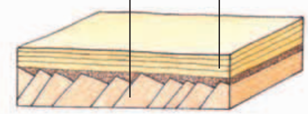
SYENITE

Sedimentary rocks

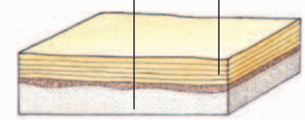
SEDIMENTARY ROCKS ARE FORMED BY THE ACCUMULATION and consolidation of sediments (see pp. 266-267). There are three main types of sedimentary rock. Clastic sedimentary rocks, such as breccia or sandstone, are formed from other rocks that have been broken down into fragments by weathering (see pp. 282-283), which have then been transported and deposited elsewhere. Organic sedimentary rocks—for example, coal (see pp. 280-281)—are derived from plant and animal remains. Chemical sedimentary rocks are formed by chemical processes. For example, rock salt is formed when salt dissolved in water is deposited as the water evaporates. Sedimentary rocks are laid down in layers, called beds or strata. Each new layer is laid down horizontally over older ones. There are usually some gaps in the sequence, called unconformities. These represent periods in which no new sediments were being laid down, or when earlier sedimentary layers were raised above sea level and eroded away.

THE GRAND CANYON, USA

EXAMPLES OF UNCONFORMITIES



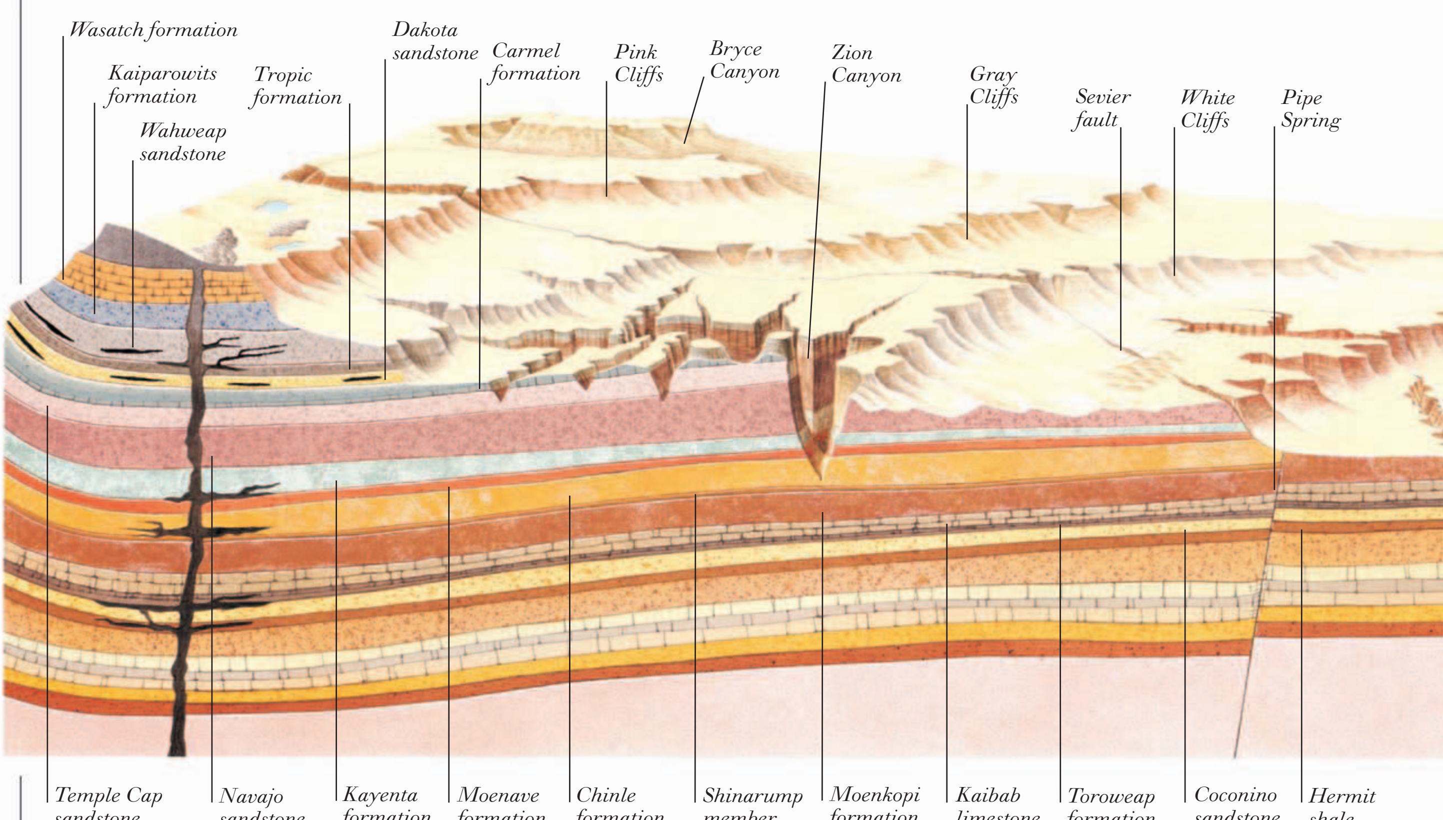
ANGULAR UNCONFORMITY



NONCONFORMITY

DISCONFORMITY

SEDIMENTARY LAYERS OF THE GRAND CANYON REGION



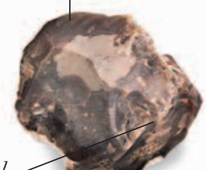
EXAMPLES OF SEDIMENTARY ROCKS

CHALK

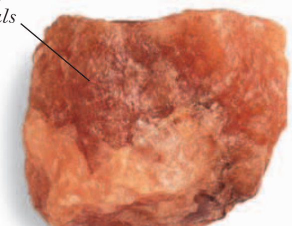
BANDED IRONSTONE

BRECCIA

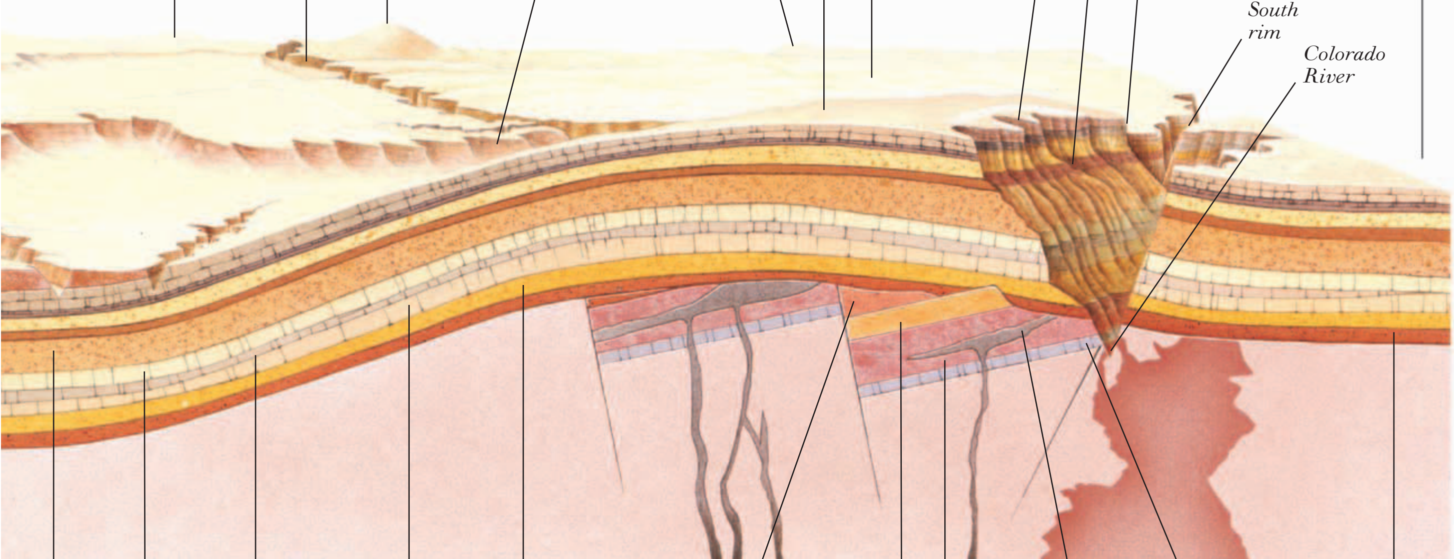
RED SANDSTONE



FLINT



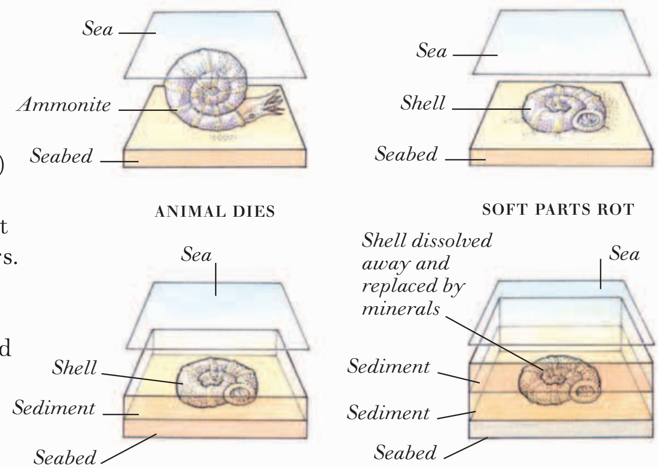
ORANGE HALITE (ROCK SALT)



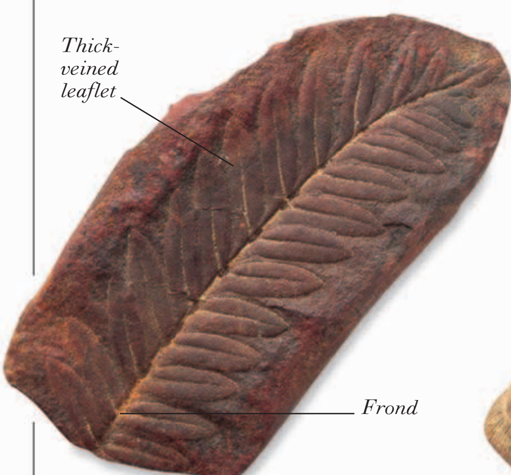
Fossils

FOSSILS ARE THE REMAINS of plants and animals that have been preserved in rock. A fossil may be the preserved remains of an organism itself, an impression of it in rock, or preserved traces (known as trace fossils) left by an organism while it was alive, such as organic carbon outlines, fossilized footprints, or droppings. Most dead organisms soon rot away or are eaten by scavengers. For fossilization to occur, rapid burial by sediment is necessary. The organism decays, but the harder parts—bones, teeth, and shells, for example—may be preserved and hardened by minerals from the surrounding sediment. Fossilization may also occur even when the hard parts of an organism are dissolved away to leave an impression called a mold. The mold is filled by minerals, thereby creating a cast of the organism. The study of fossils (paleontology) can not only show how living things have evolved, but can also help to reveal the Earth's geological history—for example, by aiding in the dating of rock strata.

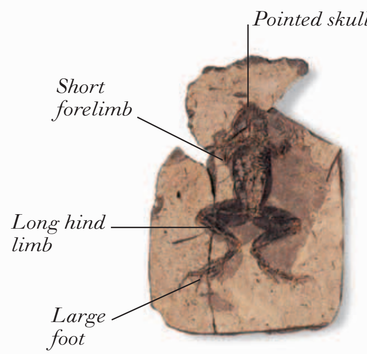
PROCESS OF FOSSILIZATION



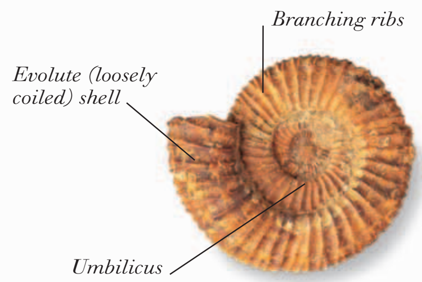
EXAMPLES OF FOSSILS



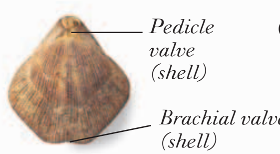
ALETHOPTERIS (SEED FERN)



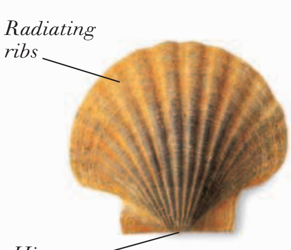
FROG (AMPHIBIAN)



PAVLOVIA (AMMONITE MOLLUSK)

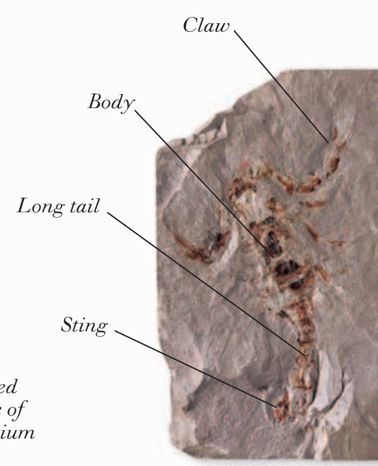


DICYOTHYRIS (BRACHIOPOD)



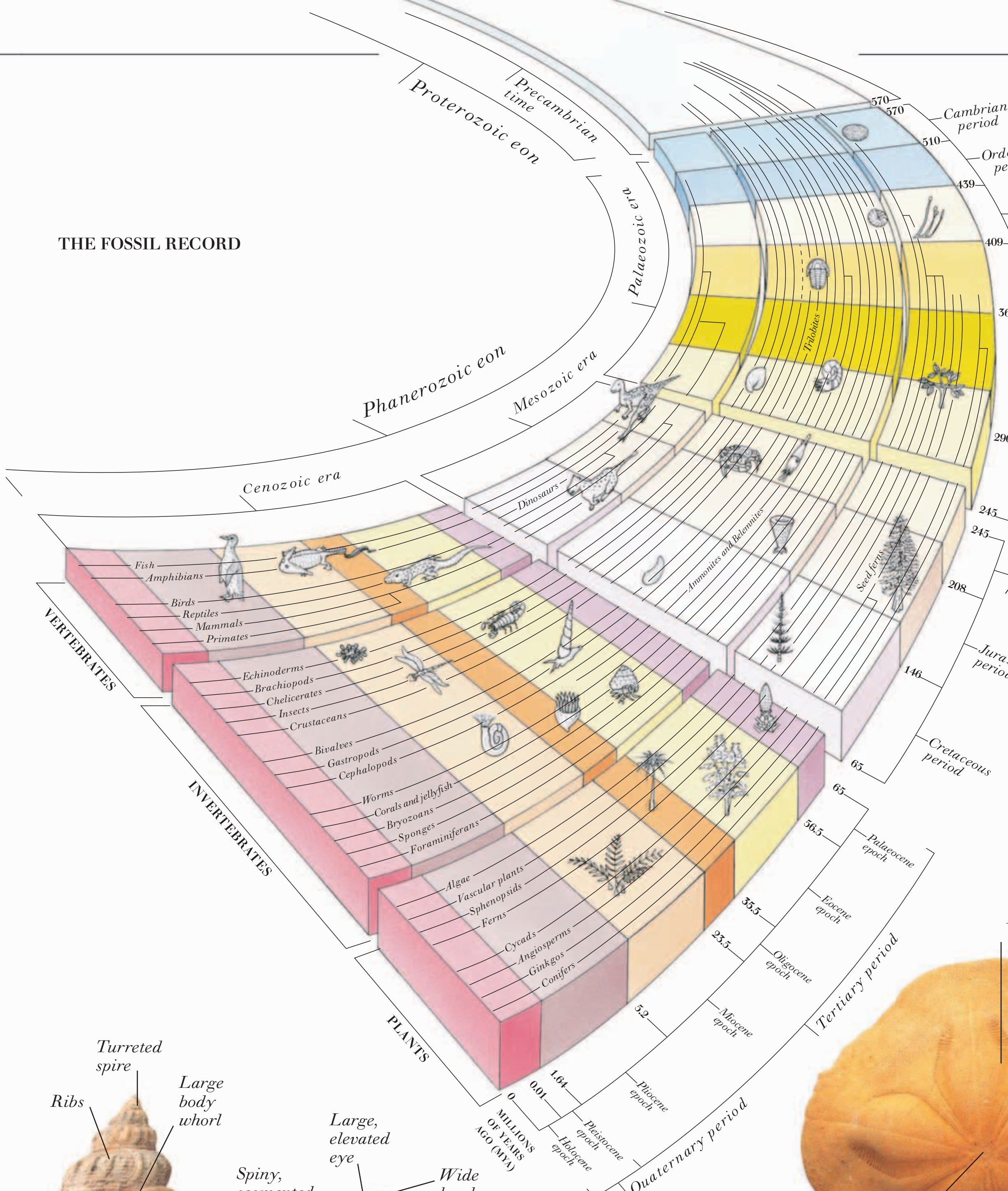
SCALLOP (BIVALVE MOLLUSK)

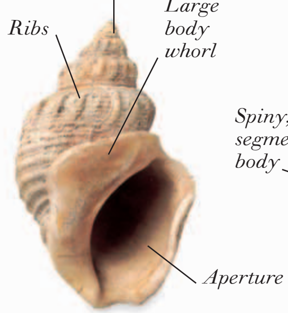
ACROTEUTHIS (BELEMNITE MOLLUSK)



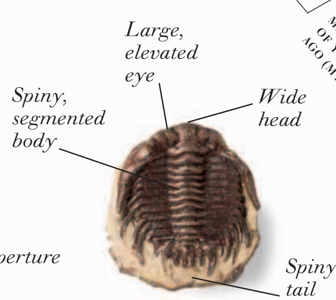
SCORPION (ARTHROPOD)

THE FOSSIL RECORD



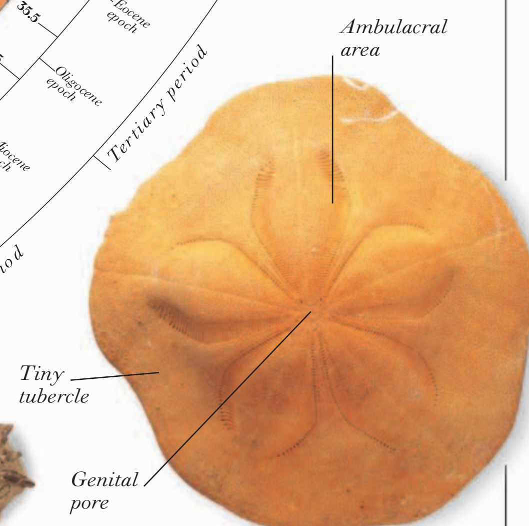


STRUTHIOLARIA (GASTROPOD MOLLUSK)



LEONASPIS (TRILOBITE)

MUD CRAB (CRUSTACEAN)



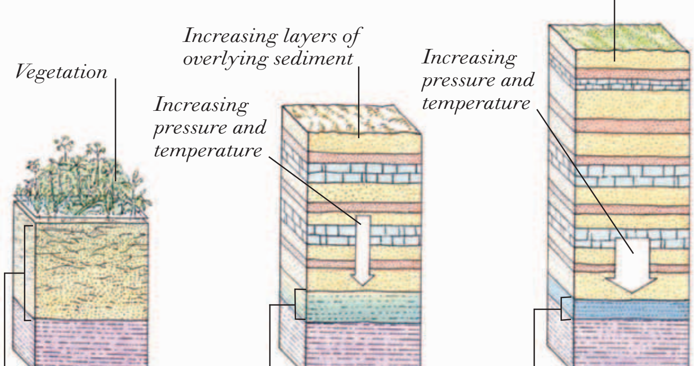
CLYPEASTER (ECHINODERM)

Mineral resources

MINERAL RESOURCES CAN BE DEFINED AS naturally occurring substances that can be extracted from the Earth and are useful as fuels and raw materials. Coal, oil, and gas – collectively called fossil fuels – are commonly included in this group, but are not strictly minerals, because they are of organic origin. Coal formation begins when vegetation is buried and partly decomposed to form peat. Overlying sediments compress the peat and transform it into lignite (soft brown coal). As the overlying sediments accumulate, increasing pressure and temperature eventually transform the lignite into bituminous and hard anthracite coals. Oil and gas are usually formed from organic matter that was deposited in marine sediments. Under the effects of heat and pressure, the compressed organic matter undergoes complex chemical changes to form oil and gas. The oil and gas percolate upwards through water-saturated, permeable rocks and they may rise to the Earth's surface or accumulate below an impermeable layer of rock that has been folded or faulted to form a trap – an anticline (upfold) trap, for example. Minerals are inorganic substances that may consist of a single chemical element, such as gold, silver, or copper, or combinations of elements (see pp. 268-269). Some minerals are concentrated in mineralization zones in rock associated with crustal movements or volcanic activity. Others may be found in sediments as placer deposits – accumulations of high-density minerals that have been weathered out of rocks, transported, and deposited (on riverbeds, for example).

OIL RIG, NORTH SEA

HOW COAL IS FORMED



PEAT

LIGNITE (BROWN COAL)

BITUMINOUS COAL

STAGES IN THE FORMATION OF COAL

PLANT MATTER

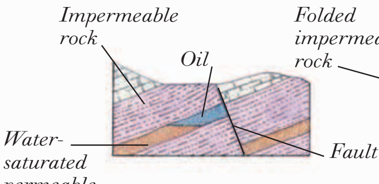
PEAT

LIGNITE (BROWN COAL)

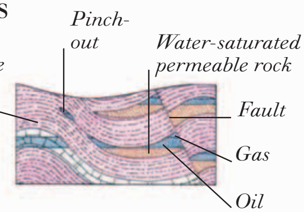
BITUMINOUS COAL

ANTHRACITE COAL

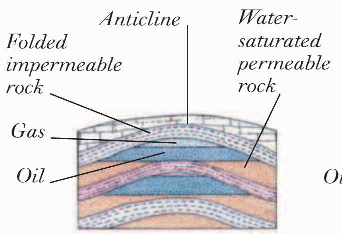
EXAMPLES OF OIL AND GAS TRAPS



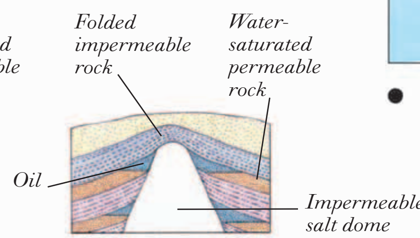
FAULT TRAP



PINCH-OUT TRAP

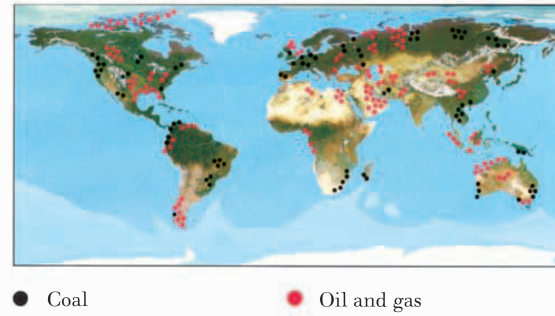


ANTICLINE TRAP

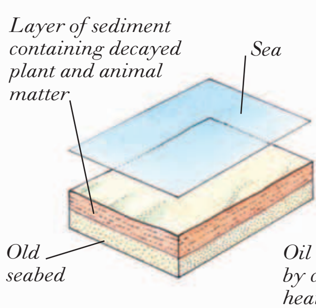


SALT-DOME TRAP

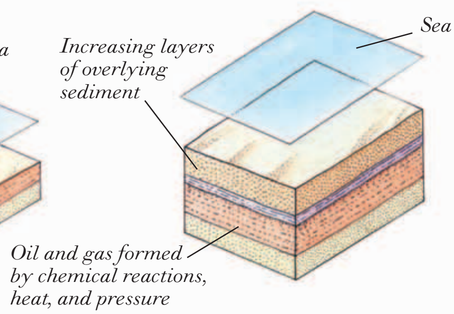
MAJOR COAL, OIL, AND GAS DEPOSITS



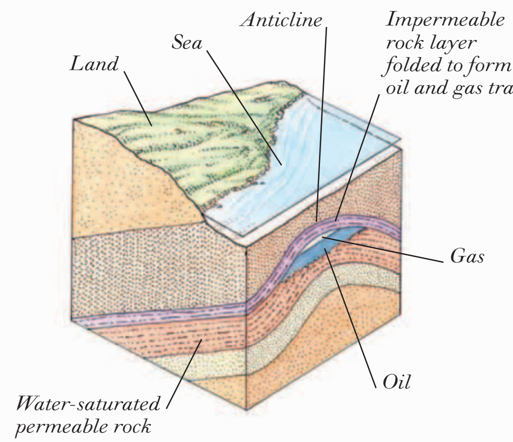
HOW AN ANTICLINE TRAP IS FORMED



DEPOSITION OF ORGANIC MATERIAL

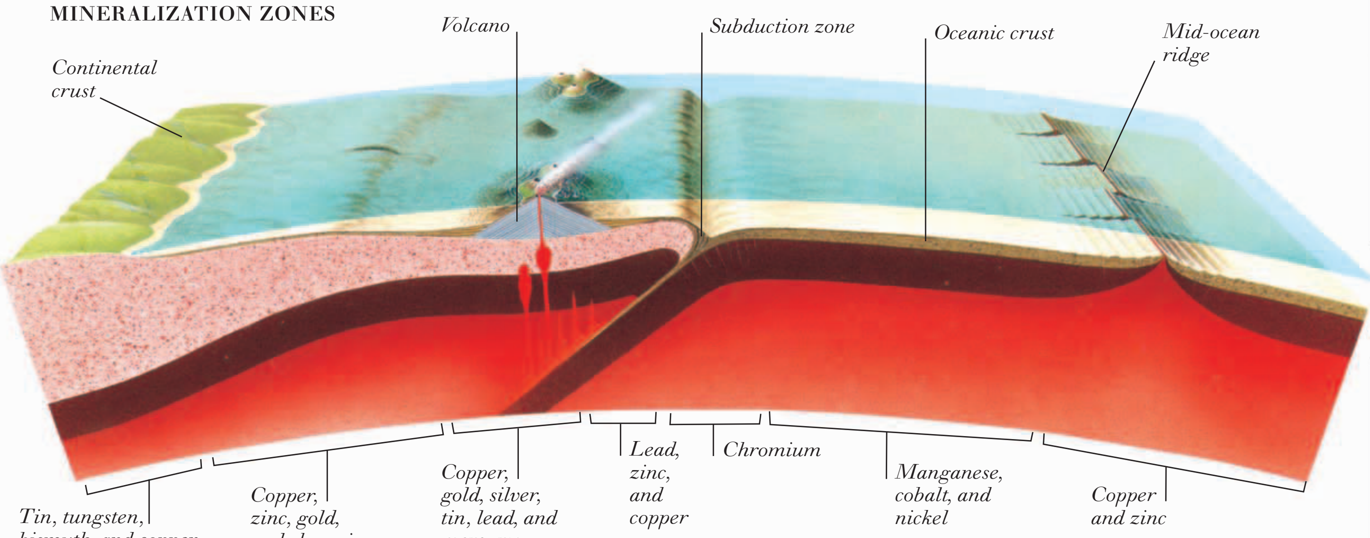


FORMATION OF OIL AND GAS



COLLECTION OF OIL AND GAS IN ANTICLINE TRAP

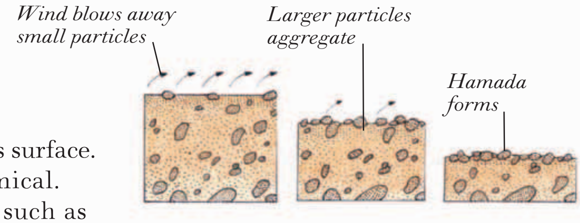
MINERALIZATION ZONES



Weathering and erosion

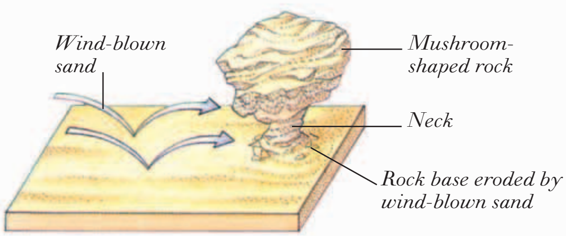
WEATHERING IS THE BREAKING DOWN of rocks on the Earth's surface. There are two main types: physical (or mechanical) and chemical. Physical weathering may be caused by temperature changes, such as freezing and thawing, or by abrasion from material carried by winds, rivers, or glaciers. Rocks may also be broken down by the actions of animals and plants, such as the burrowing of animals and the growth of roots. Chemical weathering causes rocks to decompose by changing their chemical composition—for example, rainwater may dissolve certain minerals in a rock. Erosion is the wearing away and removal of land surfaces by water, wind, or ice. It is greatest in areas of little or no surface vegetation, such as deserts, where sand dunes may form.

FORMATION OF A HAMADA (ROCK PAVEMENT)

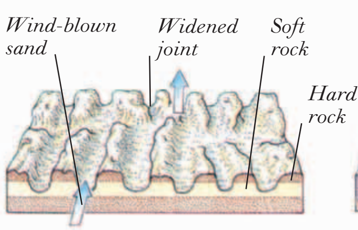


FIRST STAGE — SECOND STAGE — FINAL STAGE

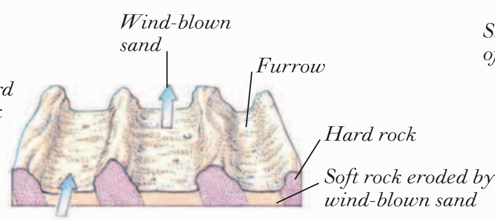
FEATURES PRODUCED BY WIND ACTION



ROCK PEDESTAL

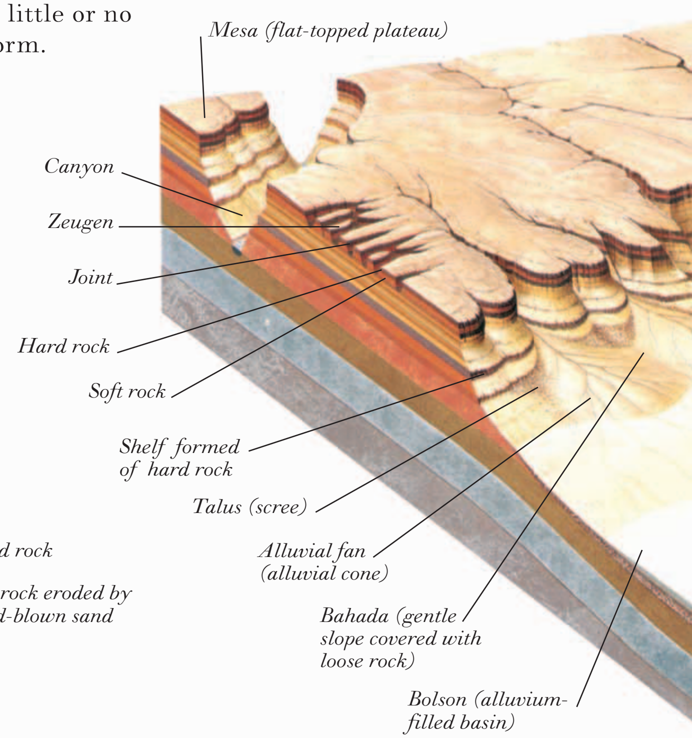


ZEUGEN

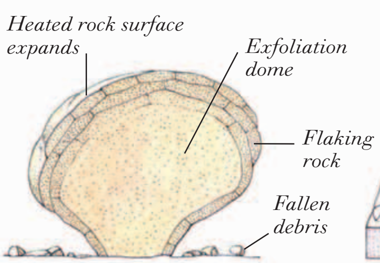


YARDANG

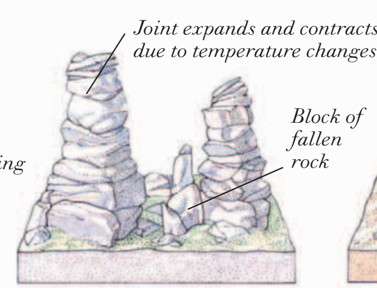
FEATURES OF WEATHERING AND EROSION



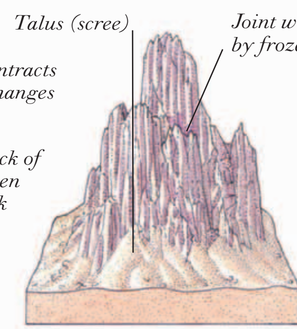
EXAMPLES OF PHYSICAL WEATHERING PROCESSES



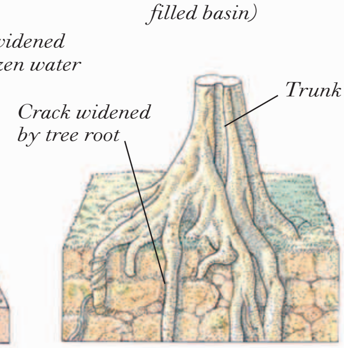
EXFOLIATION (ONION-SKIN WEATHERING)



BLOCK DISINTEGRATION

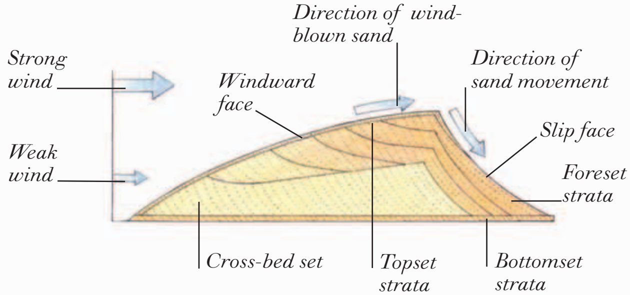


FROST WEDGING

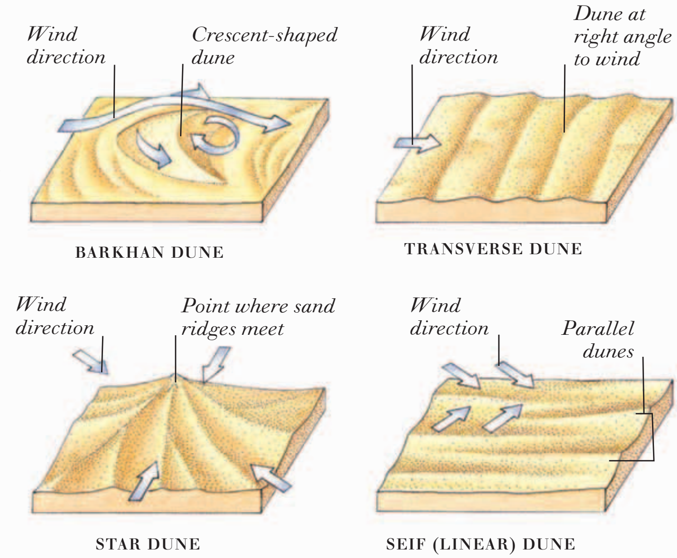


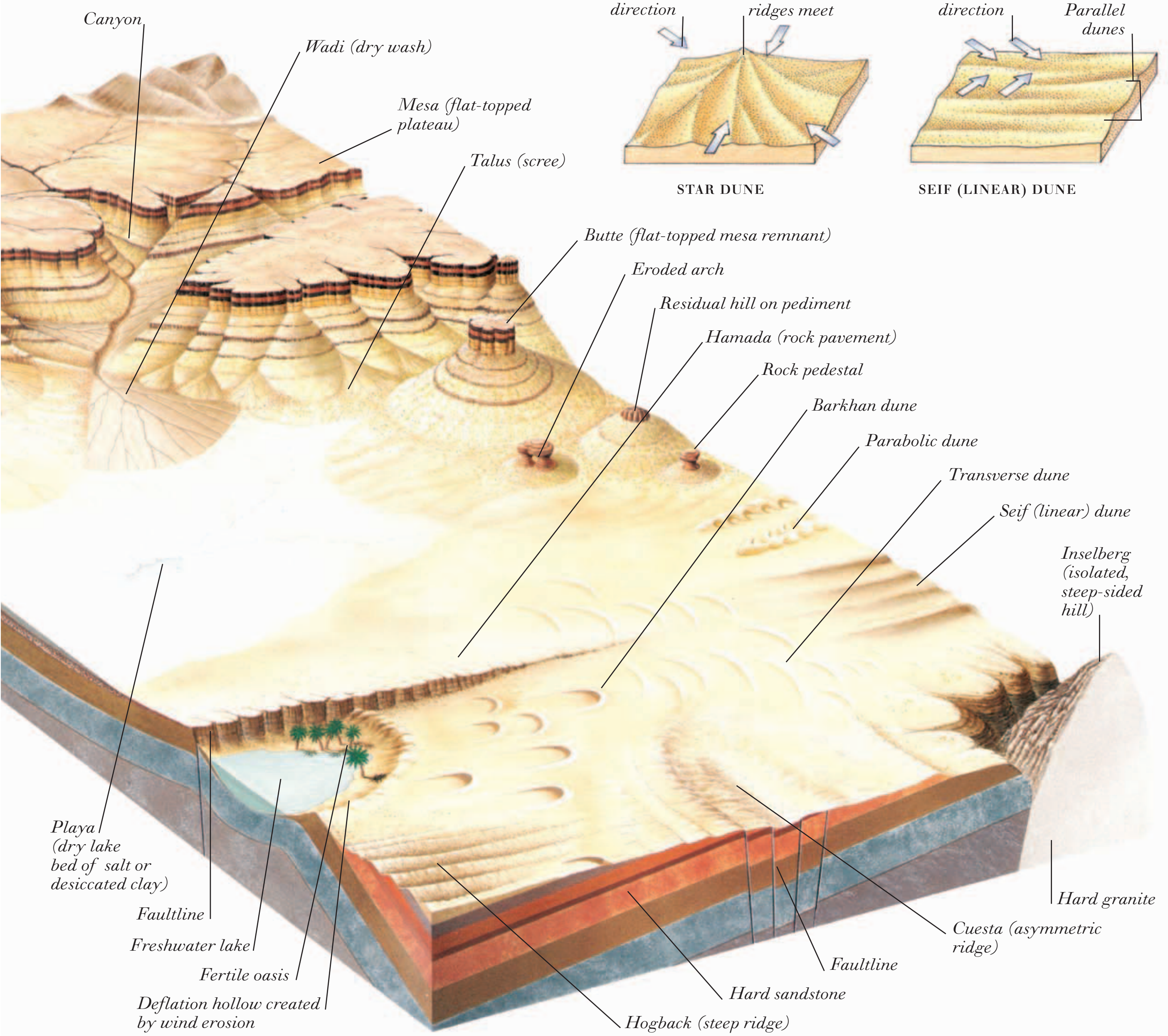
TREE ROOT ACTION

SECTION THROUGH A BARKHAN DUNE



EXAMPLES OF SAND DUNES





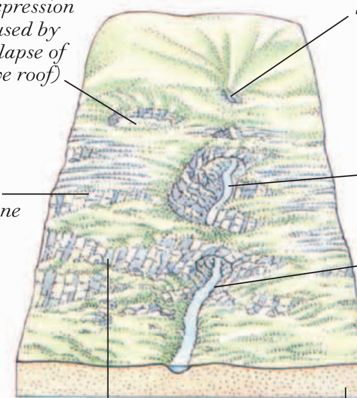
Caves

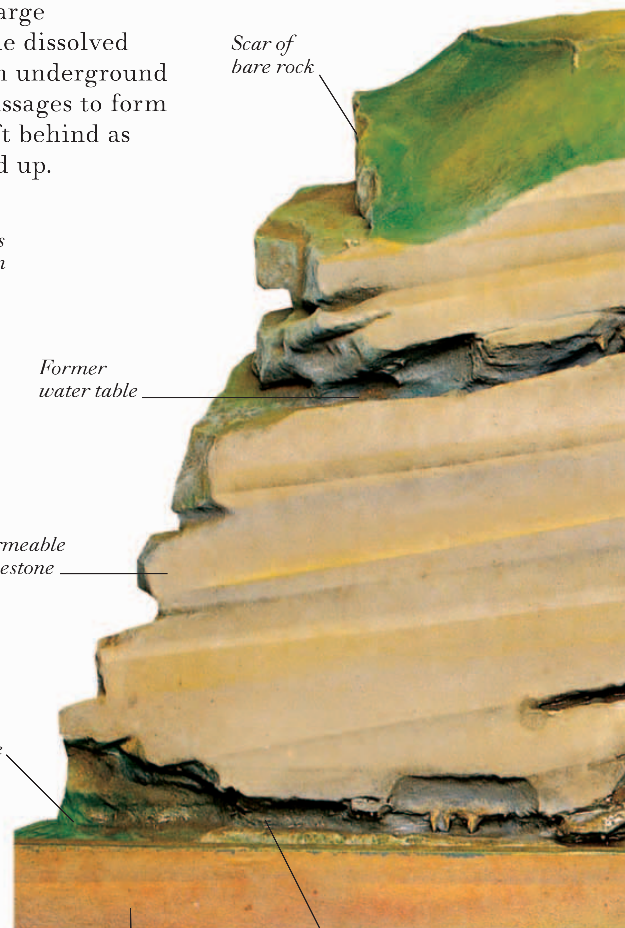
CAVES COMMONLY FORM in areas of limestone, although on coastlines they also occur in other rocks. Limestone is made of calcite (calcium carbonate), which dissolves in the carbonic acid naturally present in rainwater, and in humic acids from the decay of vegetation. The acidic water trickles down through cracks and joints in the limestone and between rock layers, breaking up the surface terrain into clints (blocks of rock), separated by grikes (deep cracks), and punctuated by sink-holes (also called swallow-holes or potholes) into which surface streams may disappear. Underground, the acidic water dissolves the rock around crevices, opening up a network of passages and caves, which can become large caverns if the roofs collapse. Various features are formed when the dissolved calcite is redeposited; for example, it may be redeposited along an underground stream to form a gour (series of calcite ridges), or in caves and passages to form stalactites and stalagmites. Stalactites develop where calcite is left behind as water drips from the roof; where the drops land, stalagmites build up.

MERGED STALACTITES

STALACTITE WITH RING MARKS

SURFACE TOPOGRAPHY OF A CAVE SYSTEM

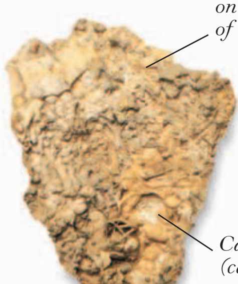




STALAGMITE FORMATIONS

CRYSTALLINE STALAGMITIC FLOOR

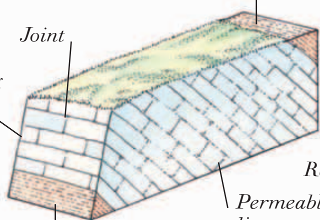
CALCAREOUS TUFA



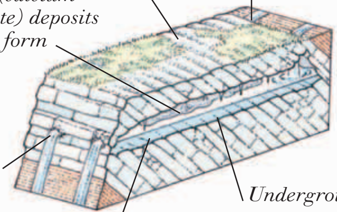
STALAGMITIC FLOOR

STALAGMITIC BOSS

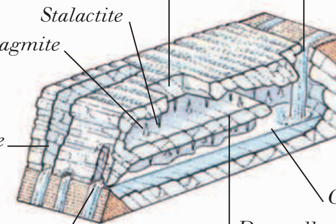
DEVELOPMENT OF A CAVE SYSTEM



STRUCTURE OF LIMESTONE STRATA

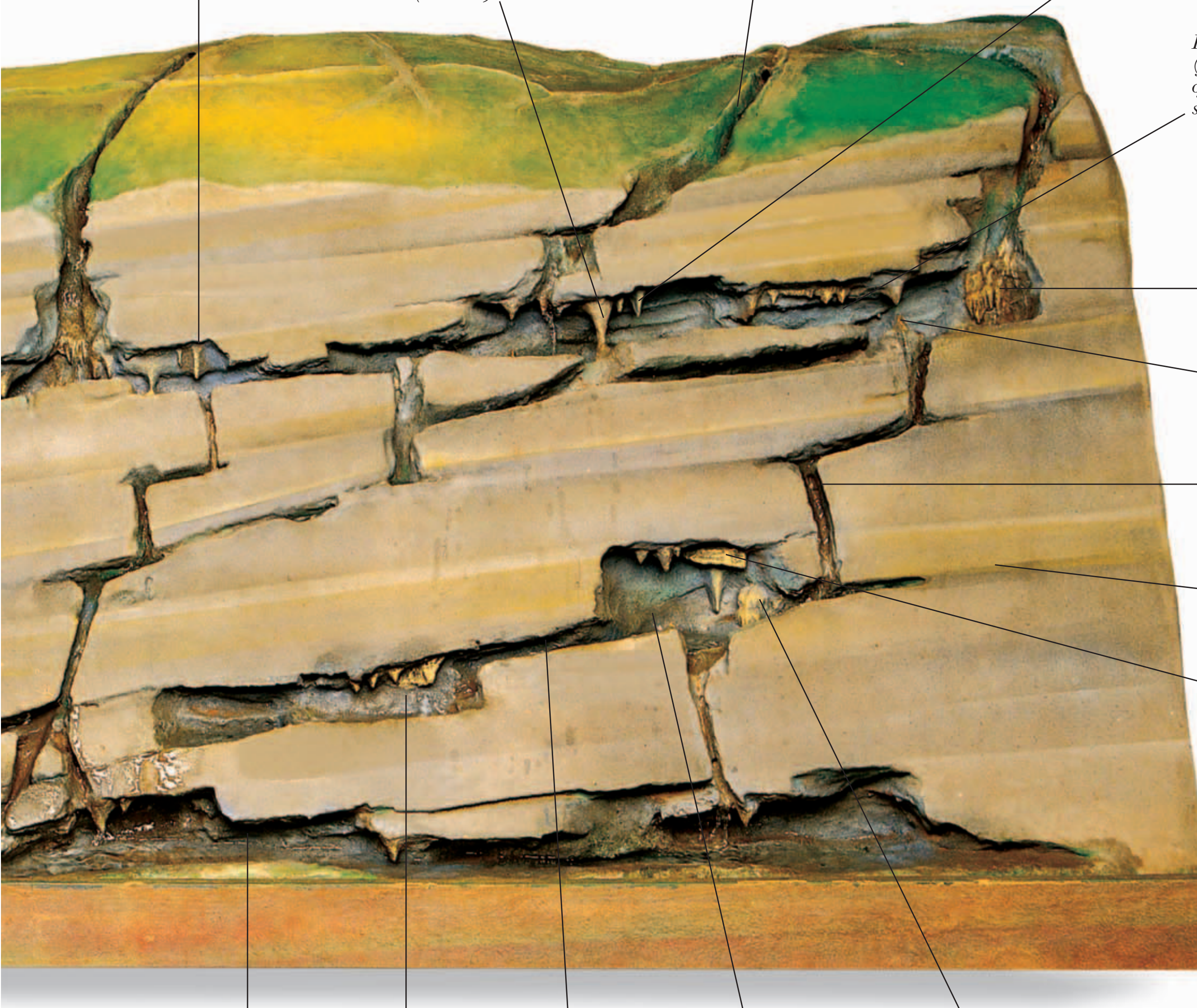


INITIAL CAVE



EXTENDED CAVE SYSTEM

INTERCONNECTED CAVE SYSTEM

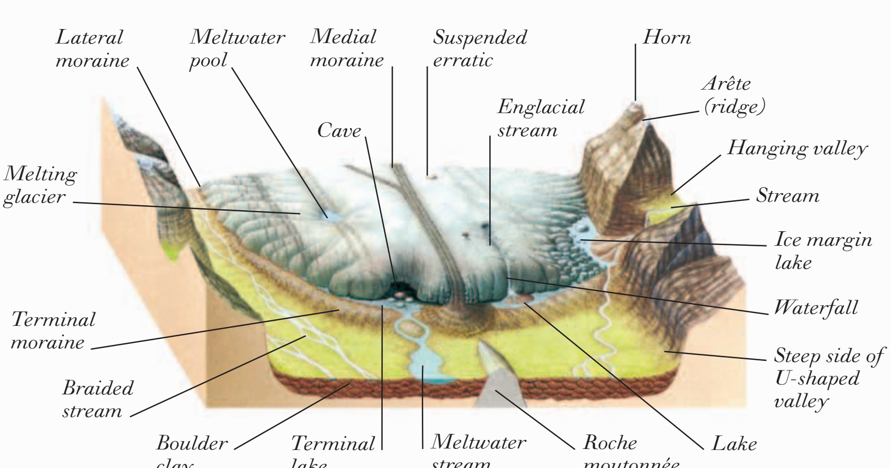


Glaciers

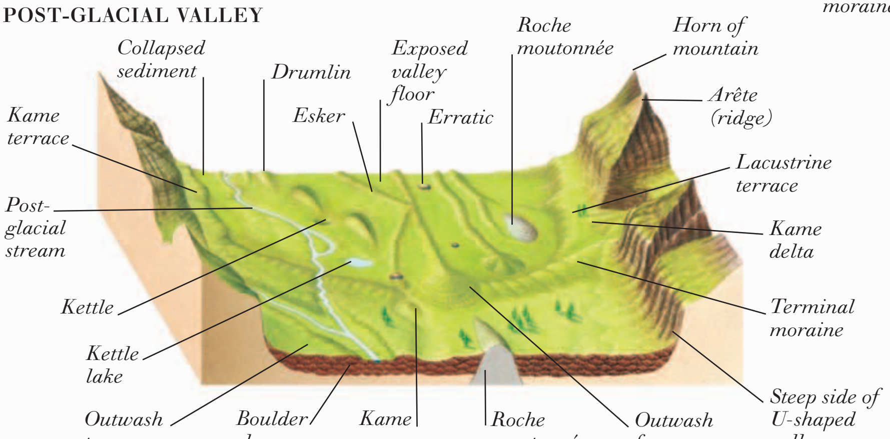
GLACIER BAY, ALASKA

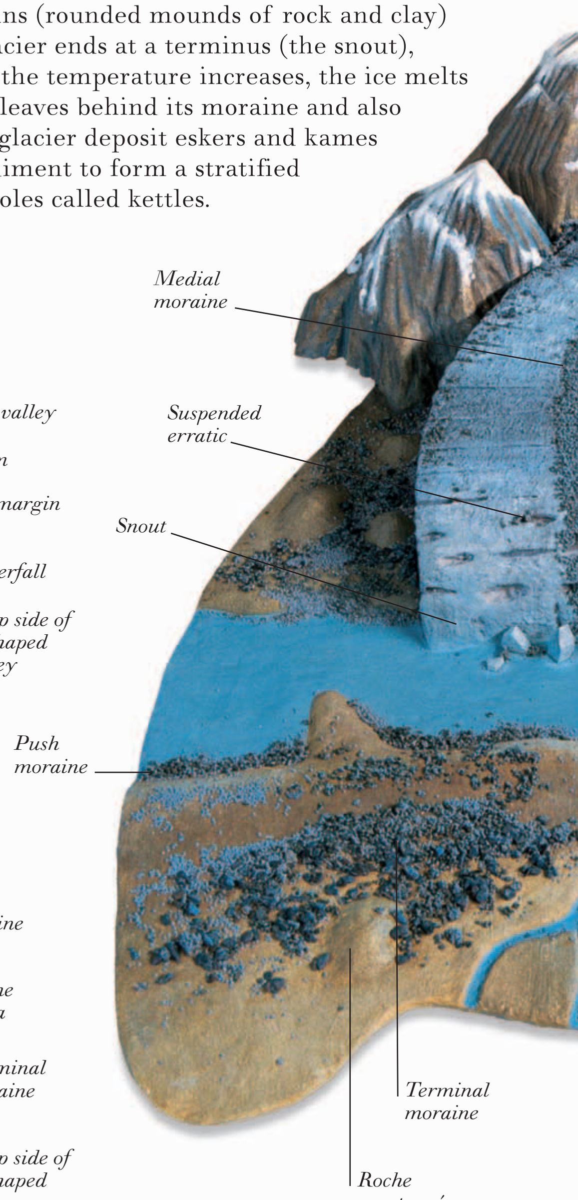
A VALLEY GLACIER IS A LARGE MASS OF ICE that forms on land and moves slowly downhill under its own weight. It is formed from snow that collects in cirques (mountain hollows also known as corries) and compresses into ice as more and more snow accumulates. The cirque is deepened by frost wedging and abrasion (see pp. 282-283), and arêtes (sharp ridges) develop between adjacent cirques. Eventually, so much ice builds up that the glacier begins to move downhill. As the glacier moves it collects moraine (debris), which may range in size from particles of dust to large boulders. The rocks at the base of the glacier erode the glacial valley, giving it a U-shaped cross-section. Under the glacier, *roches moutonnées* (eroded outcrops of hard rock) and drumlins (rounded mounds of rock and clay) are left behind on the valley floor. The glacier ends at a terminus (the snout), where the ice melts as fast as it arrives. If the temperature increases, the ice melts faster than it arrives, and the glacier retreats. The retreating glacier leaves behind its moraine and also erratics (isolated single boulders). Glacial streams from the melting glacier deposit eskers and kames (ridges and mounds of sand and gravel), but carry away the finer sediment to form a stratified outwash plain. Lumps of ice carried on to this plain melt, creating holes called kettles.

VALLEY GLACIER

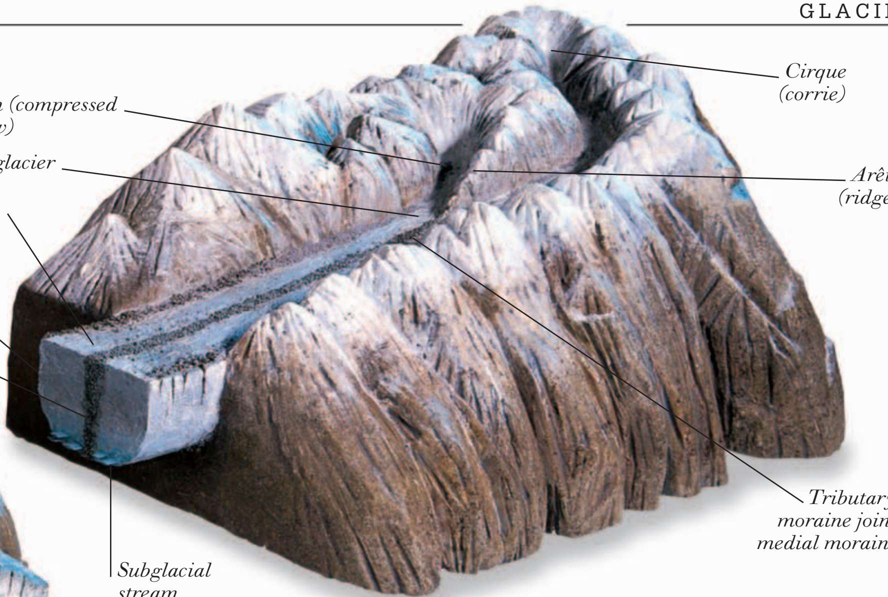


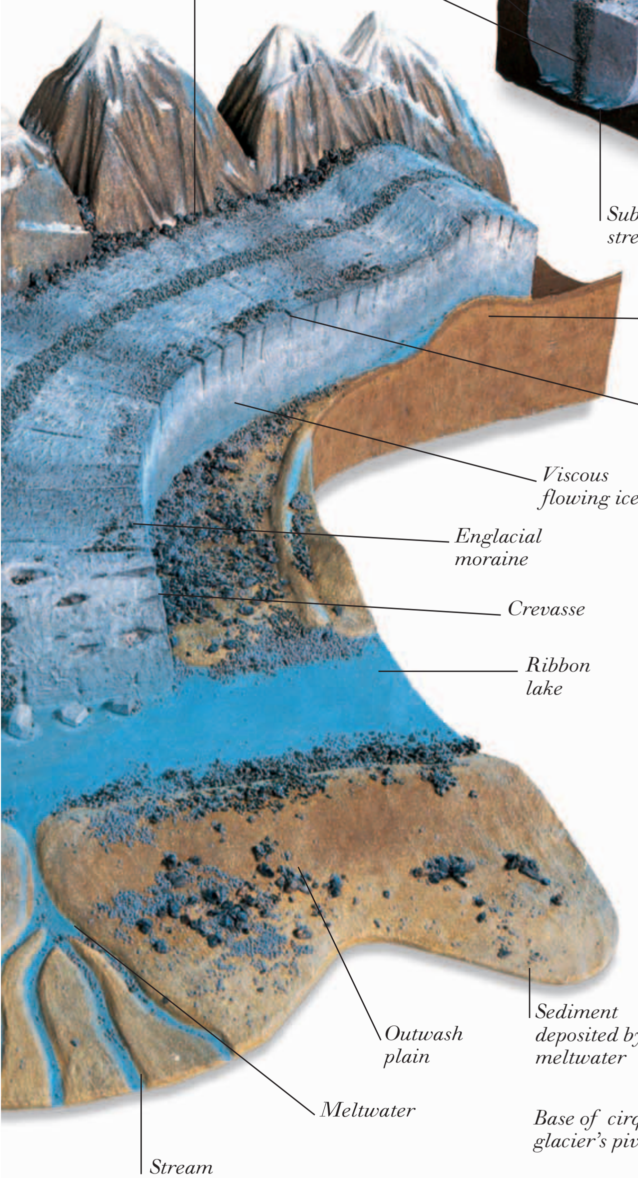
POST-GLACIAL VALLEY



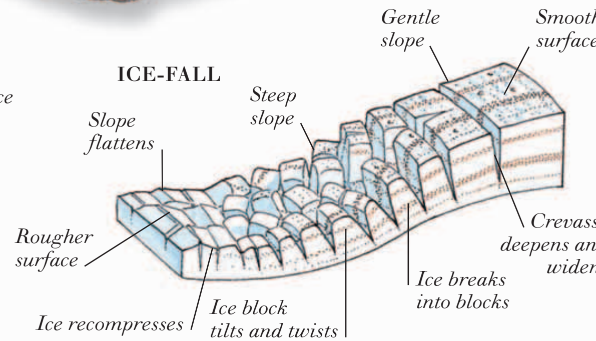


FEATURES OF A GLACIER

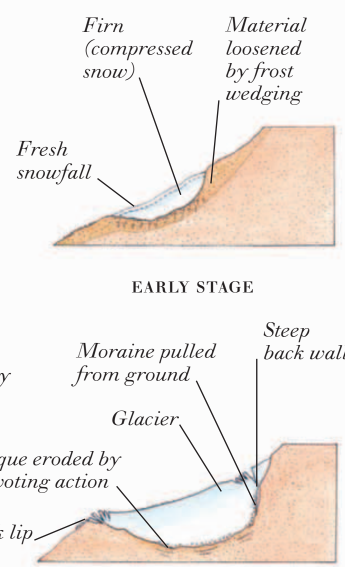




ICE-FALL



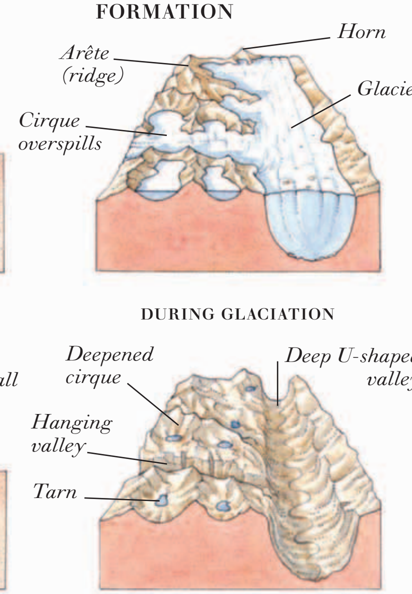
CIRQUE FORMATION



EARLY STAGE

LATER STAGE

U-SHAPED VALLEY FORMATION



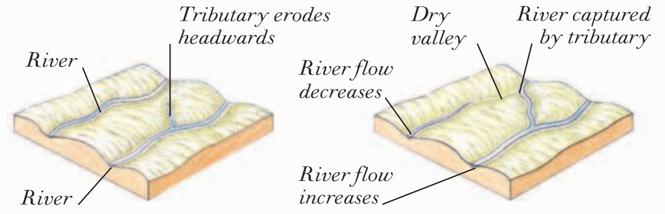
DURING GLACIATION

AFTER GLACIATION

Rivers

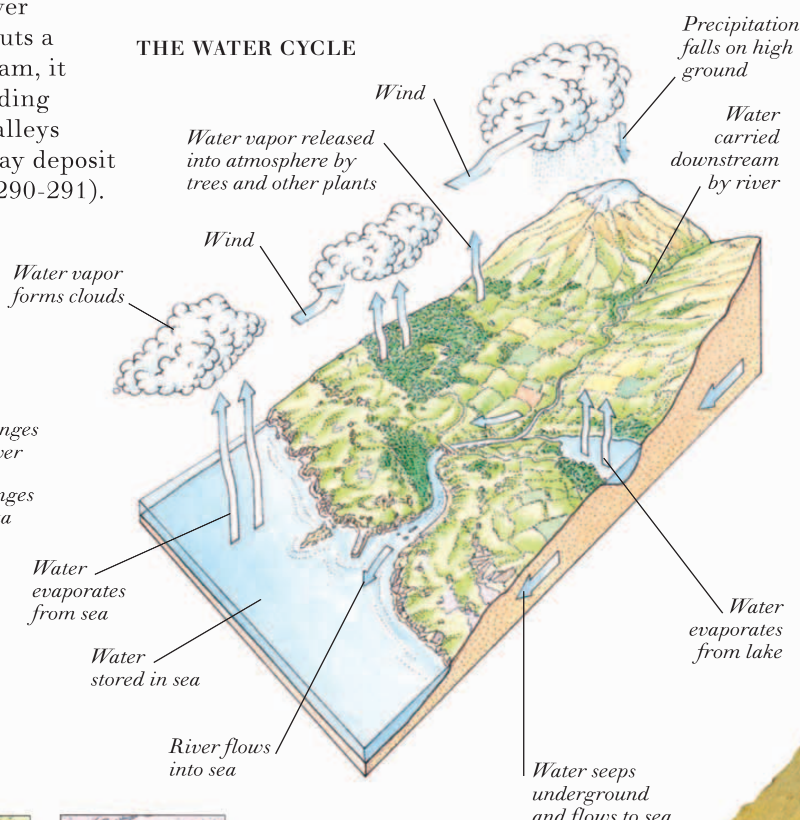
RIVERS FORM PART of the water cycle—the continuous circulation of water between the land, sea, and atmosphere. The source of a river may be a mountain spring or lake, or a melting glacier. The course that the river subsequently takes depends on the slope of the terrain and on the rock types and formations over which it flows. In its early, upland stages, a river tumbles steeply over rocks and boulders and cuts a steep-sided V-shaped valley. Farther downstream, it flows smoothly over sediments and forms winding meanders, eroding sideways to create broad valleys and plains. On reaching the coast, the river may deposit sediment to form an estuary or delta (see pp. 290-291).

RIVER CAPTURE

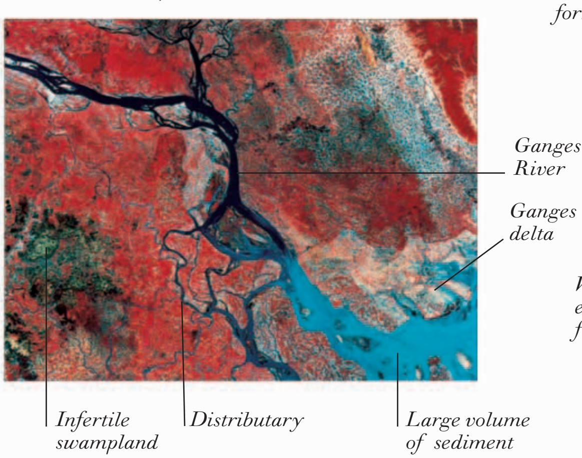


EARLY STAGE   LATER STAGE

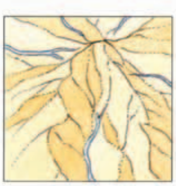
THE WATER CYCLE

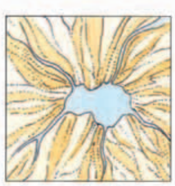


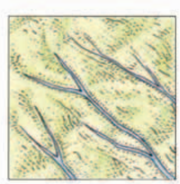
SATELLITE IMAGE OF GANGES RIVER DELTA, BANGLADESH



RIVER DRAINAGE PATTERNS

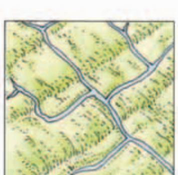

RADIAL

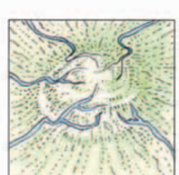

CENTRIPETAL


PARALLEL

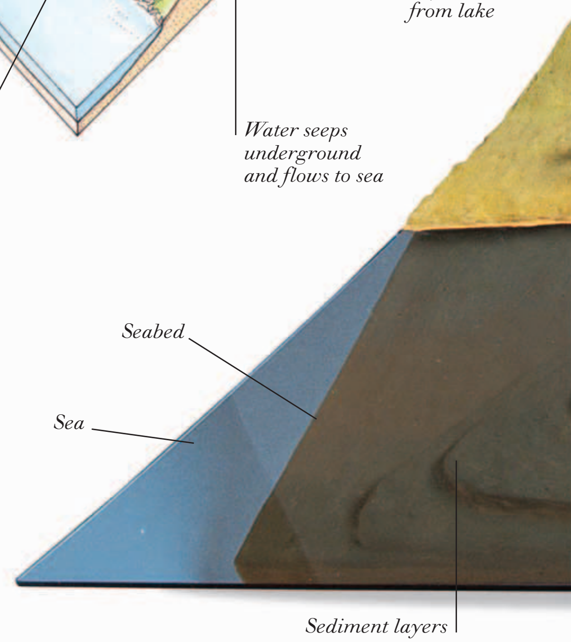

DENDRITIC


DERANGED

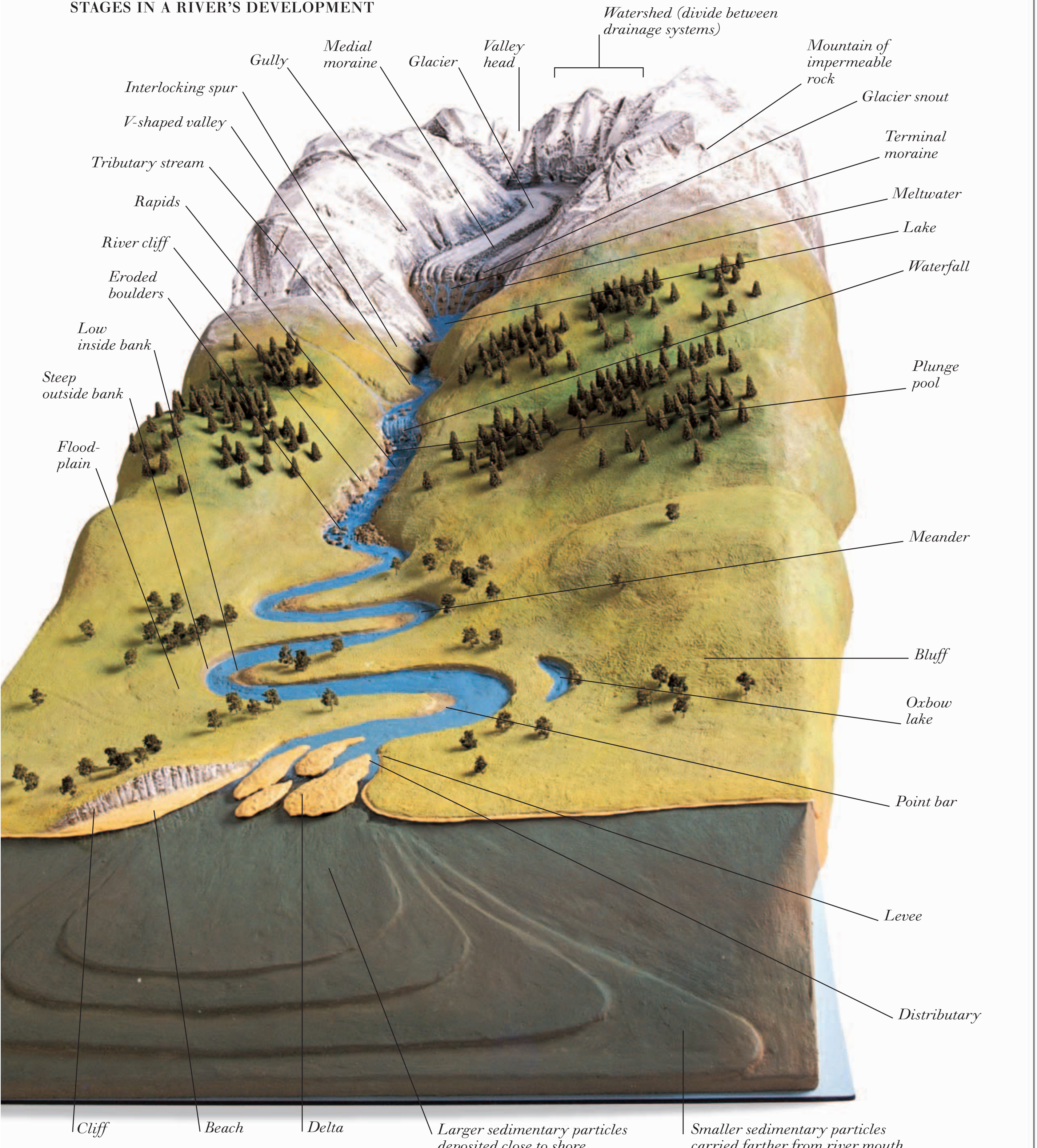

TRELLISED


ANNULAR


RECTANGULAR



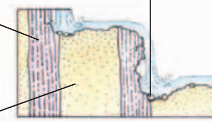
STAGES IN A RIVER'S DEVELOPMENT



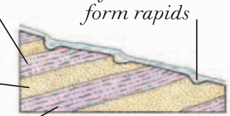
River features

RIVERS ARE ONE OF THE MAJOR FORCES that shape the landscape. Near its source, a river is steep (see pp. 288-289). It erodes downward, carving out V-shaped valleys and deep gorges. Waterfalls and rapids are formed where the river flows from hard rock to softer, more easily eroded rock. Farther downstream, meanders may form and there is greater sideways erosion, resulting in a broad river valley. The river sometimes erodes through the neck of a meander to form an oxbow lake. Sediment deposited on the valley floor by meandering rivers and during floods helps to create a floodplain. Floods may also deposit sediment on the banks of the river to form levees. As a river spills into the sea or a lake, it deposits large amounts of sediment, and may form a delta. A delta is an area of sand bars, swamps, and lagoons through which the river flows in several channels called distributaries—the Mississippi delta, for example. Often, a rise in sea level may have flooded the river mouth to form a broad estuary, a tidal section where seawater mixes with fresh water.

HOW WATERFALLS AND RAPIDS ARE FORMED

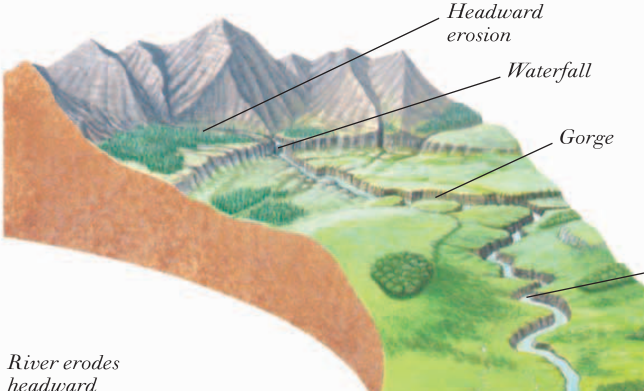
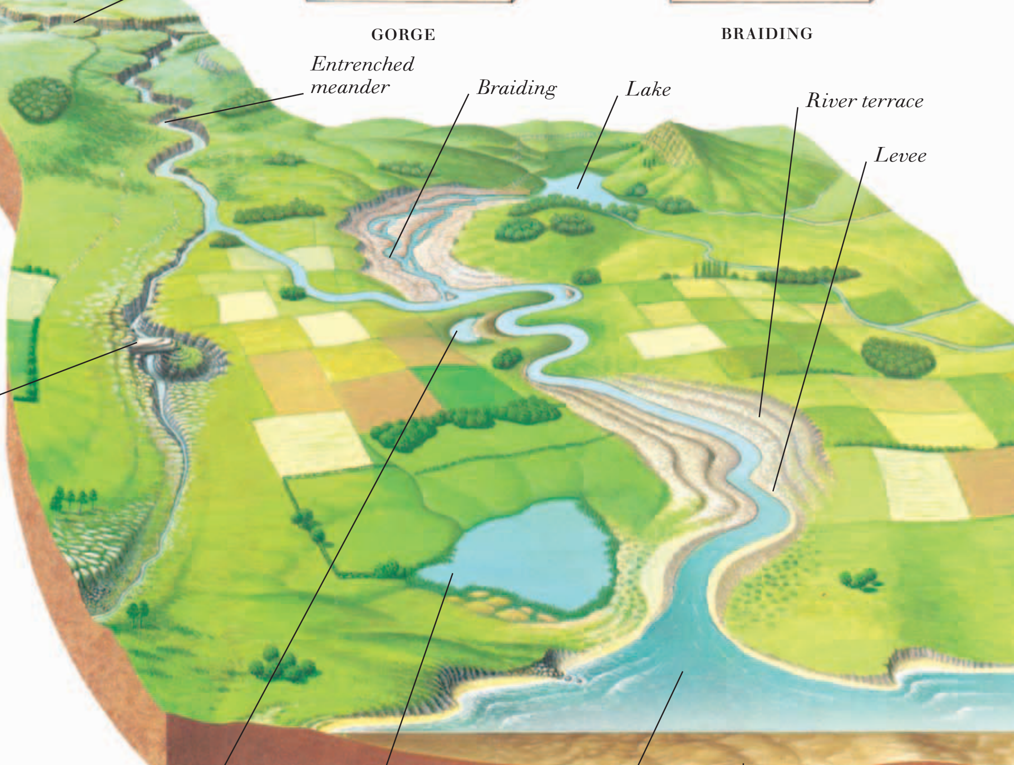


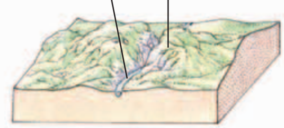
WATERFALL



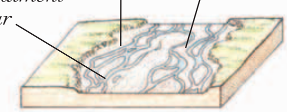
RAPIDS

A RIVER VALLEY DRAINAGE SYSTEM

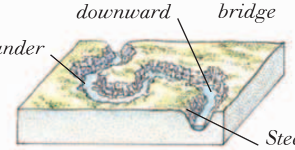


GORGE

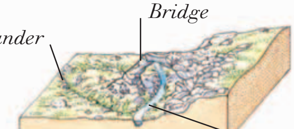


BRAIDING

HEADWARD EROSION

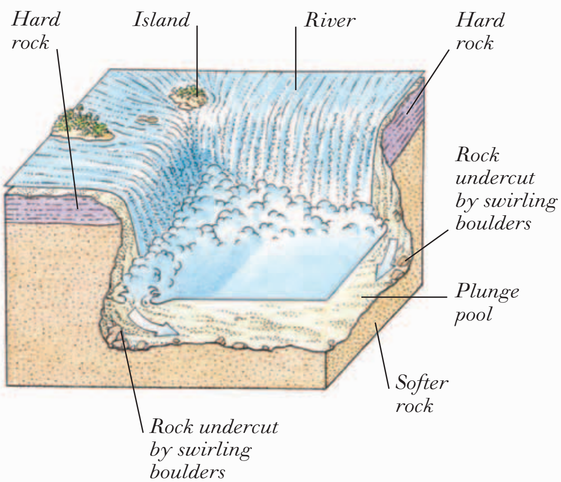


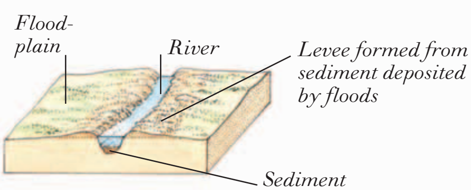
ENTRENCHED MEANDER



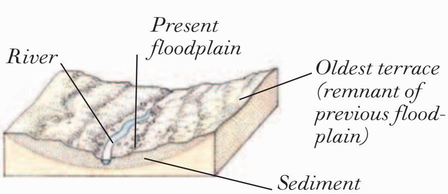
NATURAL BRIDGE

WATERFALL FEATURES

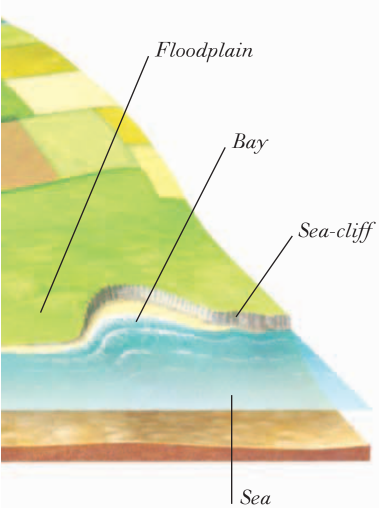




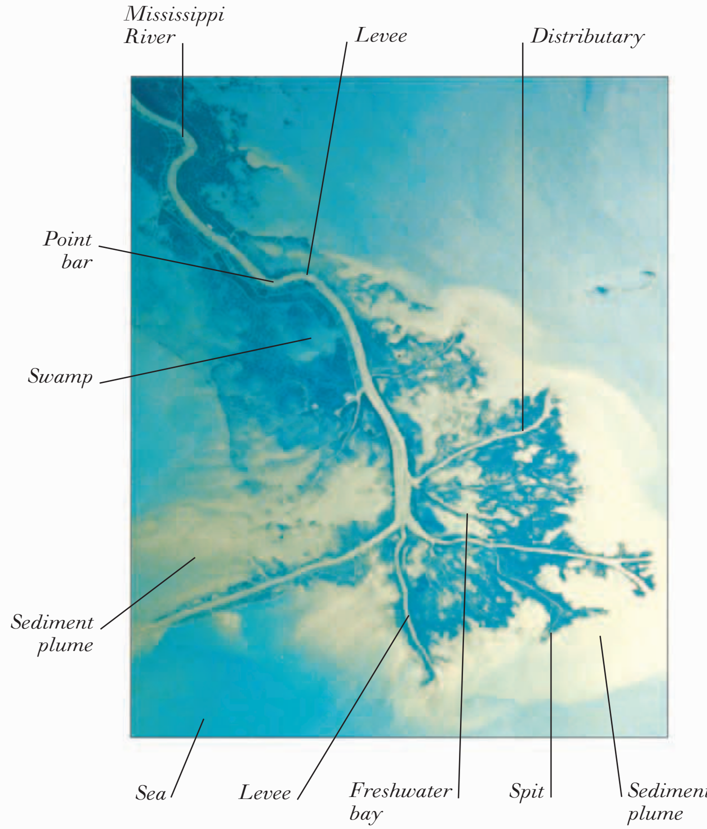
LEVEE



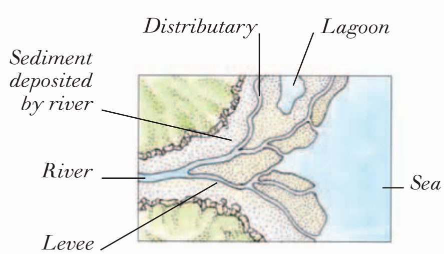
RIVER TERRACE



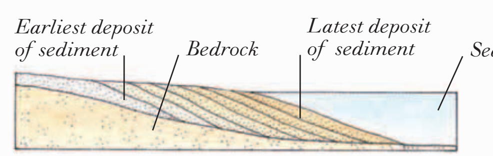
THE MISSISSIPPI DELTA



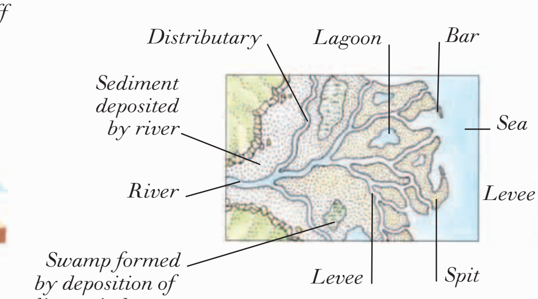
FORMATION OF A DELTA



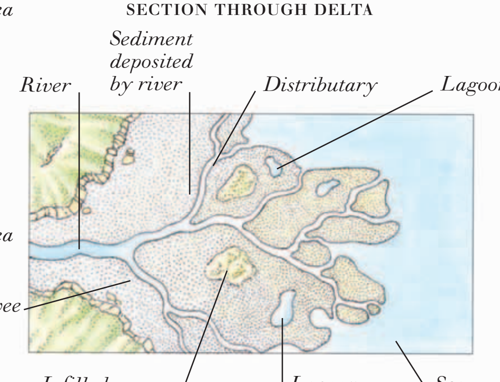
EARLY STAGE



SECTION THROUGH DELTA



MIDDLE STAGE



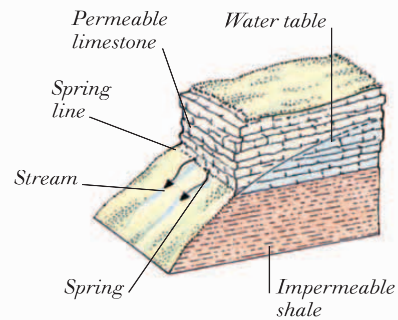
LATE STAGE

Lakes and groundwater

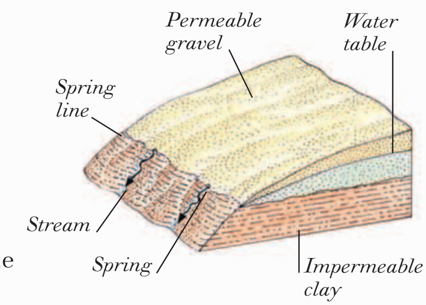
NATURAL LAKE OCCUR WHERE a large quantity of water collects in a hollow in impermeable rock, or is prevented from draining away by a barrier, such as moraine (glacial deposits) or solidified lava. Lakes are often relatively short-lived landscape features, as they tend to become silted up by sediment from the streams and rivers that feed them. Some of the more long-lasting lakes are found in deep rift valleys formed by vertical movements of the Earth's crust (see pp. 58-59)—for example, Lake Baikal in Russia, the world's largest freshwater lake, and the Dead Sea in the Middle East, one of the world's saltiest lakes. Where water is able to drain away, it sinks into the ground until it reaches a layer of impermeable rock, then accumulates in the permeable rock above it; this water-saturated permeable rock is called an aquifer. The saturated zone varies in depth according to seasonal and climatic changes. In wet conditions, the water stored underground builds up, while in dry periods it becomes depleted. Where the upper edge of the saturated zone—the water table—meets the ground surface, water emerges as springs. In an artesian basin, where the aquifer is below an aquiclude (layer of impermeable rock), the water table throughout the basin is determined by its height at the rim. In the center of such a basin, the water table is above ground level. The water in the basin is thus trapped below the water table and can rise under its own pressure along faultlines or well shafts.

LAKE BAIKAL, RUSSIA

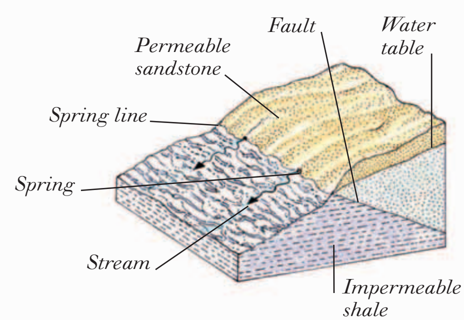
EXAMPLES OF SPRINGS



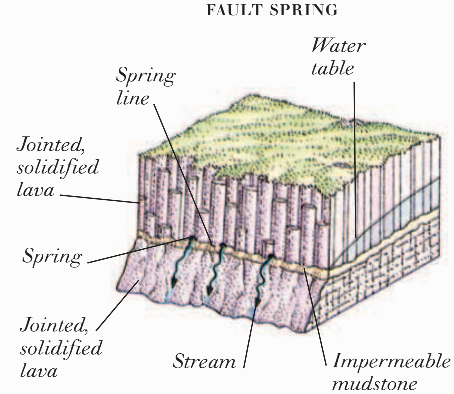
LIMESTONE SPRING



COASTAL (VALLEY) SPRING

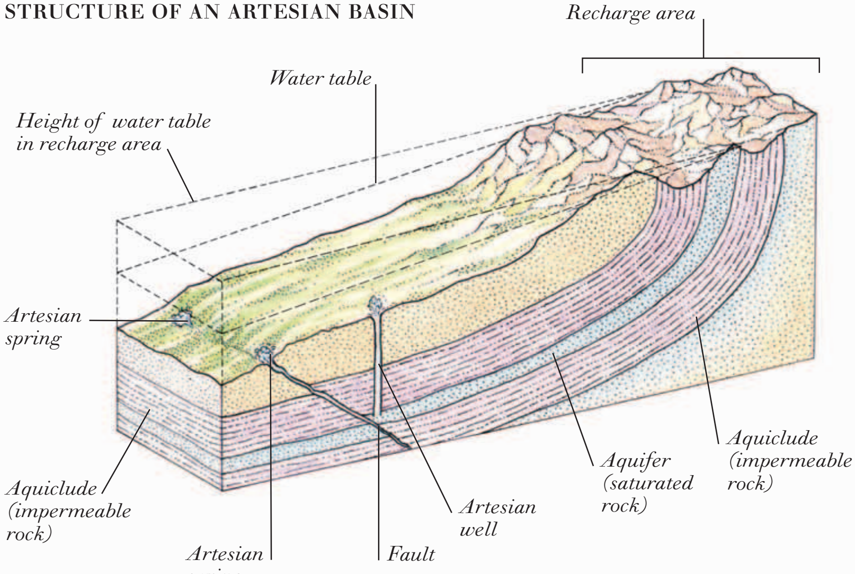


FAULT SPRING

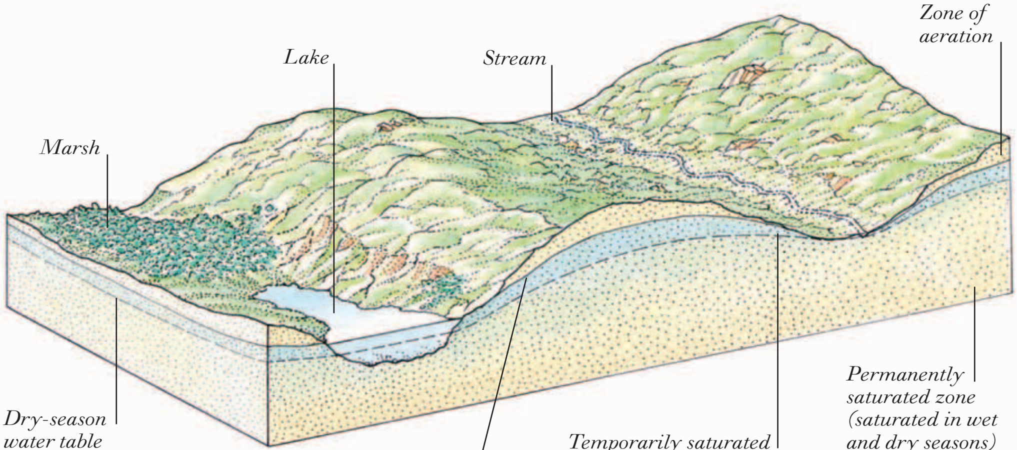


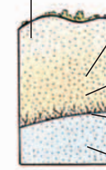
LAVA SPRING

STRUCTURE OF AN ARTESIAN BASIN



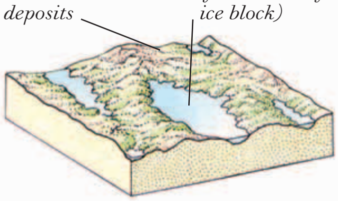
FEATURES OF A GROUNDWATER SYSTEM



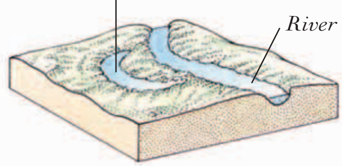


CLOSE-UP OF SURFACE LAYER

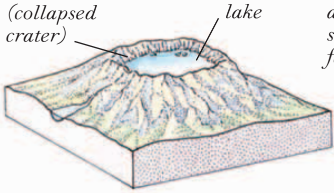
EXAMPLES OF LAKES



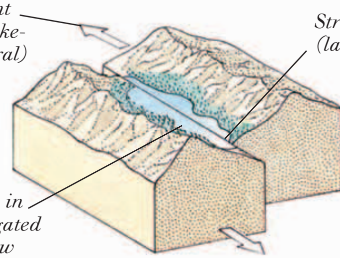
KETTLE LAKE



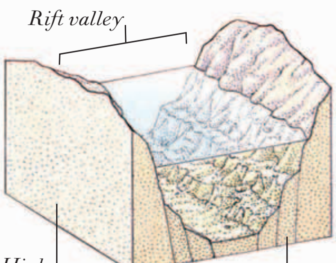
OXBOW LAKE



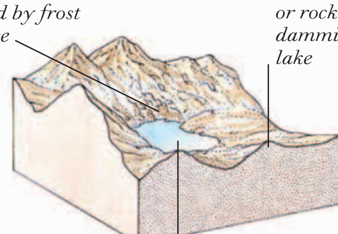
VOLCANIC LAKE



STRIKE-SLIP (LATERAL) FAULT LAKE

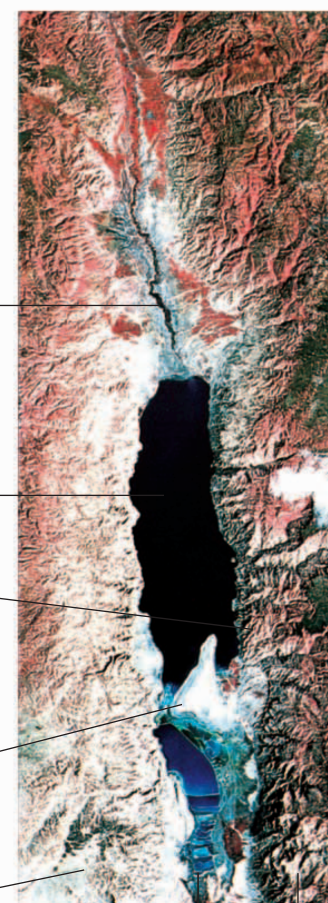


GRABEN (BLOCK-FAULT) LAKE



TARN

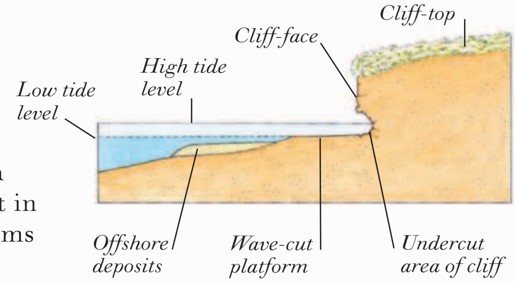
THE DEAD SEA, ISRAEL/JORDAN

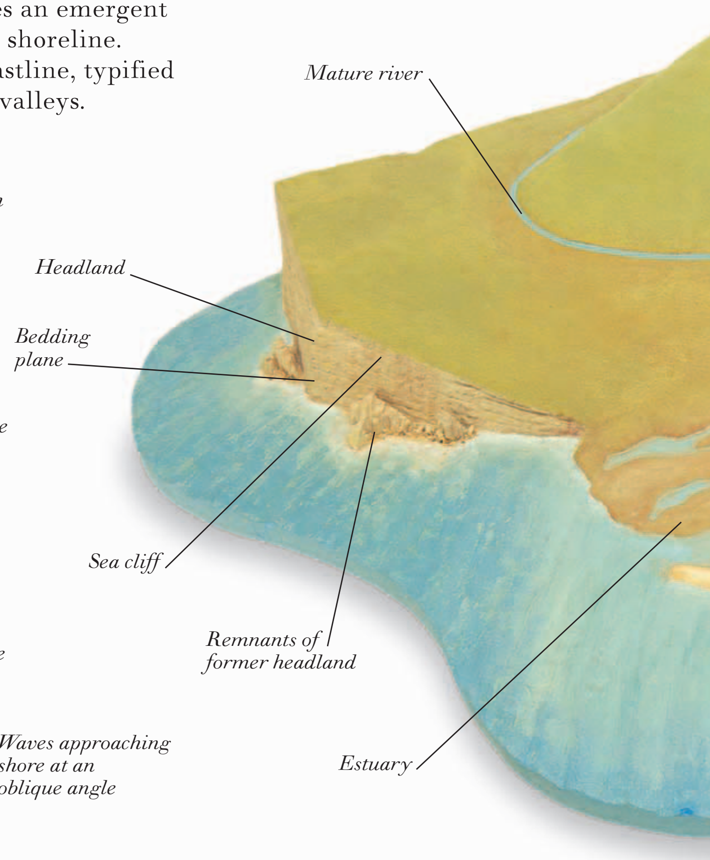


Coastlines

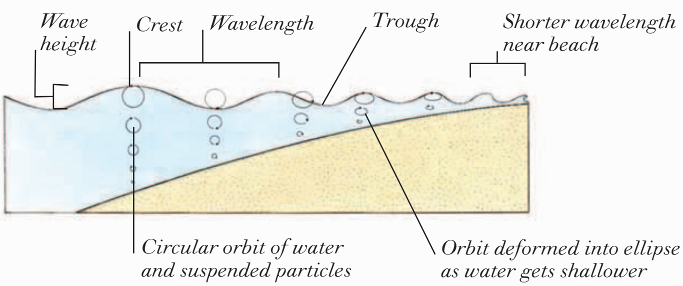
COASTLINES ARE AMONG THE MOST RAPIDLY changing landscape features. Some are eroded by waves, wind, and rain, causing cliffs to be undercut and caves to be hollowed out of solid rock. Others are built up by waves transporting sand and small rocks in a process known as longshore drift, and by rivers depositing sediment in deltas. Additional influences include the activities of living organisms such as coral, crustal movements, and sea-level variations due to climatic changes. Rising land or a drop in sea level creates an emergent coastline, with cliffs and beaches stranded above the new shoreline. Sinking land or a rise in sea level produces a drowned coastline, typified by fjords (submerged glacial valleys) or submerged river valleys.

FEATURES OF A SEA CLIFF

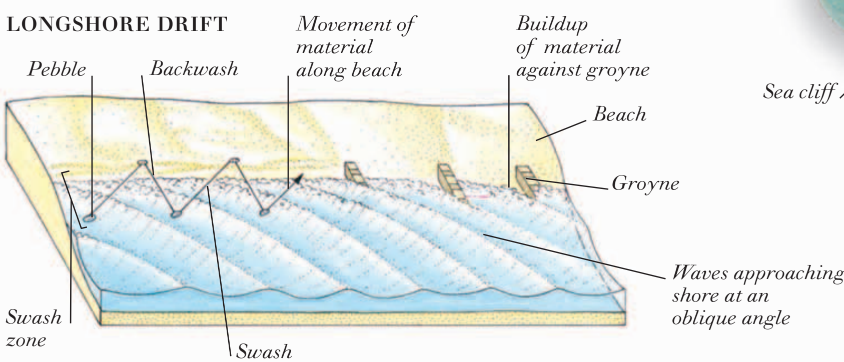




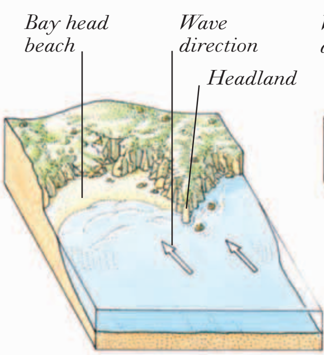
FEATURES OF WAVES



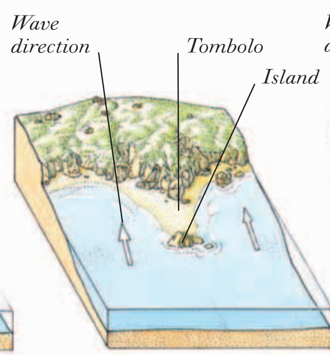
LONGSHORE DRIFT



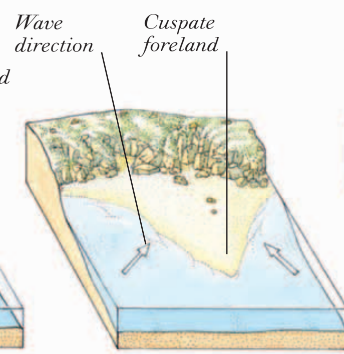
DEPOSITIONAL FEATURES OF COASTLINES



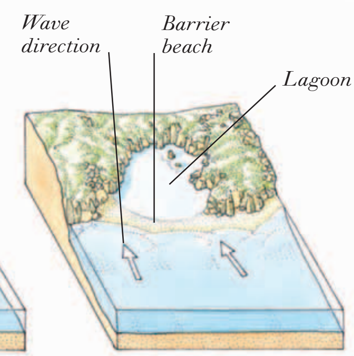
BAY HEAD BEACH



TOMBOLO

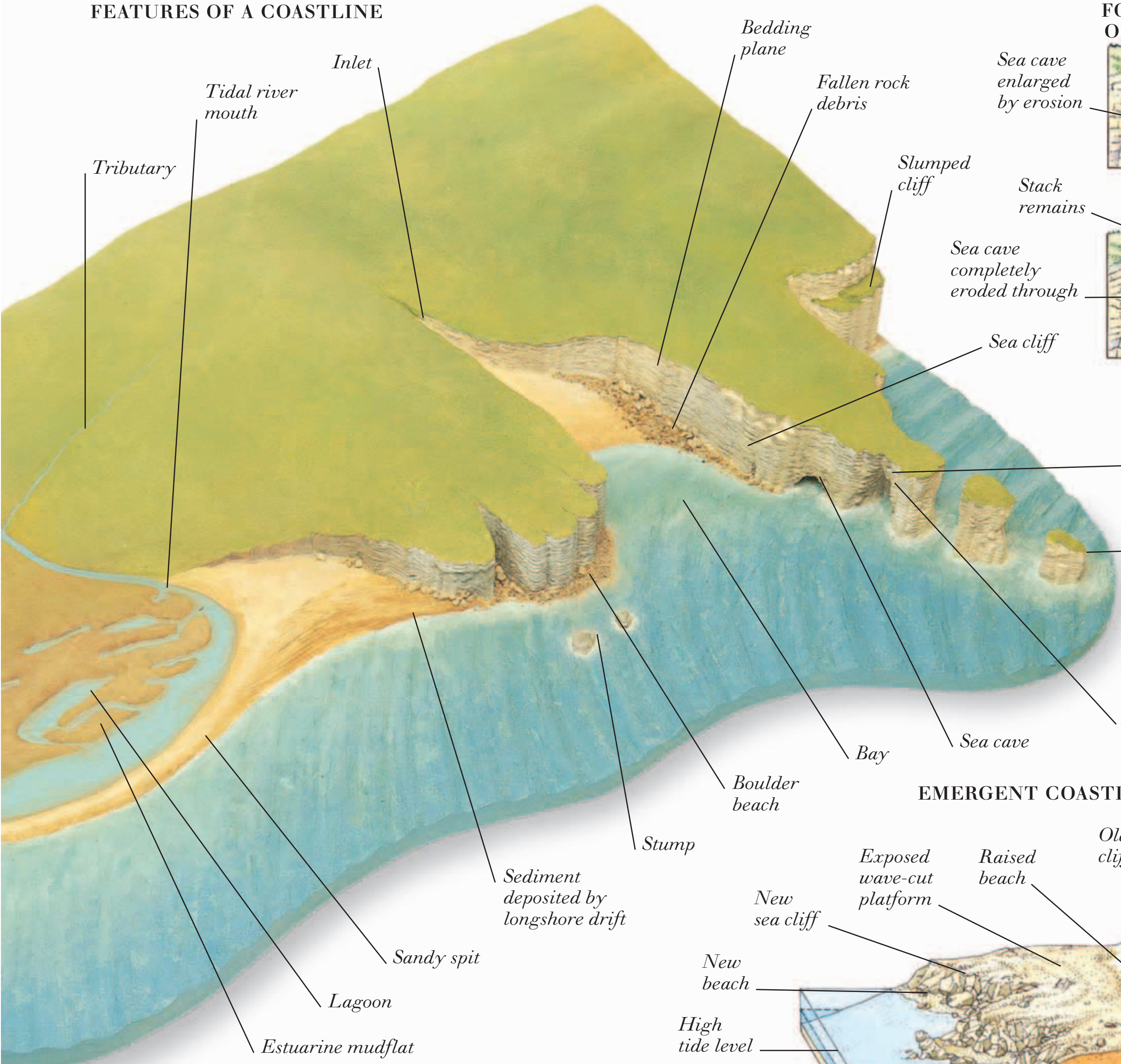


CUSPATE FORELAND

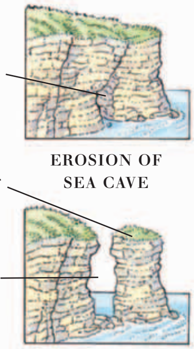


BARRIER BEACH

FEATURES OF A COASTLINE



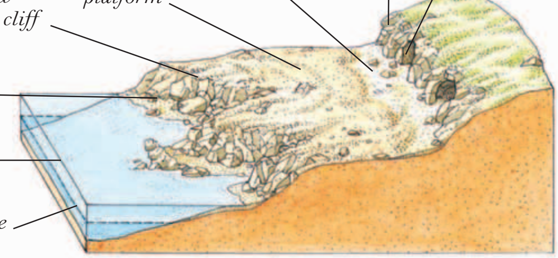
FORMATION OF A STACK



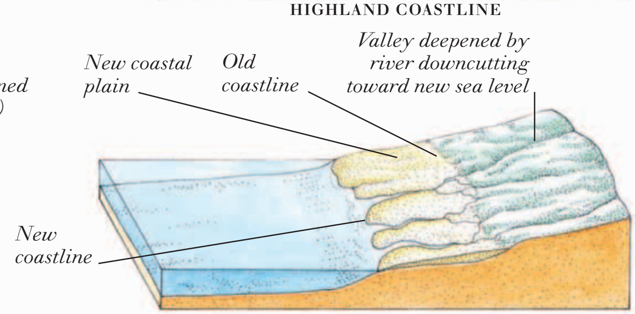
EROSION OF SEA CAVE

COLLAPSE OF SEA CAVE

EMERGENT COASTLINES

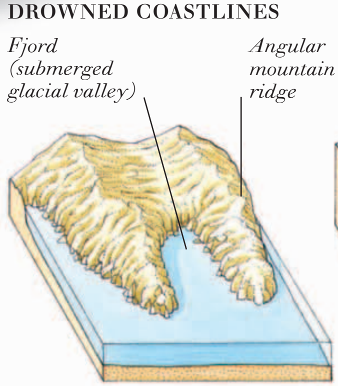


HIGHLAND COASTLINE

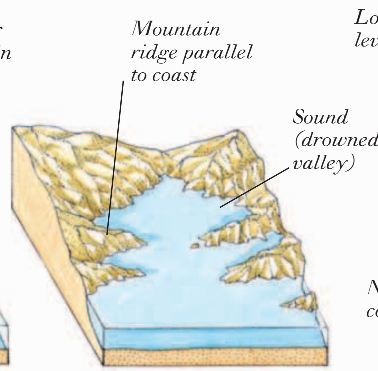


LOWLAND COASTLINE

DROWNED COASTLINES



FJORD COASTLINE

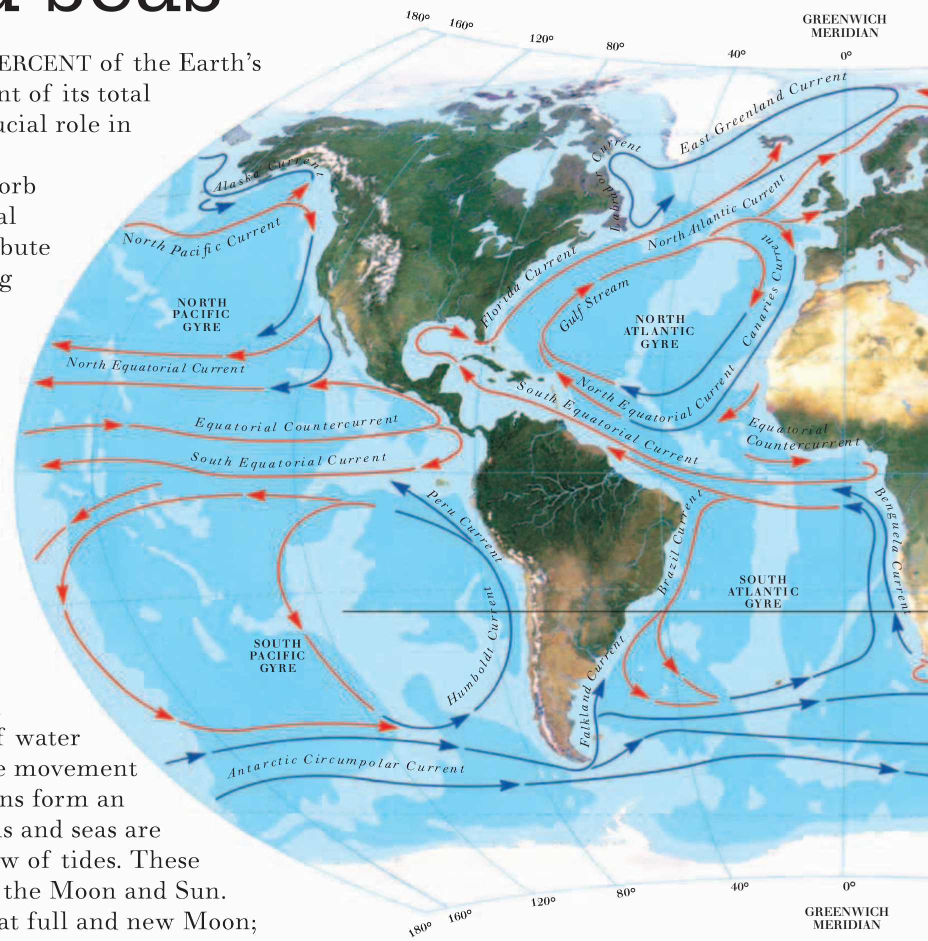


DALMATIAN/PACIFIC COASTLINE

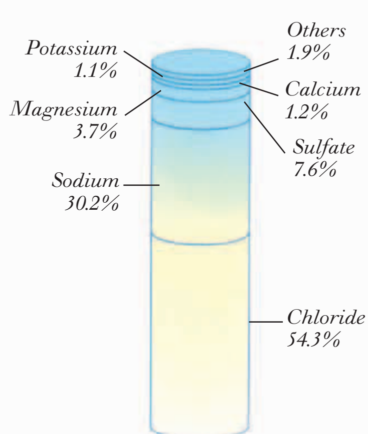
Oceans and seas

OCEANS AND SEAS COVER ABOUT 70 PERCENT of the Earth's surface and account for about 97 percent of its total water. These oceans and seas play a crucial role in regulating temperature variations and determining climate. Their waters absorb heat from the Sun, especially in tropical regions, and the surface currents distribute it around the Earth, warming overlying air masses and neighboring land in winter and cooling them in summer. The oceans are never still. Differences in temperature and salinity drive deep current systems, while surface currents are generated by winds blowing over the oceans. All currents are deflected—to the right in the Northern Hemisphere, to the left in the Southern Hemisphere—as a result of the Earth's rotation. This deflective factor is known as the Coriolis force. A current that begins on the surface is immediately deflected. This current in turn generates a current in the layer of water beneath, which is also deflected. As the movement is transmitted downward, the deflections form an Ekman spiral. The waters of the oceans and seas are also moved by the constant ebb and flow of tides. These are caused by the gravitational pull of the Moon and Sun. The highest tides (Spring tides) occur at full and new Moon; the lowest tides (neap tides) occur at first and last quarter.

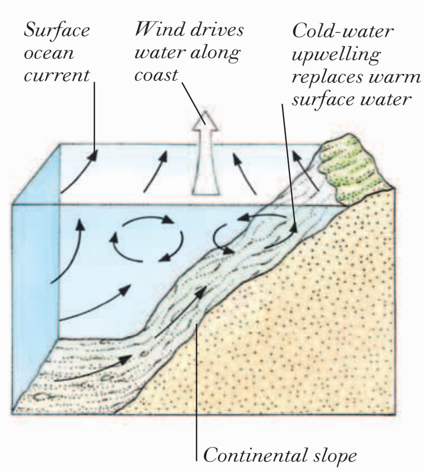
SURFACE CURRENTS



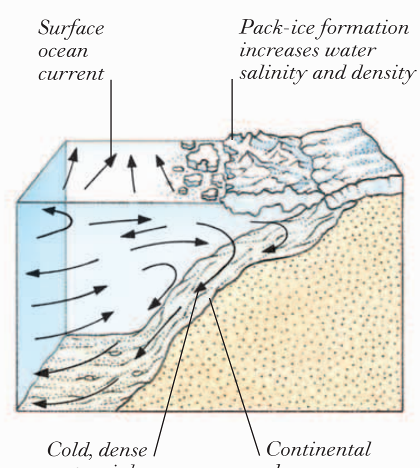
SALT CONTENT OF SEAWATER



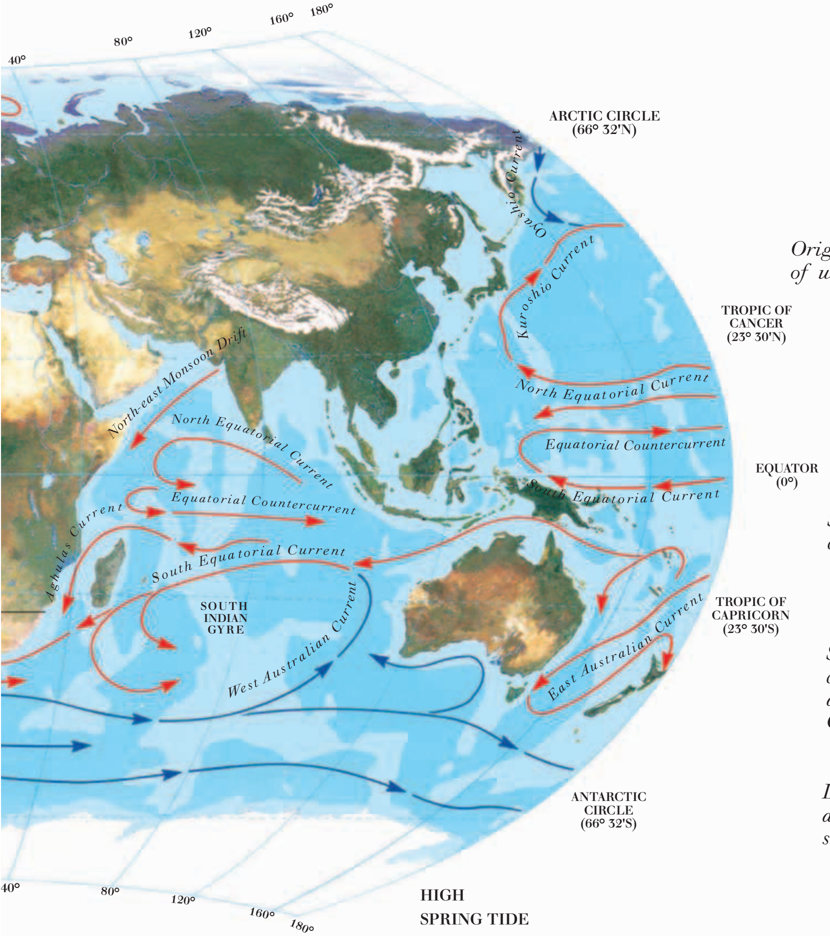
OFFSHORE CURRENTS



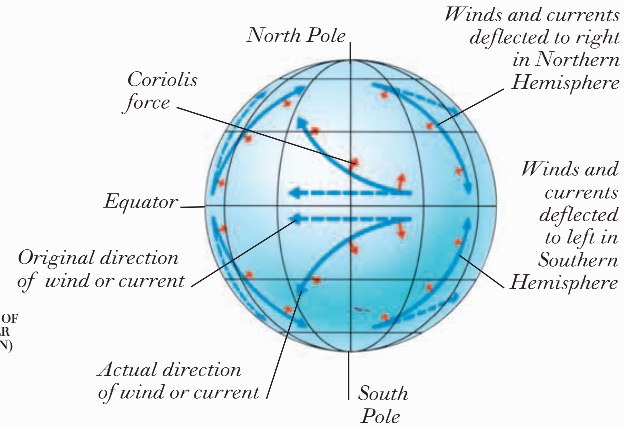
COLD-WATER UPWELLING (SOUTHERN HEMISPHERE)



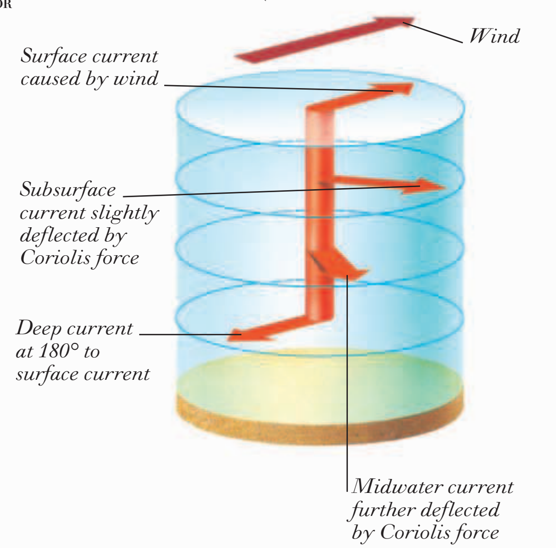
POLAR BOTTOM WATER



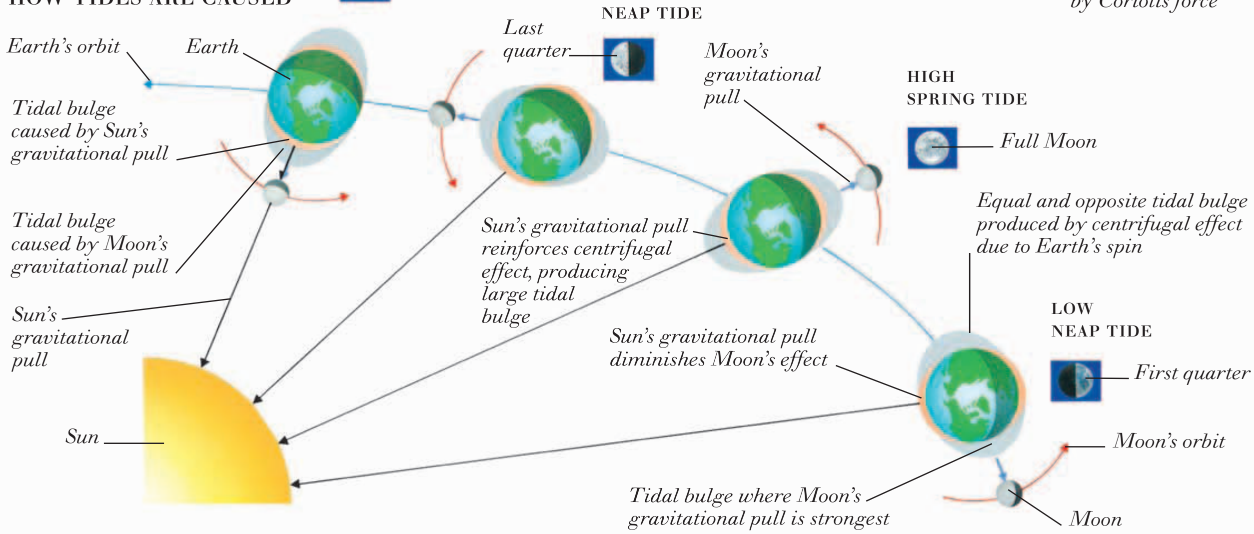
EFFECT OF CORIOLIS FORCE



EKMAN SPIRAL (NORTHERN HEMISPHERE)



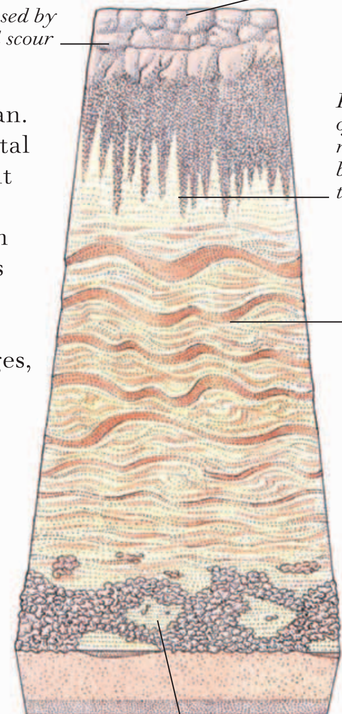
HOW TIDES ARE CAUSED



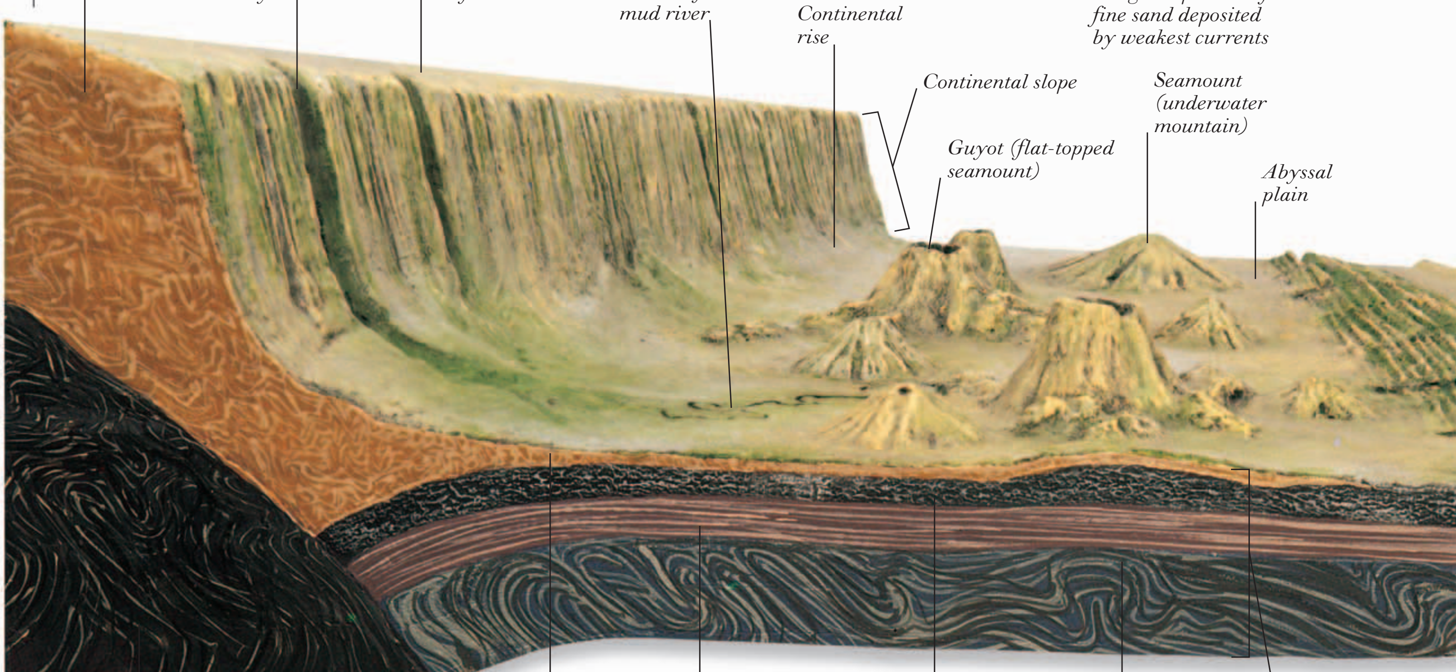
The ocean floor

THE OCEAN FLOOR COMPRISES TWO SECTIONS: the continental shelf and slope, and the deep-ocean floor. The continental shelf and slope are part of the continental crust, but may extend far into the ocean. Sloping quite gently to a depth of about 460 feet (140 m), the continental shelf is covered in sandy deposits shaped by waves and tidal currents. At the edge of the continental shelf, the seabed slopes down to the abyssal plain, which lies at an average depth of about 12,500 feet (3,800 m). On this deep-ocean floor is a layer of sediment made up of clays, fine oozes formed from the remains of tiny sea creatures, and occasional mineral-rich deposits. Echo-sounding and remote sensing from satellites has revealed that the abyssal plain is divided by a system of mountain ranges, far bigger than any on land—the mid-ocean ridge. Here, magma (molten rock) wells up from the Earth's interior and solidifies, widening the ocean floor (see pp. 58-59). As the ocean floor spreads, volcanoes that have formed over hot spots in the crust move away from their magma source; they become extinct and are increasingly submerged and eroded. Volcanoes eroded below sea level remain as seamounts (underwater mountains). In warm waters, a volcano that projects above the ocean surface often acquires a fringing coral reef, which may develop into an atoll as the volcano becomes submerged.

CONTINENTAL-SHELF FLOOR



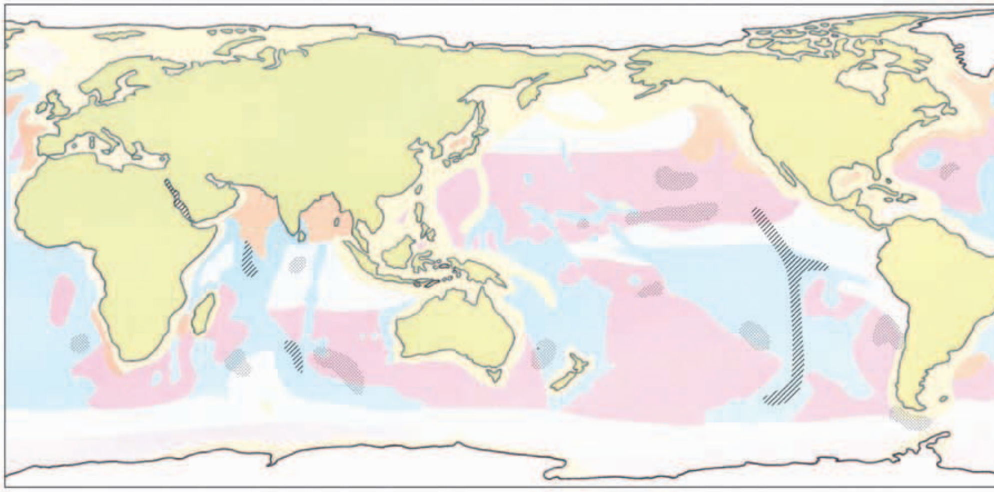
FEATURES OF THE OCEAN FLOOR



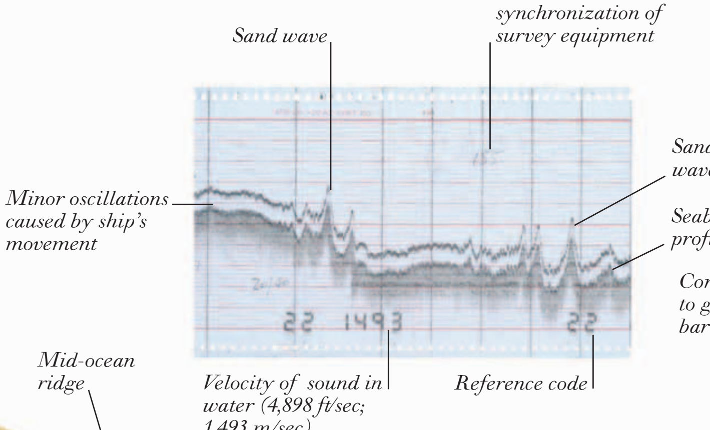
KEY

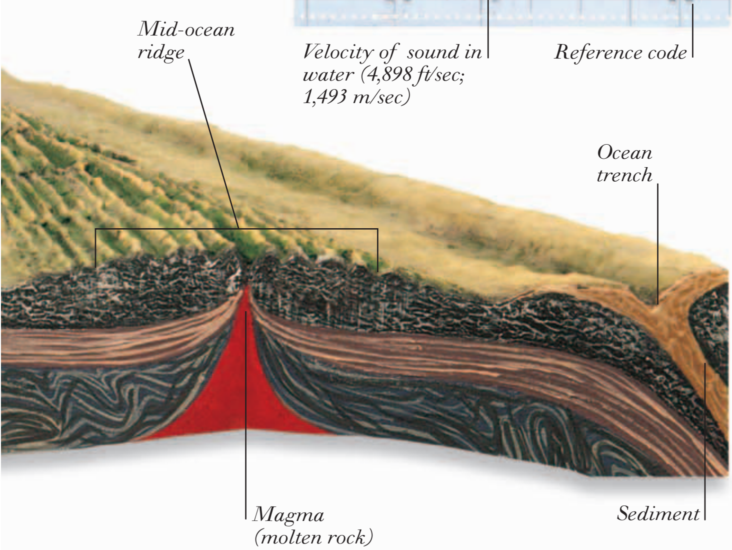
- Calcareous ooze
- Pelagic clay
- Glacial sediments
- Siliceous ooze
- Terrigenous sediments
- Continental margin sediments
- Metalliferous muds
- Major nodule fields

DEEP-OCEAN FLOOR SEDIMENTS

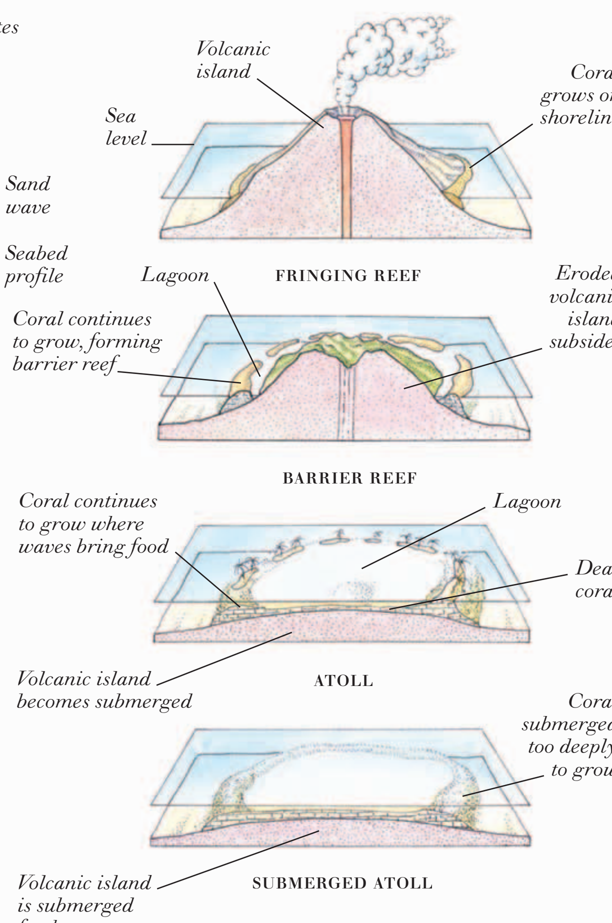


ECHO-SOUND PROFILE OF OCEAN FLOOR

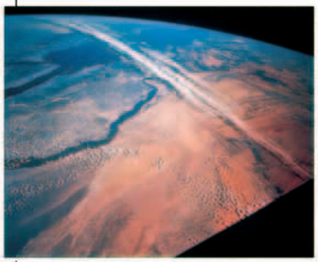




DEVELOPMENT OF AN ATOLL



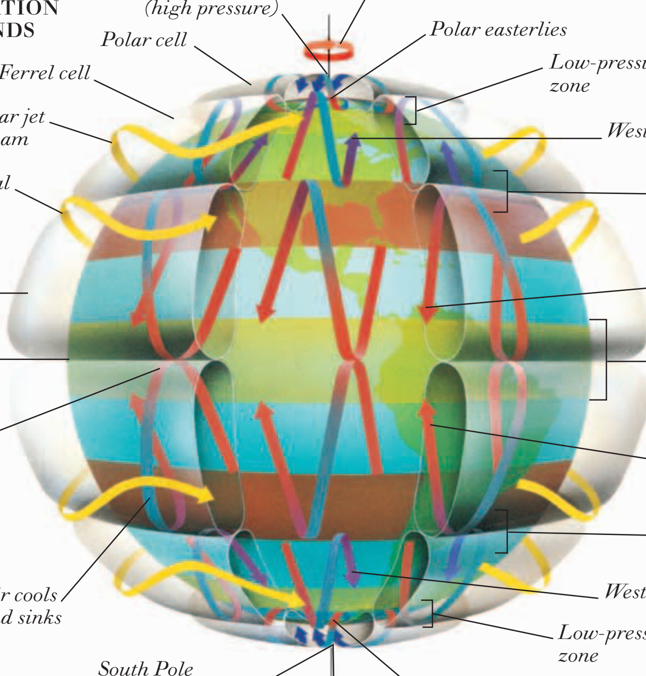
The atmosphere



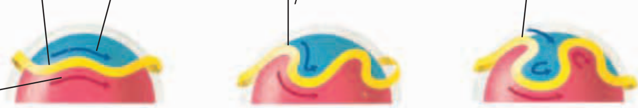
JET STREAM

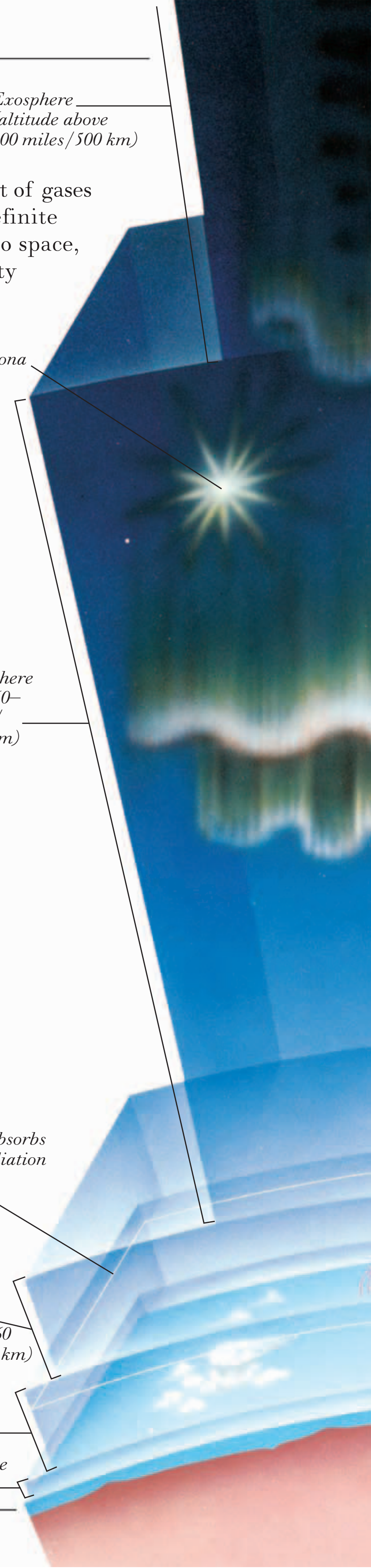
THE EARTH IS SURROUNDED BY ITS ATMOSPHERE, a blanket of gases that enables life to exist on the planet. This layer has no definite outer edge, gradually becoming thinner until it merges into space, but over 80 percent of atmospheric gases are held by gravity within about 12 miles (20 km) of the Earth's surface. The atmosphere blocks out much harmful ultraviolet solar radiation, and insulates the Earth against extremes of temperature by limiting both incoming solar radiation and the escape of reradiated heat into space. This natural balance may be distorted by the greenhouse effect, as gases such as carbon dioxide have built up in the atmosphere, trapping more heat. Close to the Earth's surface, differences in air temperature and pressure cause air to circulate between the equator and poles. This circulation, together with the Coriolis force, gives rise to the prevailing surface winds and the high-level jet streams.

ATMOSPHERIC CIRCULATION AND WINDS

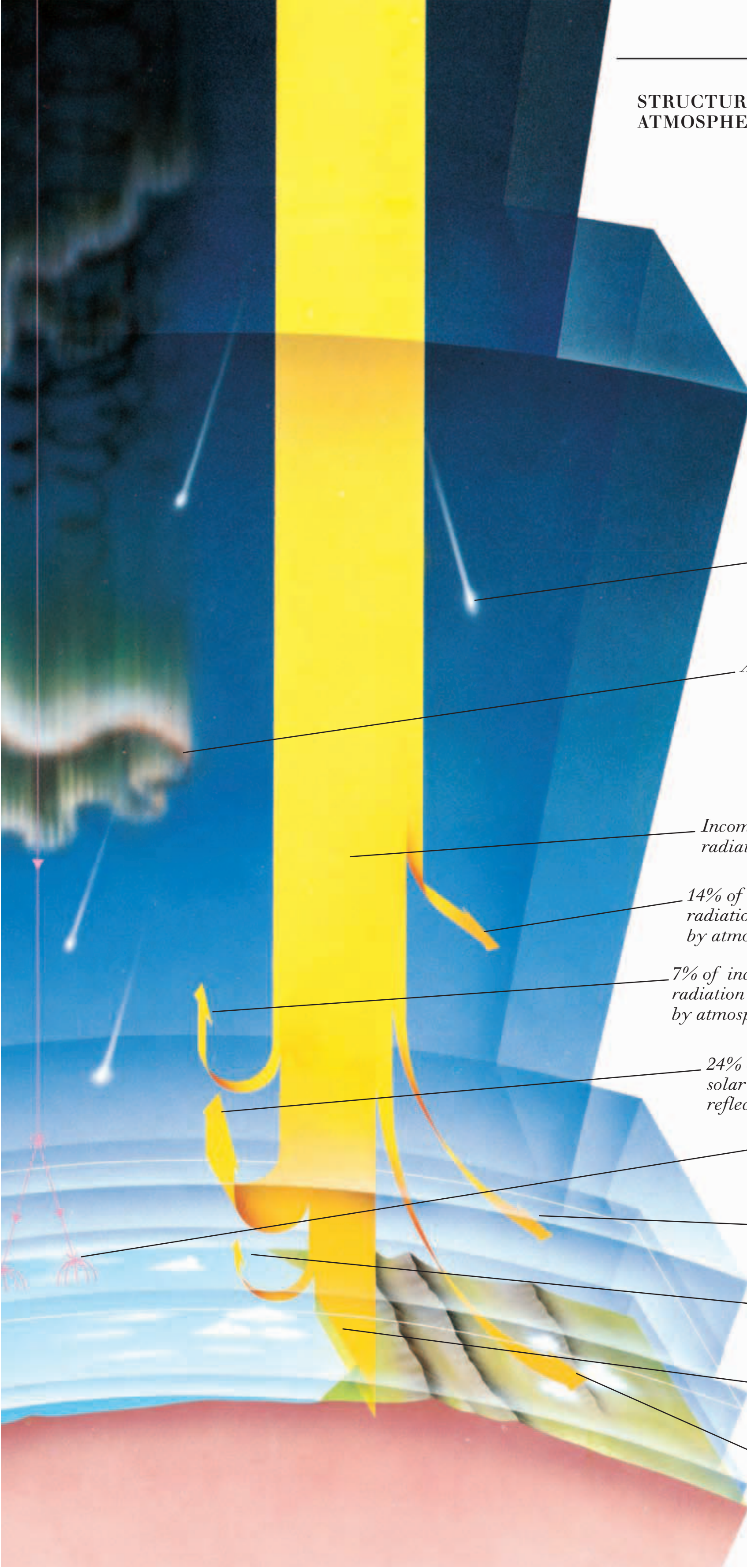


FORMATION OF ROSSBY WAVES IN THE JET STREAM

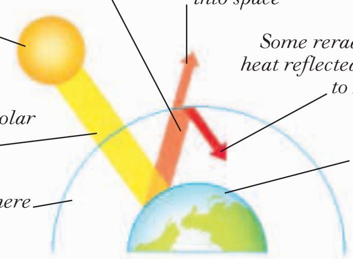




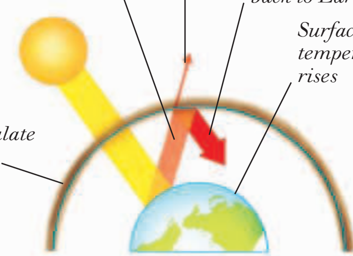
STRUCTURE OF THE ATMOSPHERE



GLOBAL WARMING



NATURALLY MODERATED GREENHOUSE EFFECT



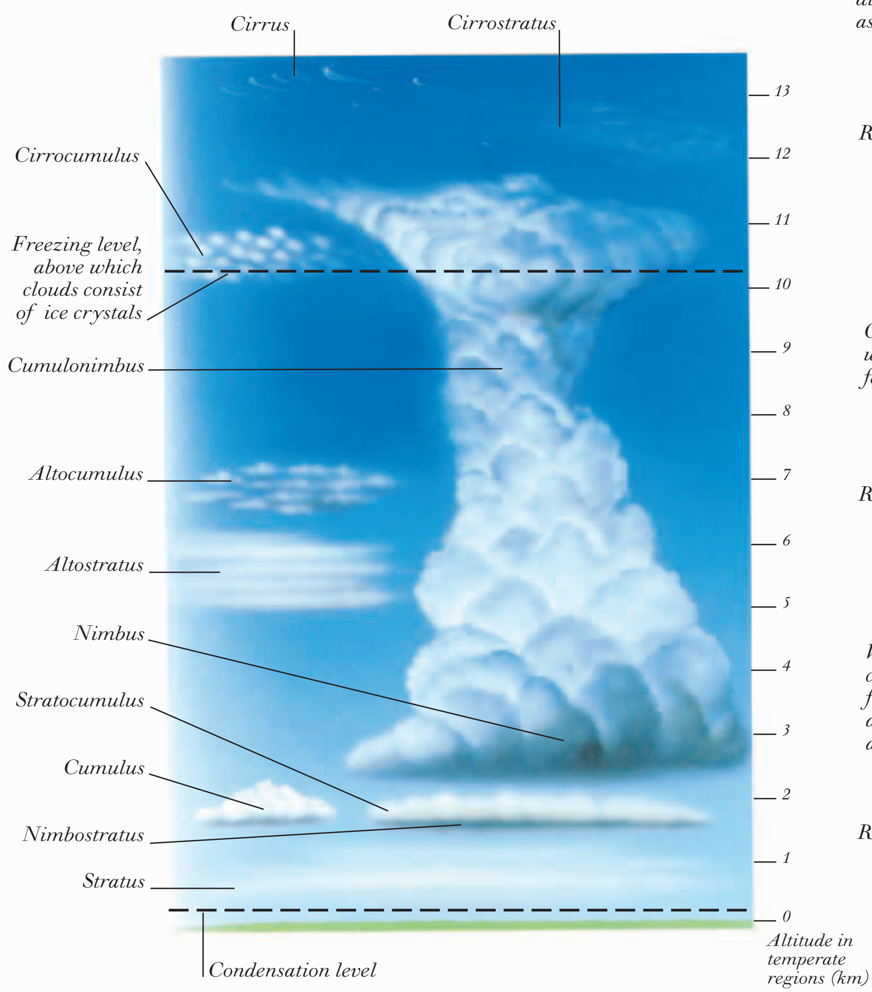
UNBALANCED GREENHOUSE EFFECT

COMPOSITION OF THE LOWER ATMOSPHERE

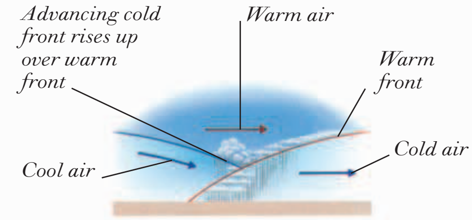
Weather

WEATHER IS DEFINED AS THE ATMOSPHERIC CONDITIONS at a particular time and place; climate is the average weather conditions for a given region over time. Weather is assessed in terms of temperature, wind, cloud cover, and precipitation, such as rain or snow. Good weather is associated with high-pressure areas, where air is sinking. Cloudy, wet, changeable weather is common in low-pressure zones with rising, unstable air. Such conditions occur at temperate latitudes, where warm air meets cool air along the polar fronts. Here, spiraling low-pressure cells known as depressions (mid-latitude cyclones) often form. A depression usually contains a sector of warmer air, beginning at a warm front and ending at a cold front. If the two fronts merge, forming an occluded front, the warm air is pushed upward. An extreme form of low-pressure cell is a hurricane (also called a typhoon or tropical cyclone), which brings torrential rain and exceptionally strong winds.

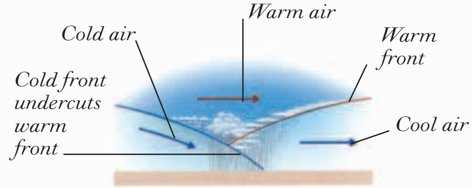
TYPES OF CLOUD



TYPES OF OCCLUDED FRONT

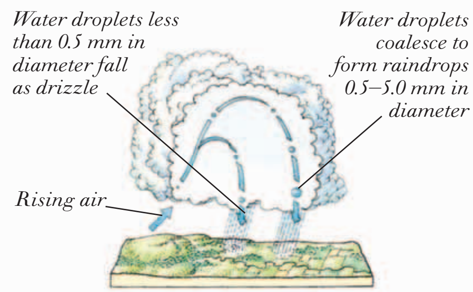


WARM OCCLUSION

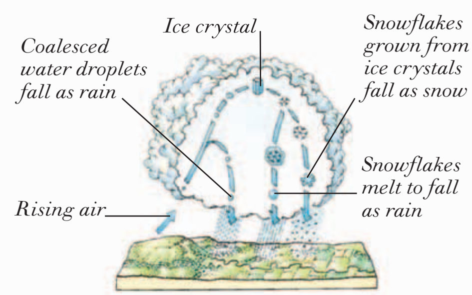


COLD OCCLUSION

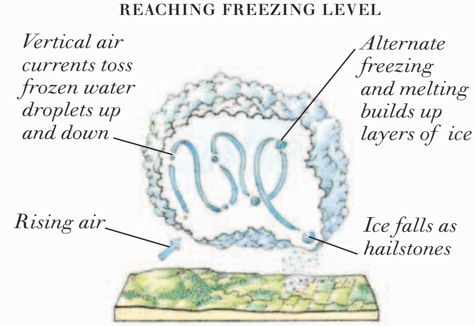
FORMS OF PRECIPITATION



RAIN FROM CLOUDS NOT REACHING FREEZING LEVEL

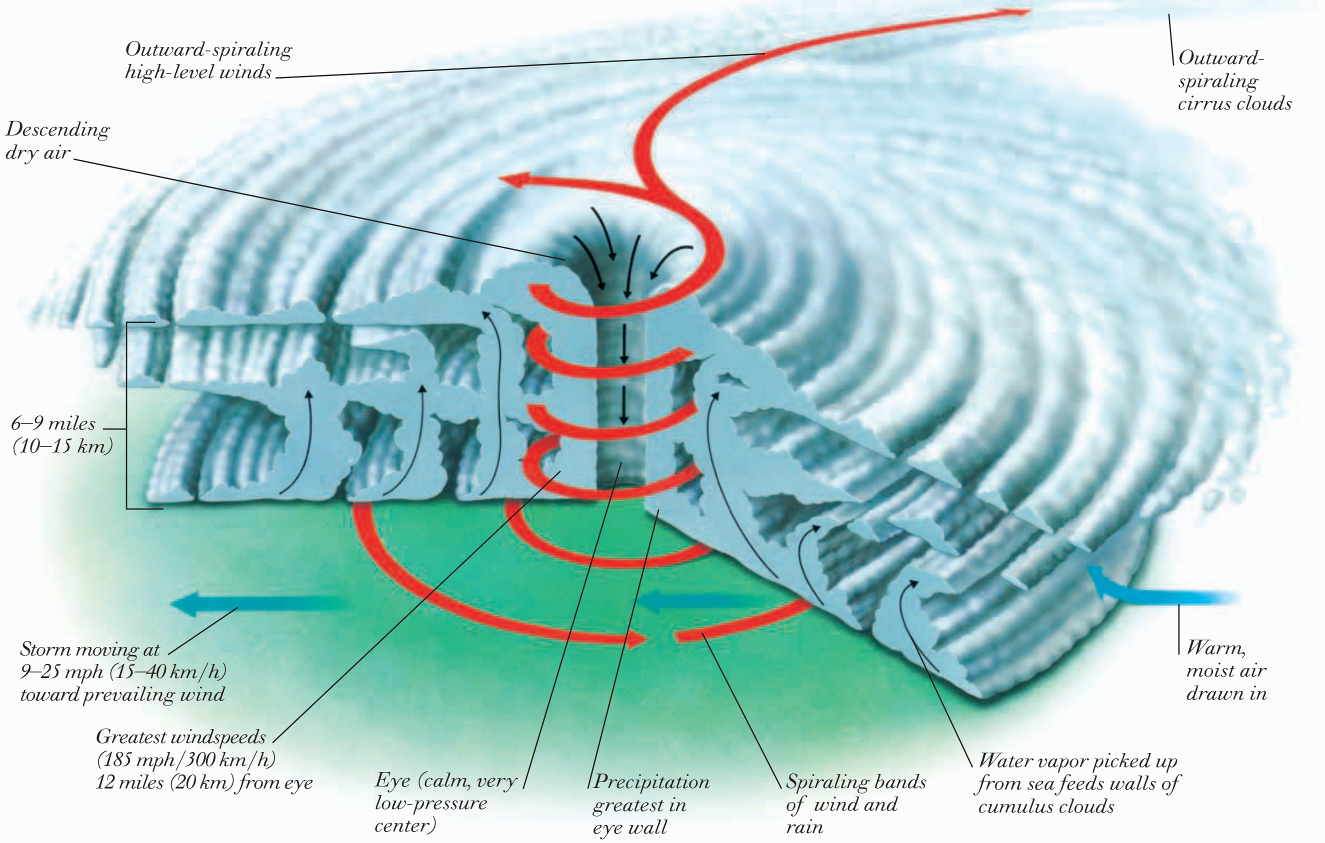


RAIN AND SNOW FROM CLOUDS REACHING FREEZING LEVEL

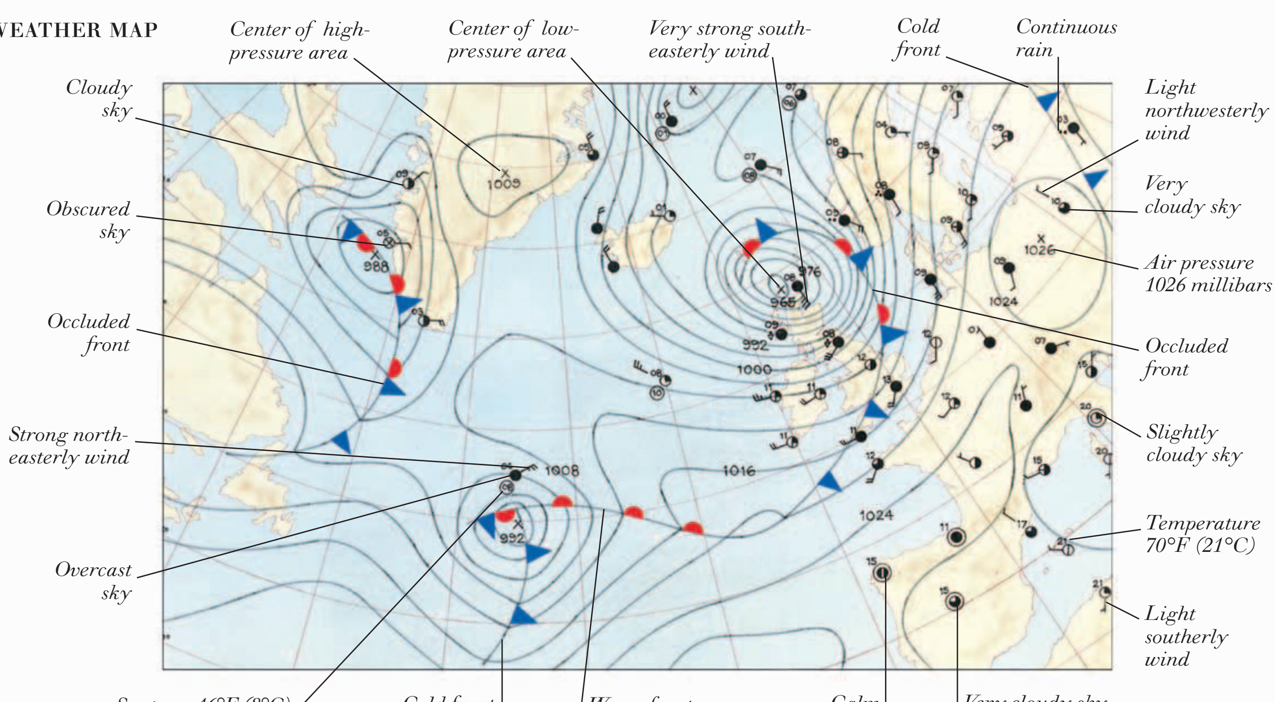


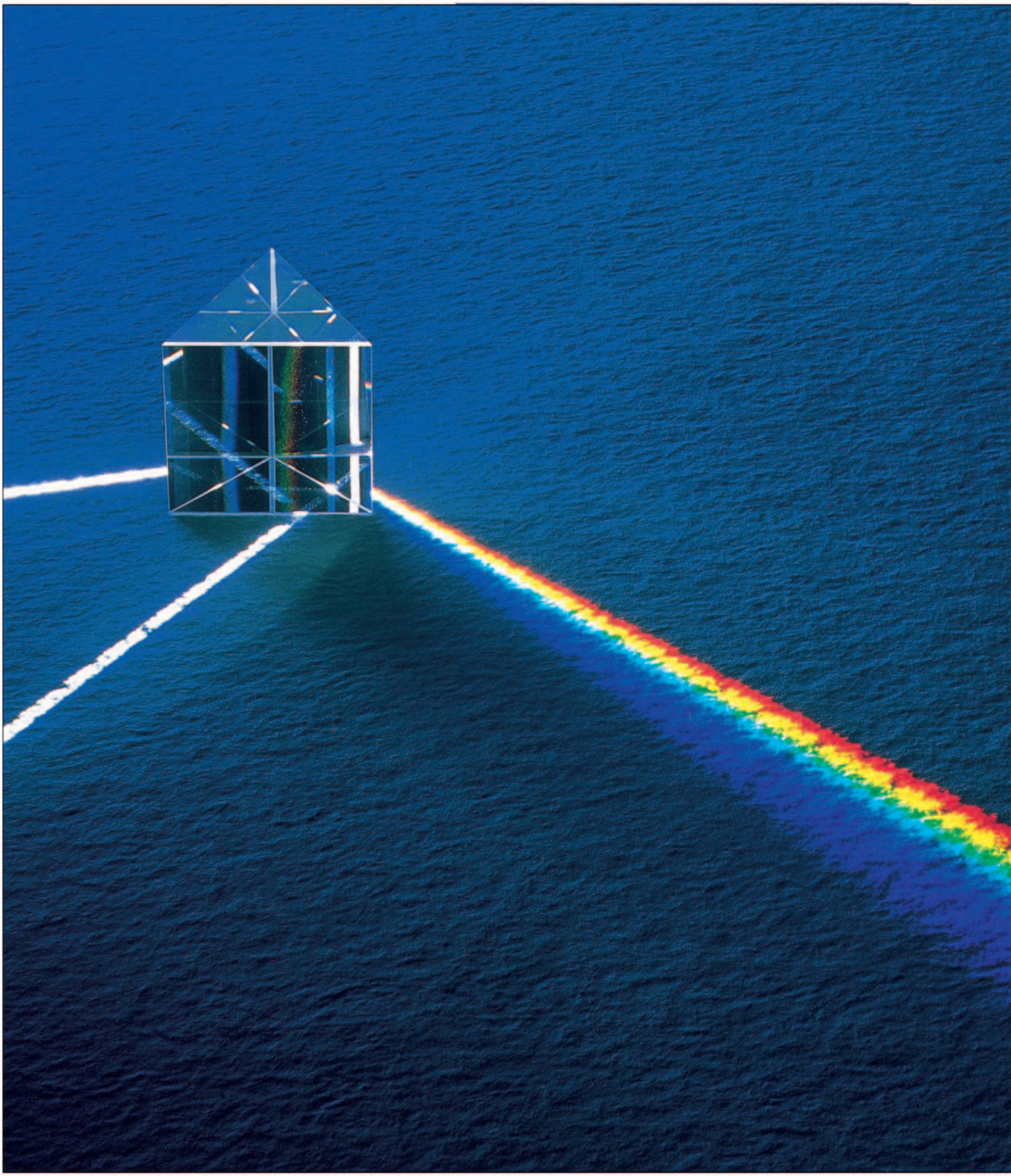
HAIL

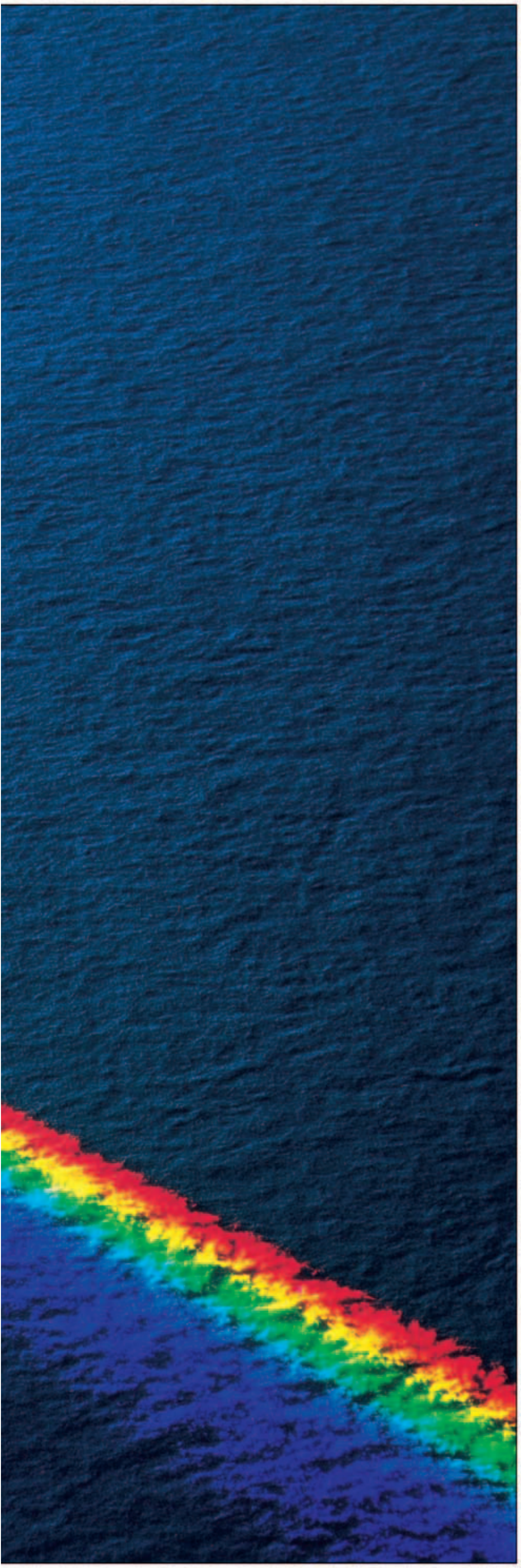
STRUCTURE OF A HURRICANE



WEATHER MAP







Physics and Chemistry

The variety of matter

PLANT AND INSECT (LIVING MATTER)

MATTER IS ANYTHING THAT HAS A MASS. It includes everything from natural substances, such as minerals or living organisms, to synthetic materials. Matter can exist in three distinct states—solid, liquid, and gas. A solid is rigid and retains its shape. A liquid is fluid, has a definite volume, and will take the shape of its container. A gas (also fluid) fills a space, so its volume will be the same as the volume of its container. Most substances can exist as a solid, a liquid, or a gas: the state is determined by temperature. At very high temperatures, matter becomes plasma, often considered to be a fourth state of matter. All matter is composed of microscopic particles, such as atoms and molecules (see pp. 308-309). The arrangement and interactions of these particles give a substance its physical and chemical properties, by which matter can be identified. There is a huge variety of matter because particles can arrange themselves in countless ways, in one substance or by mixing with others. Natural glass, for example, seems to be a solid but is, in fact, a supercool liquid: the atoms are not locked into a pattern and can flow. Pure substances known as elements (see p. 310) combine to form compounds or mixtures. Mixtures called colloids are made up of larger particles of matter suspended in a solid, liquid, or gas, while a solution is one substance dissolved in another.

TYPES OF COLLOID

HAIR GEL (SOLID IN LIQUID)

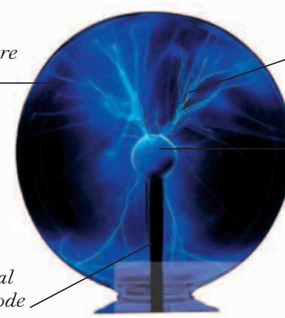
SHAVING CREAM (AIR IN LIQUID)

MIST (LIQUID IN GAS)

EXAMPLES OF MATTER

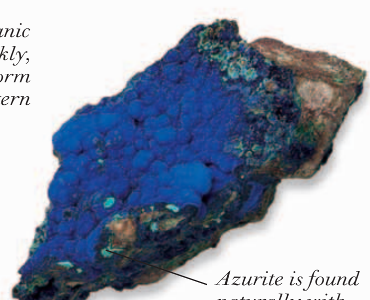
POLYETHYLENE (SYNTHETIC POLYMER)

PURE SILICON (SEMICONDUCTOR)



BALL CONTAINING HIGH-TEMPERATURE GAS (PLASMA)

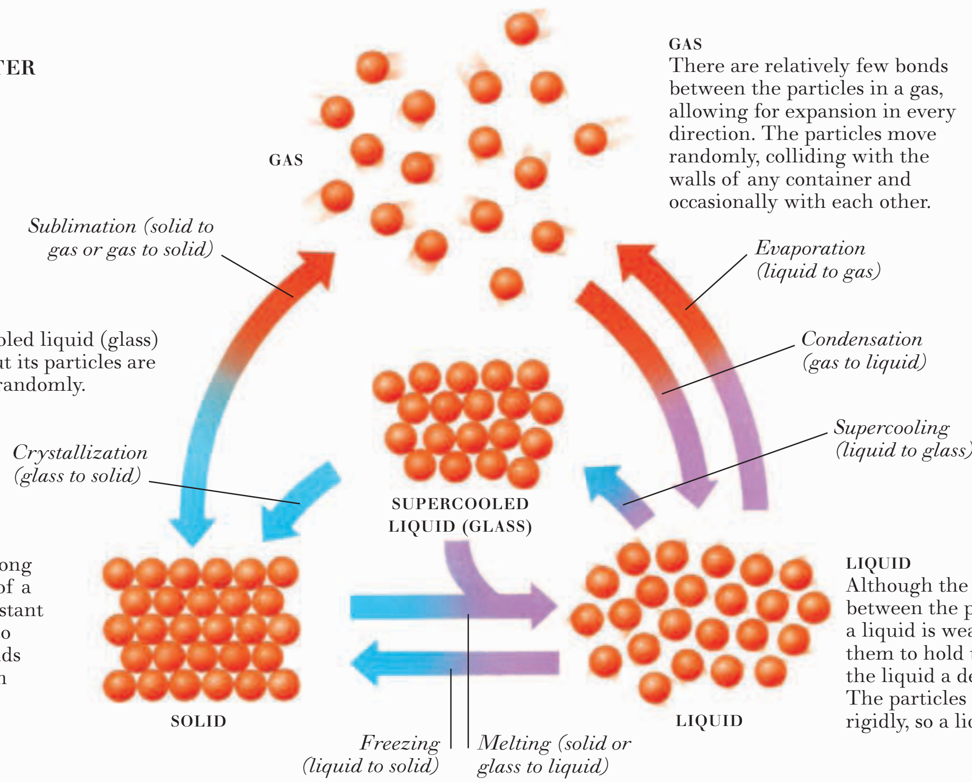
OBSIDIAN (NATURAL GLASS)



AZURITE (CRYSTALLINE MINERAL)

POTASSIUM PERMANGANATE AND WATER (SOLUTION)

STATES OF MATTER



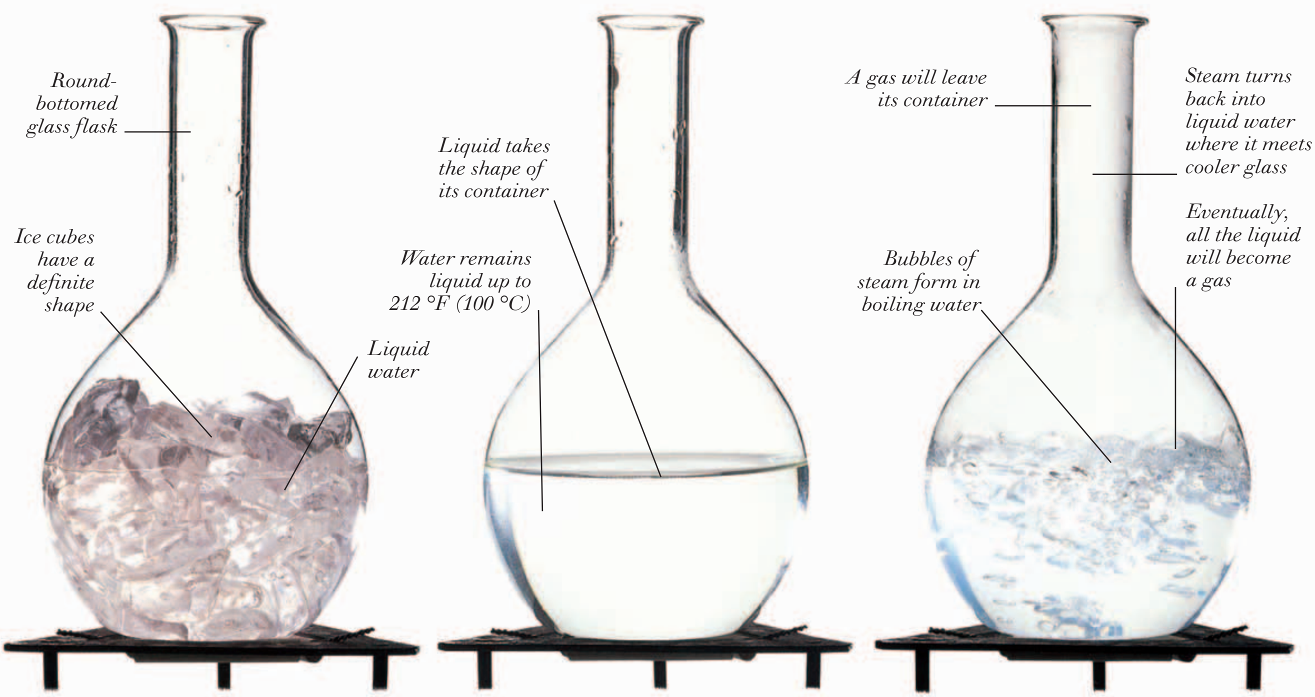
GAS
There are relatively few bonds between the particles in a gas, allowing for expansion in every direction. The particles move randomly, colliding with the walls of any container and occasionally with each other.

GLASS
A supercooled liquid (glass) is rigid, but its particles are arranged randomly.

SOLID
Held together by strong forces, the particles of a solid maintain a constant position in relation to each other. Most solids are crystals, in which particles arrange in repeating patterns.

LIQUID
Although the attraction between the particles of a liquid is weak, it allows them to hold together to give the liquid a definite volume. The particles are not held rigidly, so a liquid flows.

CHANGING STATES OF WATER

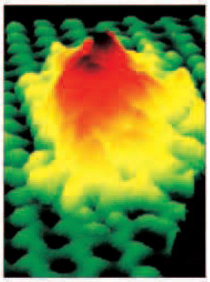


SOLID STATE: ICE
The solid state of water, ice, forms when liquid water is cooled sufficiently. Ice cubes are rigid, with a definite shape and volume.

LIQUID STATE: WATER
When the temperature of a substance rises above its freezing point, it melts to become a liquid. Ice changes to water.

GASEOUS STATE: STEAM
Above its boiling point, a substance will become a gas. When heated sufficiently, liquid water turns to steam, a colorless gas.

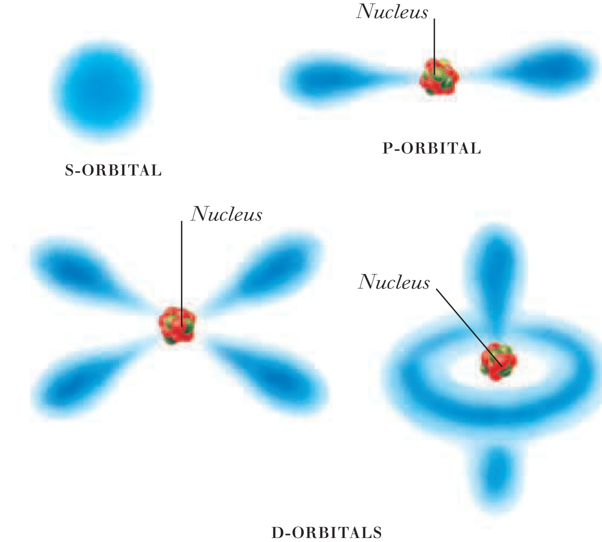
Atoms and molecules



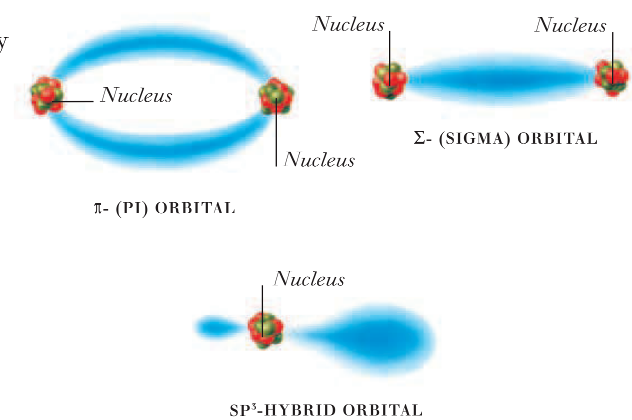
FALSE-COLOR IMAGE OF ACTUAL GOLD ATOMS

ATOMS ARE THE smallest individual parts of an element (see pp. 310-311). They are tiny, with diameters in the order of one ten-thousand-millionth of a meter (10^{-10} m). Two or more atoms join together (bond) to form a molecule of a substance known as a compound. For example, when atoms of the elements hydrogen and fluorine join together, they form a molecule of the compound hydrogen fluoride. So molecules are the smallest individual parts of a compound. Atoms themselves are not indivisible—they possess an internal structure. At their center is a dense nucleus, consisting of protons, which have a positive electric charge (see p. 316), and neutrons, which are uncharged. Around the nucleus are the negatively charged electrons. It is the electrons that give a substance most of its physical and chemical properties. They do not follow definite paths around the nucleus. Instead, electrons are said to be found within certain regions, called orbitals. These are arranged around the nucleus in "shells," each containing electrons of a particular energy. For example, the first shell (1) can hold up to two electrons, in a so-called s-orbital (1s). The second shell (2) can hold up to eight electrons, in s-orbitals (2s) and p-orbitals (2p). If an atom loses an electron, it becomes a positive ion (cation). If an electron is gained, an atom becomes a negative ion (anion). Ions of opposite charges will attract and join together, in a type of bonding known as ionic bonding. In covalent bonding, the atoms bond by sharing their electrons in what become molecular orbitals.

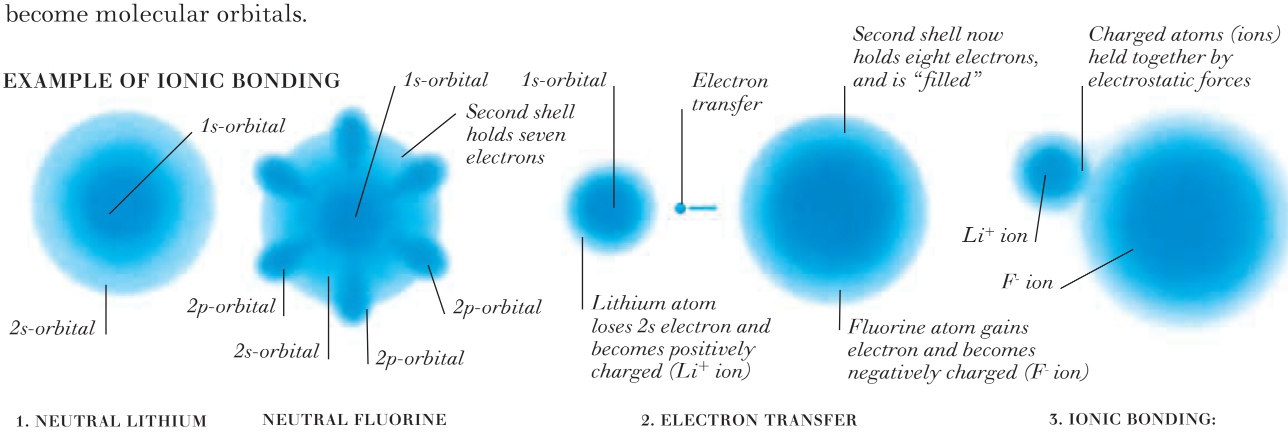
ATOMIC ORBITALS



MOLECULAR ORBITALS

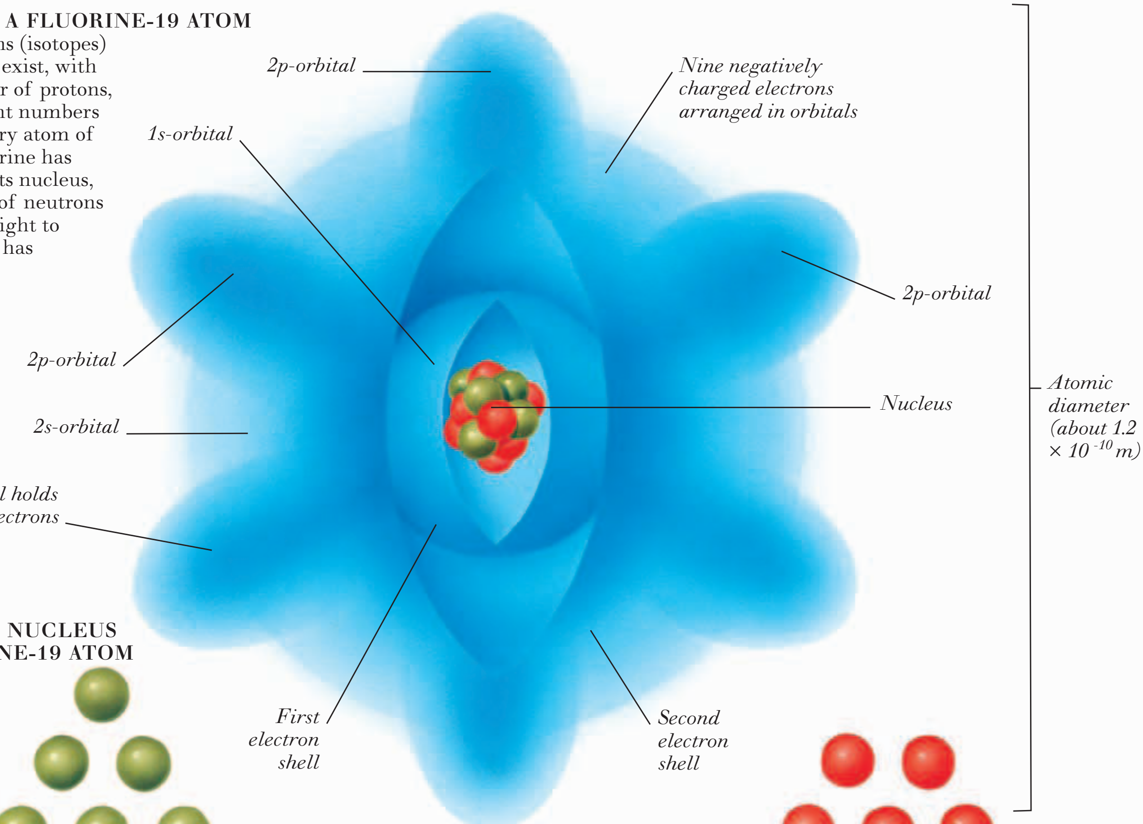


EXAMPLE OF IONIC BONDING

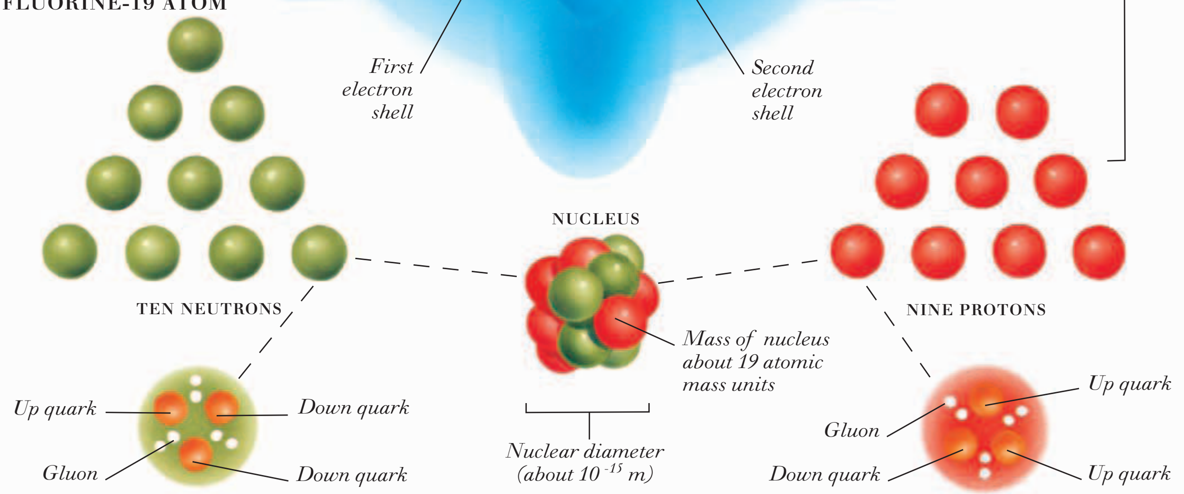


ANATOMY OF A FLUORINE-19 ATOM

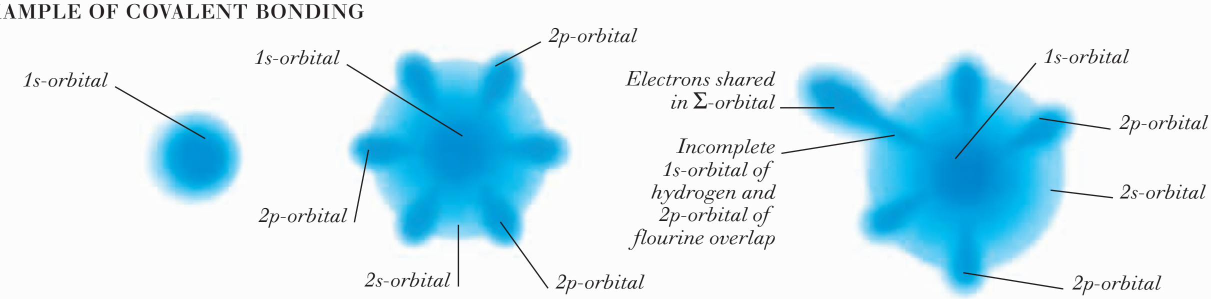
Different versions (isotopes) of each element exist, with the same number of protons, but with different numbers of neutrons. Every atom of the element fluorine has nine protons in its nucleus, but the number of neutrons can vary (from eight to 11). Fluorine-19 has 10 neutrons.



ANATOMY OF NUCLEUS OF A FLUORINE-19 ATOM



EXAMPLE OF COVALENT BONDING



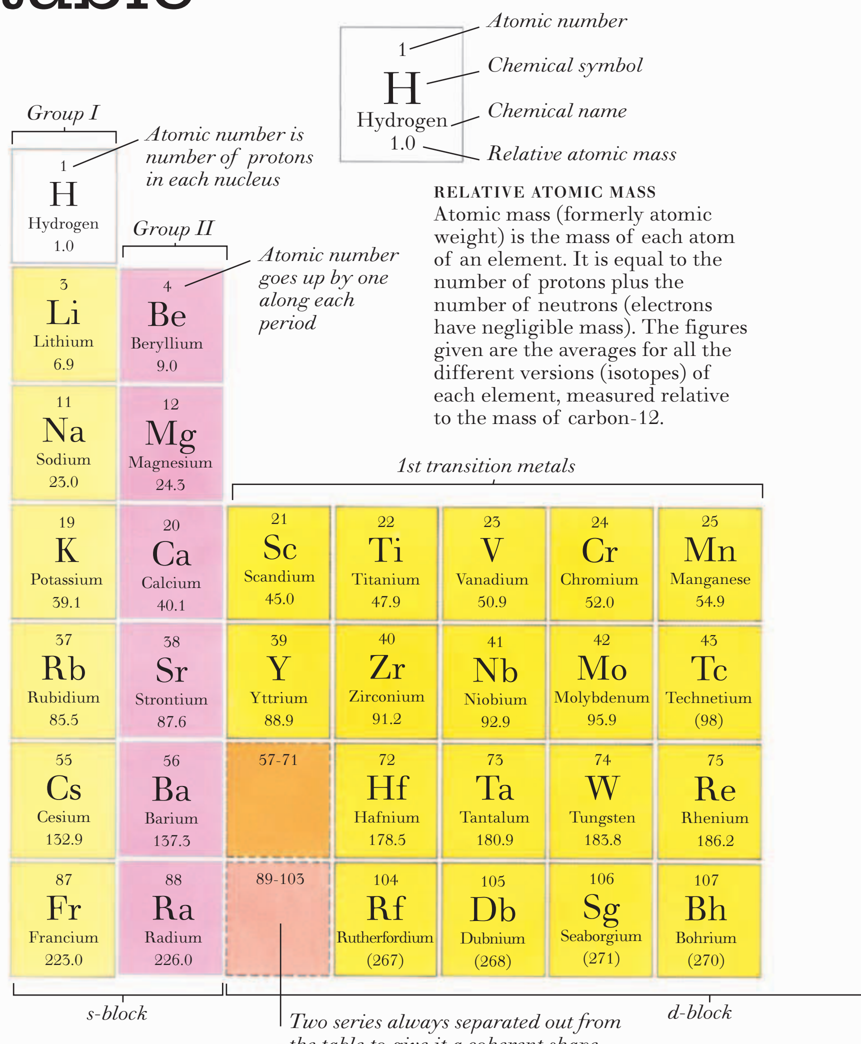
1. NEUTRAL HYDROGEN ATOM (H)

NEUTRAL FLUORINE ATOM (F)

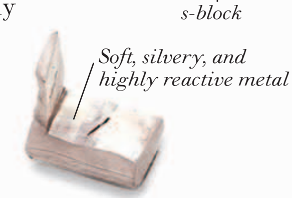
2. COVALENT BONDING: HYDROGEN FLUORIDE MOLECULE (HF)

The periodic table

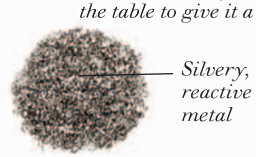
AN ELEMENT is a substance that consists of atoms of one type only. The 92 elements that occur naturally, and the 17 elements created artificially, are often arranged into a chart called the periodic table. Each element is defined by its atomic number—the number of protons in the nucleus of each of its atoms (it is also the number of electrons present). Atomic number increases along each row (period) and down each column (group). The shape of the table is determined by the way in which electrons arrange themselves around the nucleus: the positioning of elements in order of increasing atomic number brings together atoms with a similar pattern of orbiting electrons (orbitals). These appear in blocks. Electrons occupy shells of a certain energy (see pp. 308-309). Periods are ordered according to the filling of successive shells with electrons, while groups reflect the number of electrons in the outer shell (valency electrons). These outer electrons are important—they decide the chemical properties of the atom. Elements that appear in the same group have similar properties because they have the same number of electrons in their outer shell. Elements in Group 0 have "filled shells," where the outer shell holds its maximum number of electrons, and are stable. Atoms of Group I elements have just one electron in their outer shell. This makes them unstable—and ready to react with other substances.



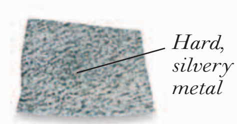
RELATIVE ATOMIC MASS
Atomic mass (formerly atomic weight) is the mass of each atom of an element. It is equal to the number of protons plus the number of neutrons (electrons have negligible mass). The figures given are the averages for all the different versions (isotopes) of each element, measured relative to the mass of carbon-12.



SODIUM: GROUP 1 METAL



MAGNESIUM: GROUP 2 METAL

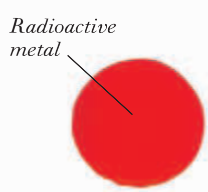


CHROMIUM: 1ST TRANSITION METAL

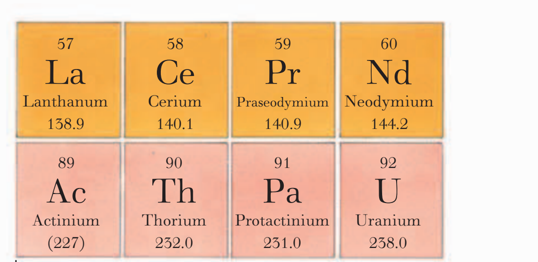
METALS AND NON-METALS
Elements at the left-hand side of each period are metals. Metals easily lose electrons and form positive ions. Non-metals, on the right of a period, tend to become negative ions. Semimetals, which have properties of both metals and non-metals, are between the two.

TYPES OF ELEMENT KEY:

- Alkali metals
- Alkaline earth metals
- Transition metals
- Lanthanides
- Actinides
- Poor metals
- Semi-metals
- Non-metals
- Noble gases
- Unknown chemical properties



PLUTONIUM: ACTINIDE SERIES METAL

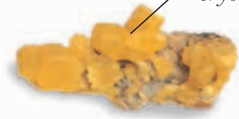


DIAMOND

ALLOTROPES OF CARBON
Some elements exist in more than one form—these are known as allotropes. Carbon powder, graphite, and diamond are allotropes of carbon. They all consist of carbon atoms, but have very different physical properties.

GRAPHITE

CARBON POWDER



SULFUR: GROUP 6 SOLID NON-METAL

IODINE: GROUP 7 SOLID NON-METAL

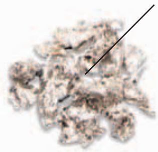
2nd transition metals · *3rd transition metals* · *Boron and carbon groups* · *Nitrogen and oxygen groups* · *Halogens*

					Group III	Group IV	Group V	Group VI	Group VII	Group 0
										2 He Helium 4.0
					5 B Boron 10.8	6 C Carbon 12.0	7 N Nitrogen 14.0	8 O Oxygen 16.0	9 F Fluorine 19.0	10 Ne Neon 20.2
					13 Al Aluminum 27.0	14 Si Silicon 28.1	15 P Phosphorus 31.0	16 S Sulfur 32.1	17 Cl Chlorine 35.5	18 Ar Argon 40.0
26 Fe Iron 55.8	27 Co Cobalt 58.9	28 Ni Nickel 58.7	29 Cu Copper 63.5	30 Zn Zinc 65.4	31 Ga Gallium 69.7	32 Ge Germanium 72.6	33 As Arsenic 74.9	34 Se Selenium 79.0	35 Br Bromine 79.9	36 Kr Krypton 83.8
44 Ru Ruthenium 101.1	45 Rh Rhodium 102.9	46 Pd Palladium 106.4	47 Ag Silver 107.9	48 Cd Cadmium 112.4	49 In Indium 114.8	50 Sn Tin 118.7	51 Sb Antimony 121.8	52 Te Tellurium 127.6	53 I Iodine 126.9	54 Xe Xenon 131.3
76 Os Osmium 190.2	77 Ir Iridium 192.2	78 Pt Platinum 195.1	79 Au Gold 197.0	80 Hg Mercury 200.6	81 Tl Thallium 204.4	82 Pb Lead 207.2	83 Bi Bismuth 209.0	84 Po Polonium (209)	85 At Astatine (210)	86 Rn Radon (222)
108 Hs Hassium (269)	109 Mt Meitnerium (278)	110 Ds Darmstadtium (281)	111 Rg Roentgenium (281)	112 Cn Copernicium (285)	113 Uut Ununtrium (286)	114 Uuq Ununquadium (289)	115 Uup Ununpentium (289)	116 Uuh Ununhexium (293)	117 Uus Ununseptium (294)	118 Uuo Ununoctium (294)

Period · *Short period* · *Long period*

d-block · *p-block*

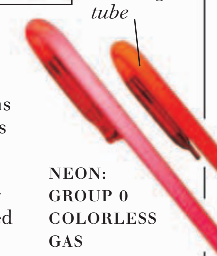
GOLD: 3RD TRANSITION METAL



TIN: GROUP 4 POOR METAL

ANTIMONY: GROUP 5 SEMI-METAL

NOBLE GASES
Group 0 contains elements that have a filled (complete) outer shell of electrons, which means the atoms do not need to lose or gain electrons by bonding with other atoms. This makes them stable and they do not easily form ions or react with other elements. Noble gases are also called rare or inert gases.



NEON: GROUP 0 COLORLESS GAS

61 Pm Promethium (145)	62 Sm Samarium 150.4	63 Eu Europium 152.0	64 Gd Gadolinium 157.3	65 Tb Terbium 158.9	66 Dy Dysprosium 162.5	67 Ho Holmium 164.9	68 Er Erbium 167.3	69 Tm Thulium 168.9	70 Yb Ytterbium 173.0	71 Lu Lutetium 175.0
93 Np Neptunium (237)	94 Pu Plutonium (244)	95 Am Americium (243)	96 Cm Curium (247)	97 Bk Berkelium (247)	98 Cf Californium (251)	99 Es Einsteinium (252)	100 Fm Fermium (257)	101 Md Mendelevium (258)	102 No Nobelium (259)	103 Lr Lawrencium (262)

f-block

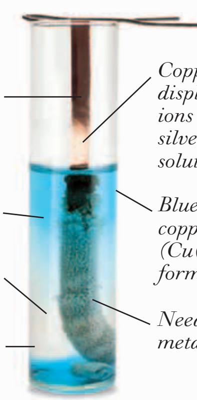
Chemical reactions

A CHEMICAL REACTION TAKES PLACE whenever bonds between atoms are broken or made. In each case, atoms or groups of atoms rearrange, making new substances (products) from the original ones (reactants). Reactions happen naturally, or can be made to happen; they may take years, or only an instant. Some of the main types are shown here. A reaction usually involves a change in energy (see pp. 314-315). In a burning reaction, for example, the making of new bonds between atoms releases energy as heat and light. This type of reaction, in which heat is given off, is an exothermic reaction. Many reactions, like burning, are irreversible, but some can take place in either direction, and are said to be reversible. Reactions can be used to form solids from solutions: in a double decomposition reaction, two compounds in solution break down and re-form into two new substances, often creating a precipitate (insoluble solid); in displacement, an element (e.g., copper) displaces another element (e.g., silver) from a solution. The rate (speed) of a reaction is determined by many different factors, such as temperature, and the size and shape of the reactants. To describe and keep track of reactions, internationally recognized chemical symbols and equations are used. Reactions are also used in the laboratory to identify matter. An experiment with candle wax, for example, demonstrates that it contains carbon and hydrogen.

SALT FORMATION (ACID ON METAL)

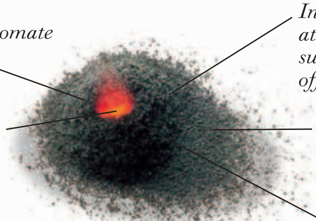
THE REACTION
Hydrochloric acid added to zinc produces zinc chloride and hydrogen.
$Zn + 2HCl \rightarrow ZnCl_2 + H_2$

DISPLACEMENT



THE REACTION
Copper metal added to silver nitrate solution produces copper nitrate and silver metal.
$Cu + 2AgNO_3 \rightarrow Cu(NO_3)_2 + 2Ag$

BURNING MATTER

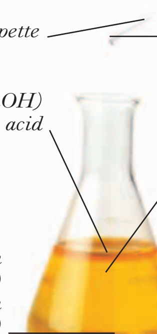


THE REACTION
When lit, ammonium dichromate combines with oxygen from air.
$(NH_4)_2Cr_2O_7 + O_2 \rightarrow Cr_2O_3 + 4H_2O + 2NO$

A REVERSIBLE REACTION

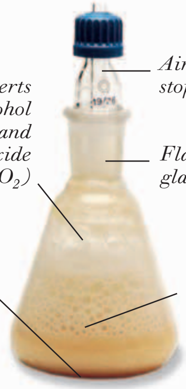
1. THE REACTANT
Potassium chromate dissolves in water to form potassium ions and chromate ions.
$K_2CrO_4 \rightarrow 2K^+ + CrO_4^{2-}$

2. THE REACTION
Addition of hydrochloric acid changes chromate ions into dichromate ions.
$2CrO_4^{2-} \rightarrow Cr_2O_7^{2-}$



3. REVERSING
Addition of sodium hydroxide changes dichromate ions back into chromate ions.
$Cr_2O_7^{2-} \rightarrow 2CrO_4^{2-}$

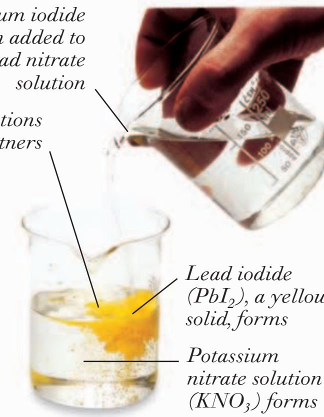
FERMENTATION



THE REACTION
Yeast converts sugar and warm water into alcohol and carbon dioxide.
$C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

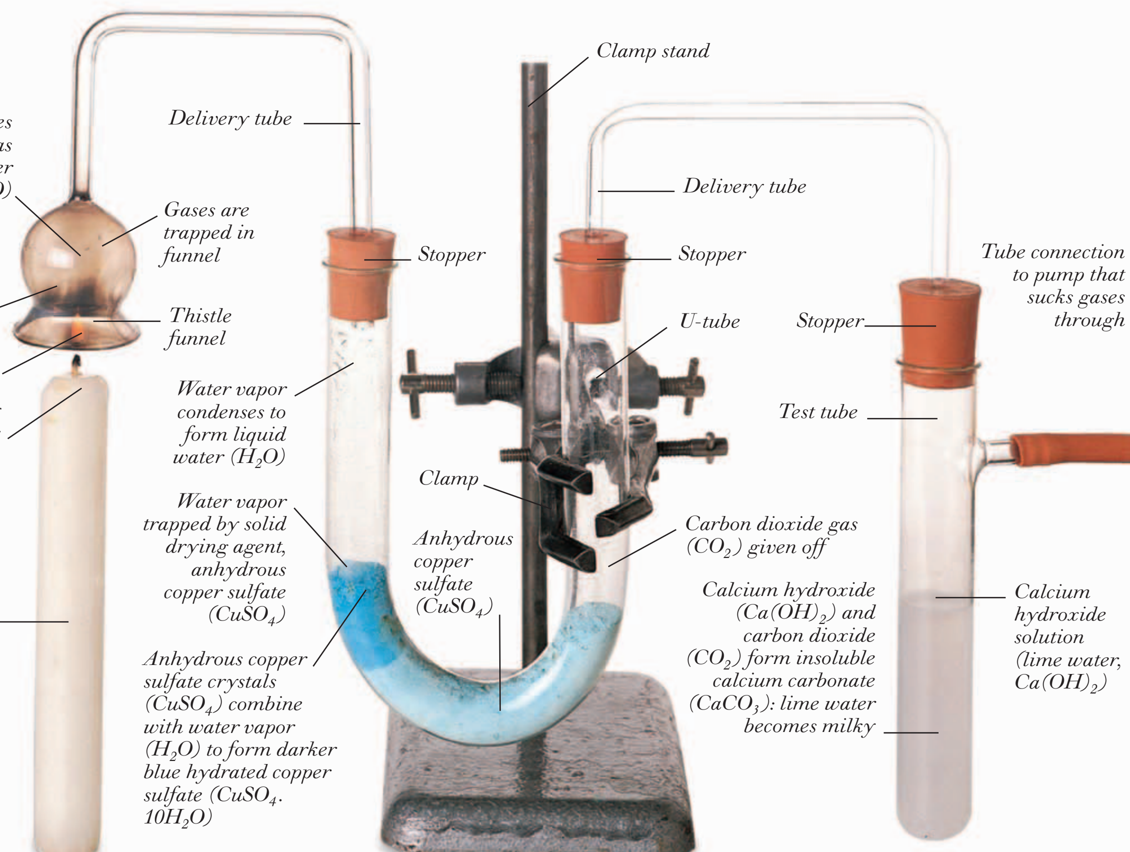
DOUBLE DECOMPOSITION

1. THE REACTANTS
Potassium iodide in water (KI) and lead nitrate in water ($Pb(NO_3)_2$) each form colorless solutions.



2. THE REACTION
When the solutions are mixed, lead iodide, a precipitate, and potassium nitrate solution are formed.
$2KI + Pb(NO_3)_2 \rightarrow PbI_2 + 2KNO_3$

TESTING CANDLE WAX, AN ORGANIC COMPOUND



1. THE BURNING REACTION
Burning wax produces carbon dioxide gas and water vapor.
$2C_{18}H_{38} + 55O_2 \rightarrow 36CO_2 + 38H_20$

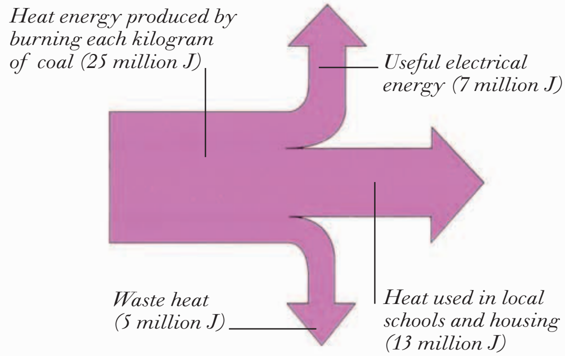
2. TESTING FOR WATER VAPOR
A solid drying agent traps water vapor, proving the presence of hydrogen in the candle wax.
$CuSO_4 + 10H_2O \rightarrow CuSO_4 . 10H_2O$

3. TESTING FOR CARBON DIOXIDE
Calcium hydroxide in solution reacts with carbon dioxide, forming a carbonate and turning milky.
$Ca(OH)_2 + CO_2 \rightarrow CaCO_3 + H_2O$

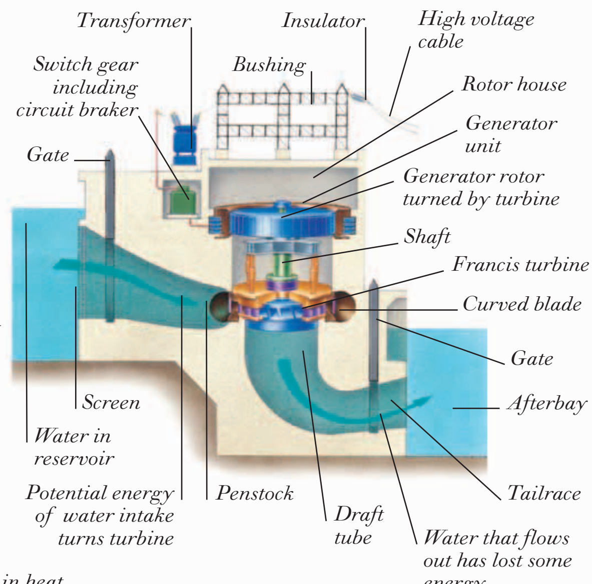
Energy

ANYTHING THAT HAPPENS—from a pin-drop to an explosion—requires energy. Energy is the capacity for "doing work" (making something happen). Various forms of energy exist, including light, heat, sound, electrical, chemical, nuclear, kinetic, and potential energies. The Law of Conservation of Energy states that the total amount of energy in the universe is fixed—energy cannot be created or destroyed. It means that energy can only change from one form to another (energy transfer). For example, potential energy is energy that is "stored," and can be used in the future. An object gains potential energy when it is lifted; as the object is released, potential energy changes into the energy of motion (kinetic energy). During transference, some of the energy converts into heat. A combined heat and power station can put some of the otherwise "waste" heat to useful effect in local schools and housing. Most of the Earth's energy is provided by the Sun, in the form of electromagnetic radiation (see pp. 316-317). Some of this energy transfers to plant and animal life, and ultimately to fossil fuels, where it is stored in chemical form. Our bodies obtain energy from the food we eat, while energy needed for other tasks, such as heating and transport, can be obtained by burning fossil fuels—or by harnessing natural forces like wind or moving water—to generate electricity. Another source is nuclear power, where energy is released by reactions in the nucleus of an atom. All energy is measured by the international unit, the joule (J). As a guide, one joule is about equal to the amount of energy needed to lift an apple one meter.

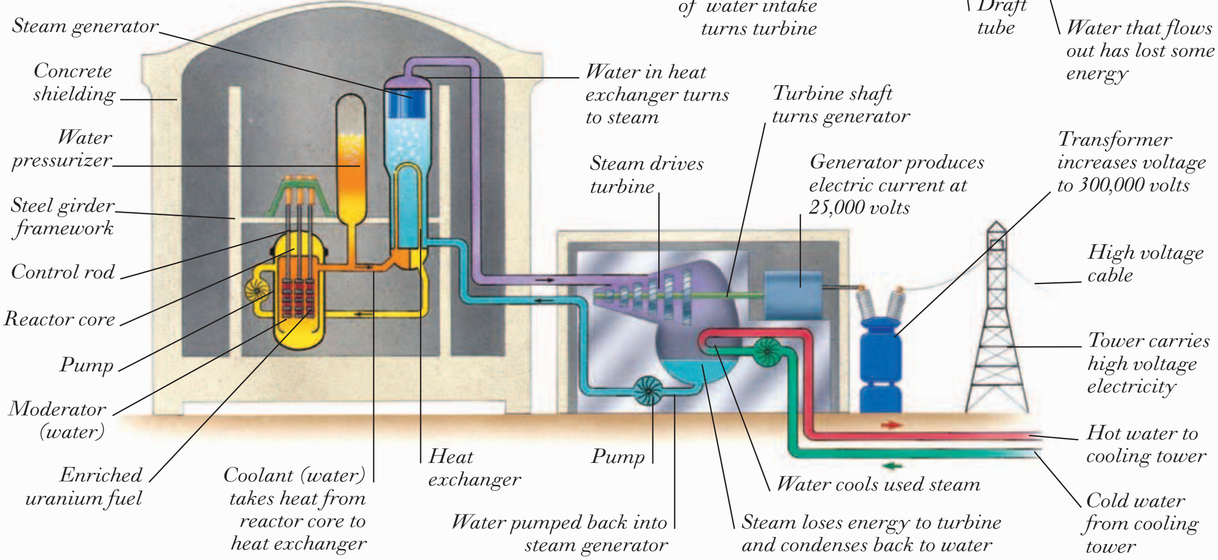
SANKEY DIAGRAM SHOWING ENERGY FLOW IN A COAL-FIRED COMBINED HEAT AND POWER STATION



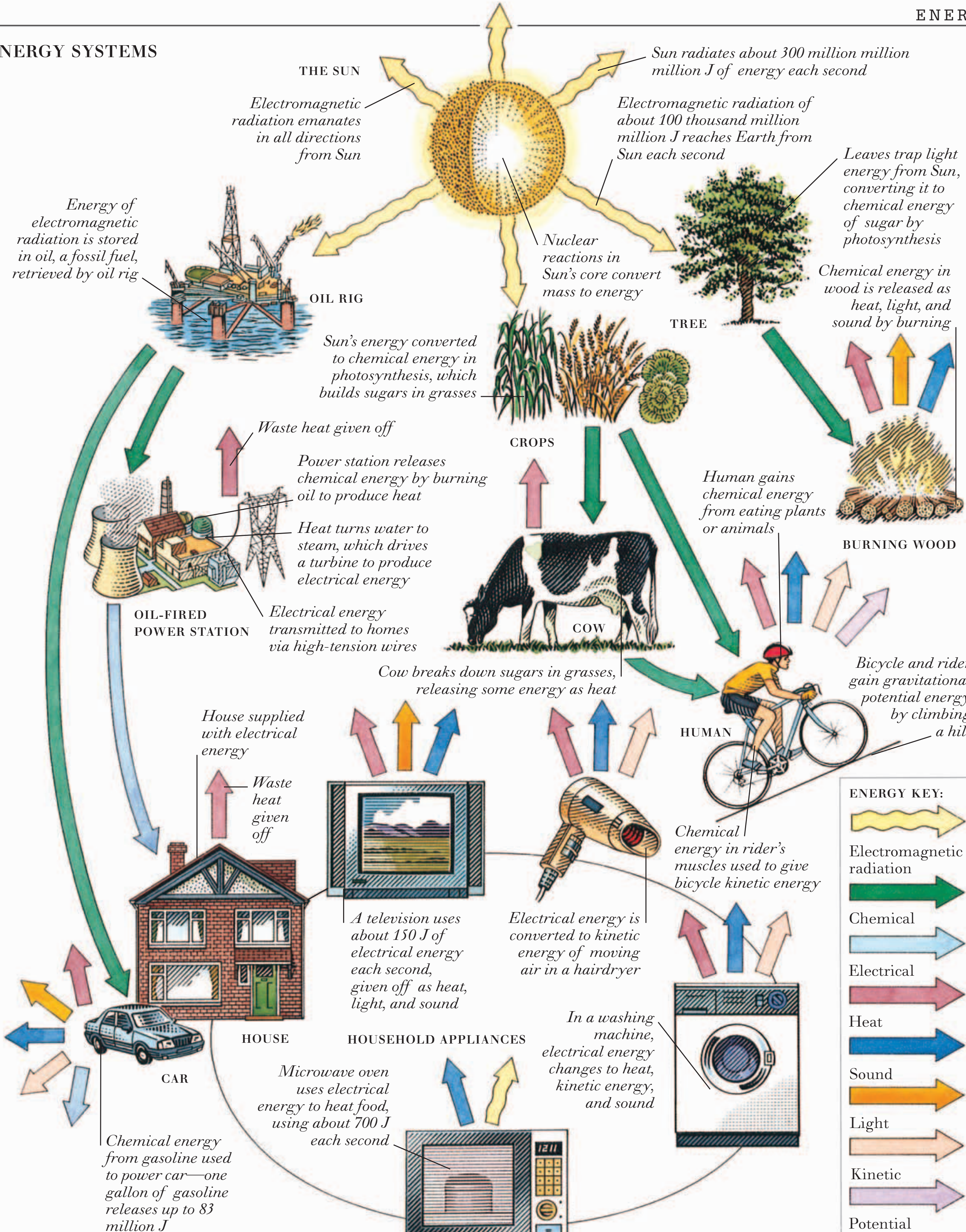
CROSS-SECTION OF HYDROELECTRIC POWER STATION WITH FRANCIS TURBINE



CROSS-SECTION OF NUCLEAR POWER STATION WITH PRESSURIZED WATER REACTOR



ENERGY SYSTEMS

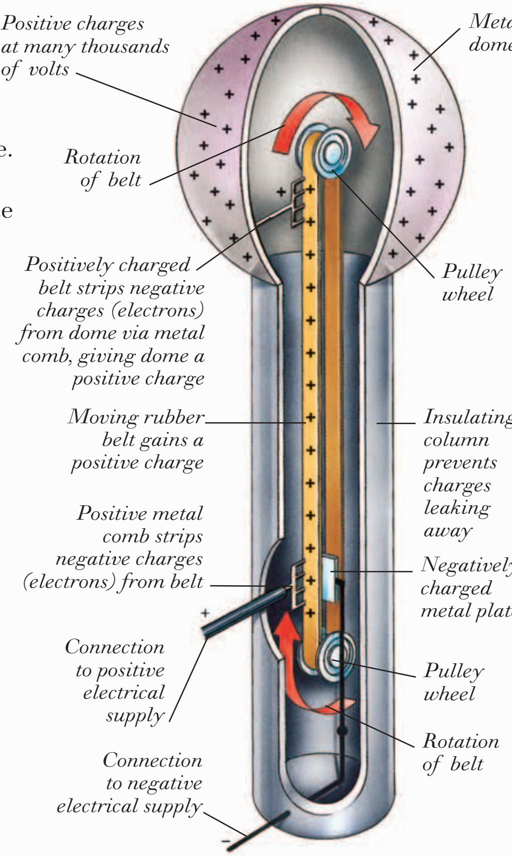


Electricity and magnetism

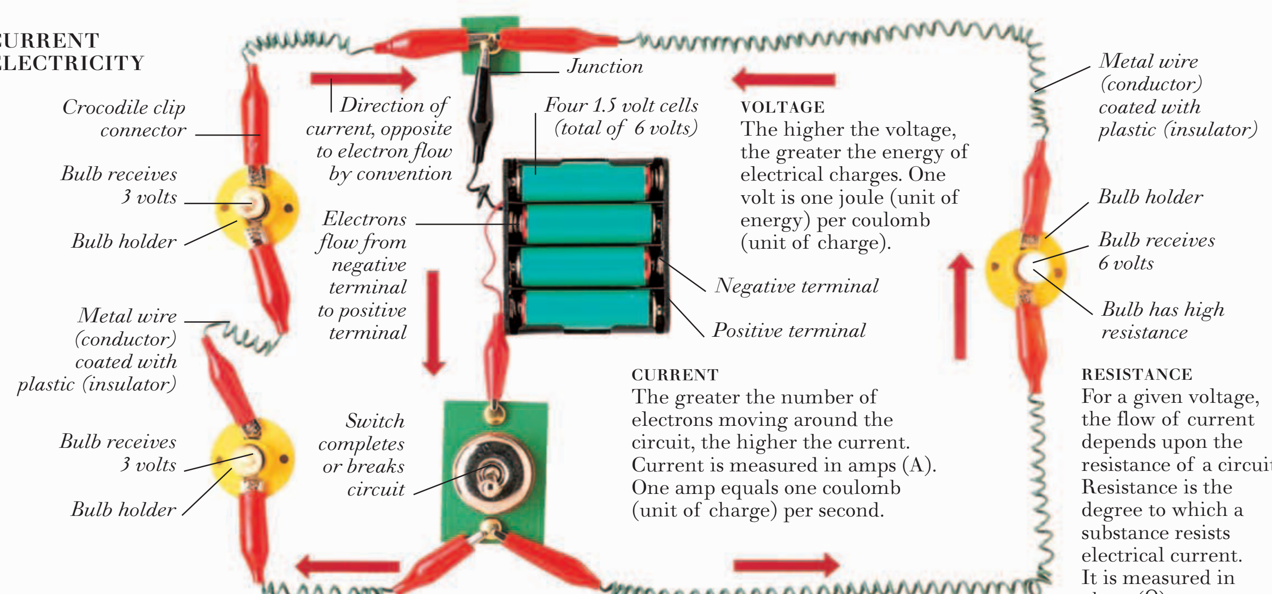
ELECTRICAL EFFECTS result from an imbalance of electric charge. There are two types of electric charge, named positive (carried by protons) and negative (carried by electrons). If charges are opposite (unlike), they attract one another, while like charges repel. Forces of attraction and repulsion (electrostatic forces) exist between any two charged particles. Matter is normally uncharged, but if electrons are gained, an object will gain an overall negative charge; if they are removed, it becomes positive. Objects with an overall negative or positive charge are said to have an imbalance of charge, and exert the same forces as individual negative and positive charges. On this larger scale, the forces will always act to regain the balance of charge. This causes static electricity. Lightning, for example, is produced by clouds discharging a huge excess of negative electrons. If charges are "free"—in a wire or material that allows electrons to pass through it—the forces cause a flow of charge called an electric current. Some substances exhibit the strange phenomenon of magnetism—which also produces attractive and repulsive forces. Magnetic substances consist of small regions called domains. Normally unmagnetized, they can be magnetized by being placed in a magnetic field. Magnetism and electricity are inextricably linked, a fact put to use in motors and generators.

LIGHTNING

VAN DE GRAAFF (ELECTROSTATIC) GENERATOR



CURRENT ELECTRICITY



SERIES ELECTRICAL CIRCUIT

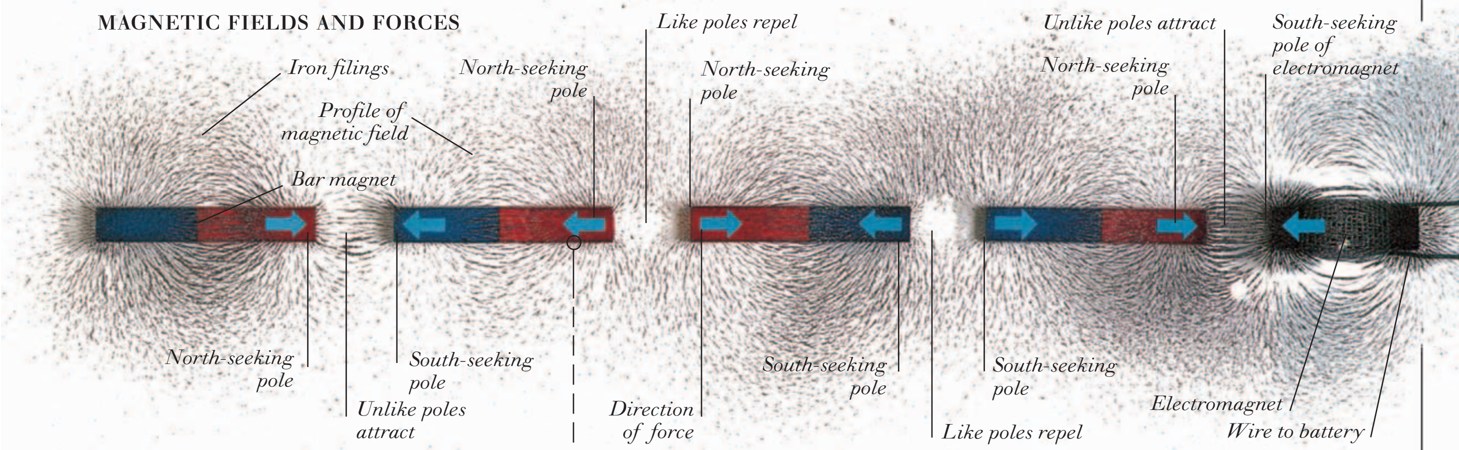
SIMPLE ELECTRICAL CIRCUIT

VOLTAGE
The higher the voltage, the greater the energy of electrical charges. One volt is one joule (unit of energy) per coulomb (unit of charge).

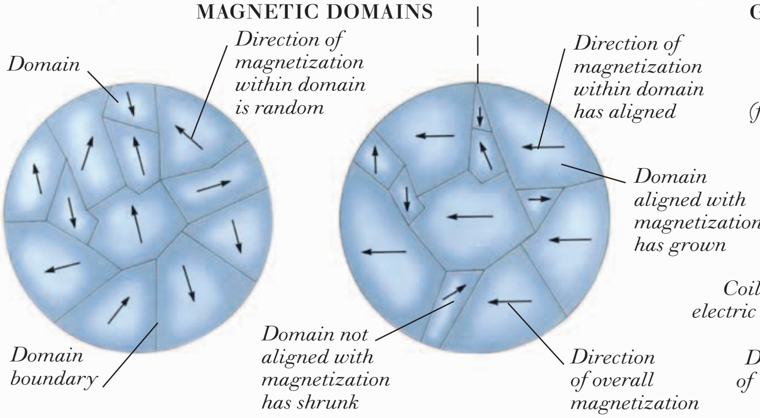
CURRENT
The greater the number of electrons moving around the circuit, the higher the current. Current is measured in amps (A). One amp equals one coulomb (unit of charge) per second.

RESISTANCE
For a given voltage, the flow of current depends upon the resistance of a circuit. Resistance is the degree to which a substance resists electrical current. It is measured in ohms (Ω).

MAGNETIC FIELDS AND FORCES



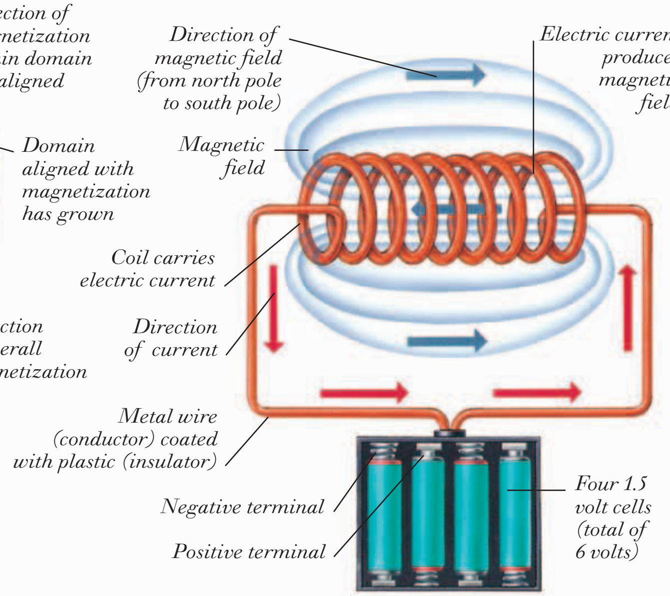
MAGNETIC DOMAINS



UNMAGNETIZED IRON

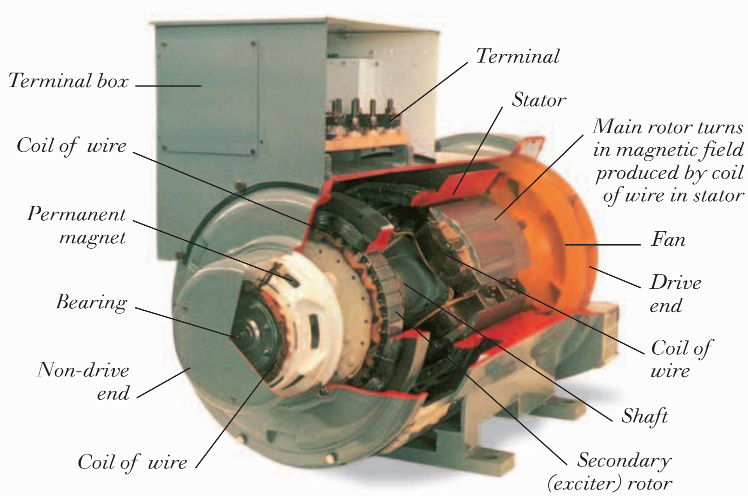
MAGNETIZED IRON IN A MAGNETIC FIELD

GENERATING MAGNETISM FROM ELECTRICITY

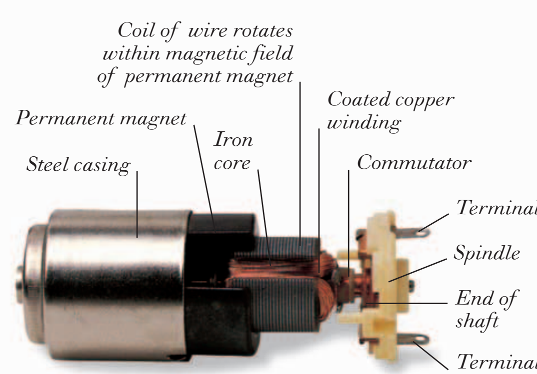


CIRCUIT WITH ELECTROMAGNET

GENERATING ELECTRICITY FROM MAGNETISM

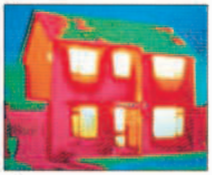


ELECTRIC GENERATOR
In a generator, the rotor rotates within the magnetic field of the stator to produce an electric current.



ELECTRIC MOTOR
In a motor, magnetic forces between the winding and permanent magnet produce a rotary motion.

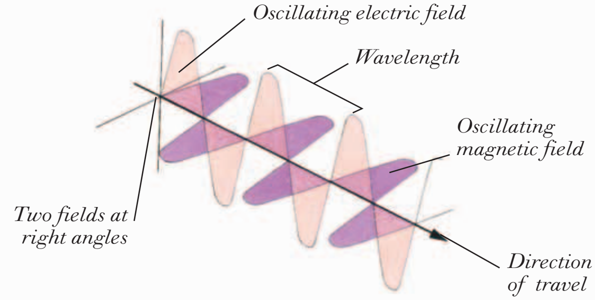
Light



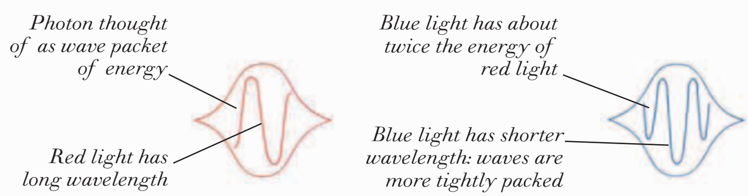
INFRARED IMAGE OF A HOUSE

LIGHT IS A FORM OF ENERGY. It is a type of electromagnetic radiation, like X-rays or radio waves. All electromagnetic radiation is produced by electric charges (see pp. 316-317): it is caused by the effects of oscillating electric and magnetic fields as they travel through space. Electromagnetic radiation is considered to have both wave and particle properties. It can be thought of as a wave of electricity and magnetism. In that case, the difference between the various forms of radiation is their wavelength. Radiation can also be said to consist of particles, or packets of energy, called photons. The difference between light and X-rays, for instance, is the amount of energy that each photon carries. The complete range of radiation is referred to as the electromagnetic spectrum, extending from low energy, long wavelength radio waves to high energy, short wavelength gamma rays. Light is the only part of the electromagnetic spectrum that is visible. White light from the Sun is made up of all the visible wavelengths of radiation, which can be seen when it is separated by using a prism. Light, like all forms of electromagnetic radiation, can be reflected (bounced back) and refracted (bent). Different parts of the electromagnetic spectrum are produced in different ways. Sometimes visible light—and infrared radiation—is generated by the vibrating particles of warm or hot objects. The emission of light in this way is called incandescence. Light can also be produced by fluorescence, a phenomenon in which electrons gain and lose energy within atoms.

MAXWELLIAN DIAGRAM OF ELECTROMAGNETIC RADIATION AS WAVES



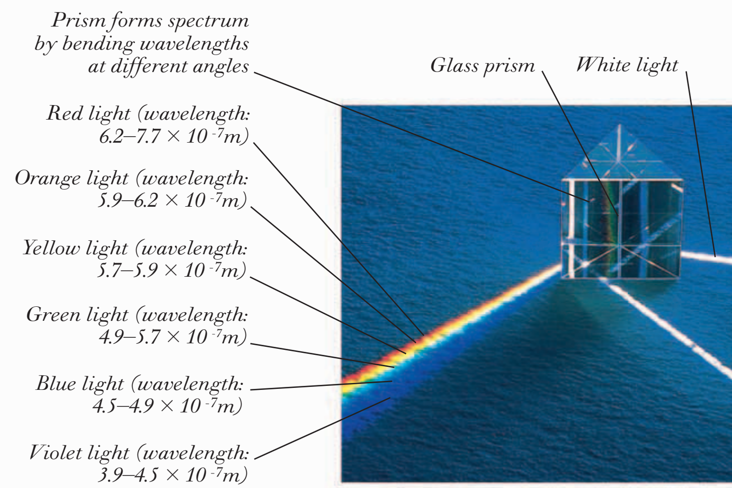
ELECTROMAGNETIC RADIATION AS PARTICLES



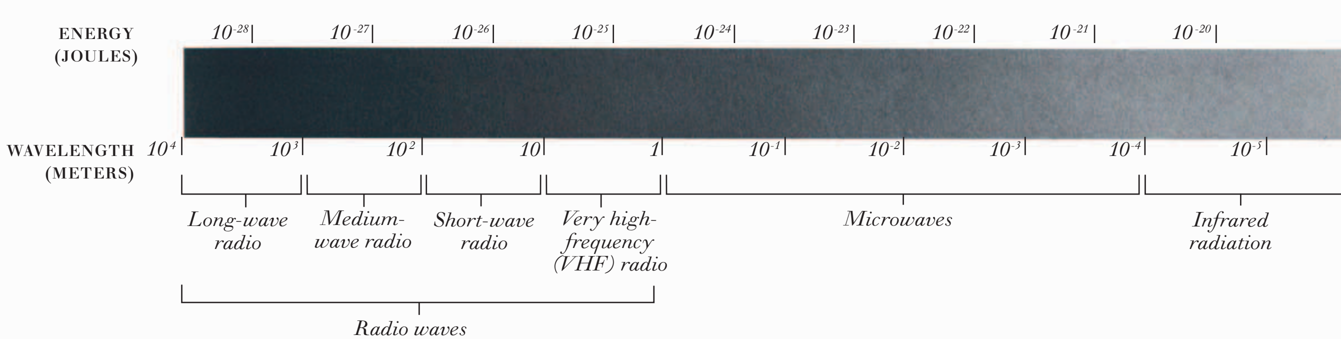
PHOTON OF RED LIGHT

PHOTON OF BLUE LIGHT

SPLITTING WHITE LIGHT INTO THE SPECTRUM

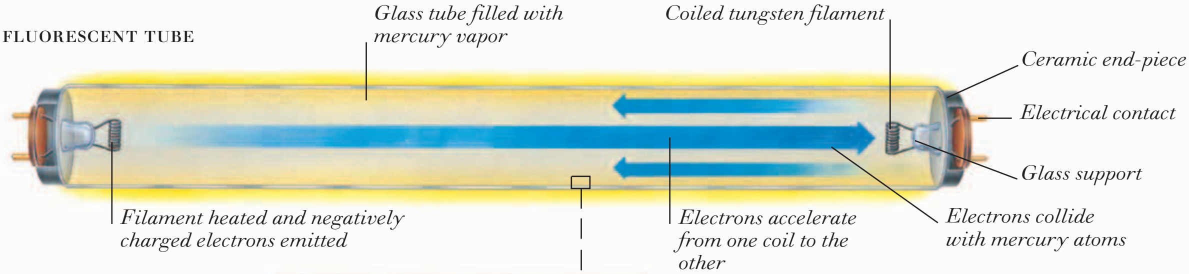


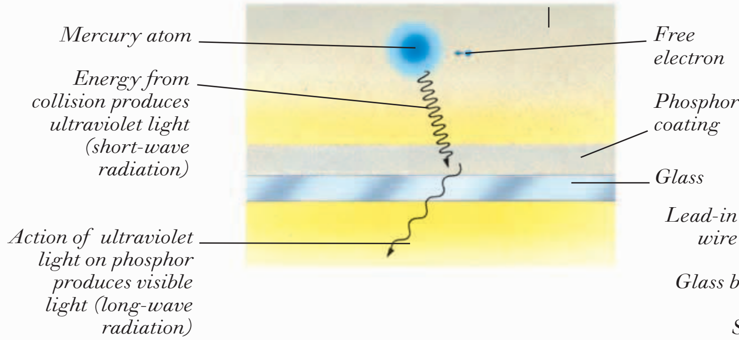
THE ELECTROMAGNETIC SPECTRUM



ARTIFICIAL LIGHT SOURCES

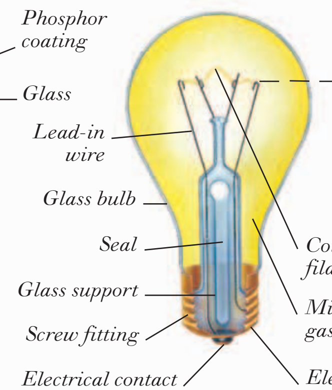
FLUORESCENT TUBE



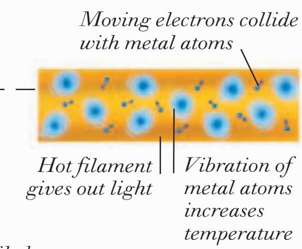


SECTION OF PHOSPHOR COATING OF FLUORESCENT TUBE: HOW FLUORESCENT LIGHT IS PRODUCED

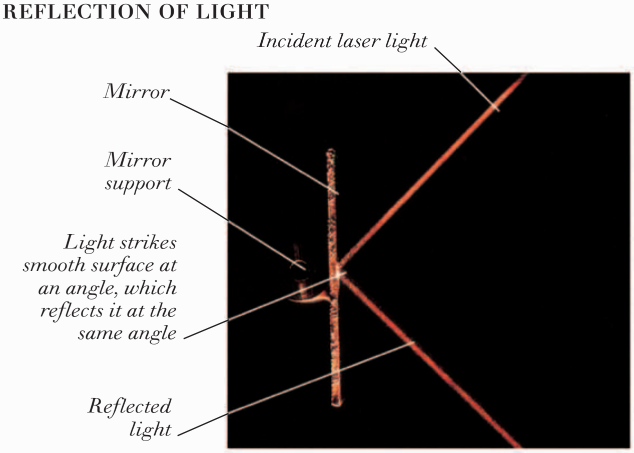
INCANDESCENT LIGHT BULB



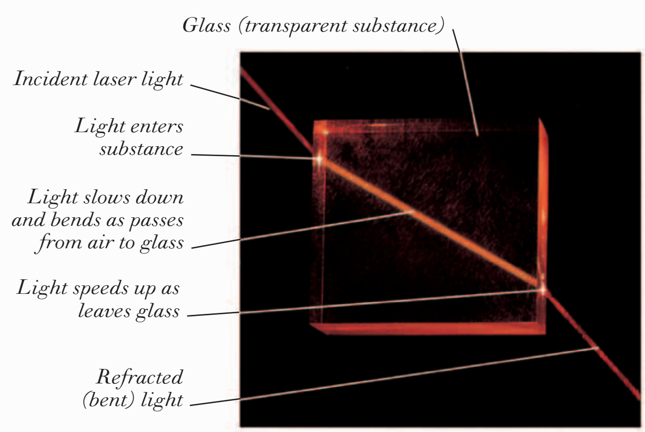
SECTION OF FILAMENT OF INCANDESCENT LIGHT BULB: HOW INCANDESCENT LIGHT IS PRODUCED

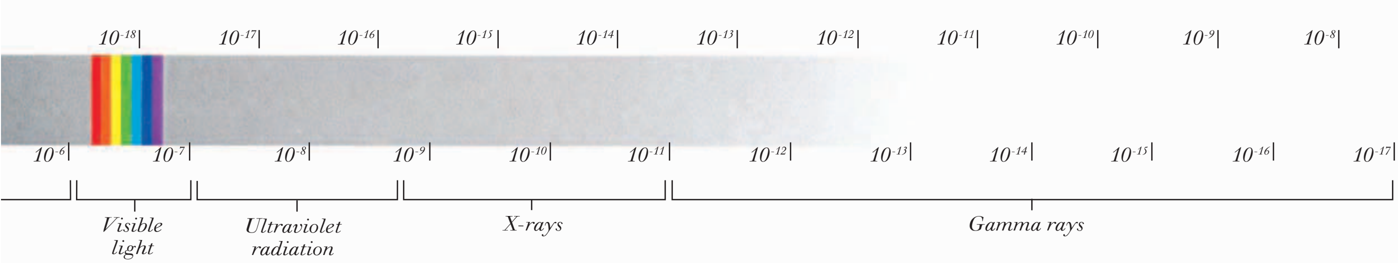


REFLECTION OF LIGHT



REFRACTION OF LIGHT

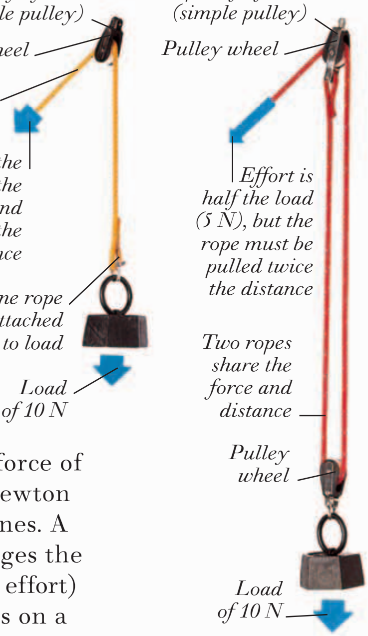




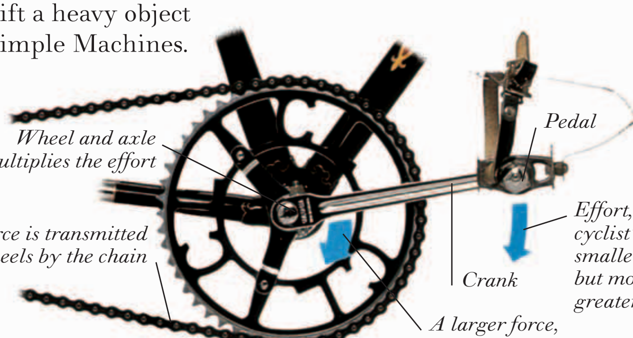
Force and motion

FORCES ARE PUSHES OR PULLS that change the motion of objects. To make a stationary object move, or a moving object stop, a force is needed. A force is also required to change the speed or direction of an object. This change in speed or direction is known as acceleration. Acceleration depends on the size (magnitude) of the force, and on the mass of the object. The effects of forces were first summarized by Isaac Newton in his three laws of motion. The international unit of force, named after him, is the newton (N), which is approximately equal to the weight of one apple. Gravity—the force of attraction between any two masses—can be measured using a newton meter (spring balance). Forces are put to useful effect in machines. A simple machine, such as a wheel and axle, is a device that changes the size or direction of an applied force. It allows an applied force (the effort) to produce another force (the load). A lever uses a bar that turns on a fulcrum to exert force. In all simple machines, there is a relationship between force and distance. A small force (in a compound pulley, for instance) moves through a large distance to lift a heavy object a small distance. This is called the Law of Simple Machines.

SIMPLE MACHINES

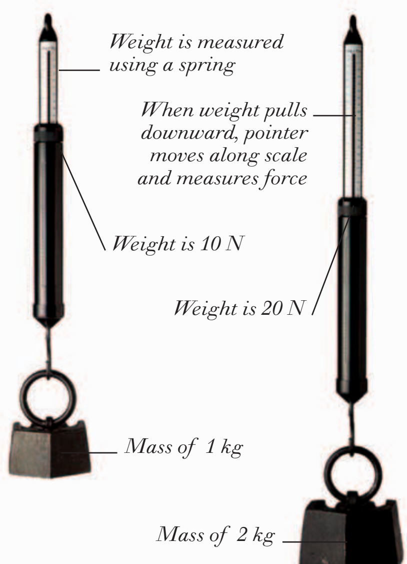


SIMPLE AND COMPOUND PULLEYS



WHEEL AND AXLE

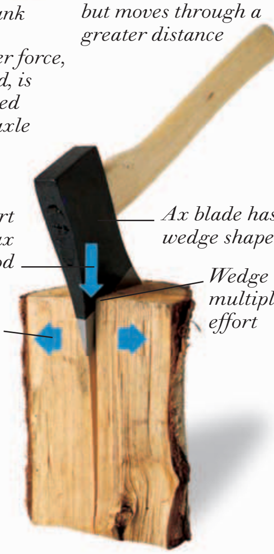
NEWTON METERS (SPRING BALANCES)



WEIGHT AND MASS

The "mass" of an object is a measure of the quantity of matter that it possesses. Mass is usually measured in grams (g) or kilograms (kg). The "weight" of an object is the force exerted on the object's mass by gravity. Since weight is a force, its unit is the newton (N).

SCREW

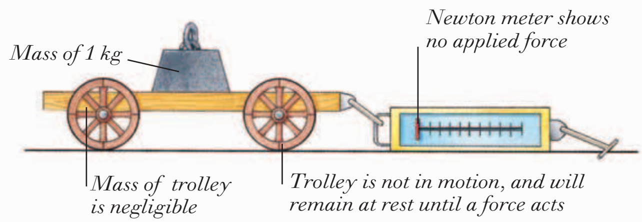


WEDGE

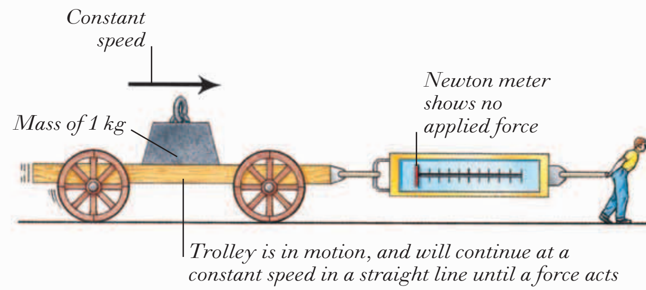
NEWTON'S THREE LAWS OF MOTION

NEWTON'S FIRST LAW

When no force acts on a body, it will continue in a state of rest or uniform motion.



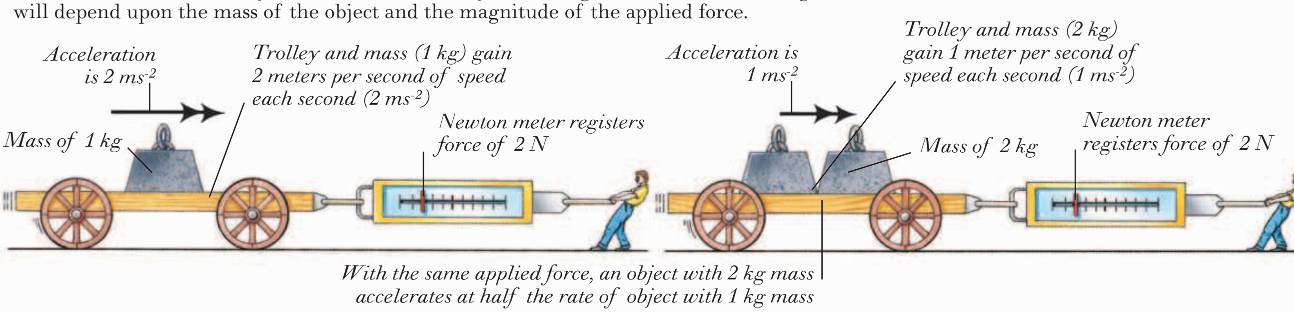
NO FORCE, NO ACCELERATION: STATE OF REST



NO FORCE, NO ACCELERATION: UNIFORM MOTION

NEWTON'S SECOND LAW

When a force acts on a body, the motion of the body will change. The size of the change will depend upon the mass of the object and the magnitude of the applied force.

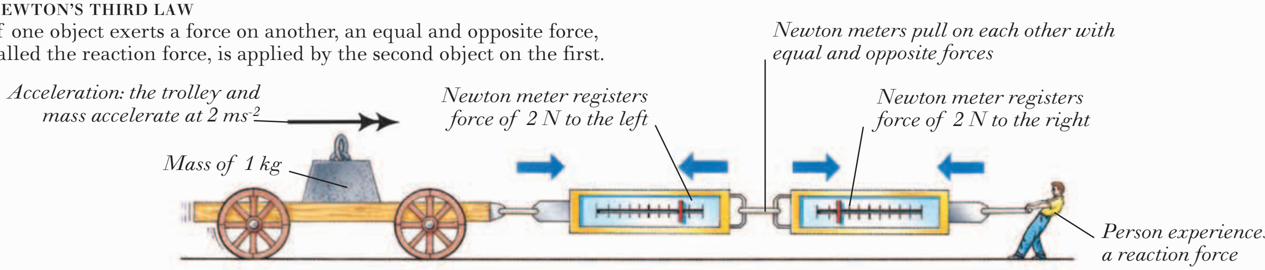


FORCE AND ACCELERATION: SMALL MASS, LARGE ACCELERATION

FORCE AND ACCELERATION: LARGE MASS, SMALL ACCELERATION

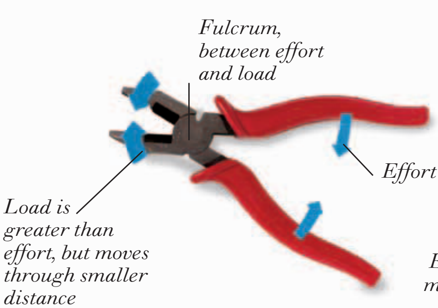
NEWTON'S THIRD LAW

If one object exerts a force on another, an equal and opposite force, called the reaction force, is applied by the second object on the first.



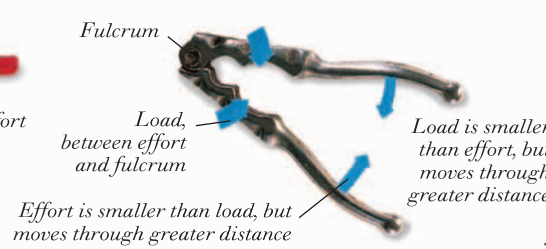
ACTION AND REACTION

THREE CLASSES OF LEVER



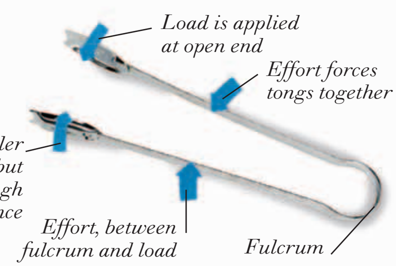
CLASS 1 LEVER

Pliers consist of two class 1 levers.



CLASS 2 LEVER

Nutcrackers consist of two class 2 levers.



CLASS 3 LEVER

Tongs consist of two class 3 levers.

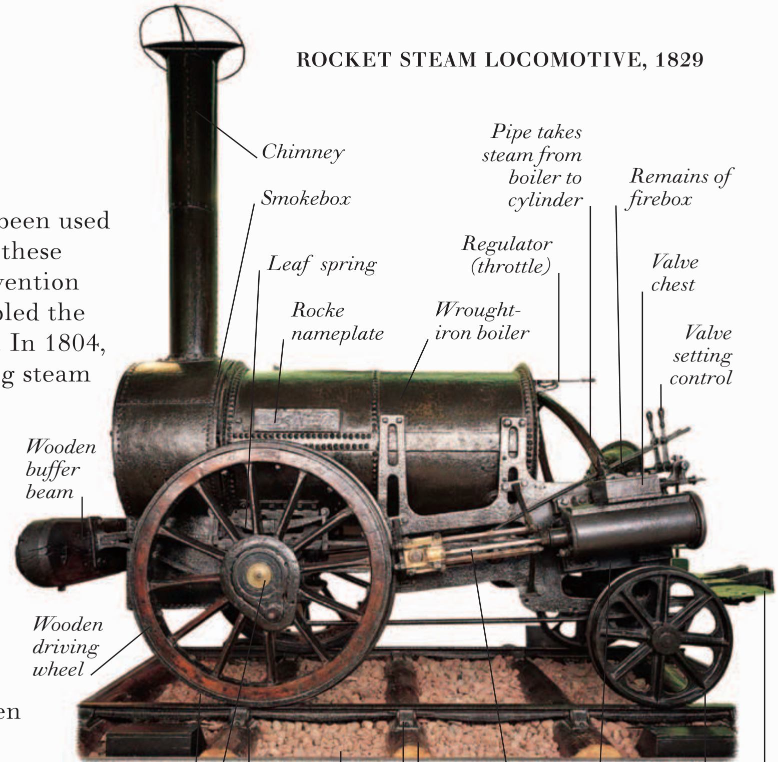

ELECTRIC

Rail and Road

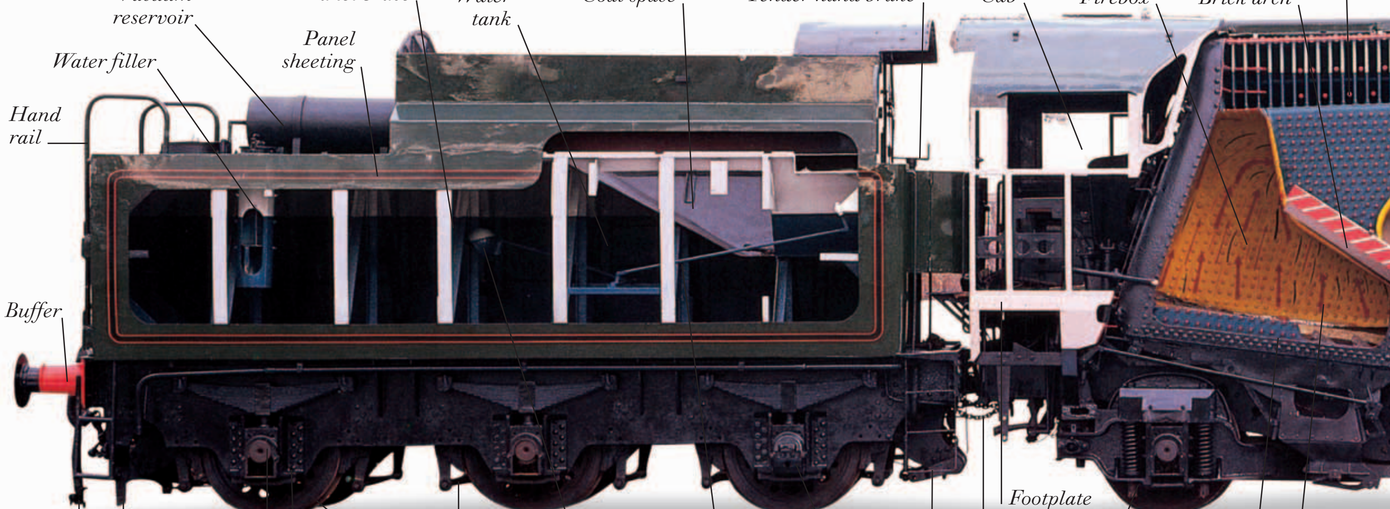
Steam locomotives

WAGONS THAT ARE PULLED along tracks have been used to transport material since the 16th century, but these trains were drawn by men or horses until the invention of the steam locomotive. Steam locomotives enabled the basic railroad system to realize its true potential. In 1804, Richard Trevithick built the world's first working steam locomotive in South Wales. It was not entirely successful, but it encouraged others to develop new designs. By 1829, the British engineer Robert Stephenson had built the Rocket, considered to be the forerunner of the modern locomotive. The Rocket was a self-sufficient unit, carrying coal to heat the boiler and a water supply for generating steam. Steam passed from the boiler to force the pistons back and forth, and this movement turned the driving wheels, propelling the train forward. Used steam was then expelled in characteristic puffs. Later steam locomotives, like Ellerman Lines and the Mallard, worked in a similar way, but on a much larger scale. The simple design and reliability of steam locomotives ensured that they changed very little in 120 years of use, before being replaced from the 1950s by more efficient diesel and electric power (see pp. 326-329).

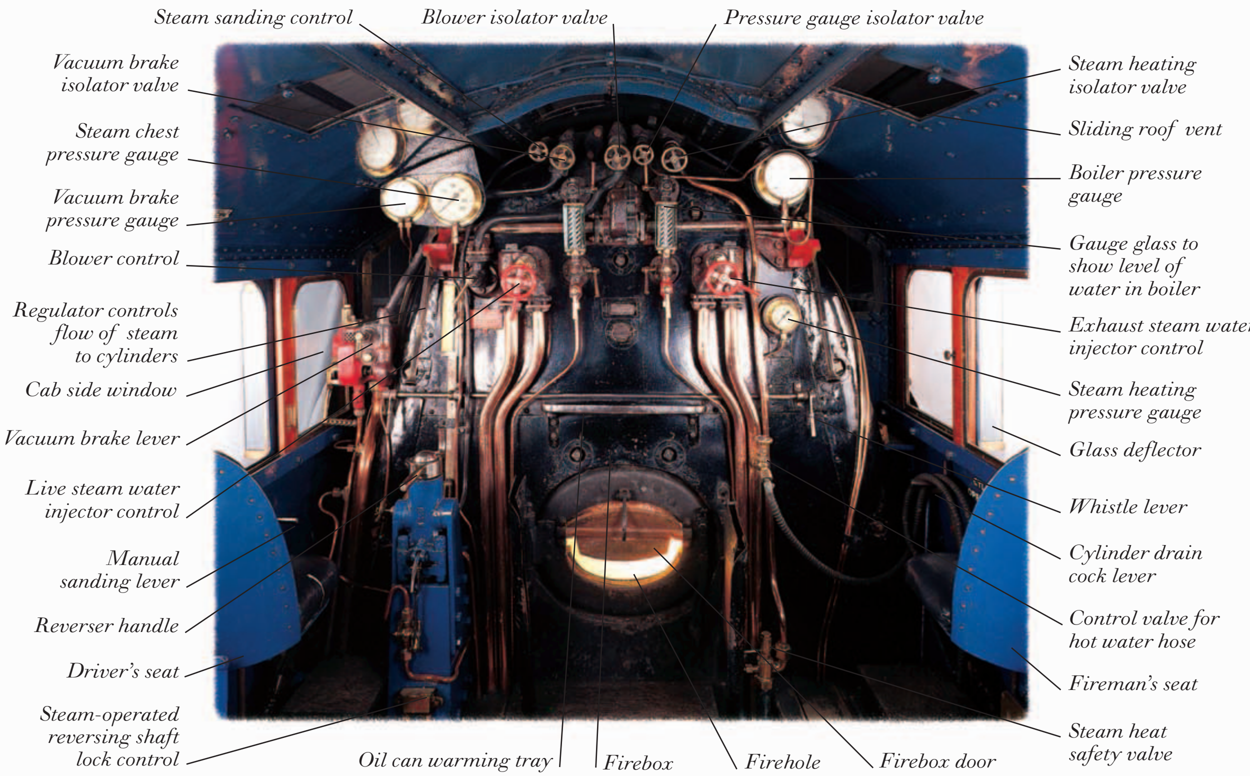
ROCKET STEAM LOCOMOTIVE, 1829

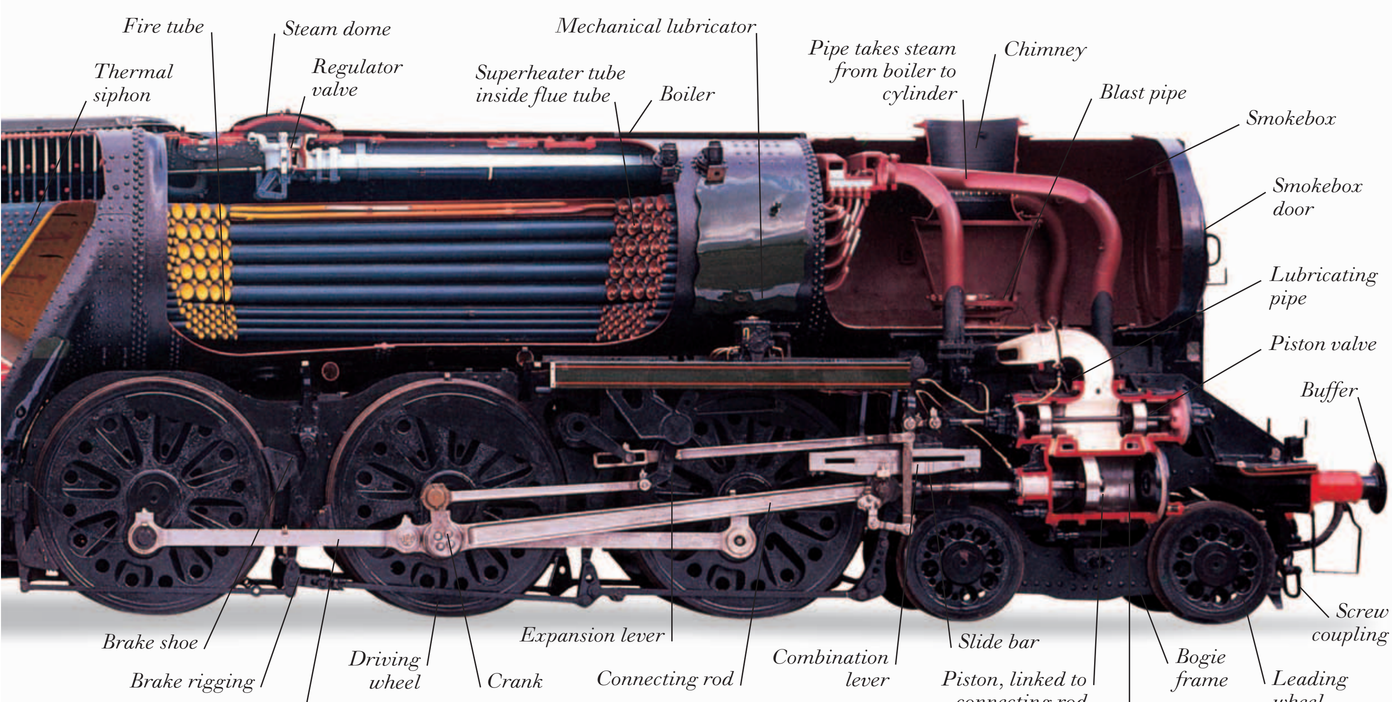


ELLERMAN LINES, 1949 (CUTAWAY VIEW)



CAB INTERIOR OF MALLARD EXPRESS STEAM LOCOMOTIVE, 1938



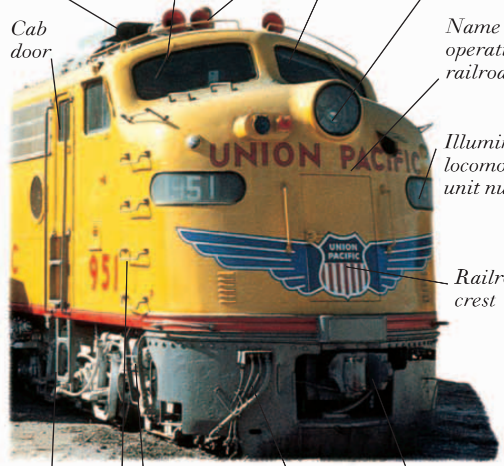


STEAM LOCOMOTIVE

Diesel trains

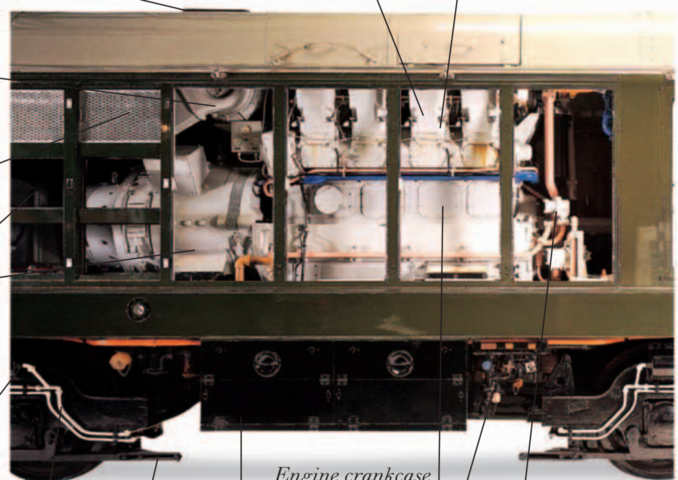
RUDOLF DIESEL FIRST DEMONSTRATED the diesel engine in Germany in 1898, but it was not until the 1940s that diesel locomotives were successfully established on both passenger and freight services in the US. Early diesel locomotives like the Union Pacific were more expensive to build than steam locomotives, but were more efficient and cheaper to operate, especially where oil was plentiful. One feature of diesel engines is that the power output cannot be coupled directly to the wheels. To convert the mechanical energy produced by diesel engines, a transmission system is needed. Almost all diesel locomotives have electric transmissions, and are known as diesel-electric locomotives. The diesel engine works by drawing air into the cylinders and compressing it to increase its temperature; a small quantity of diesel fuel is then injected into it. The resulting combustion drives the generator (more recently an alternator) to produce electricity, which is fed to electric motors connected to the wheels. Diesel-electric locomotives are essentially electric locomotives that carry their own power plants, and are used worldwide today. The Deltic diesel-electric locomotive, similar to the one shown here, replaced classic express steam locomotives, and ran at speeds up to 100 mph (160 kph).

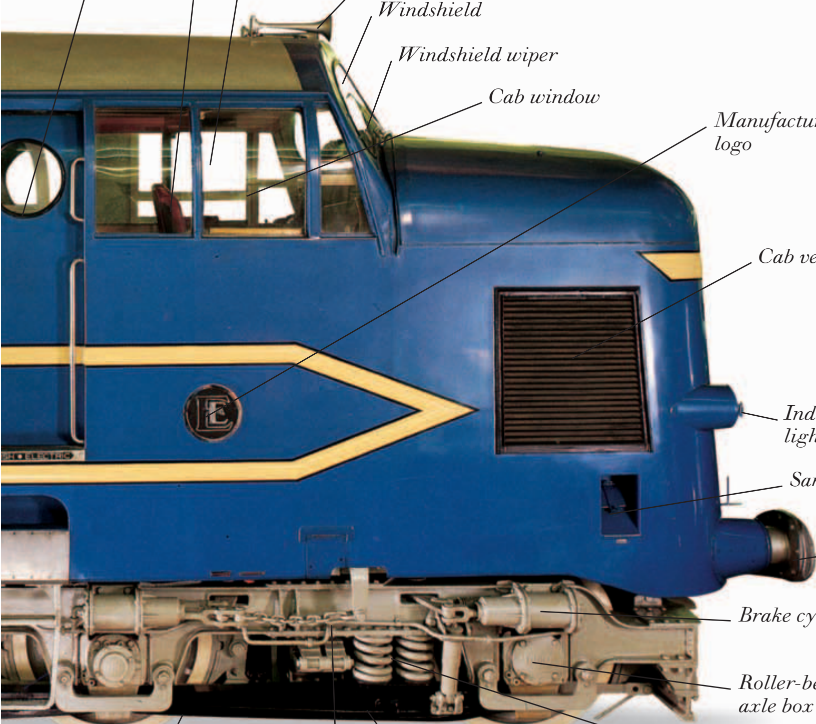
FRONT VIEW OF UNION PACIFIC DIESEL-ELECTRIC LOCOMOTIVE, 1950s



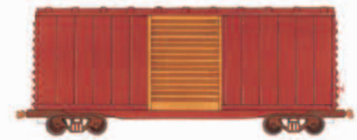
PROTOTYPE DELTIC DIESEL-ELECTRIC LOCOMOTIVE, 1956

DIESEL ENGINE OF BRITISH RAIL CLASS 20 DIESEL-ELECTRIC LOCOMOTIVE





EXAMPLES OF FREIGHT CARS



BOX CAR

HOPPER CAR

REFRIGERATOR CAR

LIVESTOCK CAR

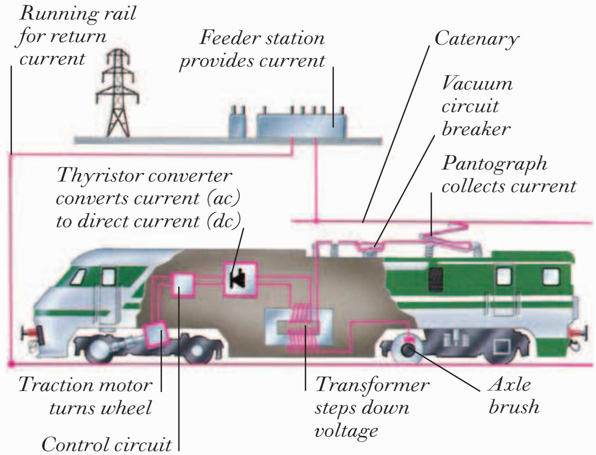
FLAT CAR WITH BULKHEADS

AUTOMOBILE CAR

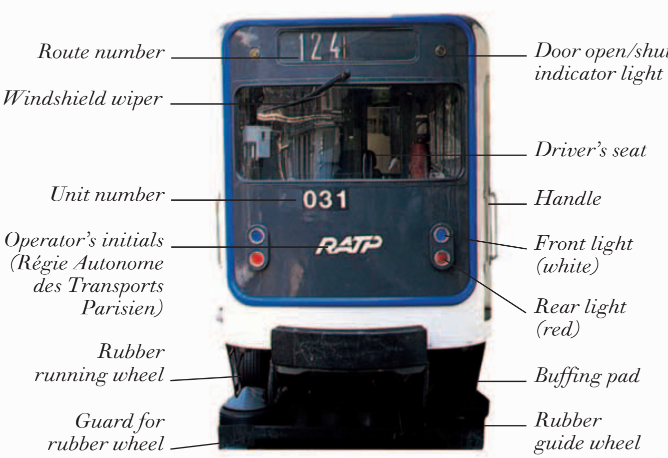
Electric and high-speed trains

THE FIRST ELECTRIC LOCOMOTIVE ran in 1879 in Berlin, Germany. In Europe, electric trains developed as a more efficient alternative to the steam locomotive and diesel-electric power. Like diesels, electric trains employ electric motors to drive the wheels but, unlike diesels, the electricity is generated externally at a power station. Electric current is picked up either from a catenary (overhead cable) via a pantograph, or from a third rail. Since it does not carry its own power-generating equipment, an electric locomotive has a better power-to-weight ratio and greater acceleration than its diesel-electric equivalent. This makes electric trains suitable for urban routes with many stops. They are also faster, quieter, and cause less pollution. The latest electric French TGV (Train à Grande Vitesse) reaches 185 mph (300 kph); other trains, like the London to Paris and Brussels Eurostar, can run at several voltages and operate between different countries. Simpler electric trains perform special duties—the "People Mover" at Gatwick Airport in London runs between terminals.

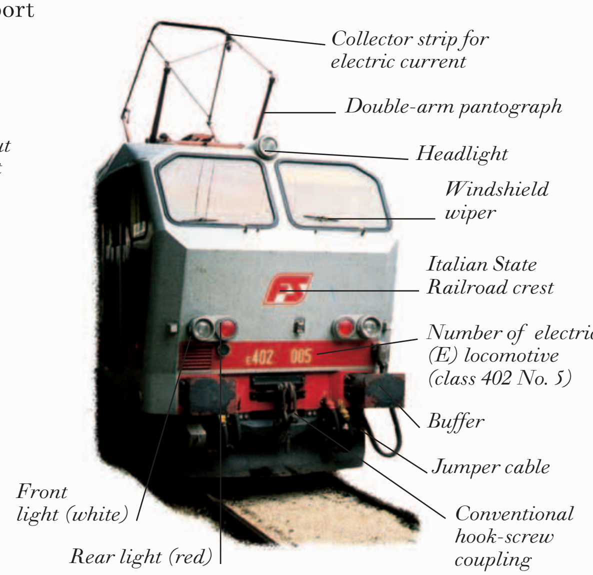
HOW ALTERNATING CURRENT (AC) ELECTRIC TRAINS WORK



FRONT VIEW OF PARIS METRO

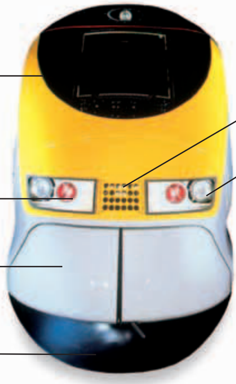


FRONT VIEW OF ITALIAN STATE RAILROADS CLASS 402 ELECTRIC LOCOMOTIVE



SIDE VIEW OF SHANGHAI MAGLEV TRAIN

EUROSTAR MULTIVOLTAGE ELECTRIC TRAIN



FRONT VIEW

SIDE VIEW

TGV ELECTRIC HIGH-SPEED TRAIN

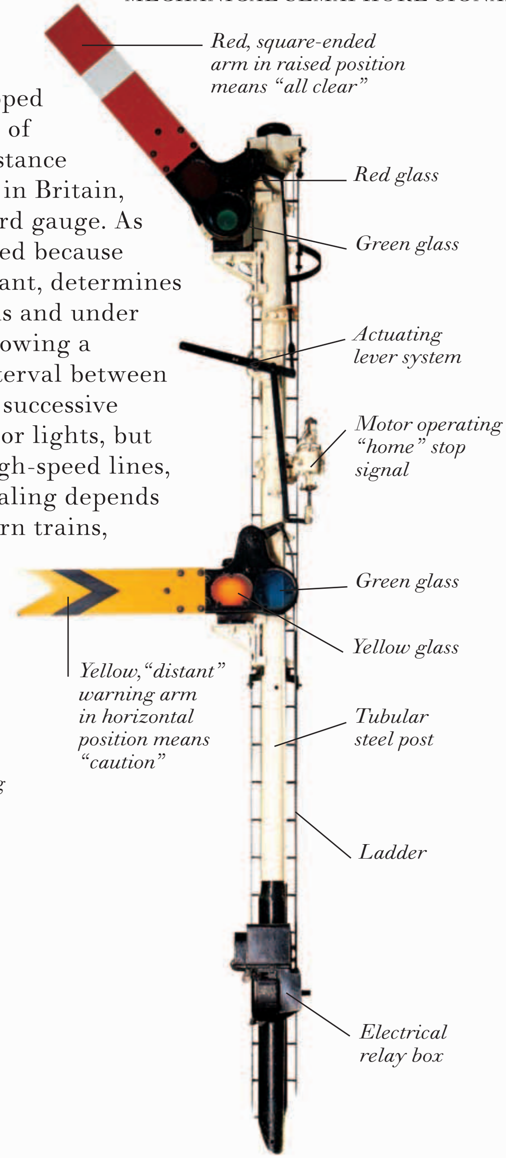
INTERIOR OF TGV

SIDE VIEW OF TGV

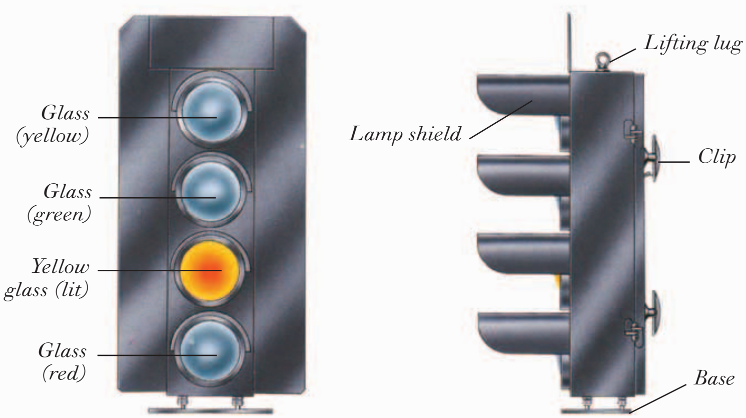
Train equipment

MODERN RAILROAD TRACK consists of two parallel steel rails clipped on to a support called a railroad tie. Railroad ties are usually made of reinforced concrete, although wood and steel are still used. The distance between the inside edges of the rails is the track gauge. It evolved in Britain, which uses a gauge of 4 ft 8½ in (1,435 mm), known as the standard gauge. As engineering grew more sophisticated, narrower gauges were adopted because they cost less to build. The loading gauge, which is equally important, determines the size of the largest loaded vehicle that may pass through tunnels and under bridges with adequate clearance. Safe train operation relies on following a signaling system. At first, signaling was based on a simple time interval between trains, but it now depends on maintaining a safe distance between successive trains traveling in the same direction. Most modern signals are color lights, but older mechanical semaphore signals are still used. On the latest high-speed lines, train drivers receive control instructions by electronic means. Signaling depends on reliable control of the train by effective braking. For fast, modern trains, which have considerable momentum, it is essential that each vehicle in the train can be braked by the driver or by a train control system, such as Automatic Train Protection (ATP). Braking is achieved by the brake shoe acting on the wheel rim (rim brakes), by disc brakes, or, increasingly, by electrical braking.

MECHANICAL SEMAPHORE SIGNAL



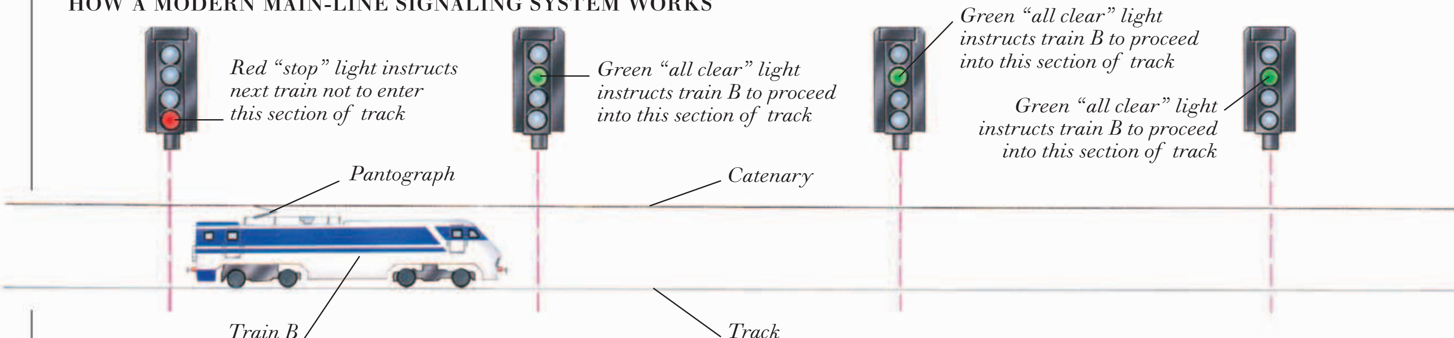
FOUR-ASPECT COLOR LIGHT SIGNAL



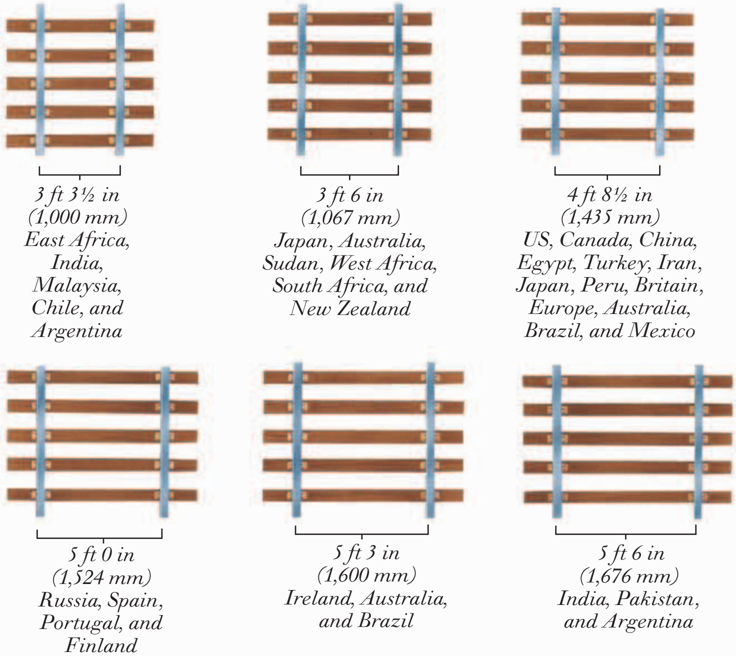
FRONT VIEW

SIDE VIEW

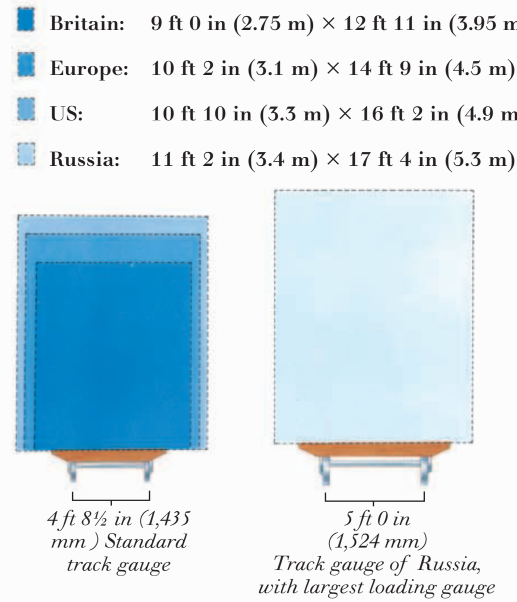
HOW A MODERN MAIN-LINE SIGNALING SYSTEM WORKS



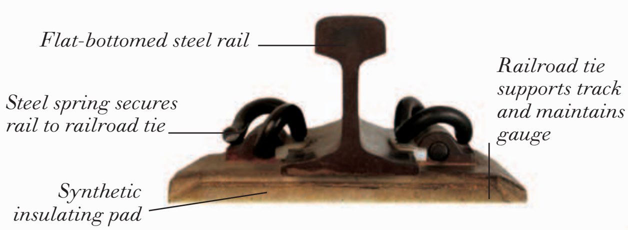
EXAMPLES OF INTERNATIONAL TRACK GAUGES



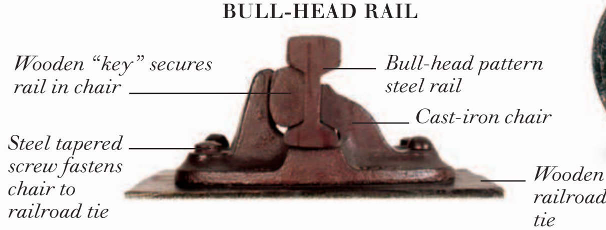
EXAMPLES OF INTERNATIONAL LOADING GAUGES



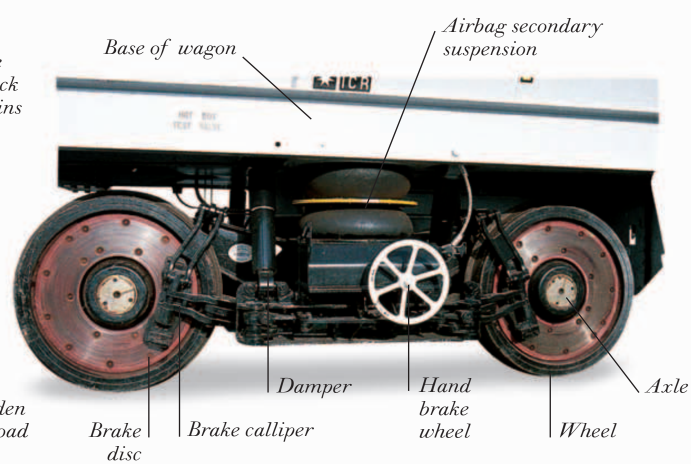
FLAT-BOTTOMED RAIL

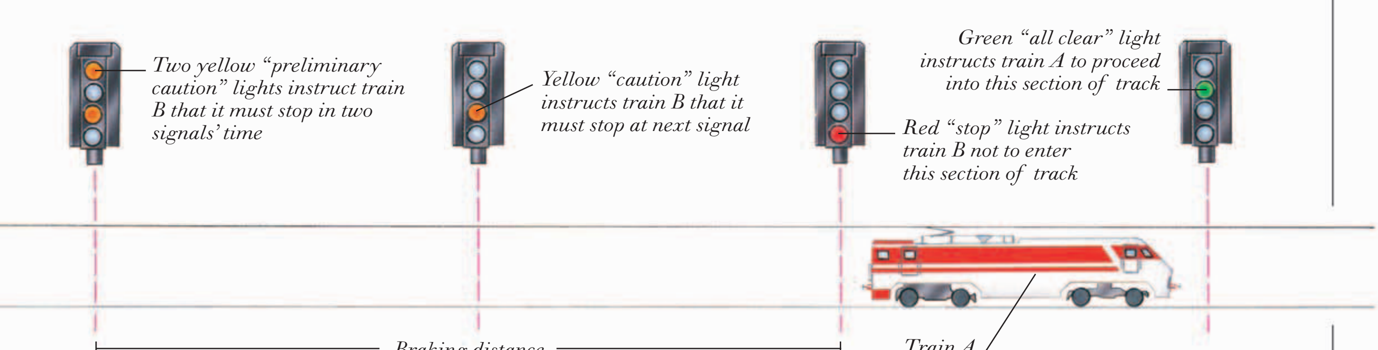


BULL-HEAD RAIL



DISC BRAKES ON MODERN WAGON BOGIE



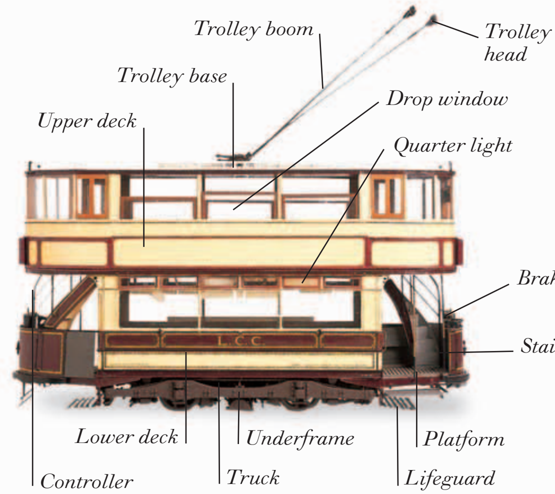


Trolleys and buses

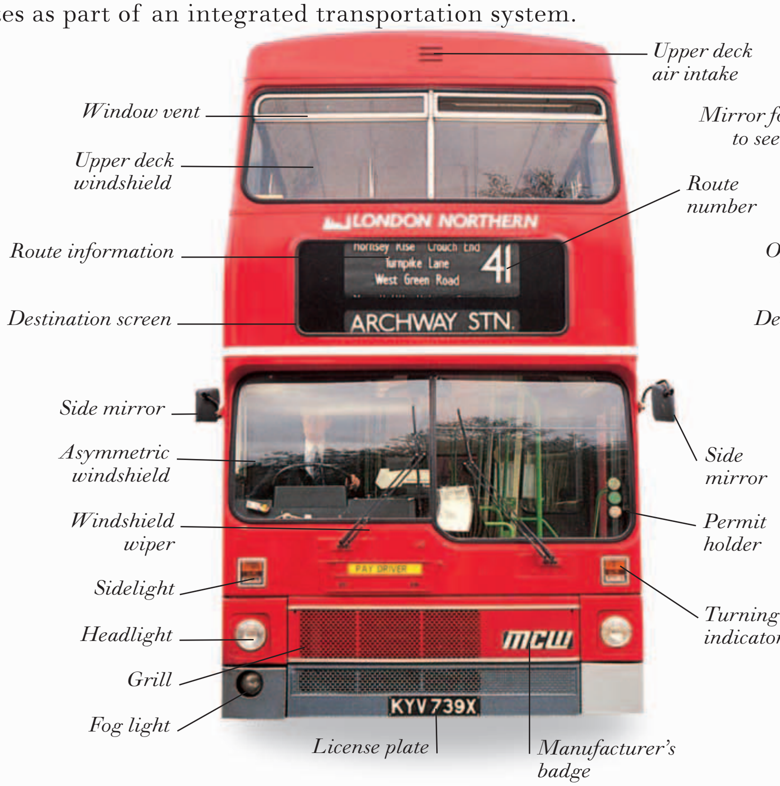
METROLINK TROLLEY, MANCHESTER, UK

AS CITY POPULATIONS exploded in the 1800s, there was an urgent need for mass transportation. Trolleys were an early solution. The first trolleys, like buses, were horse-drawn, but in 1881, electric streetcars appeared in Berlin, Germany. Electric streetcars soon became widespread throughout Europe and North America. Trolleys run on rails along a fixed route, using electric motors that receive power from overhead cables. As road networks developed, motorized buses offered a flexible alternative to trolleys. By the 1930s, they had replaced trolley systems in many cities. City buses typically have doors at both front and rear to make loading and unloading easier. Double-decker designs are popular, occupying the same amount of street space as single-decker buses but able to transport twice the number of people. Buses are also commonly used for inter-city travel and touring. Tour buses have reclining seats, large windows, luggage space, and toilets. Recently, as city traffic has become increasingly congested, many city planners have designed new electric streetcar routes to run alongside bus routes as part of an integrated transportation system.

TROLLEY, c.1900



MCW METROBUS, LONDON, UK



FRONT VIEW

SINGLE-DECKER BUS, NEW YORK CITY

SIDE VIEW

FRONT VIEW

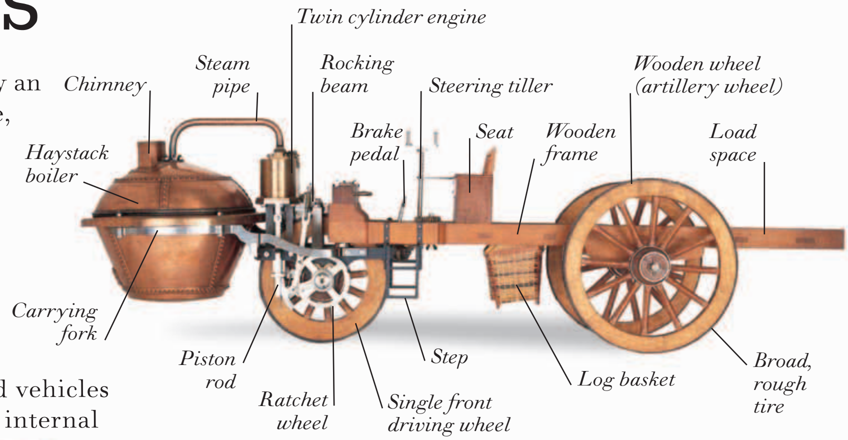
DOUBLE-DECKER TOUR BUS, PARIS, FRANCE

SIDE VIEW

The first cars

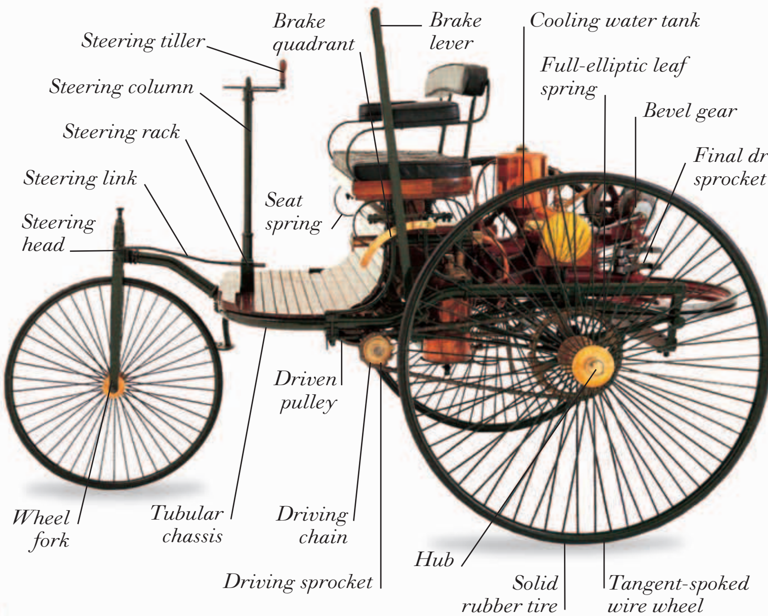
THE EARLIEST ROAD VEHICLE powered by an engine, the Cugnot steam traction engine, was built in 1770. More practical steam carriages, such as the Bordino, were available in the early 19th century, but they were heavy and cumbersome. Restrictive laws and the introduction of railroads, faster and able to carry more passengers, saw the decline of "cars" powered by steam. It was not until 1860 that the first practical power unit for road vehicles was developed, with the invention of the internal combustion engine by the Belgian Etienne Lenoir. By around 1890, Karl Benz and Gottlieb Daimler in Germany, and Albert de Dion and Armand Peugeot in France were building cars for sale to the public. These early cars, despite being primitive, expensive, and produced in limited numbers, heralded the age of the automobile.

STEAM-POWERED CUGNOT FARDIER, 1770

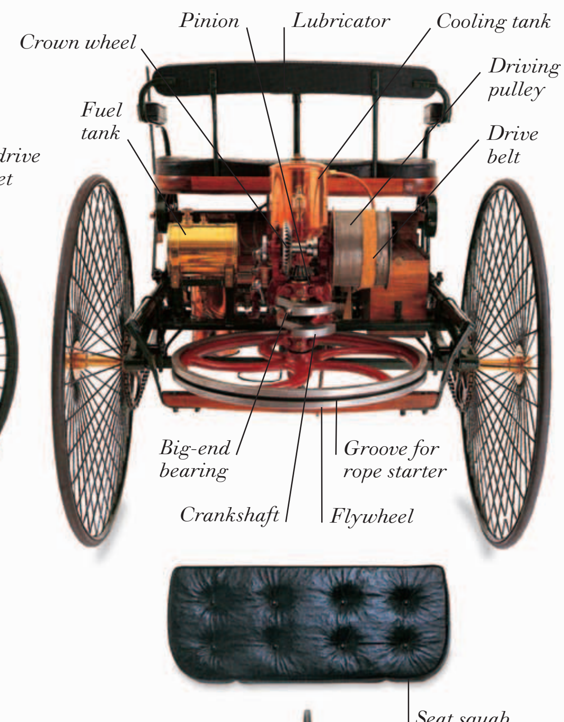


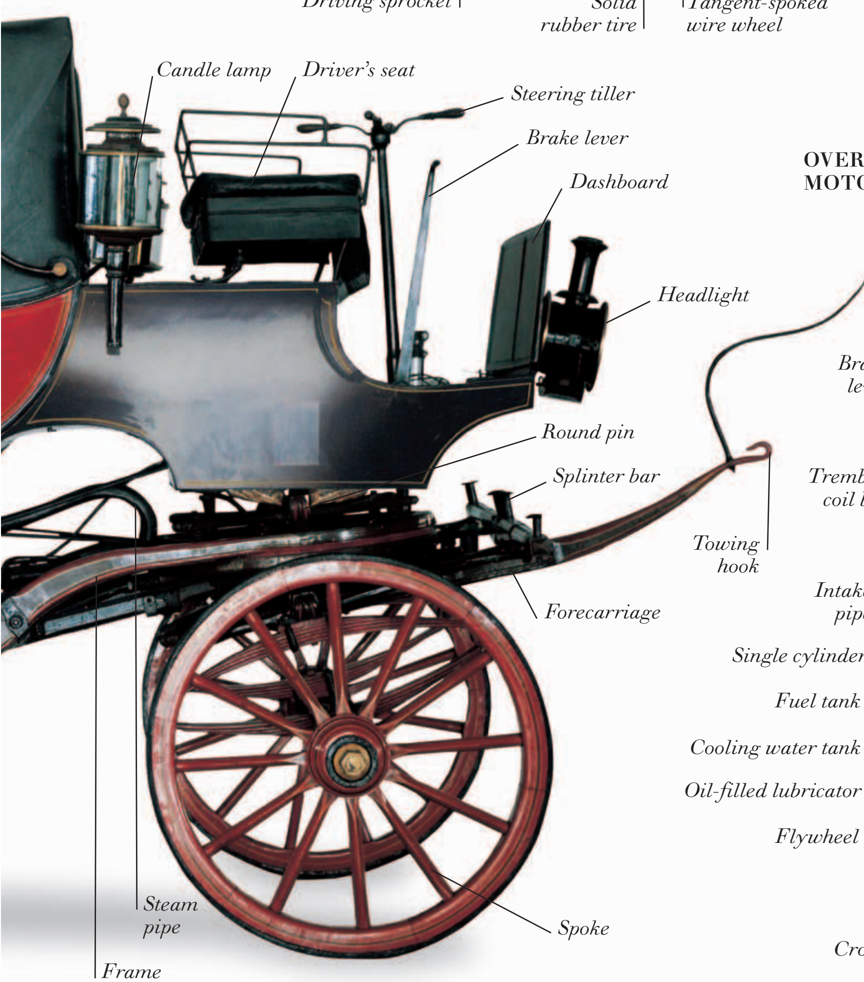
BORDINO STEAM CARRIAGE, 1854

SIDE VIEW OF GAS-DRIVEN BENZ MOTORWAGEN, 1886

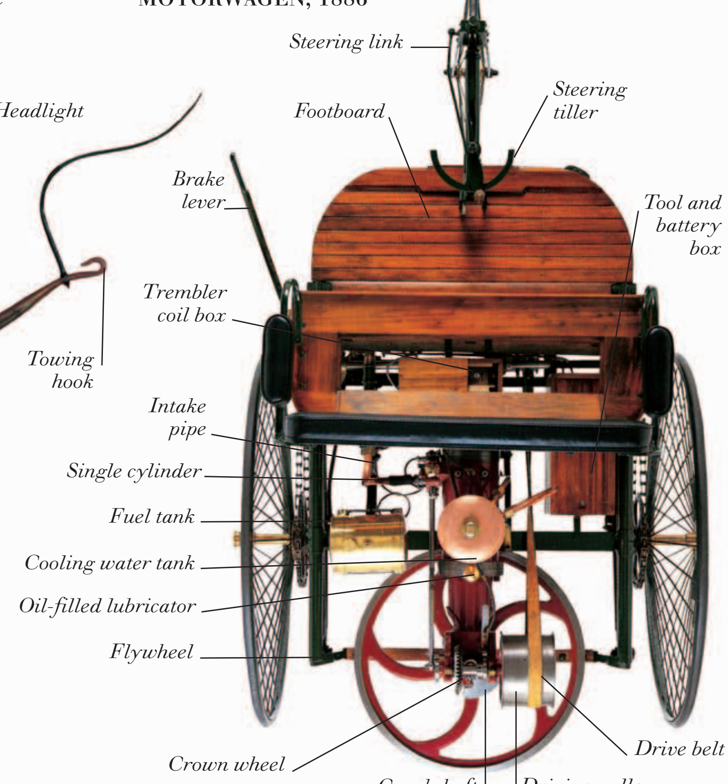


REAR VIEW OF BENZ MOTORWAGEN, 1886





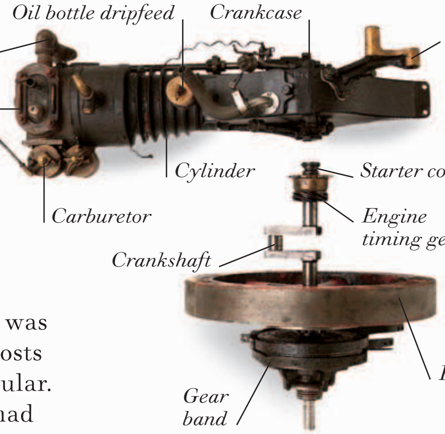
OVERHEAD VIEW OF BENZ MOTORWAGEN, 1886



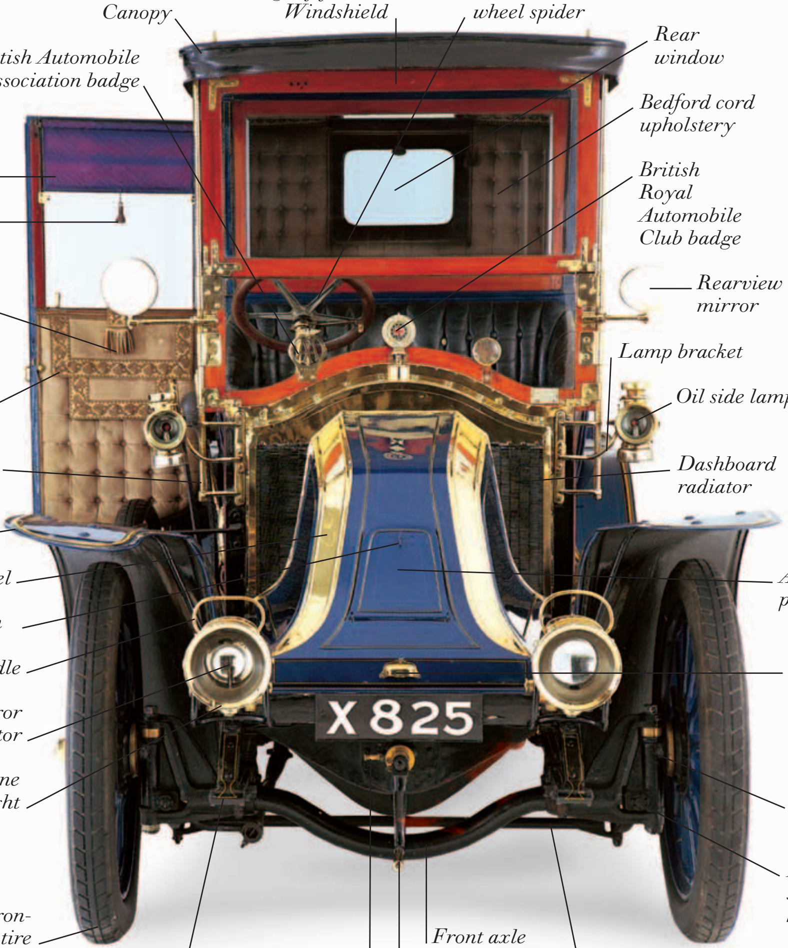
Elegance and utility

DURING THE FIRST DECADE OF THE 20TH CENTURY, the motorist who could afford it had a choice of some of the finest cars ever made. These handbuilt cars were powerful and luxurious, using the finest woods, leathers, and cloths, and bodywork made to the customer's individual requirements; some had six-cylinder engines as big as 15 liters. The price of such cars was several times that of an average house, and their yearly running costs were also very high. As a result, basic, utilitarian cars became popular. Costing perhaps one-tenth of the price of a luxury car, these cars had very little trim and often had only single-cylinder engines.

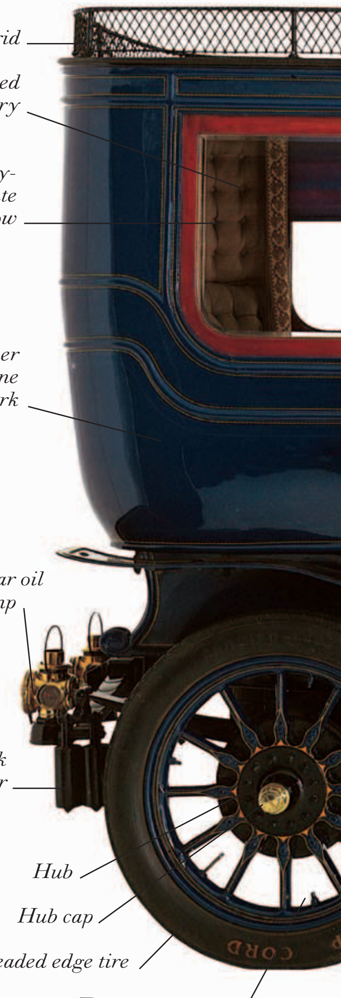
1904 OLDSMOBILE SINGLE-CYLINDER ENGINE



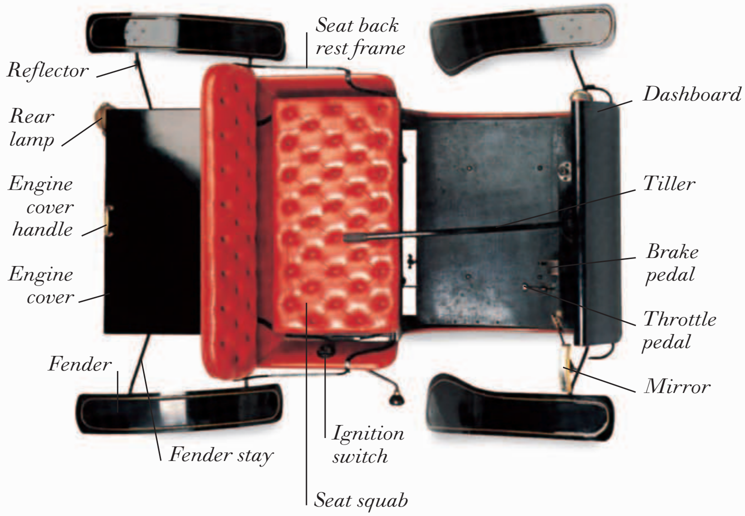
FRONT VIEW OF 1906 RENAULT



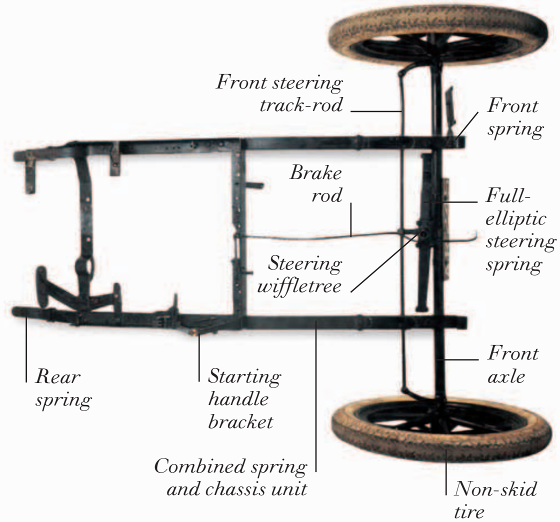
SIDE VIEW OF 1906 RENAULT

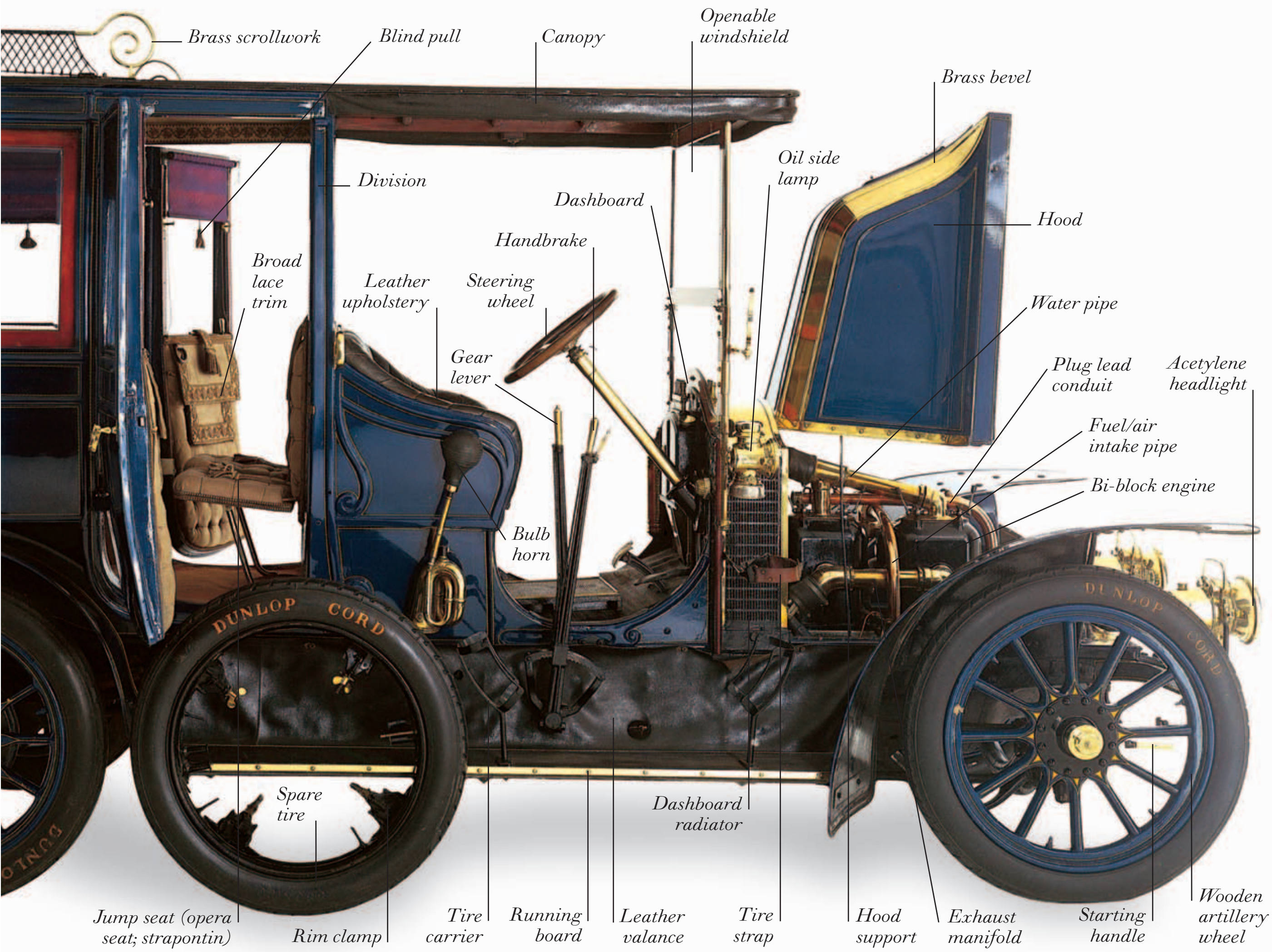


1904 OLDSMOBILE TRIM AND BODYWORK



1904 OLDSMOBILE CHASSIS

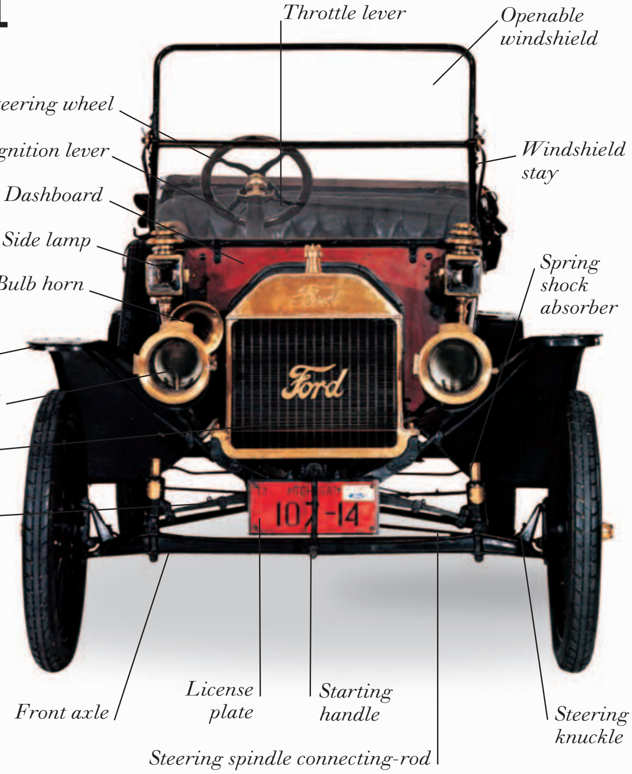




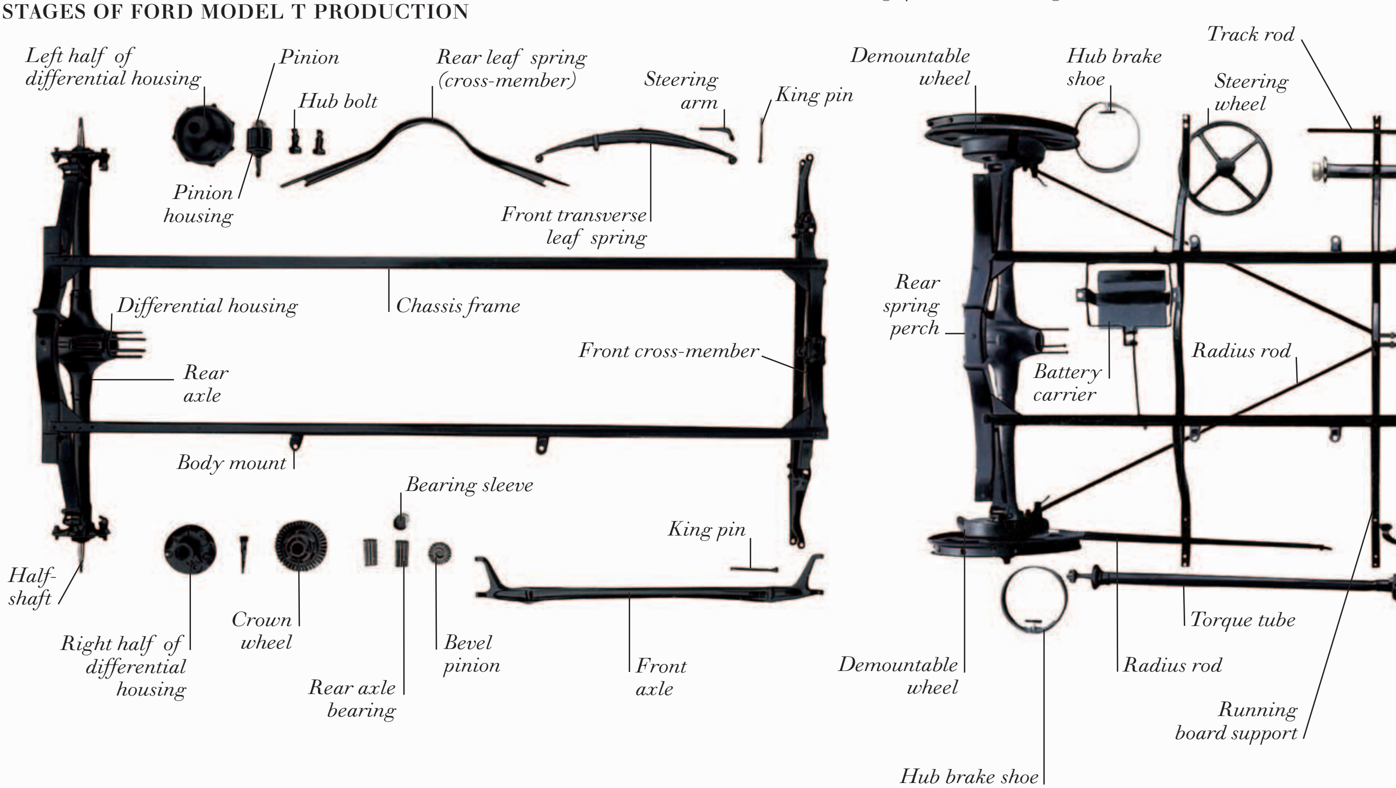
Mass-production

THE FIRST CARS WERE HAND-ASSEMBLED from individually built parts, a time-consuming procedure that required skilled mechanics and made cars very expensive. This problem was solved, in America, by a Detroit car manufacturer named Henry Ford; he introduced mass-production by using standardized parts, and later combined these with a moving production line. The work was brought to the workers, each of whom performed one simple task in the construction process as the chassis moved along the line. The first mass-produced car, the Ford Model T, was launched in 1908 and was available in a limited range of body styles and colors. However, when the production line was introduced in 1914, the color range was cut back; the Model T became available, as Henry Ford said, in "any color you like, so long as it's black." Ford cut the production time for a car from several days to about 12 hours, and eventually to minutes, making cars much cheaper than before. As a result, by 1920 half the cars in the world were Model T Fords.

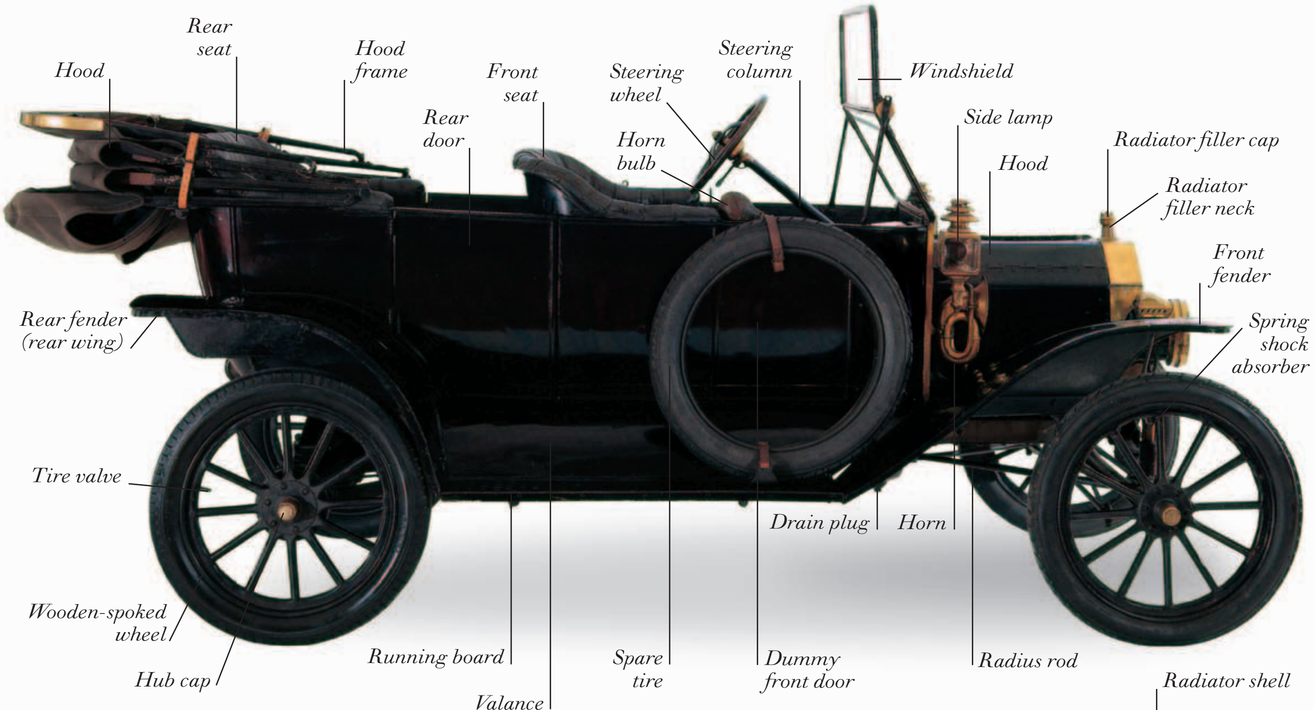
FRONT VIEW OF 1913 FORD MODEL T

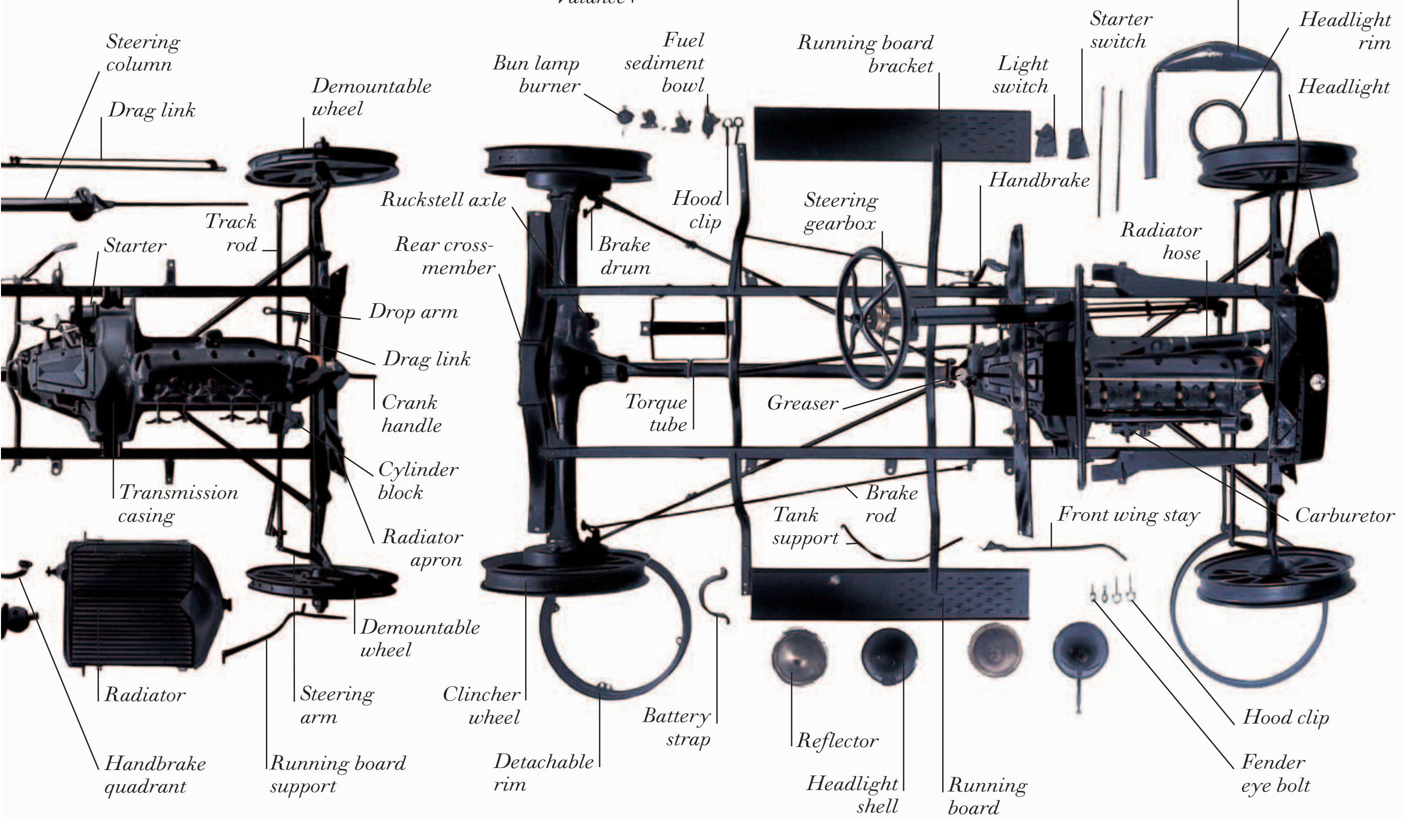


STAGES OF FORD MODEL T PRODUCTION



SIDE VIEW OF 1913 FORD MODEL T



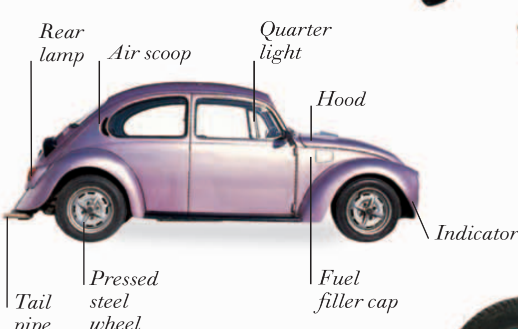


The "people's car"

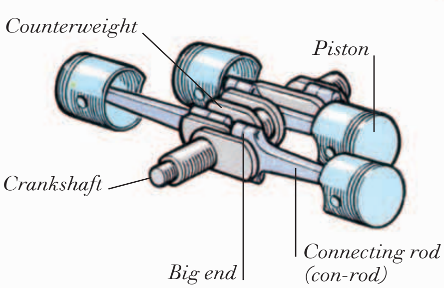
THE MOST POPULAR CAR in the history of car manufacture is the Volkswagen Beetle, originally called the KdF Wagen. The car was developed in Germany in the 1930s by Dr. Ferdinand Porsche. At that time, Germany had only half the number of cars of Britain or France, and Adolf Hitler took a personal interest in the development of the Volkswagen ("people's car"). The intention was to provide a new industry, new jobs, and a car so cheap that anyone with a job could afford it. Dr. Porsche designed a car that was cheap to build and run; its rear-mounted, air-cooled engine cut down the number of parts needed and also reduced weight. However, few civilians managed to obtain the Beetle before the outbreak of World War II in 1939. After the war, the Beetle proved so popular that eventually more than 20 million were sold.

WORKING PARTS OF VOLKSWAGEN BEETLE

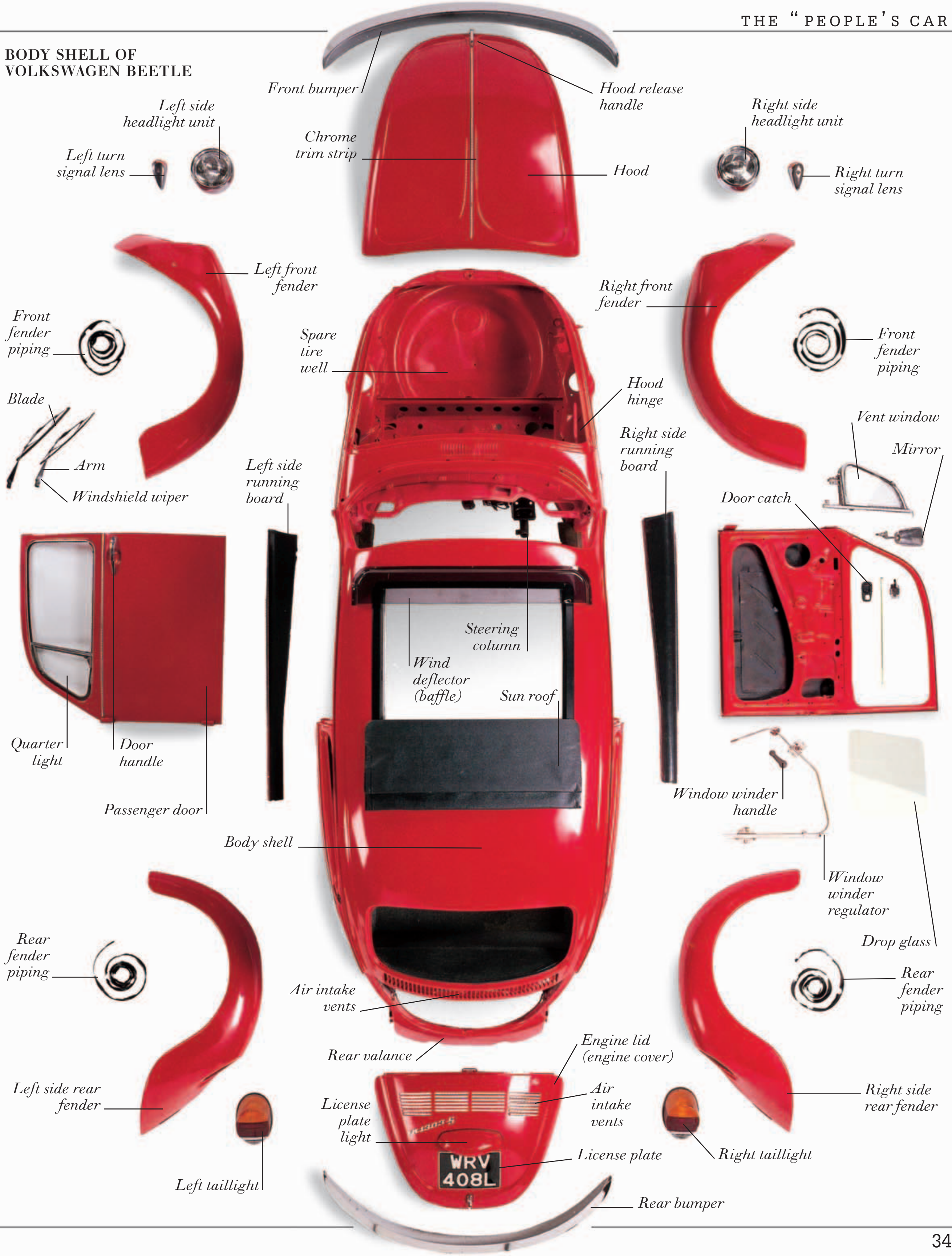
CUSTOMIZED VOLKSWAGEN BEETLE



FLAT-FOUR CYLINDER ARRANGEMENT



BODY SHELL OF VOLKSWAGEN BEETLE

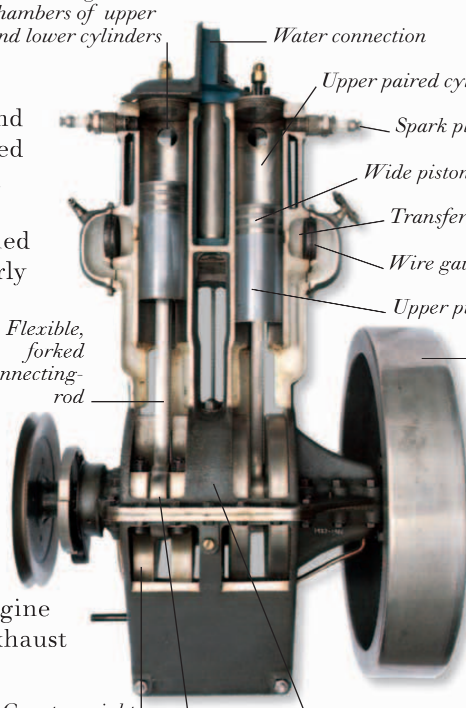


Early engines

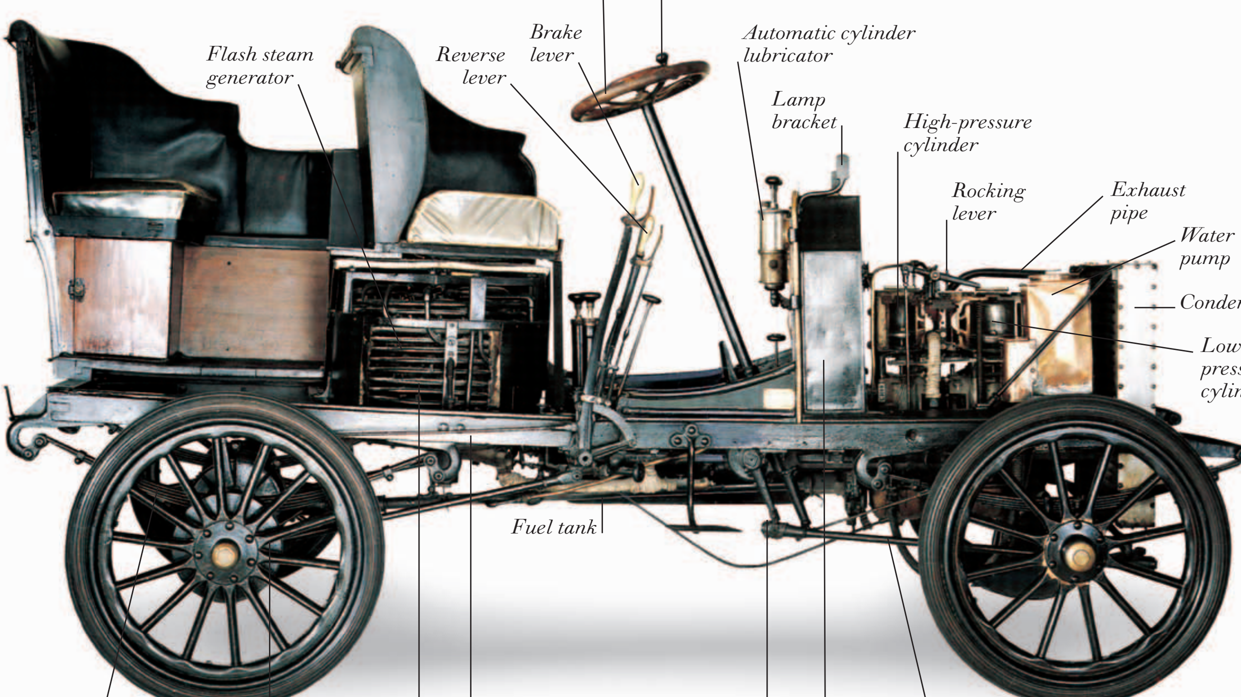
STEAM AND ELECTRICITY were used to power cars until early this century, but neither power source was ideal. Electric cars had to stop frequently to recharge their heavy batteries, and steam cars gave smooth power delivery but were too complicated for the average driver to use. A rival power source, the internal combustion engine, was invented in 1860 by Etienne Lenoir (see pp. 334-335). This engine converted the force of a controlled explosion into rotary motion, to turn the wheels of a vehicle. Early variations on this basic model included sleeve valves, separately cast cylinders, and the two-stroke combustion cycle. Today, many internal combustion engines, including the Wankel rotary and diesels (see pp. 346-347), use the four-stroke cycle, first demonstrated by Nikolaus Otto in 1876. The Otto cycle, often described as "suck, squeeze, bang, blow," has proved the best method of ensuring that the engine turns over smoothly and that exhaust emissions are controllable.

BERSEY ELECTRIC CAB, 1896

TROJAN TWO-STROKE ENGINE, 1927

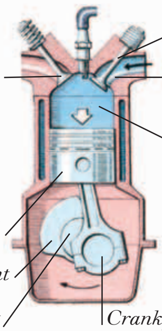


SECTIONED WHITE STEAM CAR, 1903

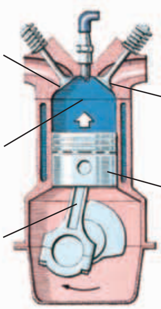


CYCLE OF A FOUR-STROKE INTERNAL COMBUSTION ENGINE

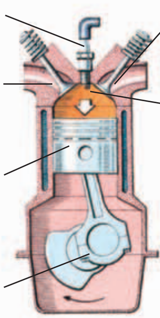
INDUCTION STROKE ("SUCK")



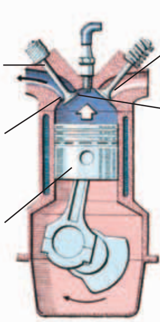
COMPRESSION STROKE ("SQUEEZE")



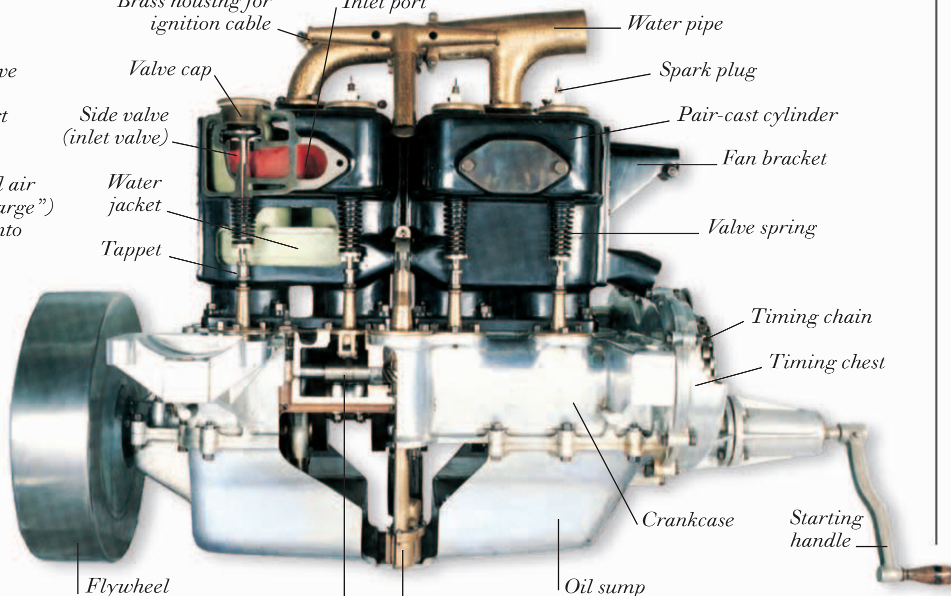
POWER STROKE ("BANG")



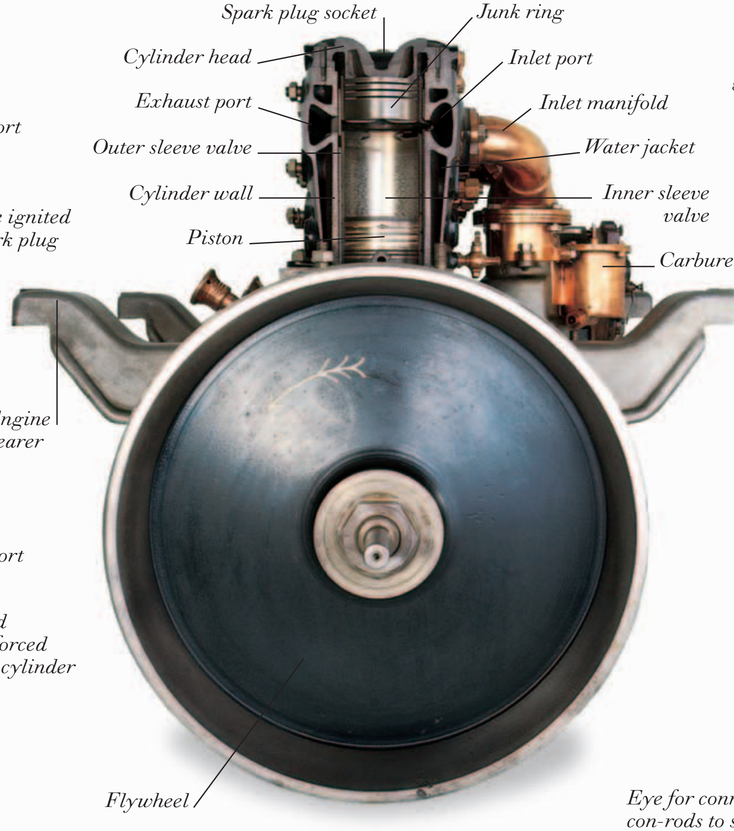
EXHAUST STROKE ("BLOW")



16-HORSEPOWER HUMBER ENGINE, 1911



DAIMLER DOUBLE-SLEEVE VALVE ENGINE, 1910



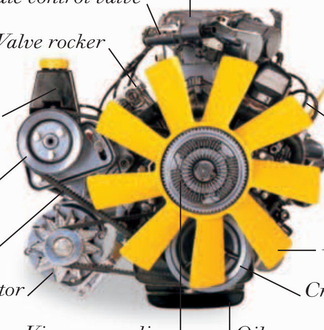
OUTER SLEEVE VALVE

INNER SLEEVE VALVE

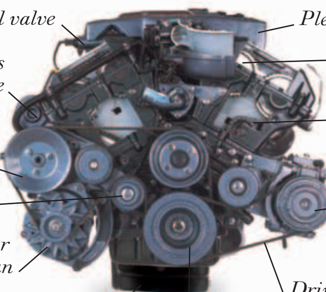
Modern engines

TODAY'S GASOLINE ENGINE WORKS on the same basic principles as the first car engines of a century ago, although it has been greatly refined. Modern engines, often made from special metal alloys, are much lighter than earlier engines. Computerized ignition systems, fuel injectors, and multivalve cylinder heads achieve a more efficient combustion of the fuel/air mixture (the charge) so that less fuel is wasted. As a result of this greater efficiency, the power and performance of a modern engine are increased, and the level of pollution in the exhaust gases is reduced. Exhaust pollution levels today are also lowered by the increasing use of special filters called catalytic converters, which absorb many exhaust pollutants. The need to produce ever more efficient engines means that it can take up to seven years to develop a new engine for a family car, at a cost of many millions of dollars.

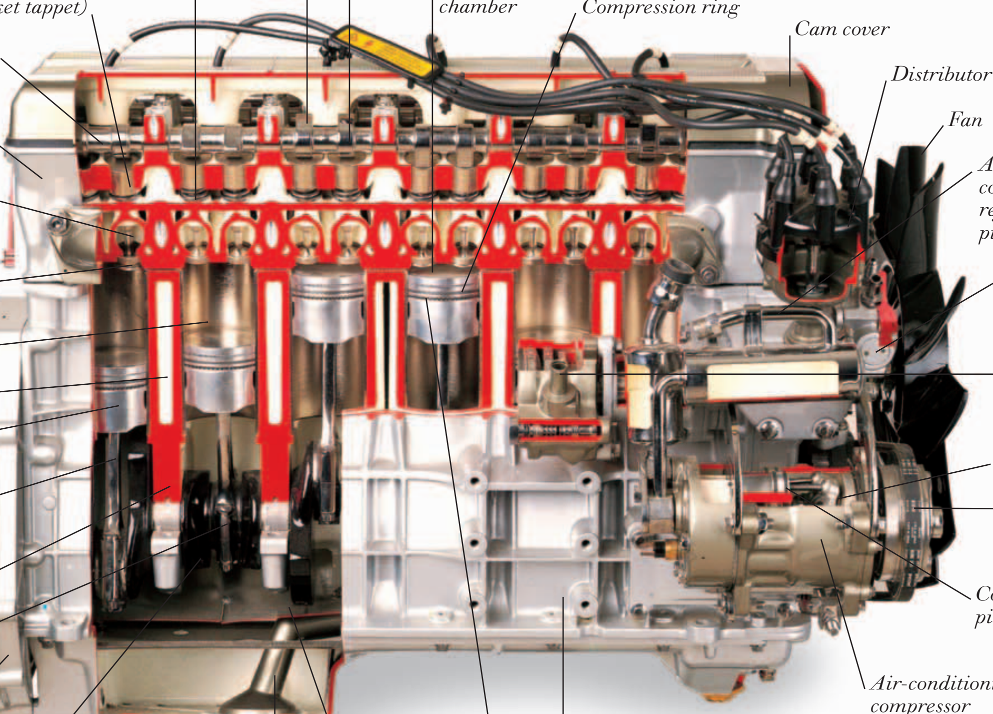
FRONT VIEW OF A FORD COSWORTH V6 12-VALVE



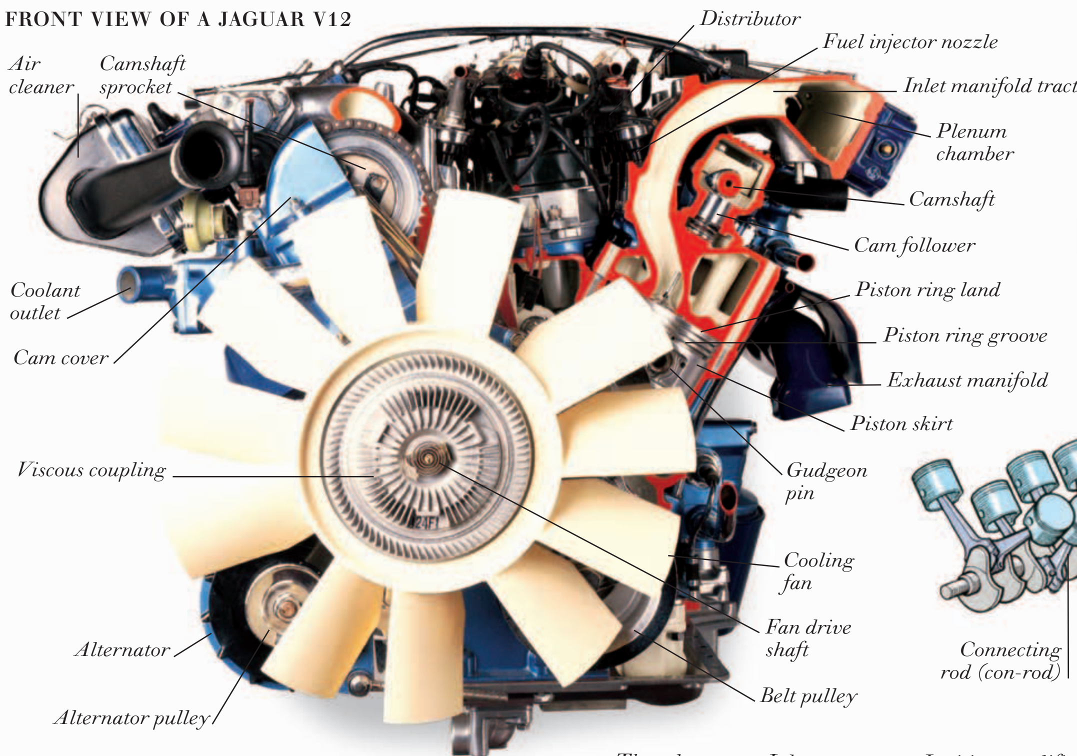
FRONT VIEW OF A FORD COSWORTH V6 24-VALVE

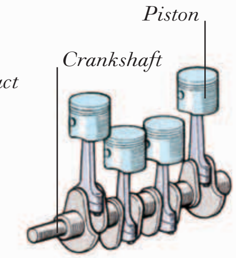


SECTIONED VIEW OF A JAGUAR STRAIGHT 6

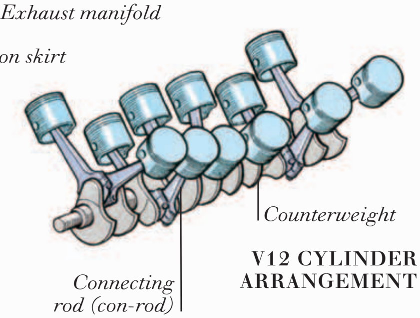


FRONT VIEW OF A JAGUAR V12



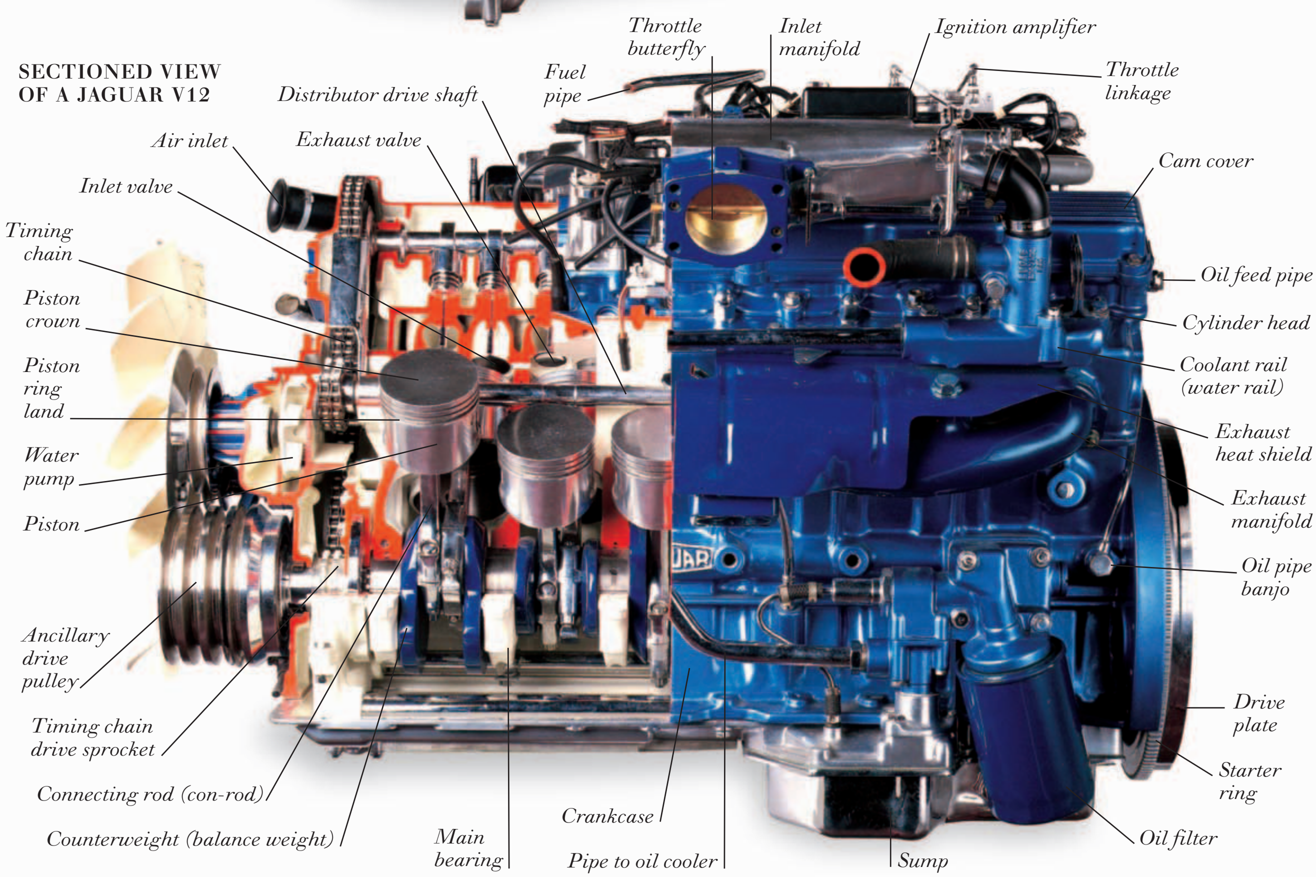


STRAIGHT 4 CYLINDER ARRANGEMENT



V12 CYLINDER ARRANGEMENT

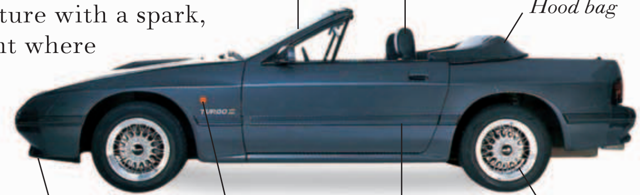
SECTIONED VIEW OF A JAGUAR V12



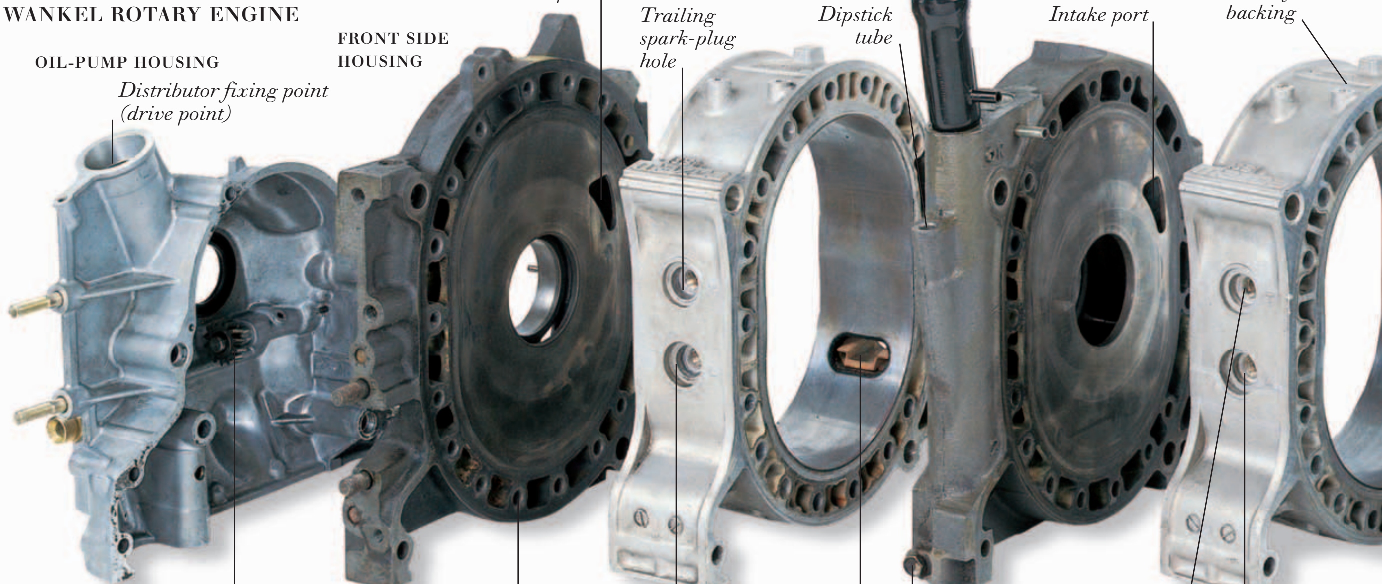
Alternative engines

THE MOST COMMON TYPE OF ALTERNATIVE ENGINE is the diesel engine, which, instead of igniting the compressed fuel/air mixture with a spark, uses compression alone, heating the mixture to the point where it explodes. A diesel engine's fuel consumption is low in comparison with similarly sized piston engines, despite its heavier, reinforced moving parts and cylinder block. Another type of engine is the rotary-combustion, first successfully developed by Felix Wankel in the 1950s. Its two trilobate (three-sided) rotors revolve in housings shaped in a fat figure-eight. The four sequences of the four-stroke cycle, which occur consecutively in a piston engine, occur simultaneously in a rotary engine, producing power in a continuous stream.

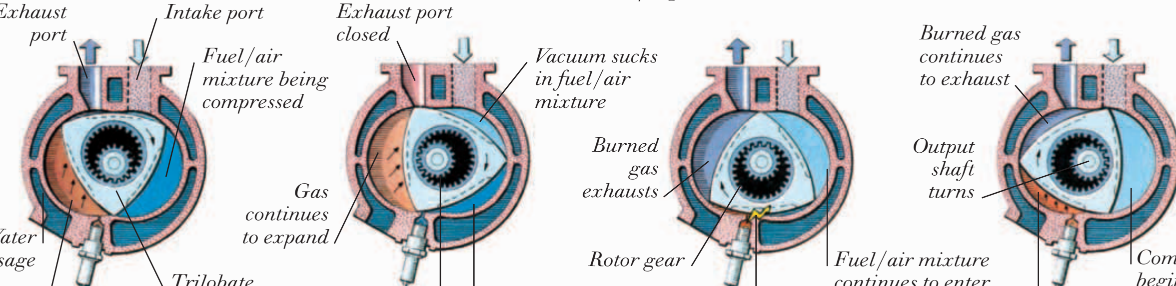
ROTARY-ENGINED MAZDA RX-7



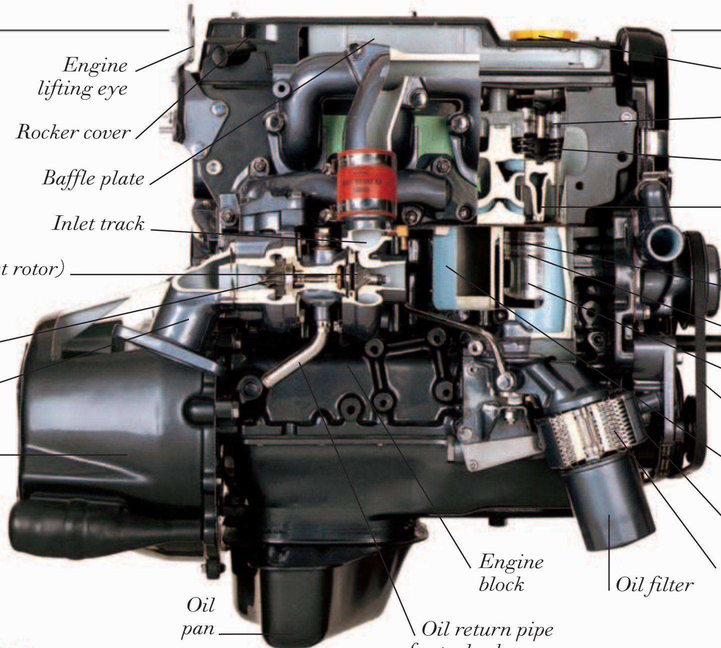
WANKEL ROTARY ENGINE



THE WANKEL ROTARY CYCLE

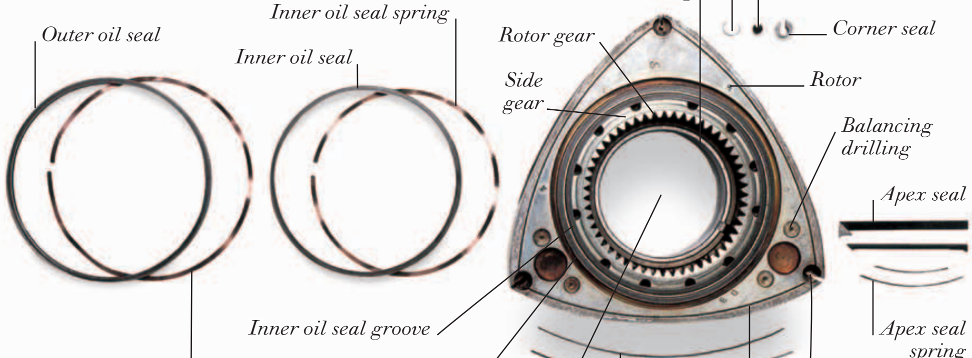


FORD TURBOCHARGED DIESEL ENGINE

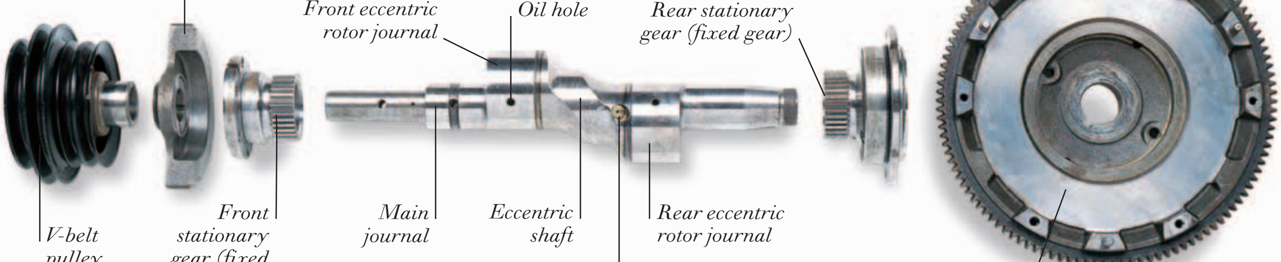


REAR SIDE HOUSING

ROTOR AND SEALS



OUTPUT SHAFT

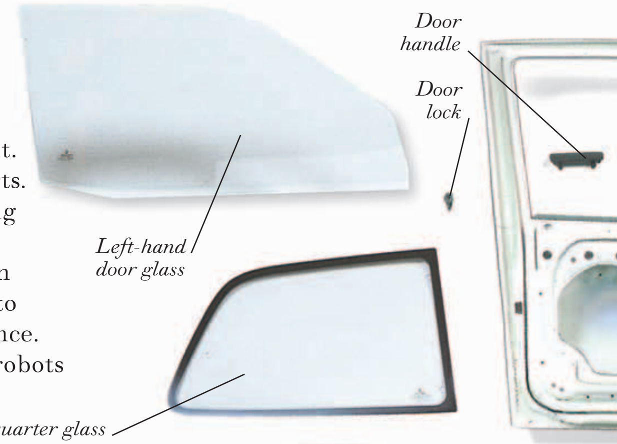


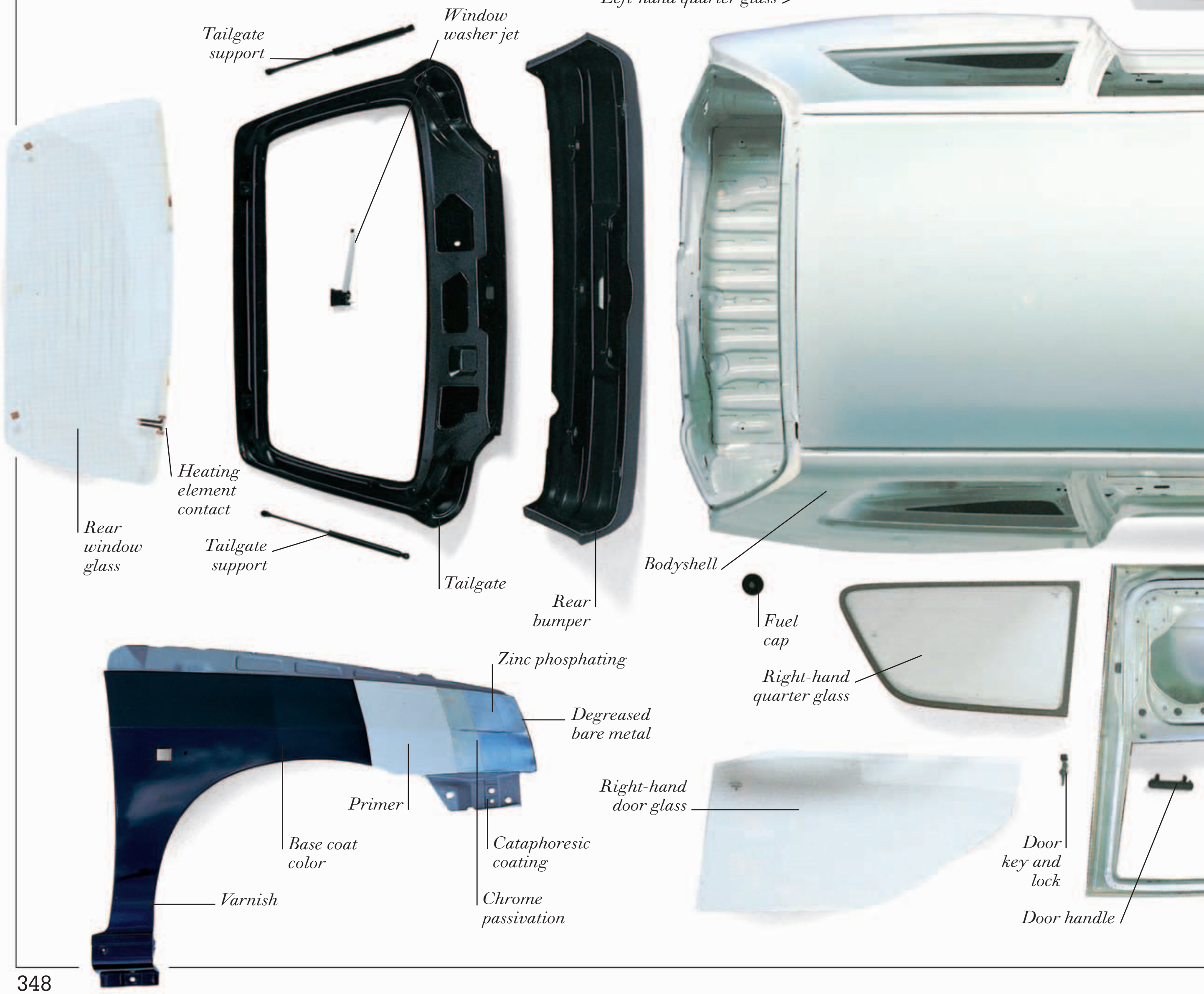
Bodywork

RENAULT LOGO

The body of a modern mass-produced car is built on the monocoque (single-shell) principle, in which the roof, side panels, and floor are welded into a single integral unit. This bodyshell protects and supports the car's internal parts. Steel and glass are used to construct the bodyshell, creating a unit that is both light and strong. Its lightness helps to conserve energy, while its strength protects the occupants. Modern bodywork is designed with the aid of computers, which are used to predict factors such as aerodynamic efficiency and impact-resistance. High-technology is also employed on the production line, where robots are used to assemble, weld, and paint the body.

BODYWORK OF A RENAULT CLIO



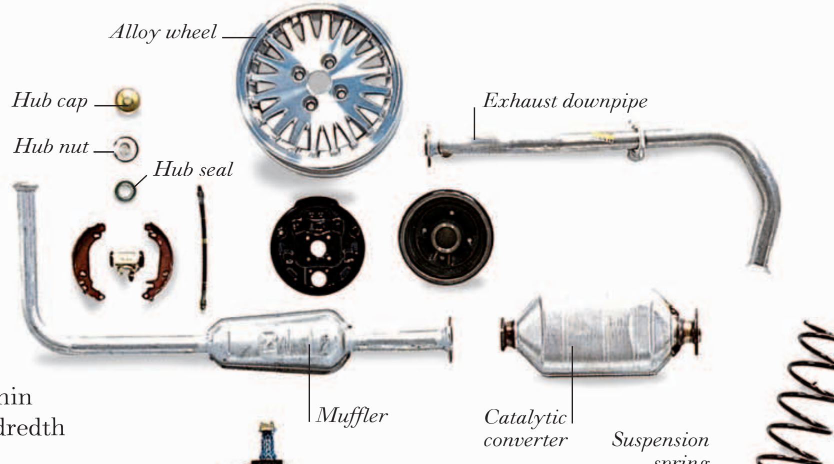


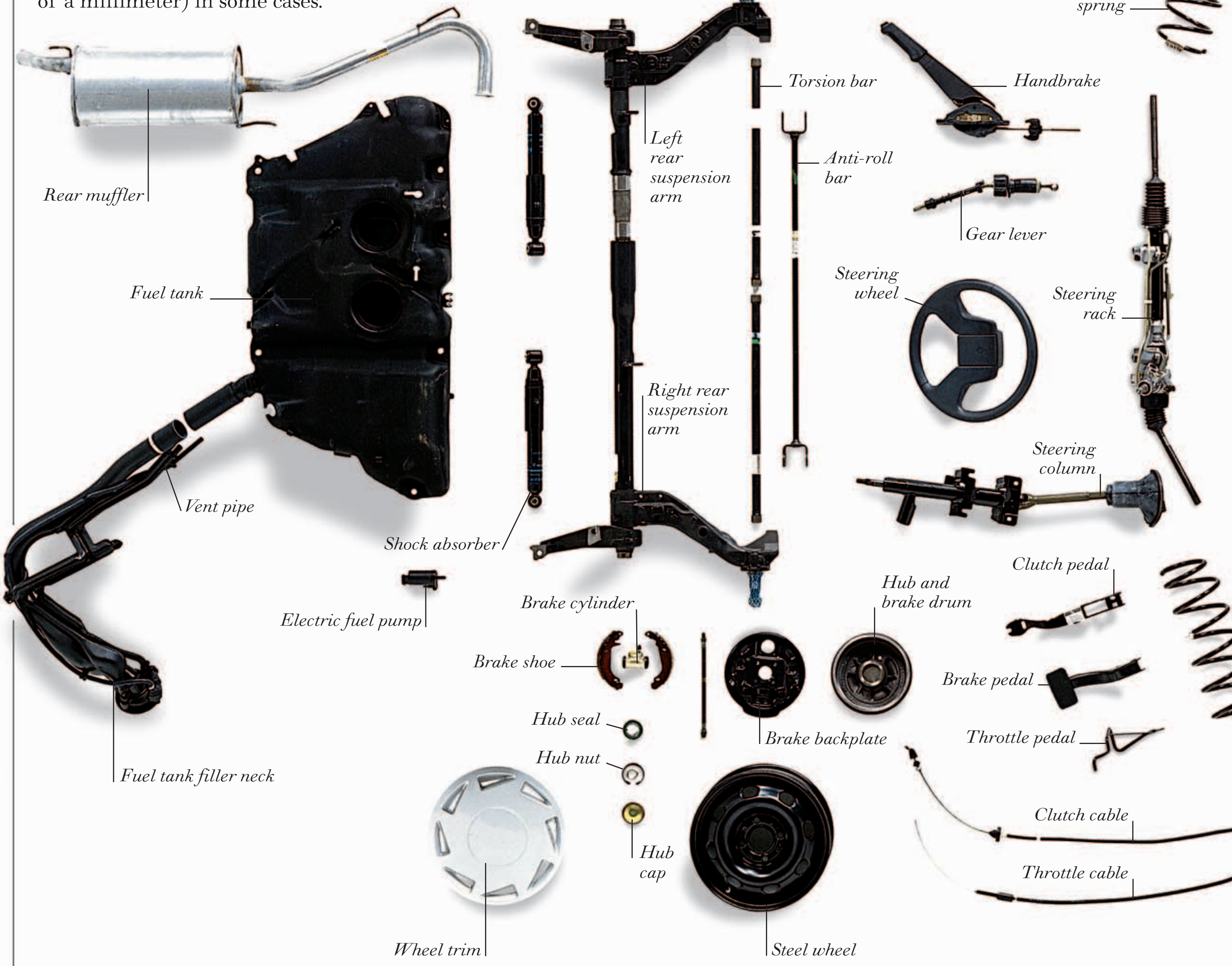
SIDE VIEW OF A RENAULT CLIO

FRONT VIEW OF A RENAULT CLIO

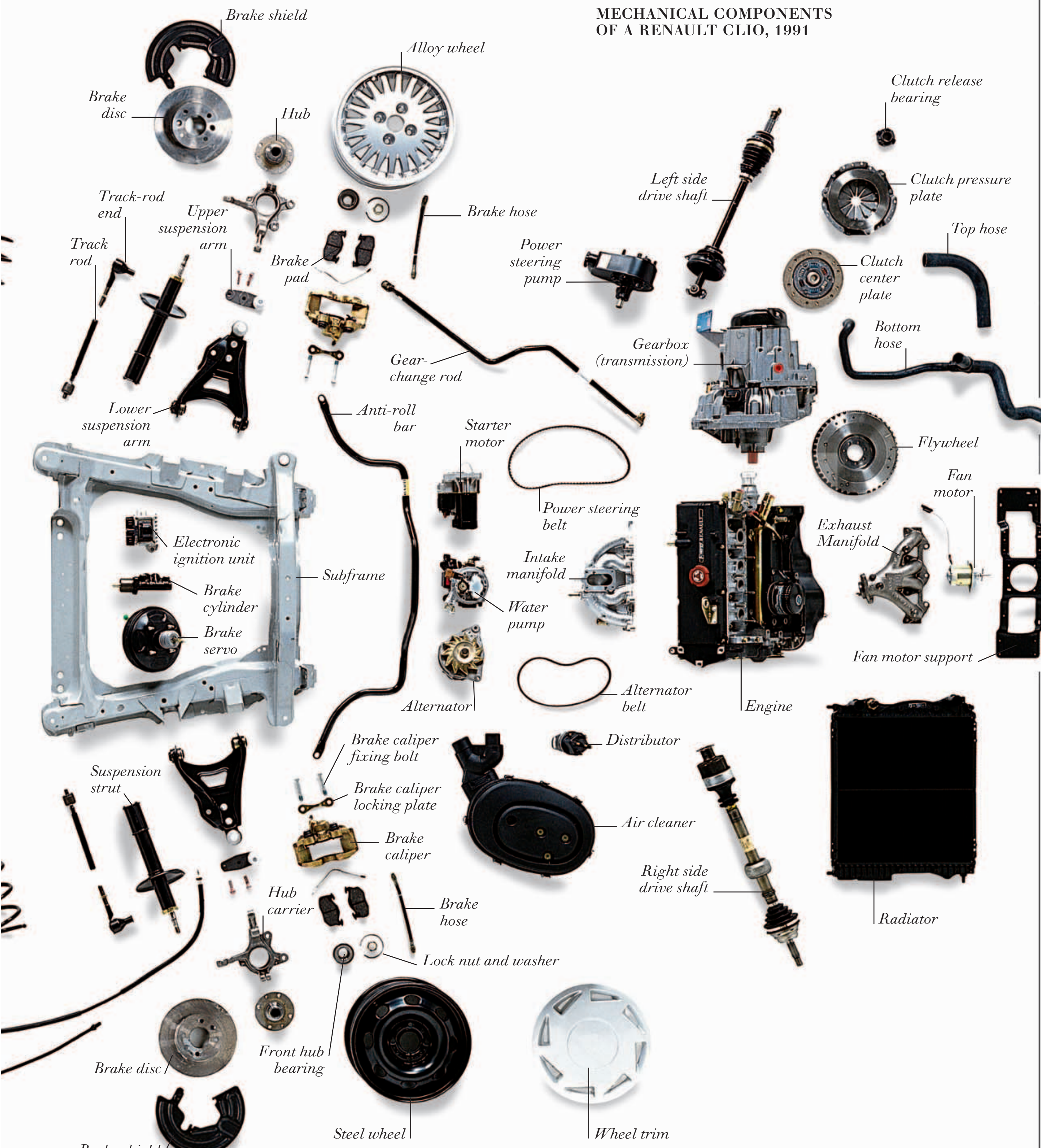
Mechanical components

A TYPICAL MODERN CAR has several thousand individual mechanical components. These are assembled to form the car's various mechanical systems: engine and exhaust, transmission, steering, suspension, and brakes. To ensure that each system functions properly, components are manufactured to extremely fine tolerances—to within about one ten-thousandth of an inch (one five-hundredth of a millimeter) in some cases.



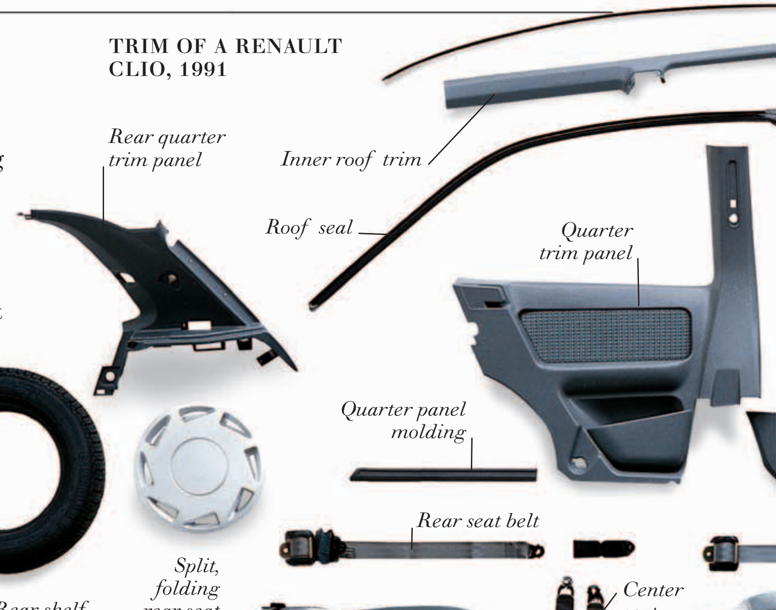


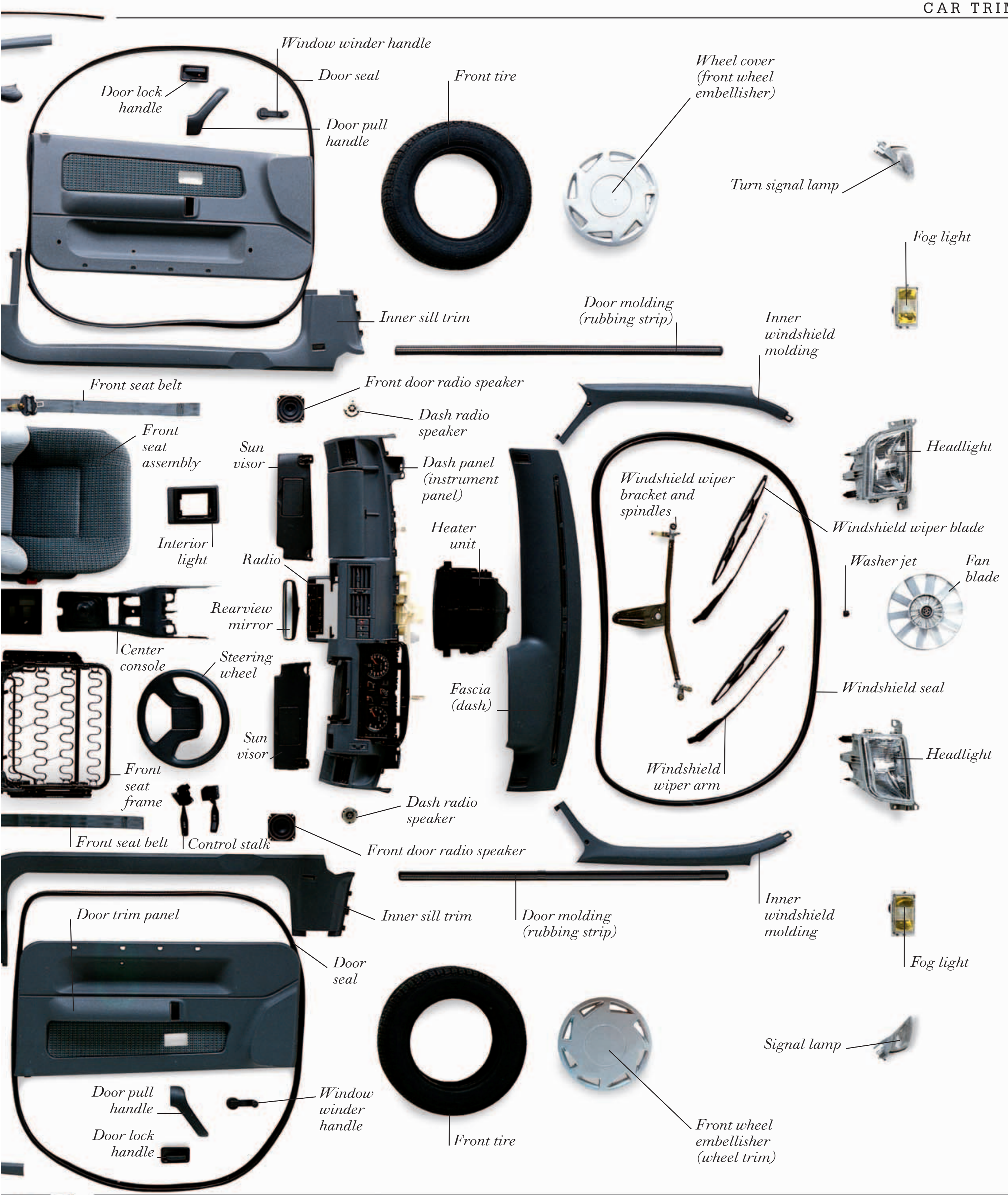
MECHANICAL COMPONENTS OF A RENAULT CLIO, 1991



Car trim

A MODERN CAR HAS TWO TYPES OF TRIM, according to the materials used: hard (chrome and plastics) and soft (upholstery materials). Safety and comfort are priorities in the trim's design: seats help the occupants to maintain a comfortable posture, rubber seals keep out dirt and moisture, and headlights light the way. Older cars had interior or leather paneling cut and fitted by craftsmen; modern cars use precisely molded plastics and seat fabrics cut by robot-controlled lasers to reduce costs and production time. Doors are now trimmed off the production line so that complex wiring can be built in.



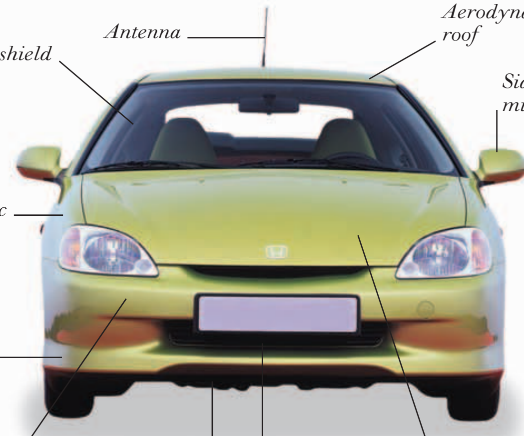


Window winder handle
Door seal
Door lock handle
Door pull handle
Front tire
Wheel cover (front wheel embellisher)
Turn signal lamp
Fog light
Inner sill trim
Door molding (rubbing strip)
Inner windshield molding
Front seat belt
Front door radio speaker
Dash radio speaker
Front seat assembly
Sun visor
Dash panel (instrument panel)
Headlight
Windshield wiper bracket and spindles
Windshield wiper blade
Heater unit
Interior light
Radio
Washer jet
Fan blade
Rearview mirror
Center console
Steering wheel
Fascia (dash)
Windshield seal
Sun visor
Headlight
Front seat frame
Windshield wiper arm
Dash radio speaker
Front seat belt
Control stalk
Front door radio speaker
Door trim panel
Inner sill trim
Door molding (rubbing strip)
Inner windshield molding
Door seal
Fog light
Signal lamp
Door pull handle
Window winder handle
Door lock handle
Front tire
Front wheel embellisher (wheel trim)

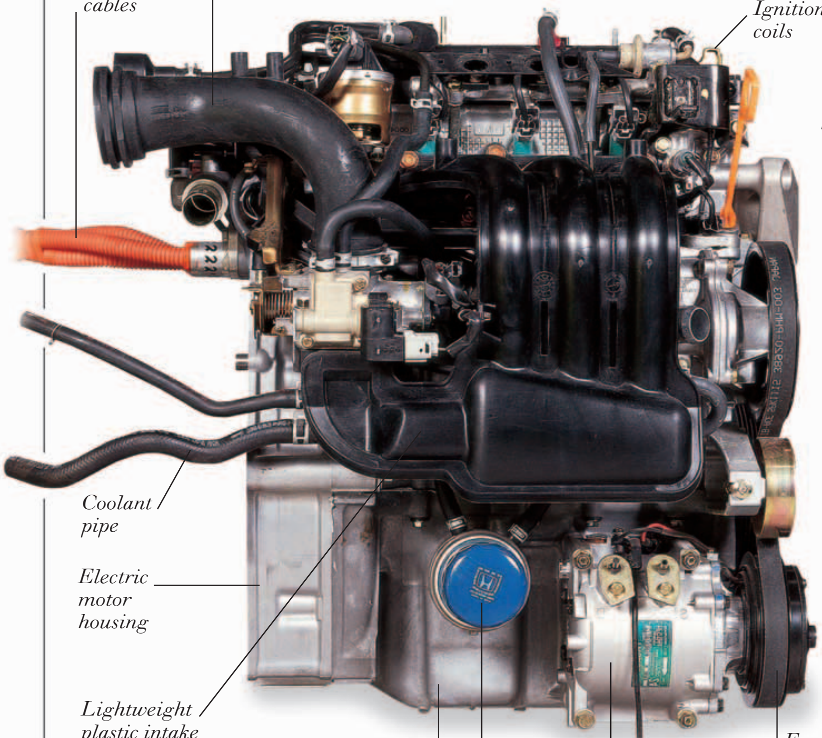
Hybrid car

THERE HAVE BEEN SEVERAL proposed alternatives to conventional gas- or diesel-powered cars, including cars that use solar or battery power. The object is to lower harmful emissions and conserve natural resources. One of the alternatives already in production is the hybrid car. A hybrid vehicle uses two or more fuels. Examples include diesel-electric trains and mopeds. The latter combine the power of a gasoline engine with pedal power. In a hybrid car, gas consumption is reduced by the provision of additional power by an electric motor during acceleration. The motor is driven by power from on-board batteries that are recharged by an engine-driven generator when the car is decelerating or cruising. Some hybrid cars transfer energy from the wheels to a flywheel during braking. The flywheel drives the generator, which recharges the batteries.

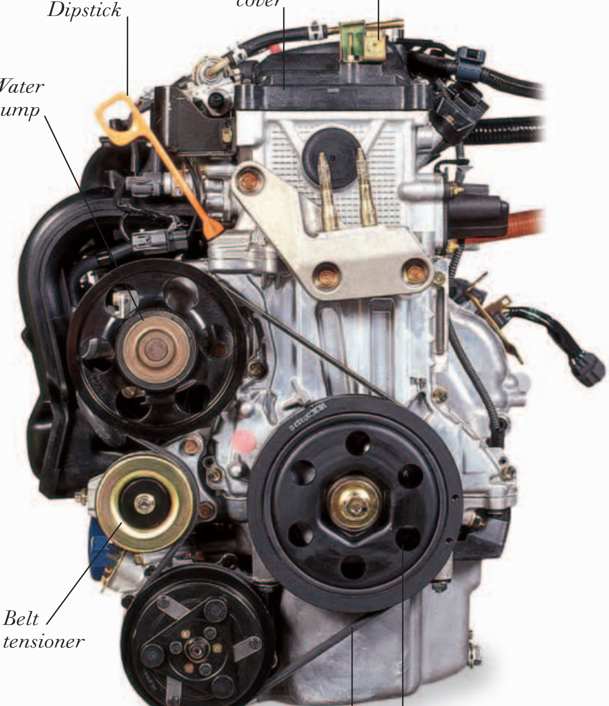
HONDA INSIGHT



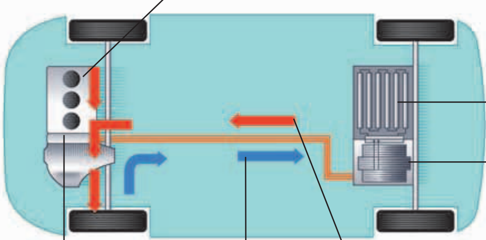
SIDE VIEW OF 1-LITER VTEC ENGINE



FRONT VIEW OF 1-LITER VTEC ENGINE

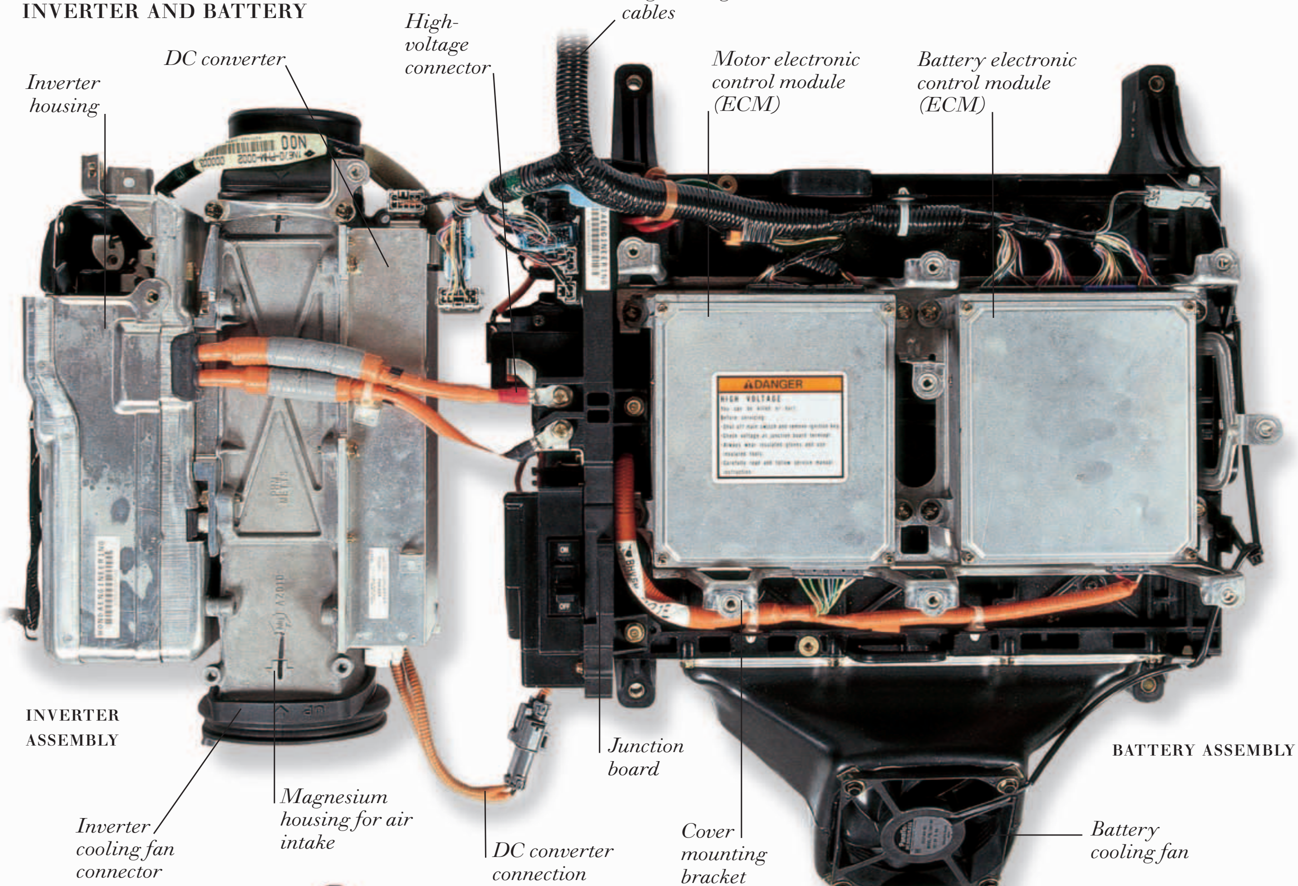


HOW HYBRID POWER WORKS



REAR VIEW

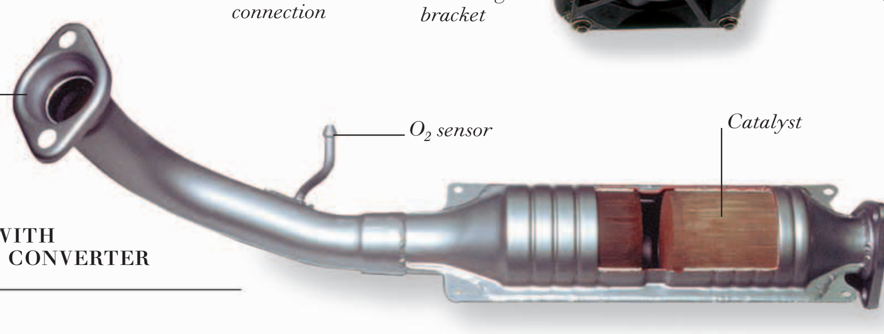
INVERTER AND BATTERY



INVERTER ASSEMBLY

BATTERY ASSEMBLY

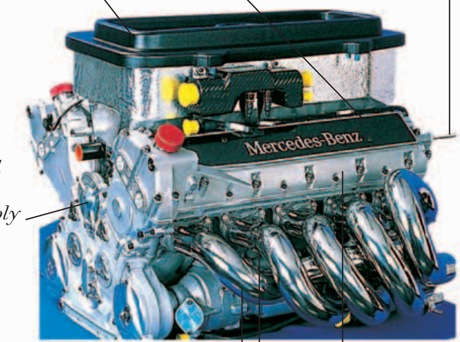
EXHAUST WITH CATALYTIC CONVERTER



Race cars

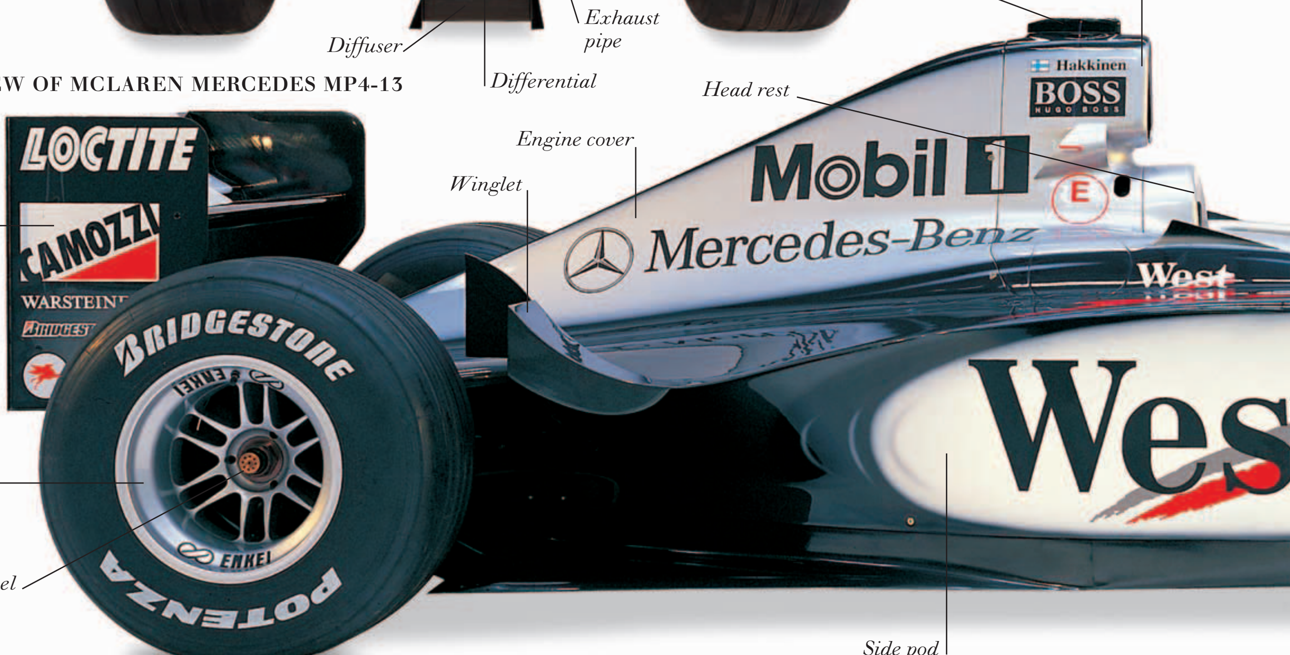
SINCE THE ADVENT OF DRIVING, race cars have been a major focus of innovation in car design. Features that are now commonplace, such as disc brakes, turbochargers, and even safety belts, were used first on competition cars. Research into race cars has contributed to a new understanding of engine performance, aerodynamics, and tire adhesion, and has led to the development of ultralight materials such as carbon fiber for car bodies. A modern McLaren Formula One car has a low, streamlined body and an open cockpit but, unlike its forerunner, it also has front and rear wings that push the wheels firmly on to the track, huge tires for extra grip, and electronic sensors that continually relay information to the pits about the car's performance.

72° V10 ENGINE

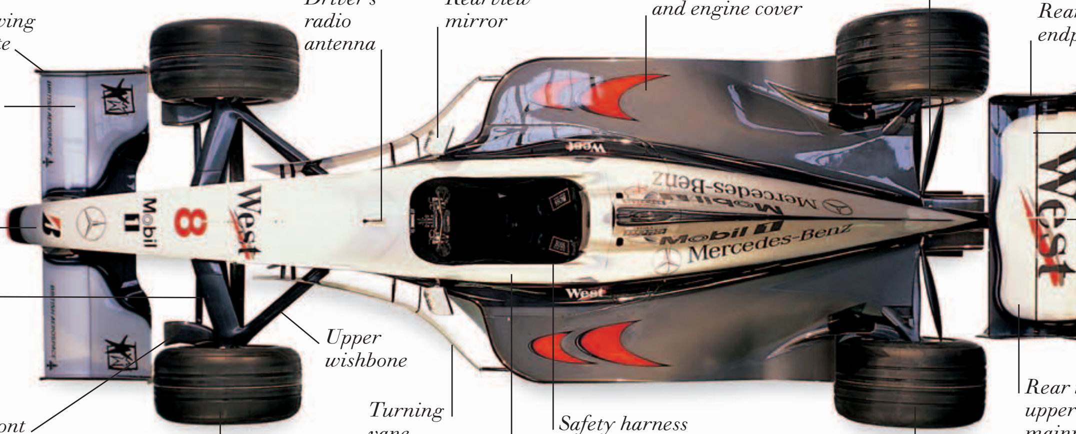


BACK VIEW OF MCLAREN MERCEDES MP4-13

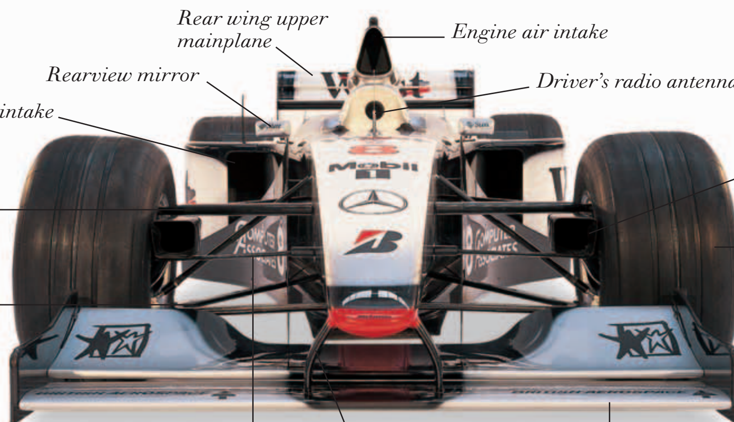
SIDE VIEW OF MCLAREN MERCEDES MP4-13

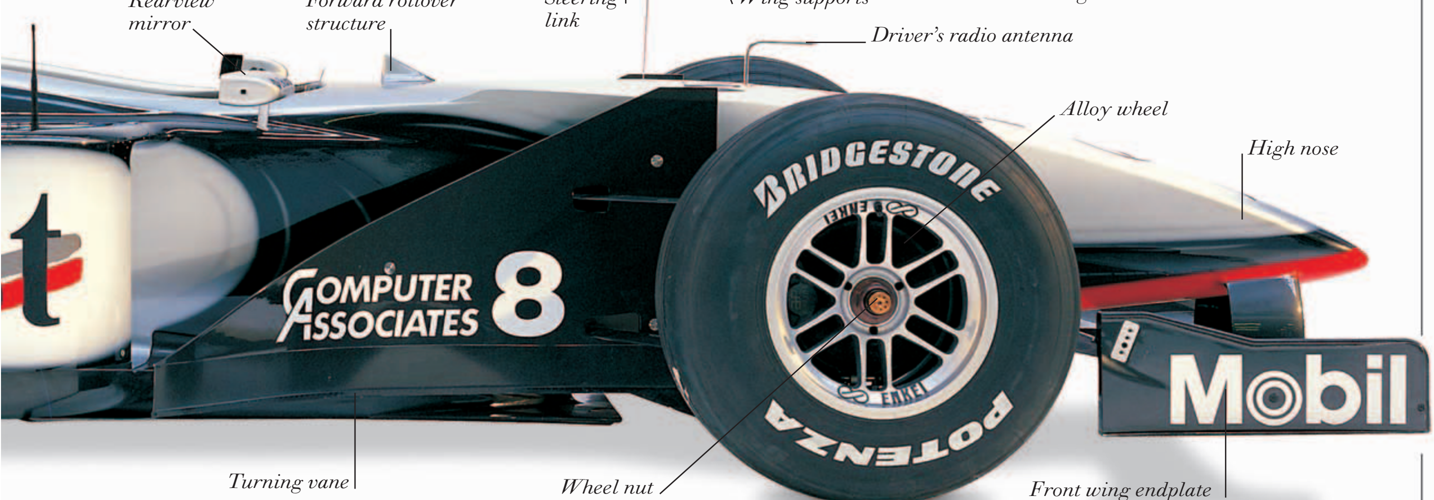


OVERHEAD VIEW OF MCLAREN MERCEDES MP4-13



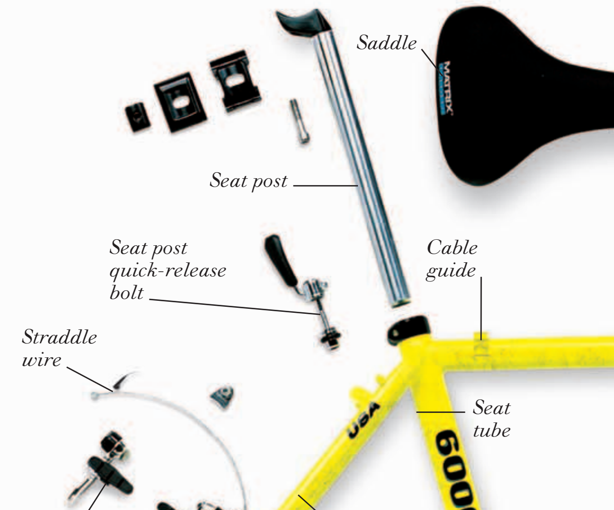
FRONT VIEW OF MCLAREN MERCEDES MP4-13

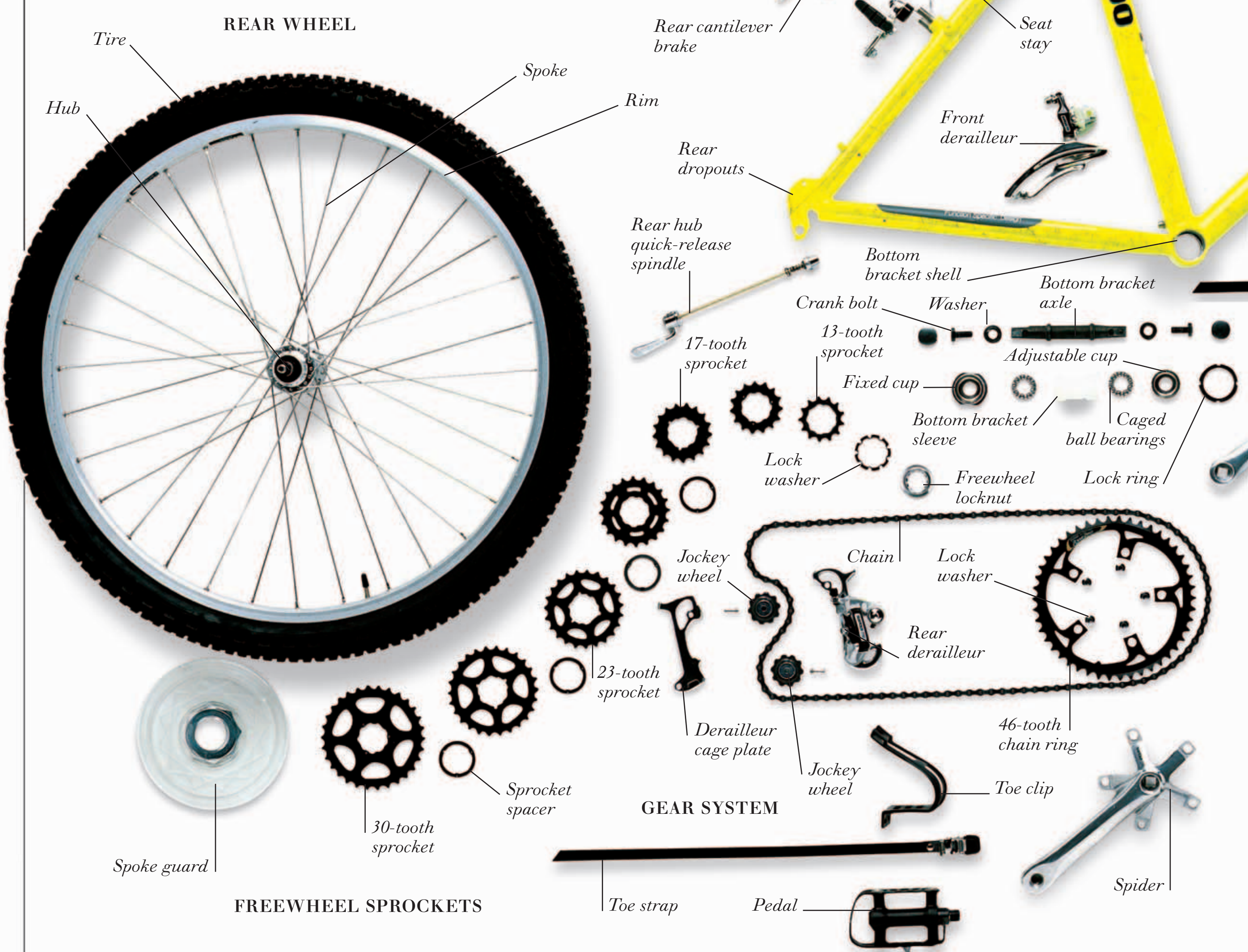


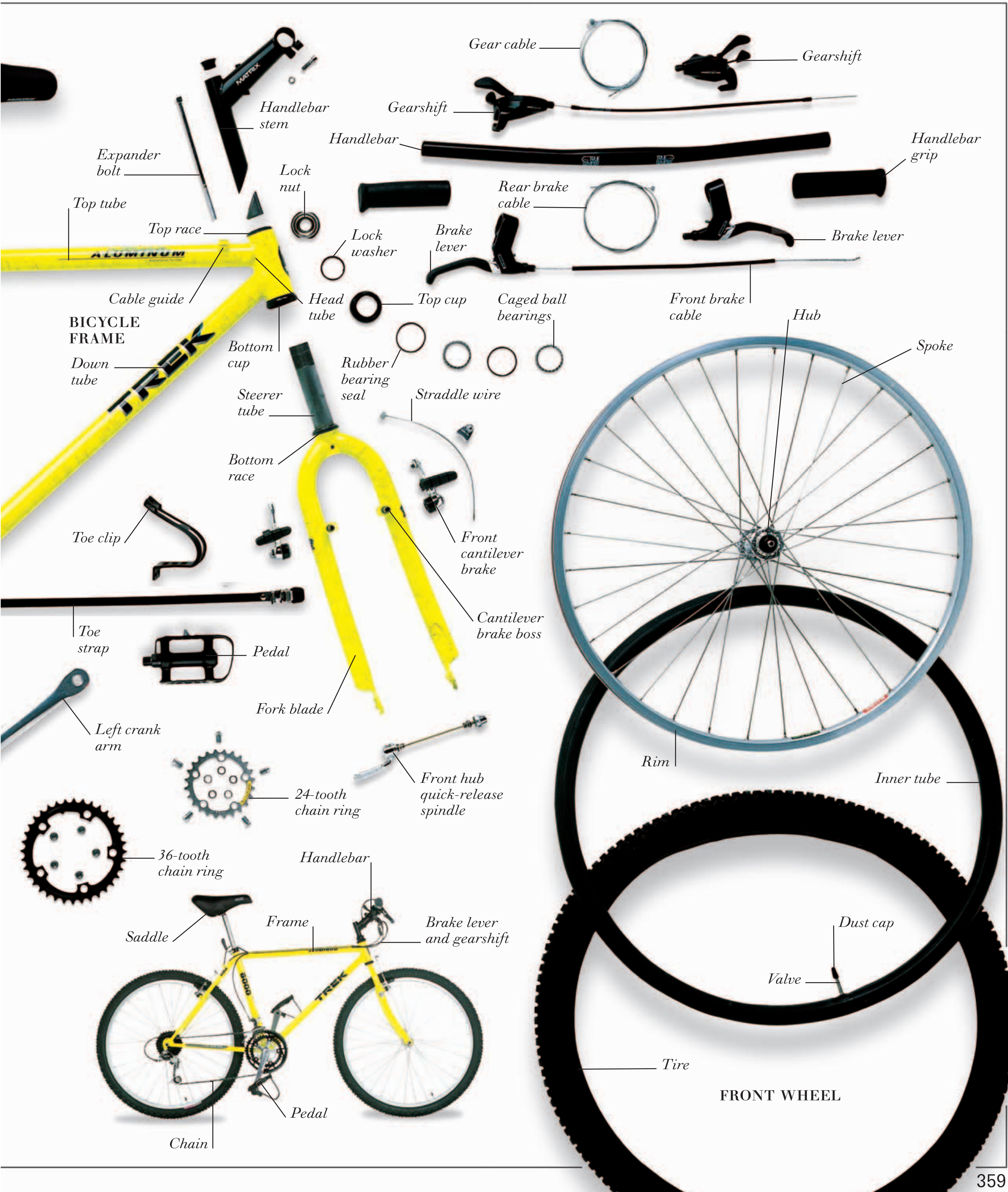


Bicycle anatomy

THE BICYCLE IS A TWO-WHEELED, light-weight machine, which is propelled by human power. It is efficient, cheap, easily manufactured, and one of the world's most popular forms of transportation. The first pedal-driven bicycle was built in Scotland in 1839. Since then the basic design—of a frame, wheels, brakes, handlebars, and saddle—has been gradually improved, with the addition of a chain, gear system, and pneumatic tires (tires inflated with air). The recent invention of the mountain bike (all-terrain bike) has been an important development. With its strong, rugged frame, wide tires, and 21 gears, a mountain bike enables riders to reach rough and hilly areas that were previously inaccessible to cyclists.






Gear cable
Gearshift
Handlebar stem
Gearshift
Handlebar
Handlebar grip
Expander bolt
Lock nut
Rear brake cable
Top tube
Top race
Lock washer
Brake lever
Brake lever
Cable guide
Head tube
Top cup
Caged ball bearings
Front brake cable
Hub
BICYCLE FRAME
Bottom cup
Spoke
Down tube
Rubber bearing seal
Steerer tube
Straddle wire
Bottom race
Toe clip
Front cantilever brake
Cantilever brake boss
Toe strap
Pedal
Fork blade
Left crank arm
Rim
Front hub quick-release spindle
24-tooth chain ring
Inner tube
36-tooth chain ring
Handlebar
Saddle
Frame
Brake lever and gearshift
Dust cap
Valve
Tire
FRONT WHEEL
Pedal
Chain

Bicycles

ALTHOUGH ALL BICYCLES are made up of the same basic components, they can vary greatly in design. A racing bike, such as the Eddy Merckx model, with its light frame and steep head- and seat-angles, is built for speed. Its design forces the rider to adopt the "aerotuck," a crouched, aerodynamic position. While a touring bike resembles the racing bike in many respects, it is designed for comfort and stability on long-distance journeys. Touring bikes are characterized by more relaxed frame angles, heavy chain stays that support the rear panniers, and a long wheelbase (the distance between the wheel axles) for reliable handling. All-round bicycles, known as "hybrids," combine the light weight and speed of sports bikes with the rugged durability of mountain bikes (see pp. 358-359). Bicycles that are not designed for conventional road use include time-trial bikes, which have a short head tube, sloping top tube, "aero" handlebars, and aerodynamic tubing. Most Human Powered Vehicles (HPVs) are recumbents—the rider has a recumbent position—which maximize power output and minimize drag (resistance). Essential to the safety of all riders are helmets, and both front and rear lights; locks protect against theft.

FRONT AND REAR LIGHTS

HELMET

EDDY MERCKX RACING BICYCLE

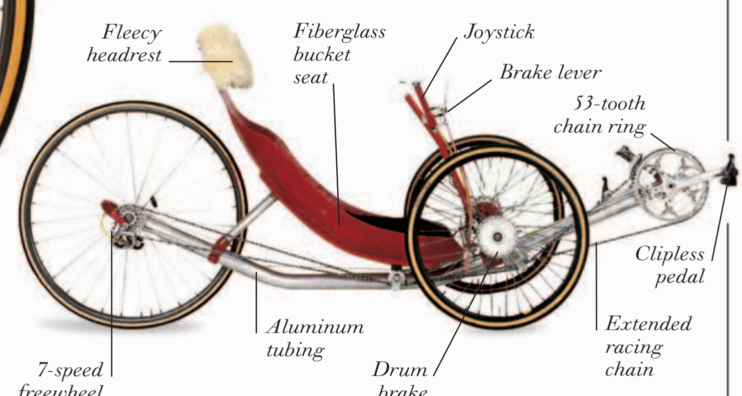
STEEL LOCK

CANNONDALE SH600 HYBRID BICYCLE

CANNONDALE ST1000 TOURING BICYCLE

ROSSIN ITALIAN TIME-TRIAL BICYCLE

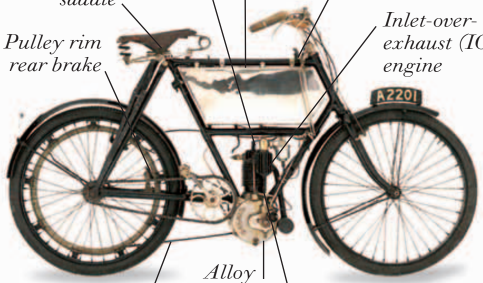
WINDCHEETAH SL MARK VI “SPEEDY” RACING HPV BICYCLE



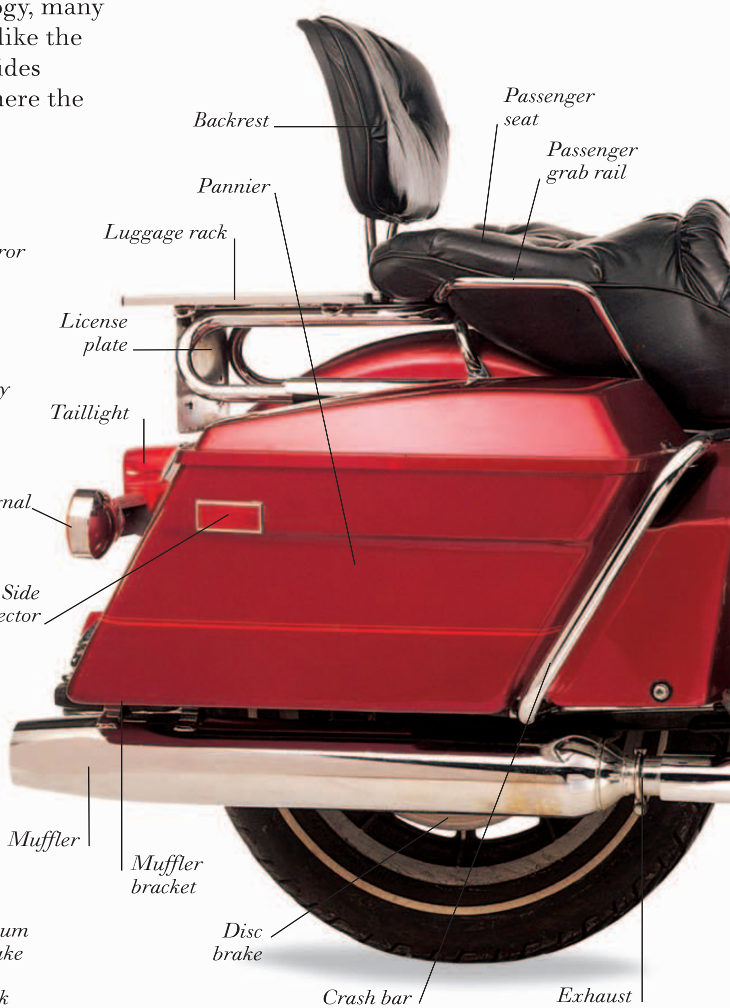
The motorcycle

THE MOTORCYCLE HAS EVOLVED from a motorized cycle—a basic bicycle with an engine—into a sophisticated, high-performance machine. In 1901, the Werner brothers established the most viable location for the engine by positioning it low in the center of the chassis (see pp. 364-365): the new Werner became the basis for the modern motorcycle. Motorcycles are used for many purposes—for commuting, delivering messages, touring, and racing—and different machines have been developed according to the demands of different types of rider. The Vespa scooter, for instance, which is small-wheeled, economical, and easy-to-ride, was designed to meet the needs of the commuter. Sidecars provided transportation for the family until the arrival of cheap cars caused their popularity to decline. Enthusiast riders generally favor larger capacity machines that are capable of greater performance and offer more comfort. Four-cylinder machines have been common since the Honda CB750 appeared in 1969. Despite advances in motorcycle technology, many riders are attracted to the traditional looks of motorcycles like the twin-cylinder Harley-Davidson. The Harley-Davidson Glides exploit the style of the classic American V-twin engine, where the cylinders are placed in a V-formation.

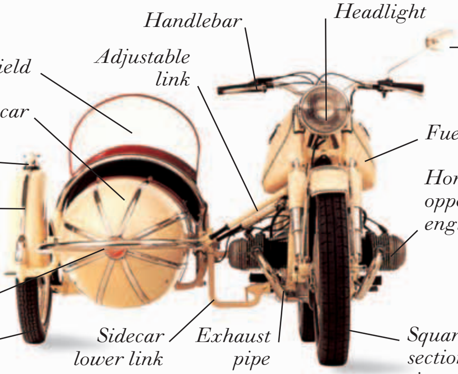
1901 WERNER MOTORCYCLE



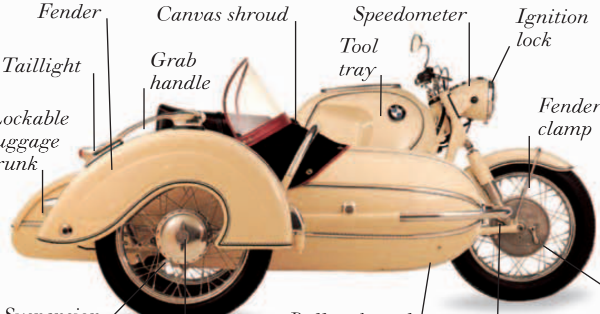
1988 HARLEY-DAVIDSON FLHS ELECTRA GLIDE



1965 BMW R/60 WITH 1952 STEIB CHAIR

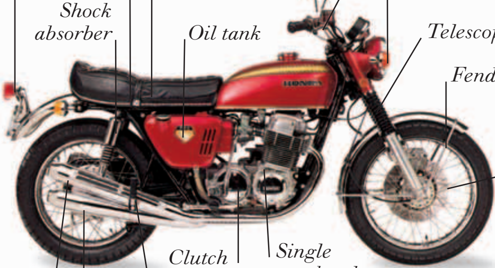


FRONT VIEW

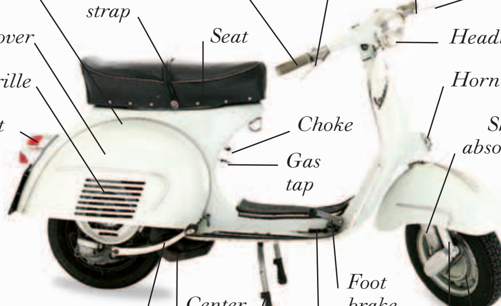


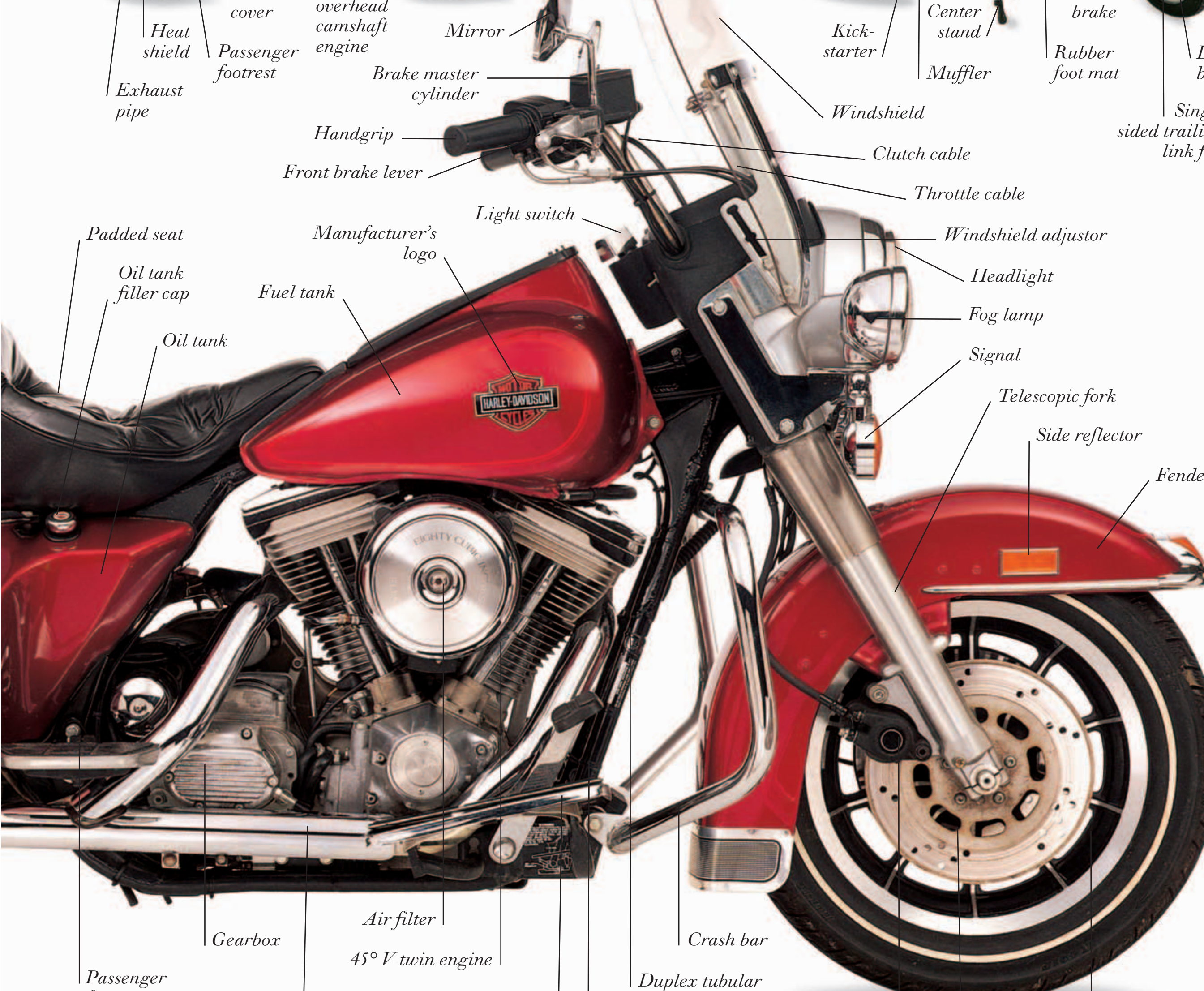
SIDE VIEW

1969 HONDA CB750



1963 VESPA GRAND SPORT 160 MARK 1

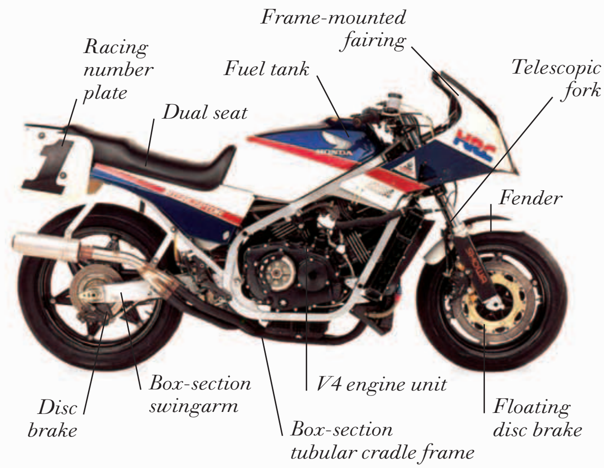




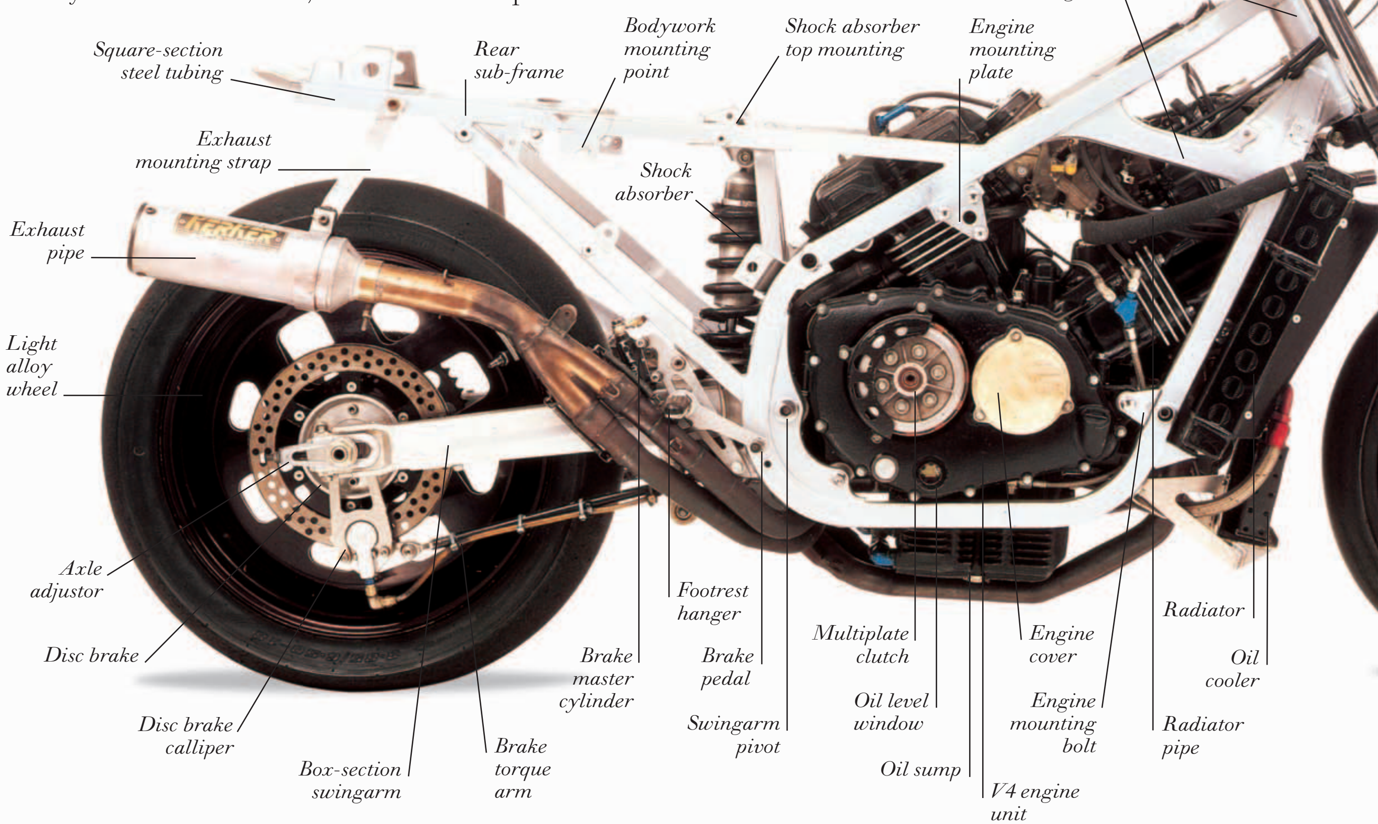
The motorcycle chassis

THE MOTORCYCLE CHASSIS is the main "body" of the motorcycle, to which the engine is attached. Consisting of the frame, wheels, suspension, and brakes, the chassis performs various functions. The frame, which is built from steel or alloy, keeps the wheels in line to maintain the handling of the motorcycle, and serves as a structure for mounting other components. The engine and gearbox unit is bolted into place, while items such as the seat, the fenders, and the fairing are more easily removable. Suspension cushions the rider from irregularities in the road surface. In most suspension systems, coil springs controlled by an oil damper separate the main mass of the motorcycle from the wheels. At the front, the spring and damper are usually incorporated in a telescopic fork; the rear employs a pivoted swingarm. The suspension also helps to retain maximum contact between the tires and the road, necessary for effective braking and steering. Drum brakes were common until the 1970s, but modern motorcycles use disc brakes, which are more powerful.

1985 HONDA VF750 WITH BODYWORK

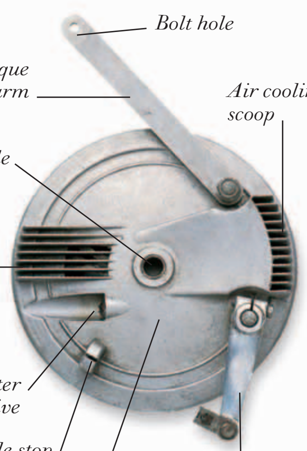


1985 HONDA VF750 WITH BODYWORK REMOVED

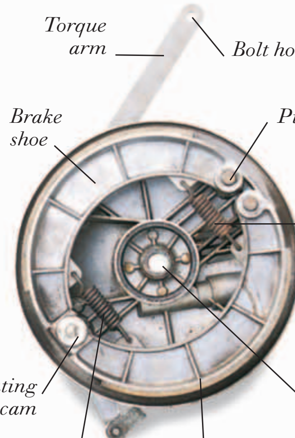


DRUM BRAKE

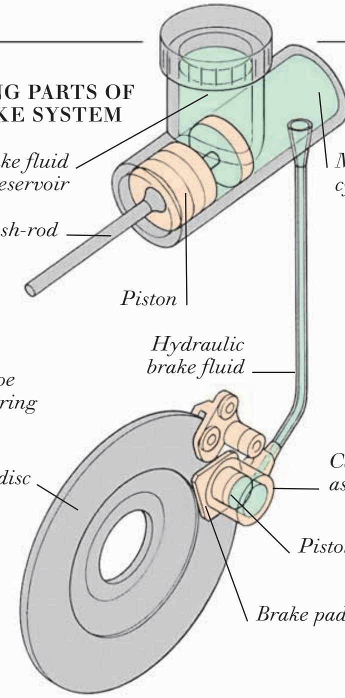
EXTERIOR OF DRUM BRAKE

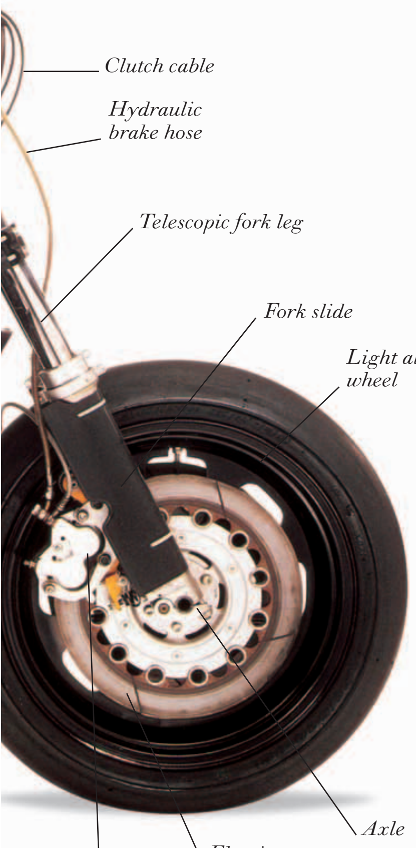


INTERIOR OF DRUM BRAKE



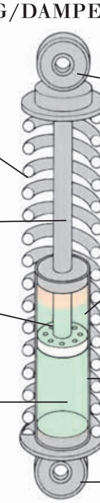
OPERATING PARTS OF DISC BRAKE SYSTEM





SPRING/DAMPER UNIT

HOW A SPRING/DAMPER UNIT WORKS



TYPES OF TIRE

RACING SLICK TIRE

TUBELESS SPORTS TIRE

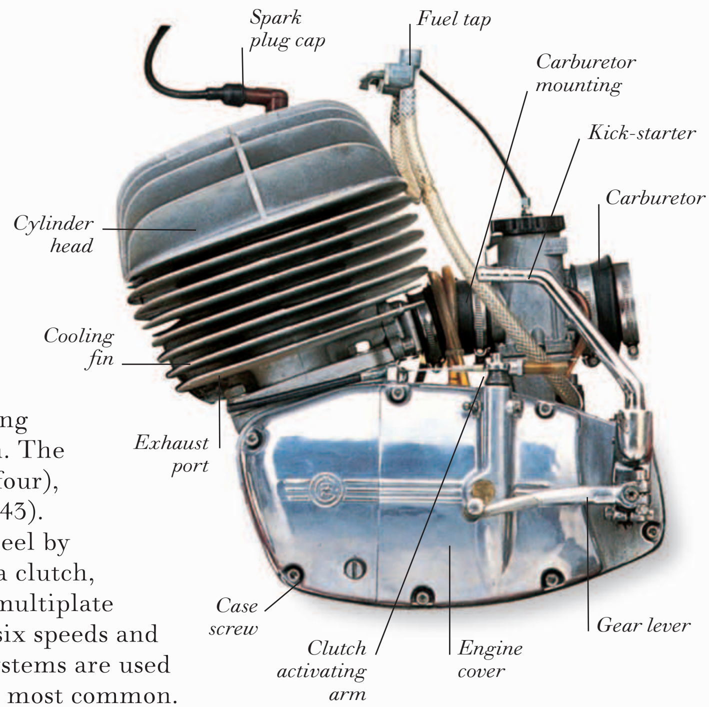
TRIALS TIRE

GENERAL-USE TIRE

Motorcycle engines

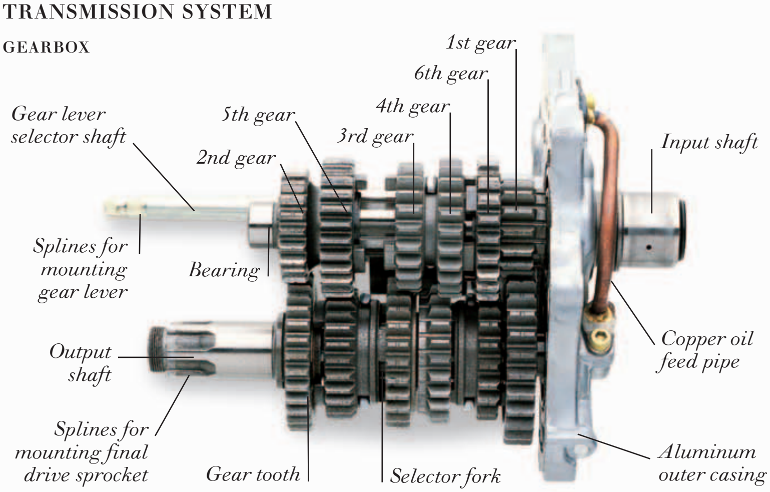
MOTORCYCLE ENGINES must be lightweight and compact and have a good power output. They have between one and six cylinders, can be cooled by air or water, and the capacity of the combustion chamber varies from 49cc (cubic centimeters) to 1500cc. Two types of internal combustion engine are common: the four-stroke, which is used in cars (see pp. 342-343), and the two-stroke. A basic two-stroke engine has only three moving parts—the crankshaft, the connecting rod, and the piston—but the power output is high. The engine fires every two strokes (rather than every four), giving a “power stroke” every revolution (see p. 343). Power is conveyed from the engine to the rear wheel by the transmission system. This usually consists of a clutch, a gearbox, and a final drive system. Clutches are multiplate devices, which run in oil. Gearboxes have five or six speeds and are operated by foot pedal. Shaft and belt drive systems are used in some cases, but chain drive to the rear wheel is most common.

EXTERIOR OF STANDARD TWO-STROKE ENGINE

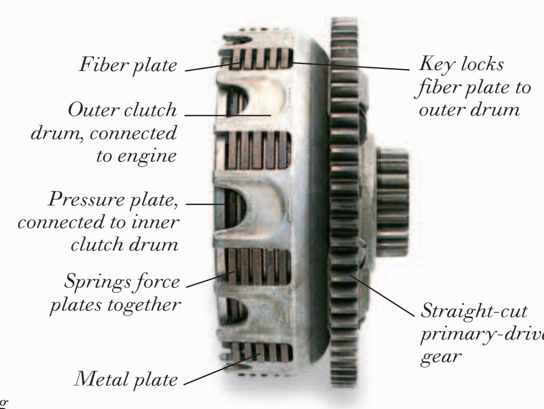


TRANSMISSION SYSTEM

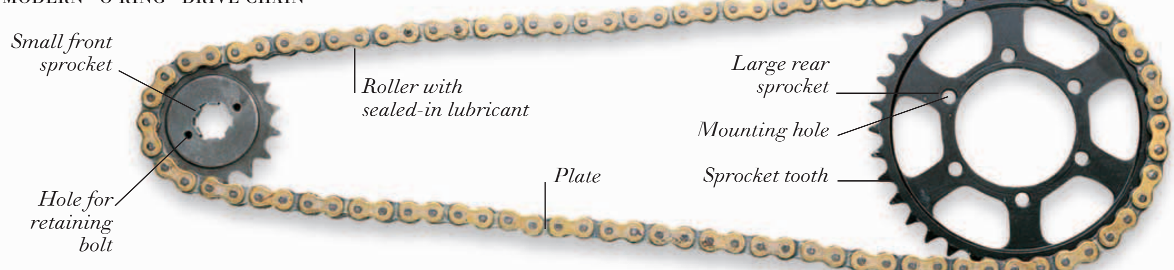
GEARBOX



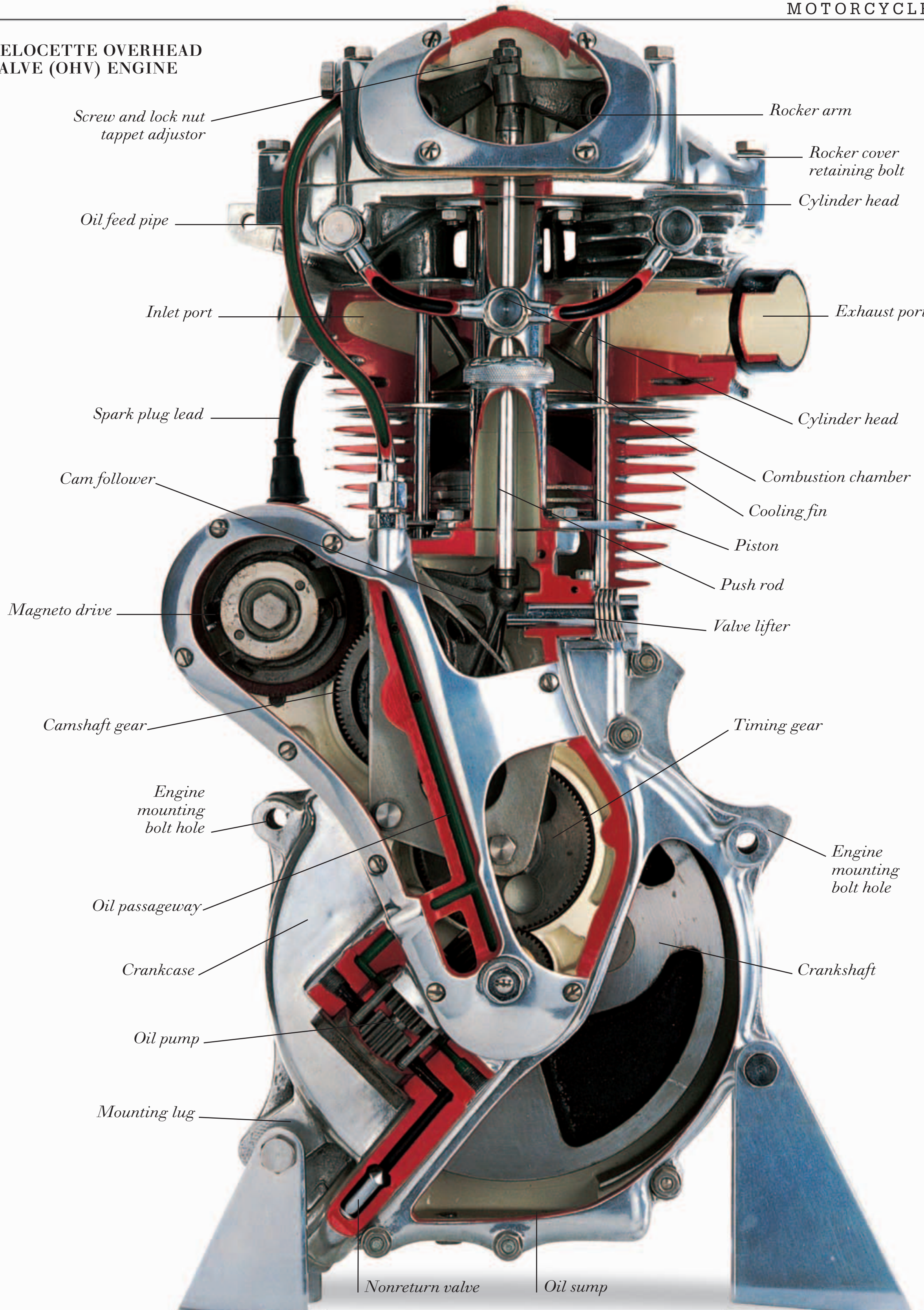
MULTIPLATE CLUTCH



MODERN “O RING” DRIVE CHAIN



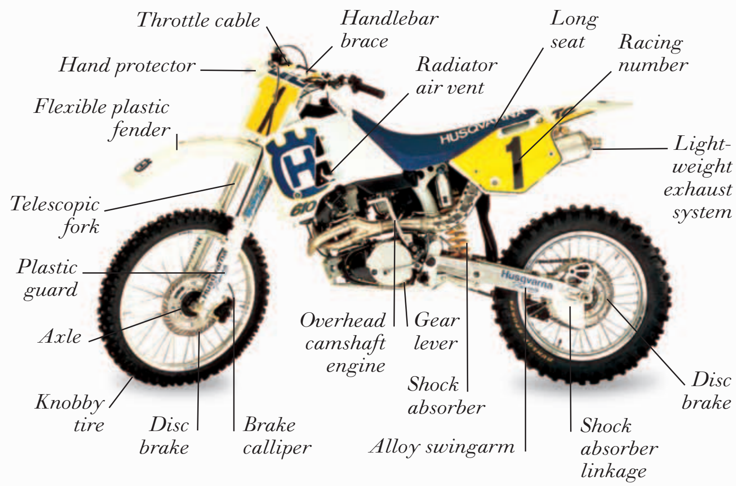
VELOCETTE OVERHEAD VALVE (OHV) ENGINE



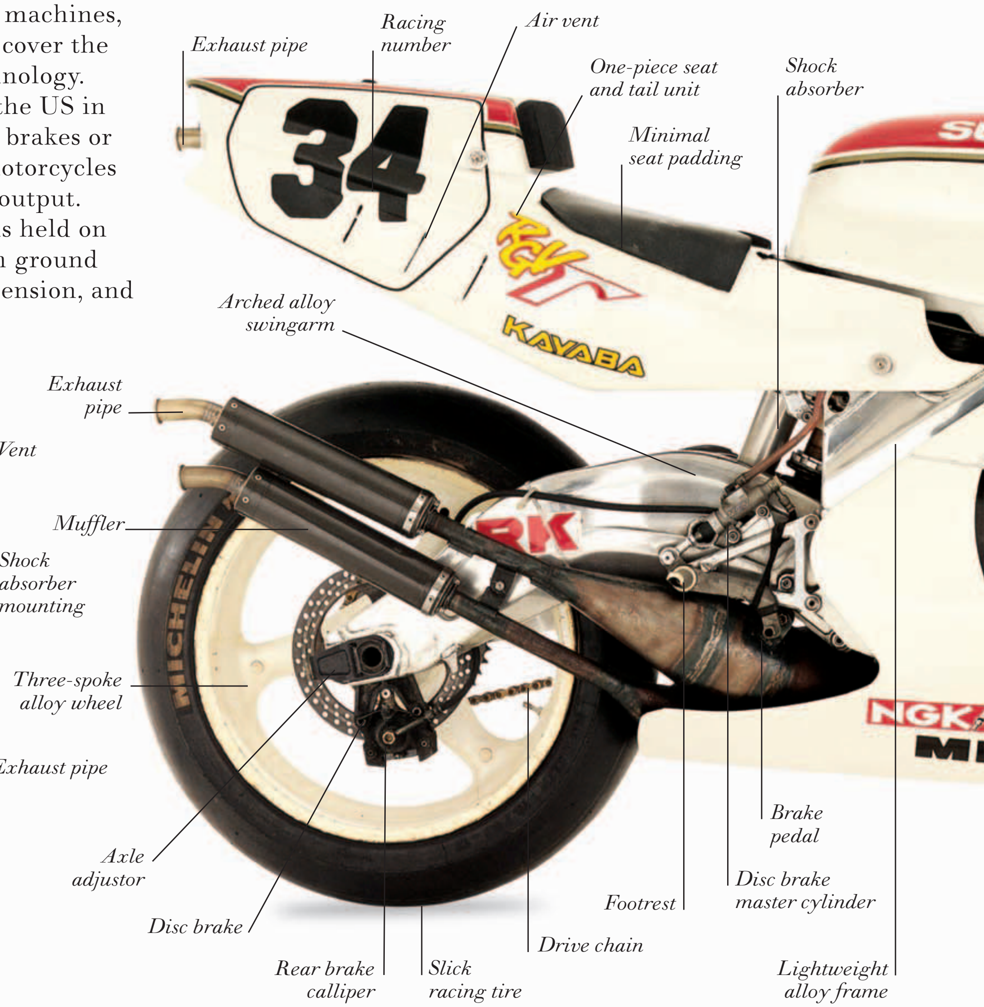
Competition motorcycles

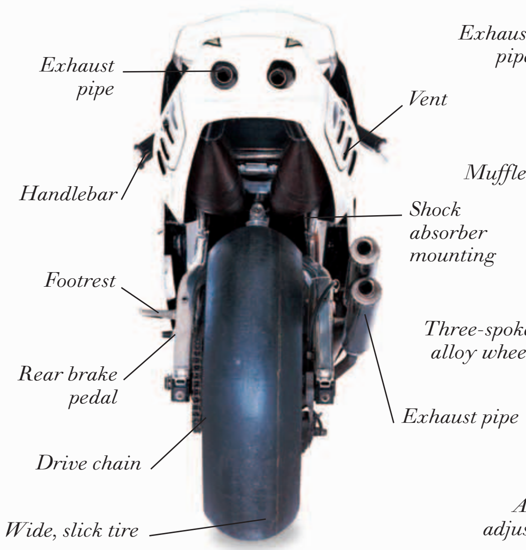
THERE ARE MANY TYPES of motorcycle sport and in each, a specialized machine has evolved to perform to specific requirements. Races take place on roads or tracks or "off-road," in fields, dirt tracks, and even the desert. "Grand Prix" world championships in road-racing are contested by three classes: 125cc, 250cc two-strokes; the top class of 500cc two-strokes; and 900cc four-stroke machines. The latest racing sidecars have more in common with racing cars than motorcycles. The rider and passenger operate within an all-enclosing, aerodynamic fairing. The Suzuki RGV500 shown here, like other Grand Prix machines, carries advertising, which helps to cover the cost of developing motorcycle technology. In Speedway, which originated in the US in 1902, motorcycles operate without brakes or a gearbox. Off-road competition motorcycles have less emphasis on high power output. In Motocross, for example, which is held on rough terrain, they must have high ground clearance, flexible long-travel suspension, and tires with a chunky tread pattern.

1992 HUSQVARNA MOTOCROSS TC610



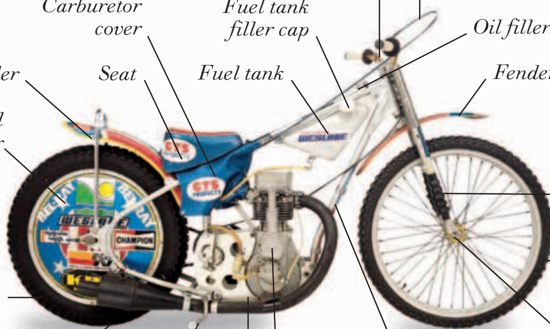
1992 SUZUKI RGV500
SIDE VIEW





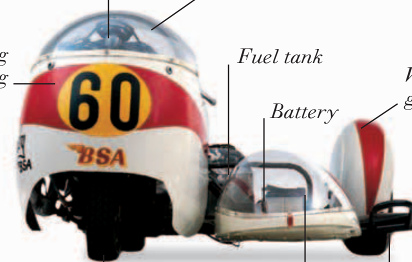
REAR VIEW

1981 WESLAKE SPEEDWAY

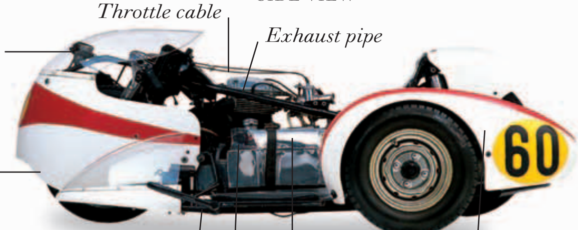


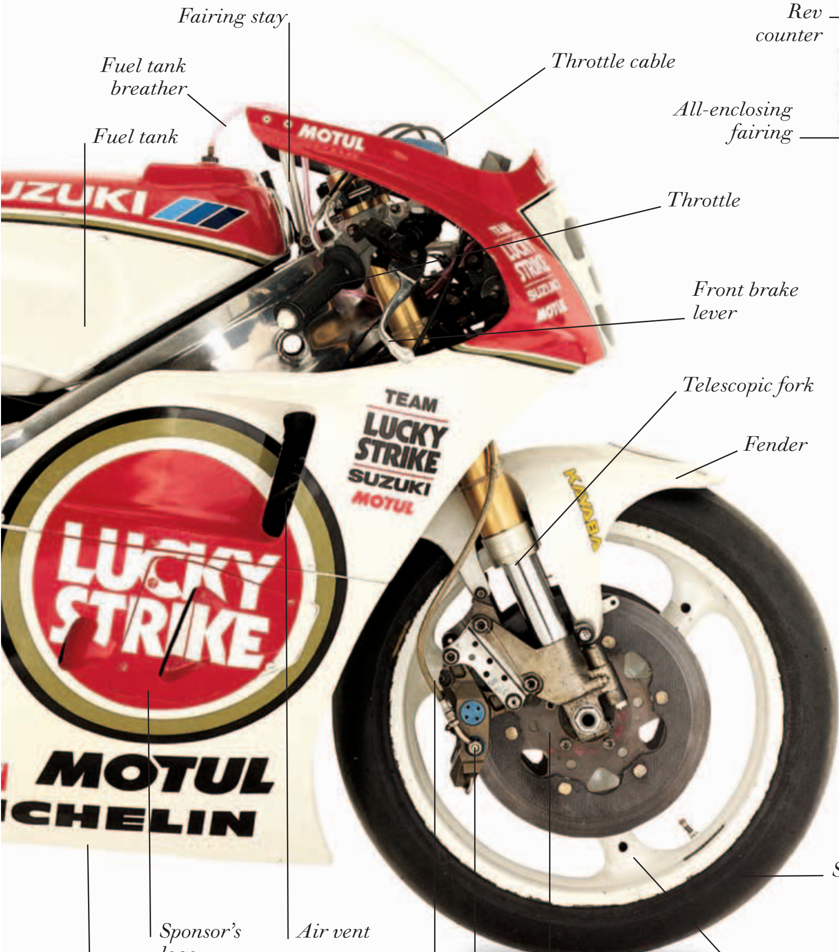
1968 KIRBY BSA RACING SIDECAR

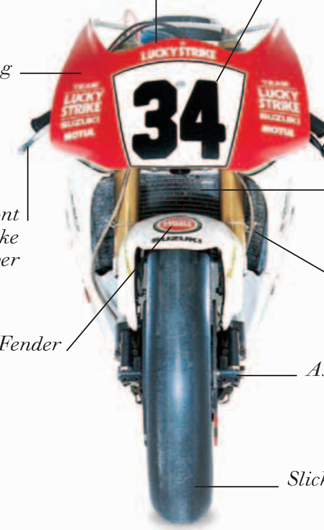
FRONT VIEW



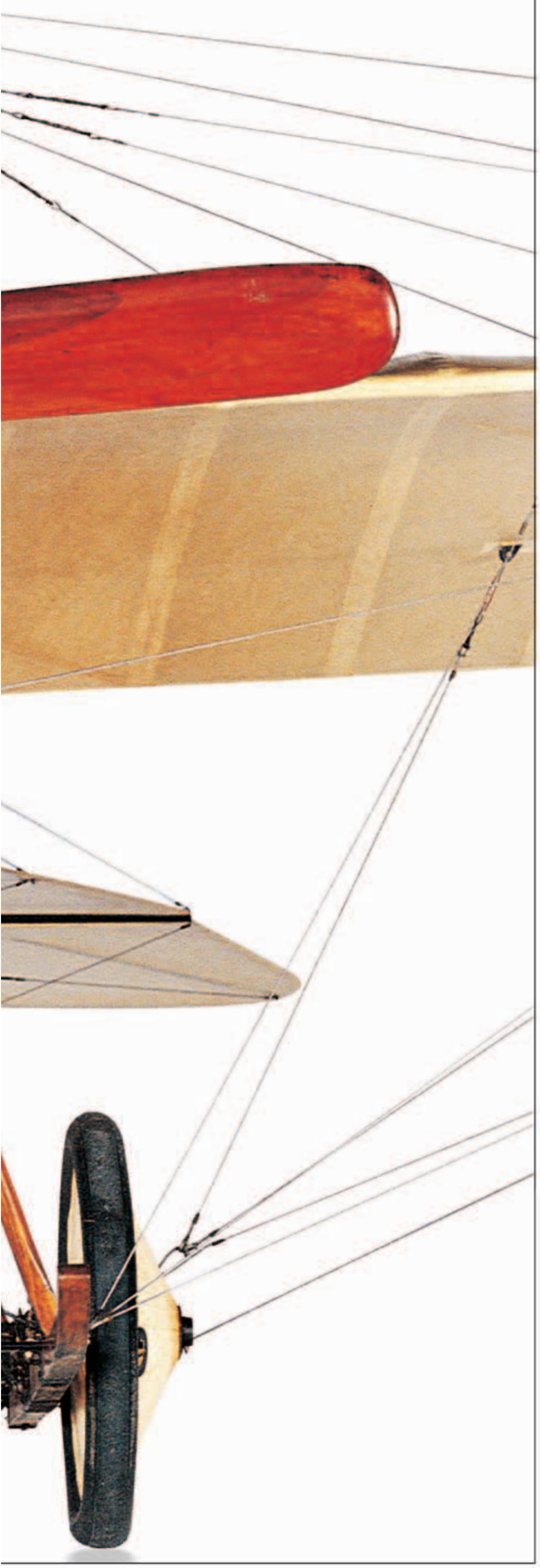
SIDE VIEW







FRONT VIEW

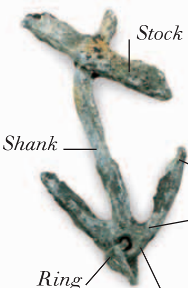


Sea and Air

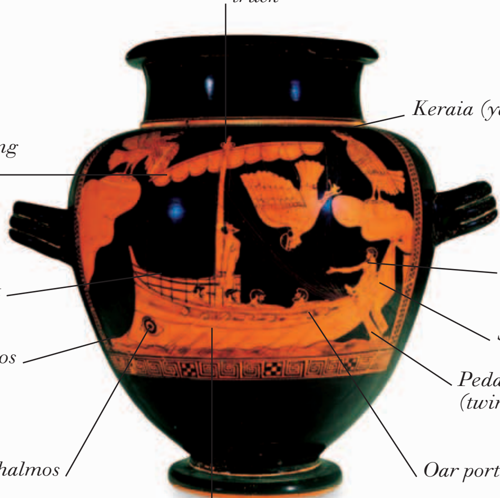
Ships of Greece and Rome

IN THE EXPANSIVE EMPIRES OF GREECE AND ROME, powerful fleets were needed for battle, trade, and communication. Greek galleys were powered by a sail and many oars. A new armament, the embolos (ram), was fitted on to the galley bow. Since ramming duels required fast and maneuverable boats, extra rows of oarsmen were added, culminating in the trireme. During the fifth and fourth centuries BC, the trireme dominated the Mediterranean. It was powered by 170 oarsmen, rowing with one oar each. The oarsmen were ranged on three levels, as the model opposite shows. The trireme also carried archers and soldiers for boarding. Galleys were pulled out of the water when not in use, and were kept in dockyard ship-sheds. The merchant ships of the Greeks and Romans were mighty vessels, too. The full-bodied Roman corbita, for example, could hold up to 400 tons (440 metric tons) and carried a cargo of spices, gems, silk, and animals. The construction of these boats was based on a stout hull with planking secured by mortice and tenon. Some of these ships embarked on long voyages, sailing even as far as India. To make them easier to steer, corbitas set a fore sail called an "artemon." It flew from a forward-leaning mast that was a forerunner of the long bowsprits carried by the great clipper ships of the 19th century.

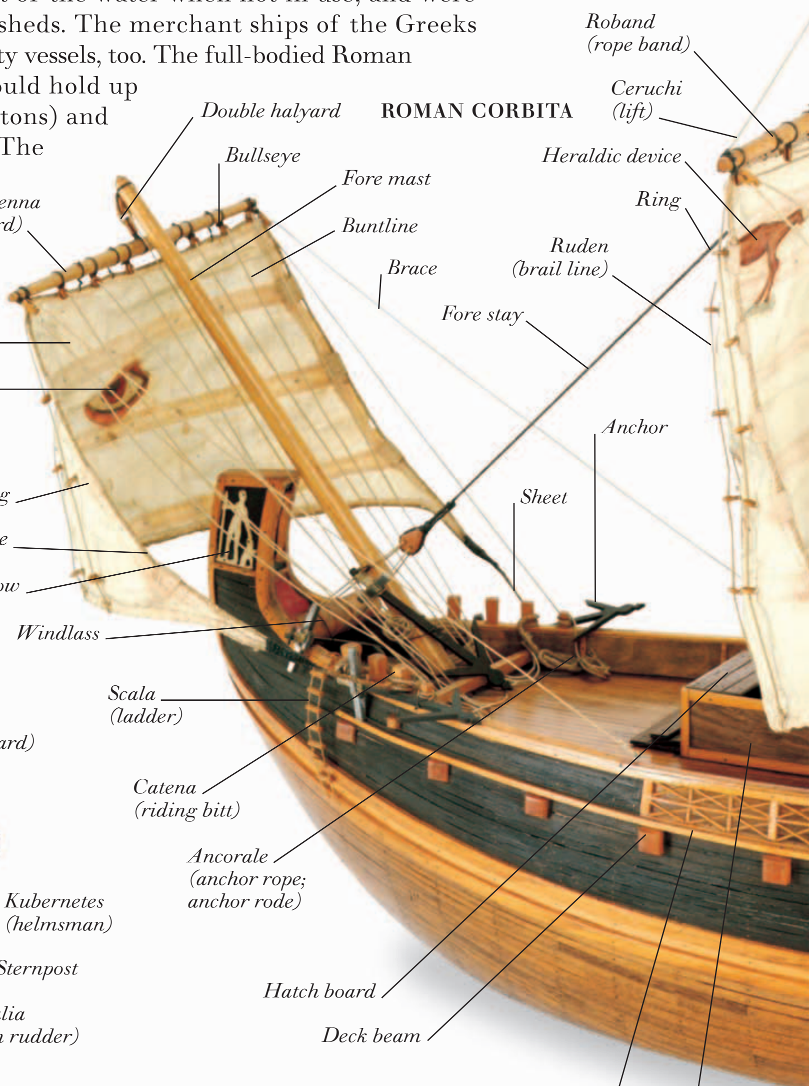
ROMAN ANCHOR

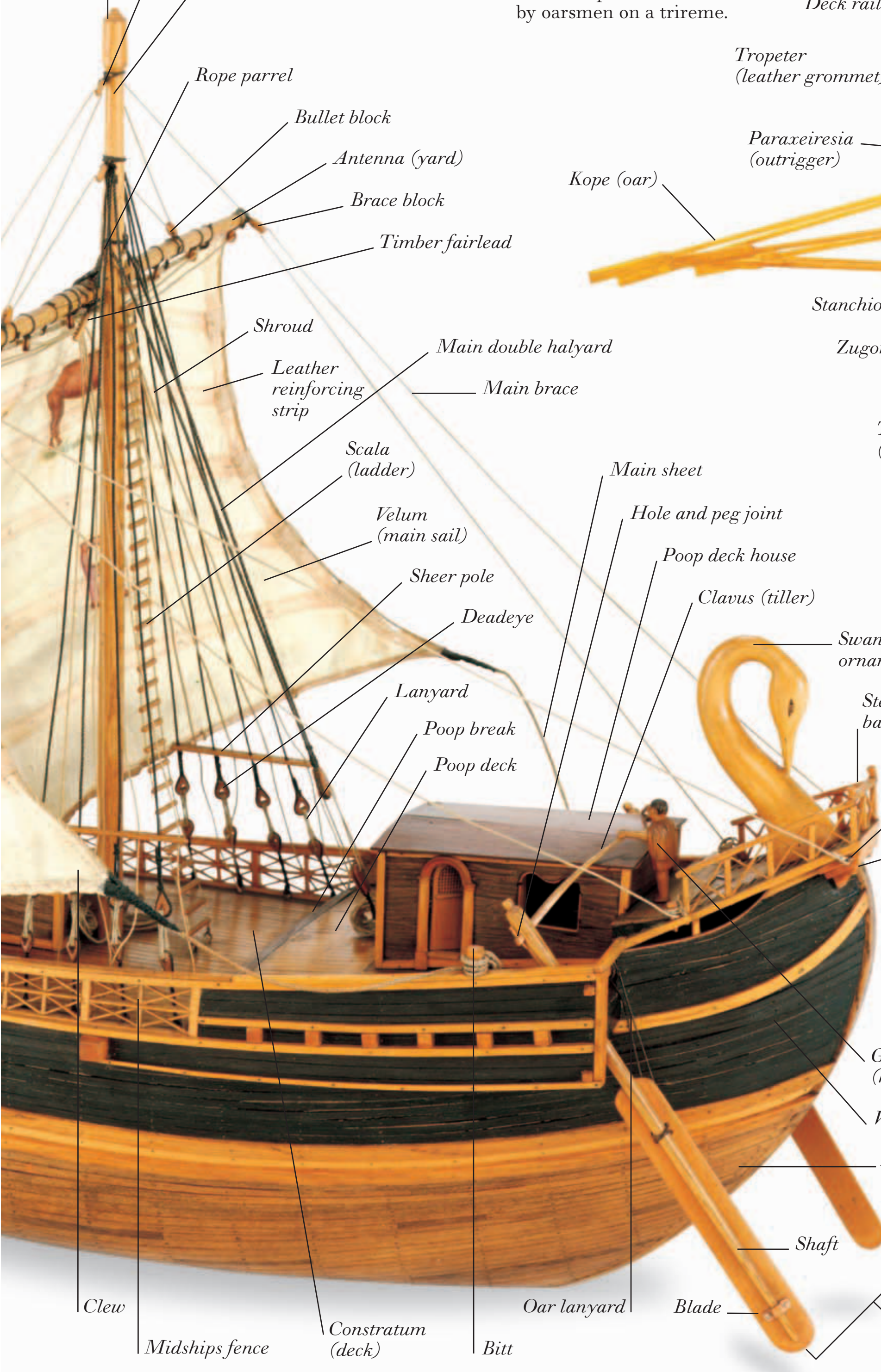


ATTIC VASE SHOWING A GALLEY

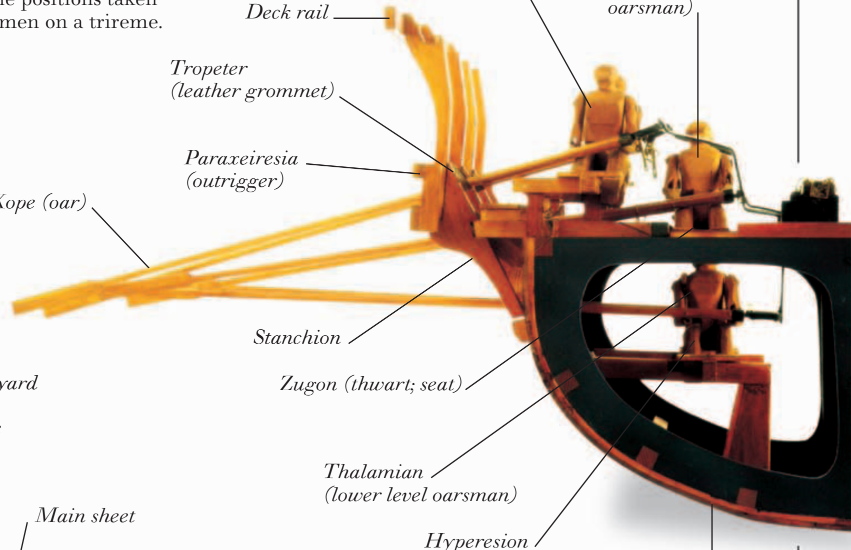


ROMAN CORBITA

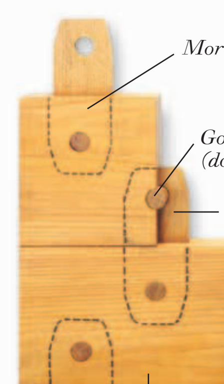




ROWING POSITIONS ON A GREEK TRIREME (TRIERE)
The katastroma (deck) has been removed from this model to show the positions taken by oarsmen on a trireme.



MORTICE-AND-TENON FASTENINGS FOR HULL PLANKS

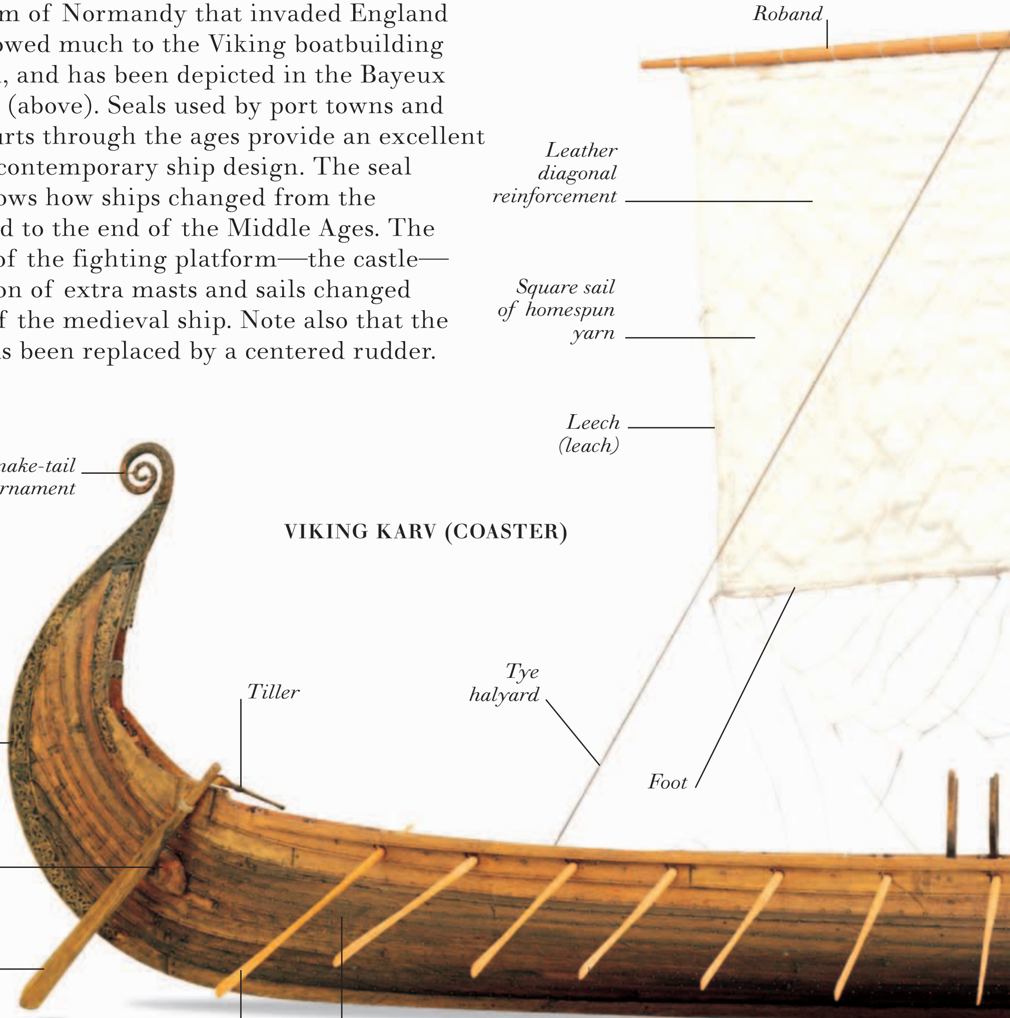


Viking ships

IN THE DARK AGES and early medieval times, the longships of Scandinavia were one of the most feared sights for people of northern Europe. The Vikings launched raids from Scandinavia every summer in longships equipped with a single steering oar on the right, or "steerboard," side (hence "starboard"). A longship had one row of oars on each side and a single sail. The hull had clinker (overlapping) planks. Prowheads adorned fighting ships during campaigns of war. The sailing longship was also used for local coastal travel. The karv below was probably built as transport for an important family, while the smaller faering (top right) was a rowing boat only. The fleet of William of Normandy that invaded England in 1066 owed much to the Viking boatbuilding tradition, and has been depicted in the Bayeux Tapestry (above). Seals used by port towns and royal courts through the ages provide an excellent record of contemporary ship design. The seal opposite shows how ships changed from the Viking period to the end of the Middle Ages. The introduction of the fighting platform—the castle—and the addition of extra masts and sails changed the character of the medieval ship. Note also that the steering oar has been replaced by a centered rudder.

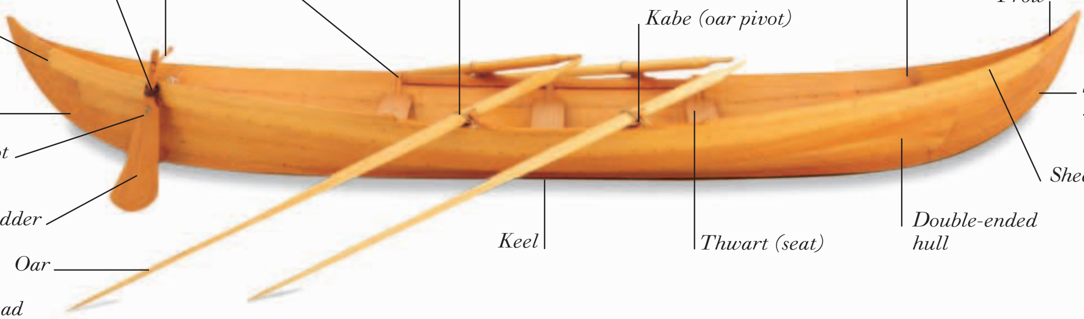
BOATBUILDERS' TOOLS

DRAGON PROWHEAD

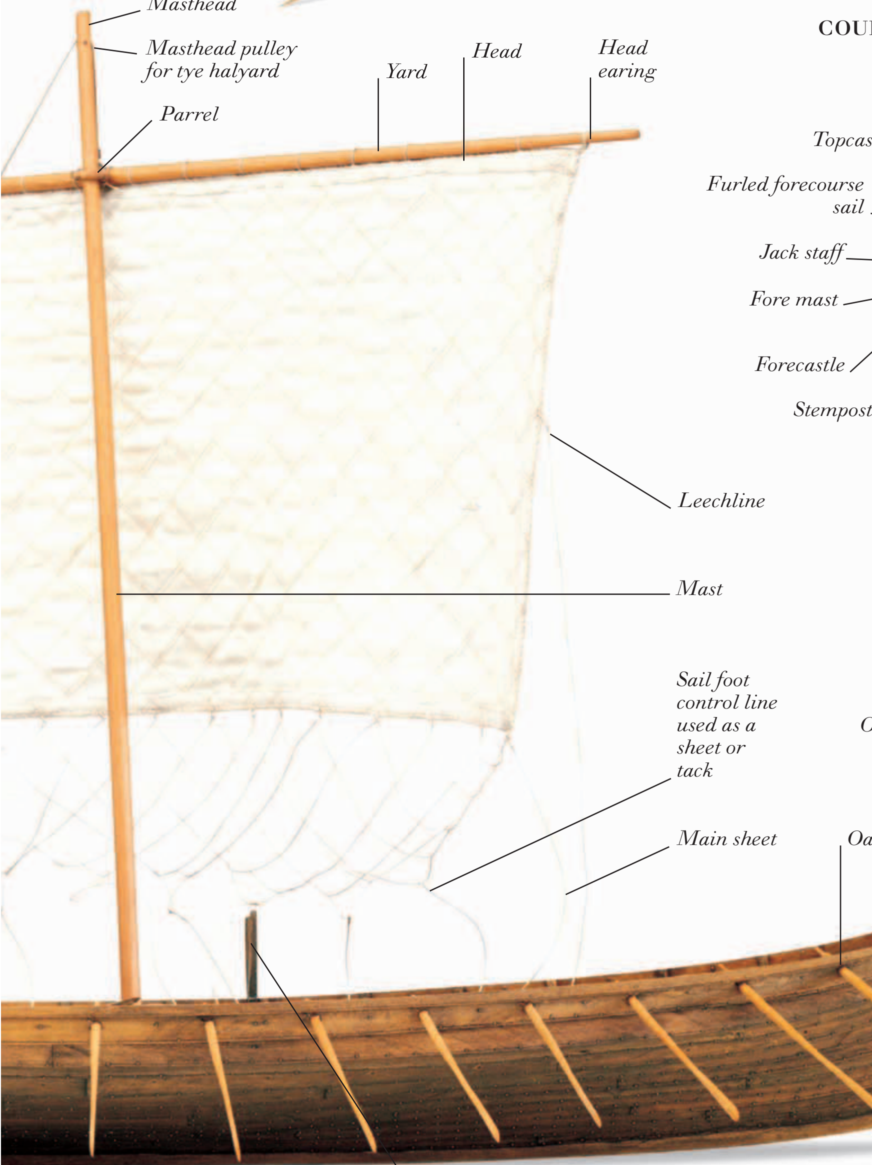


VIKING KARV (COASTER)

FAERING (VIKING ROWING BOAT)



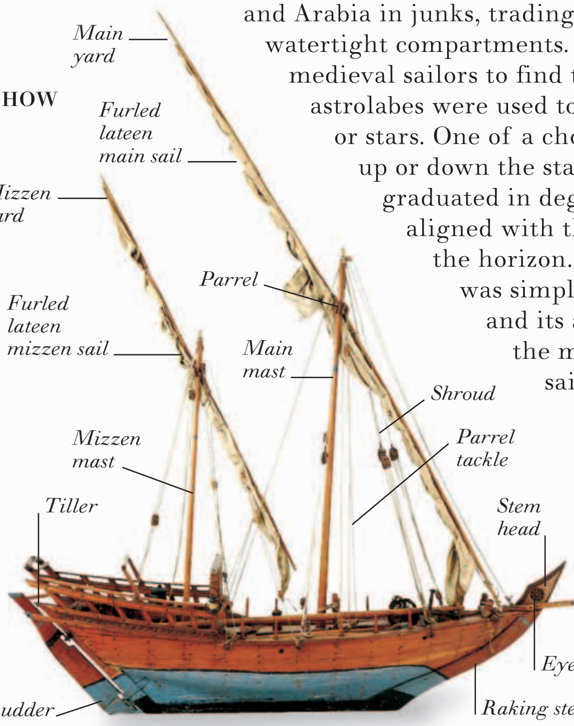
COURT SEAL SHOWING A THREE-MASTED, SQUARE-RIGGED SHIP



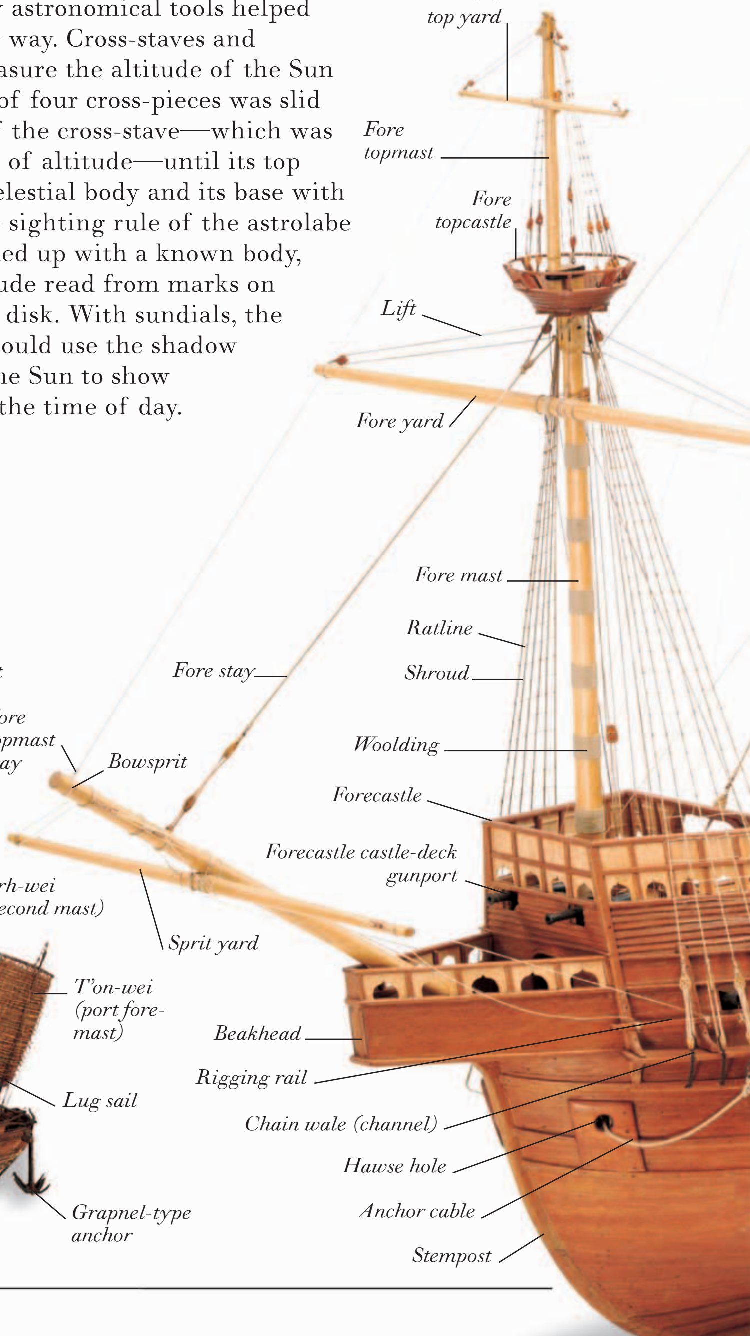
Medieval warships and traders

FROM THE 16TH CENTURY, SHIPS WERE BUILT WITH A NEW FORM OF HULL, constructed from carvel (edge-to-edge) planking. Warships of the time, like King Henry VIII of England's Mary Rose, boasted awesome fire power. This ship carried both long-range cannon in bronze, and short-range, anti personnel guns in iron. Elsewhere, ships took on a multiformity of shapes. Dhows transported slaves from East Africa to Arabia, their fore-and-aft rigged lateen sails allowing them to sail close to the wind around the lands of the Indian Ocean. The Chinese sailed to East Africa and Arabia in junks, trading goods that were carried in watertight compartments. New astronomical tools helped medieval sailors to find their way. Cross-staves and astrolabes were used to measure the altitude of the Sun or stars. One of a choice of four cross-pieces was slid up or down the staff of the cross-stave—which was graduated in degrees of altitude—until its top aligned with the celestial body and its base with the horizon. The sighting rule of the astrolabe was simply lined up with a known body, and its altitude read from marks on the metal disk. With sundials, the sailor could use the shadow of the Sun to show the time of day.

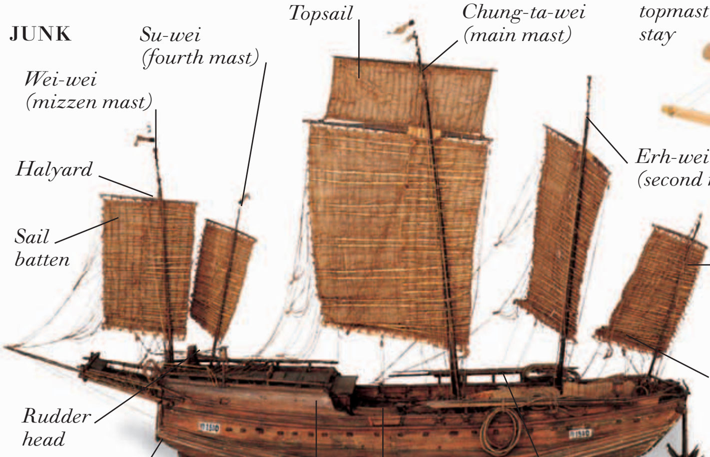
DHOW

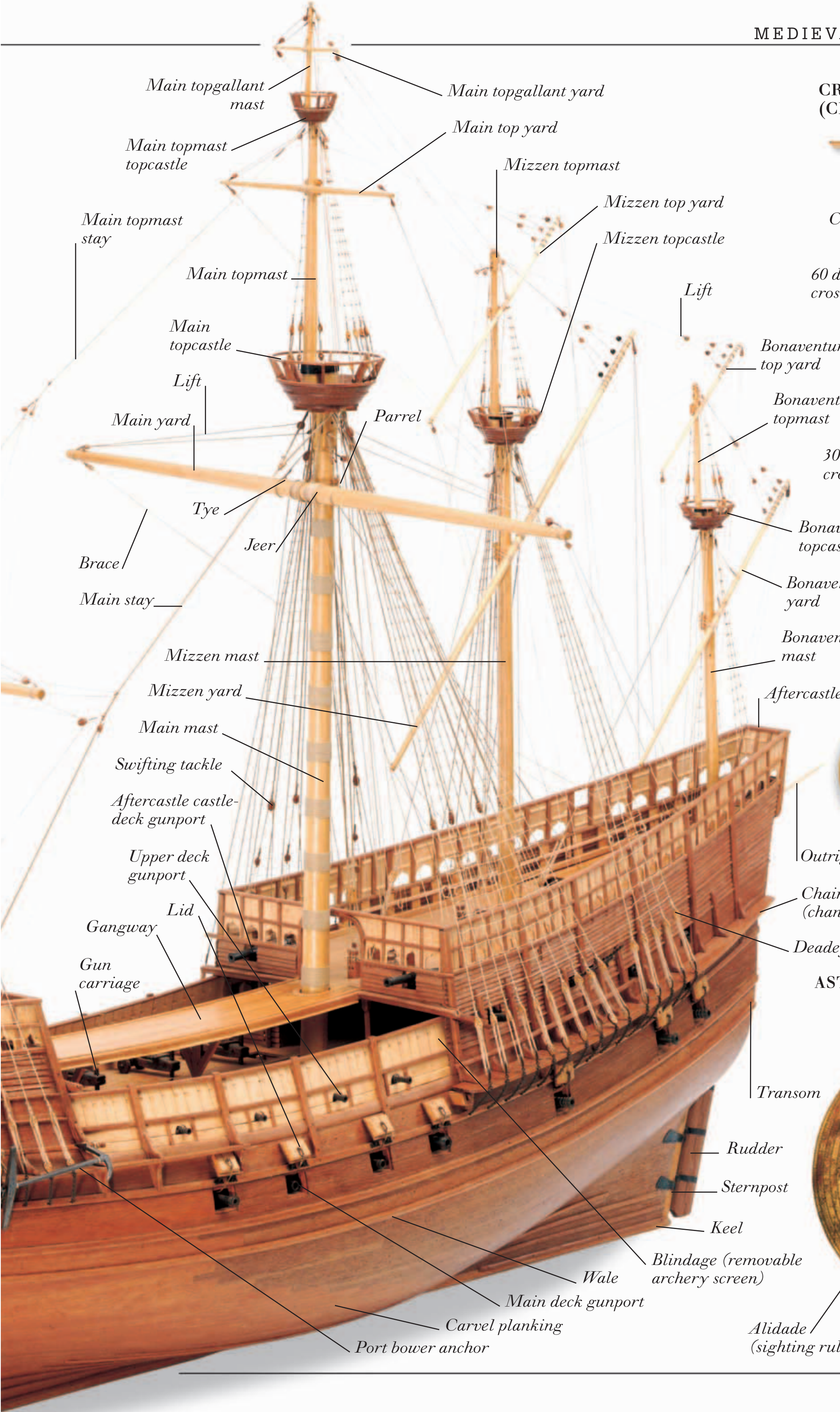


SAILING WARSHIP

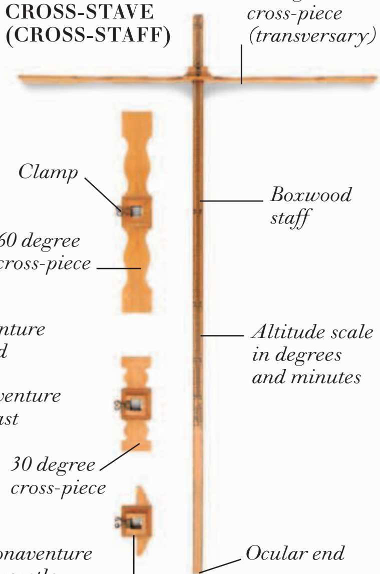


JUNK



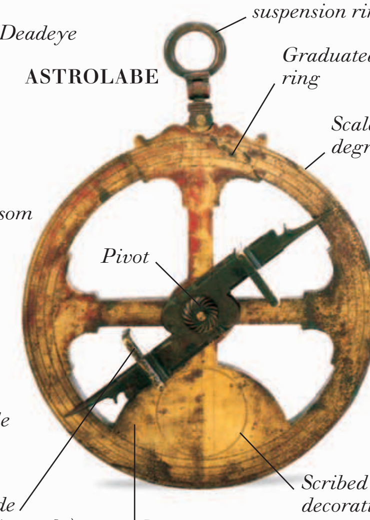


CROSS-STAVE (CROSS-STAFF)



SUNDIAL

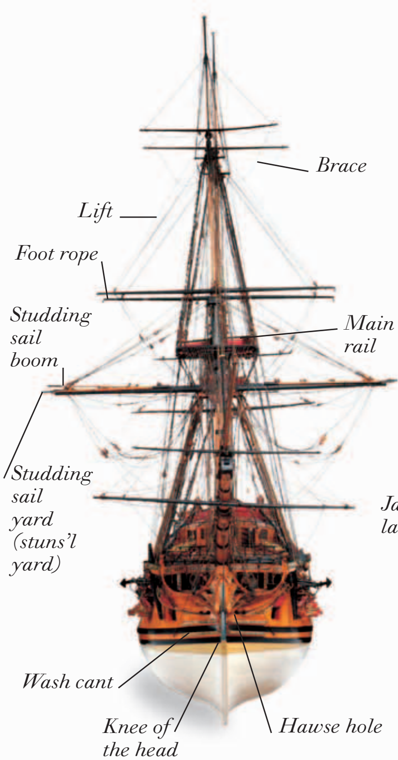
ASTROLABE



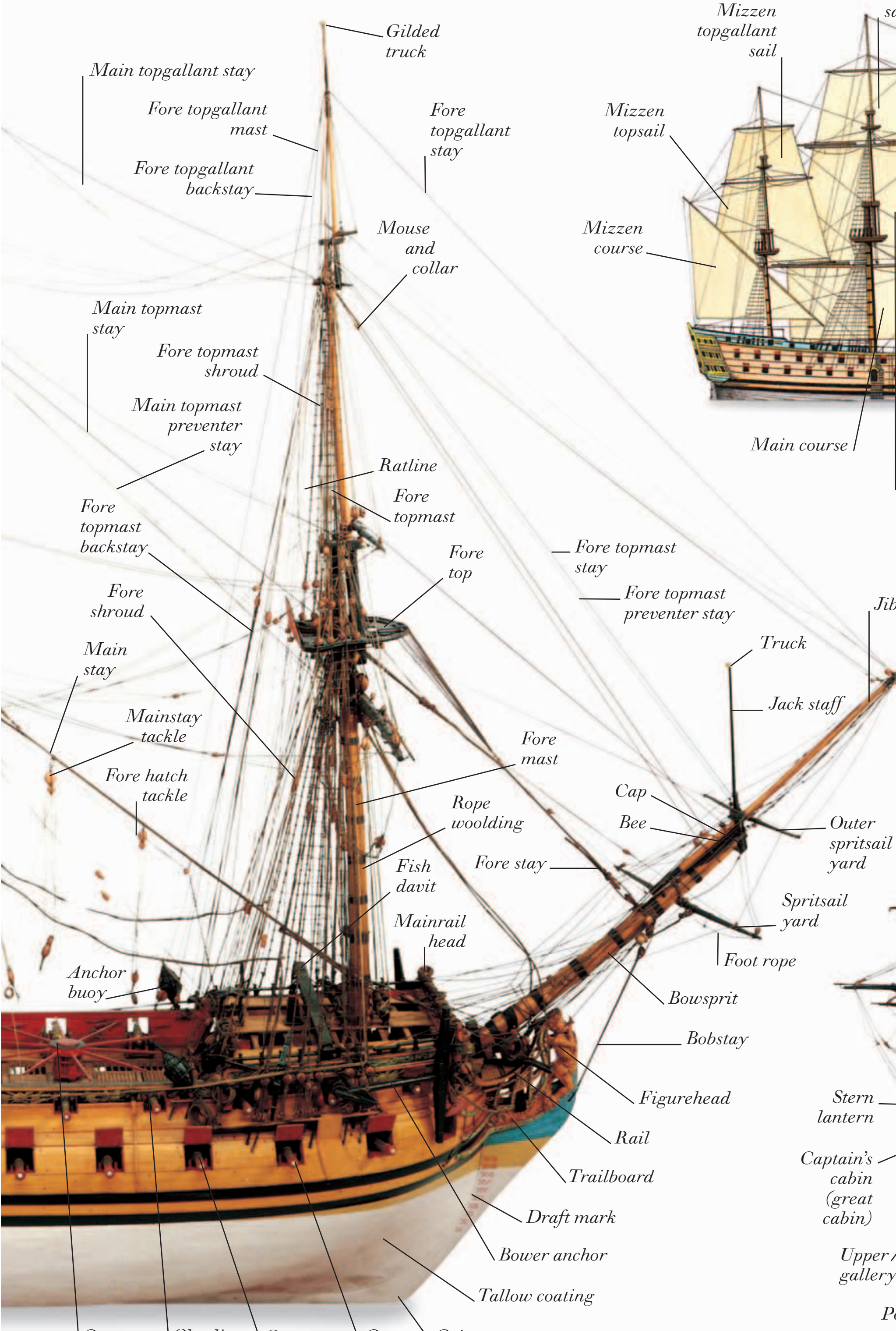
The expansion of sail

BY THE 18TH CENTURY, SAILING SHIPS had become fast and effective floating fortresses. The navies of the north European powers competed with each other by building heavily-armed fighting ships called "men-of-war." The distinctive round stern of the ship below, with its open gallery, balcony, and elaborate wood carving is typical of the period. Hulls around this time were semicircular in cross-section, although many boat designers were soon to return to the V-shaped hulls used by the Vikings. Ships of the period carried more sail than ever before. A labyrinth of rigging supported the masts and yards from which the profusion of square sails were set. Ships grew higher, as extra masts were fitted above the lower mast, and the bowsprit became longer to allow the ship to carry staysails, spritsails, and jibsails. Ships went into battle in single file, so that broadsides from the multiple decks of guns would have maximum effect. Ships were classified by rates, the rating of a vessel depending on how many guns it had. A first rate ship had more than 100 guns. The guns fired solid round shot, usually made of iron.

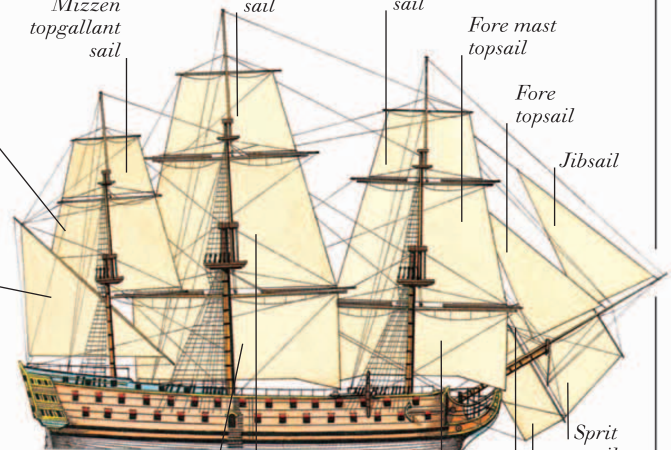
BOW



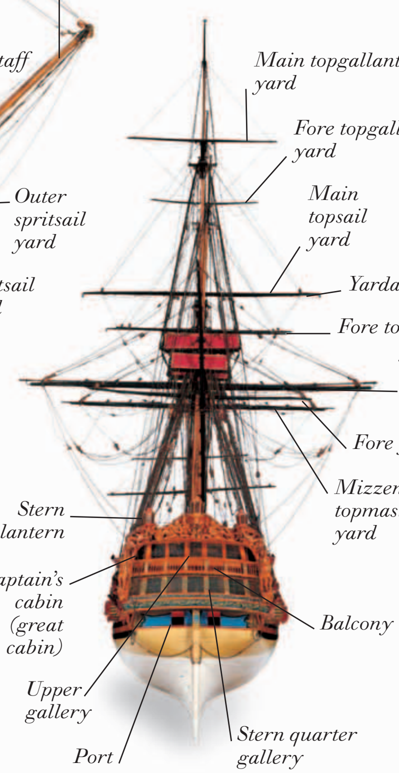
WOODEN SAILING SHIP



SAIL PATTERN OF A 74-GUN SHIP



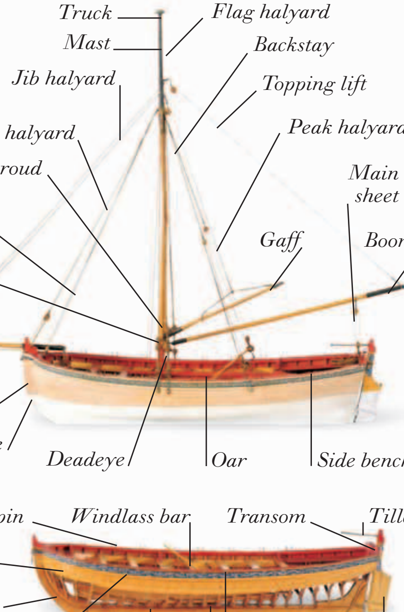
STERN



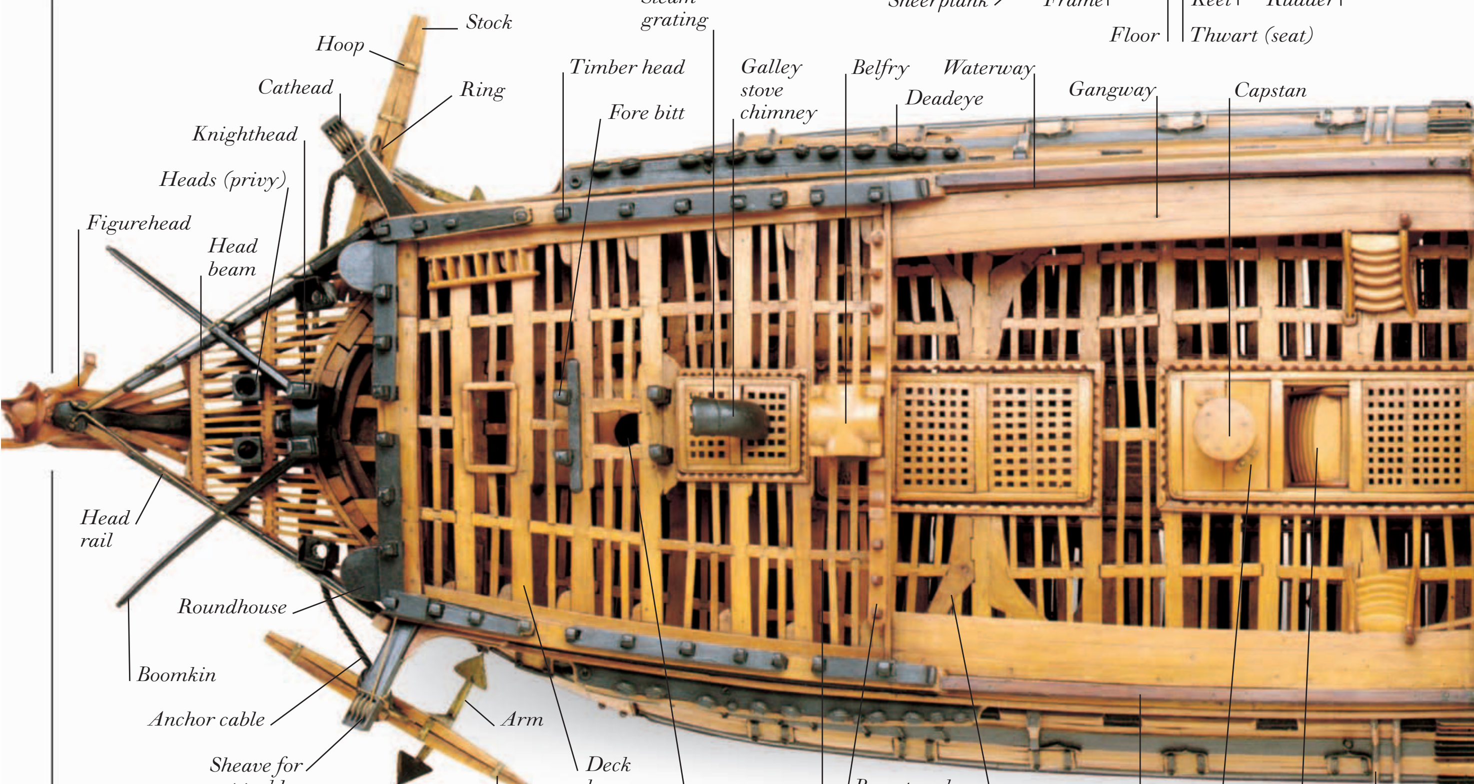
A ship of the line

THE 74-GUN WOODEN SHIP WAS A MAINSTAY of British and French battlefleets in the late 18th and early 19th centuries. This "ship of the line" was heavy enough to fight with the most potent of rivals, yet nimble, too. The length of such a ship was determined by the number of guns required for each deck, allowing enough room for crews to man them. The gun deck was about 170 ft (52 m) long. The decks had to be very strong to carry the weight of the guns. The deck planks have been removed on the vessel pictured below, to show just how close together the beams had to be to make the hull strong enough. Only timber with a perfect grain was used. The upper deck was open at the waist, but afore and abaft were officers' cabins. The forecastle and quarterdeck carried light guns and acted as platforms for working rigging and for reconnaissance. The ship's longboats (launches) were carried on booms between the gangways.

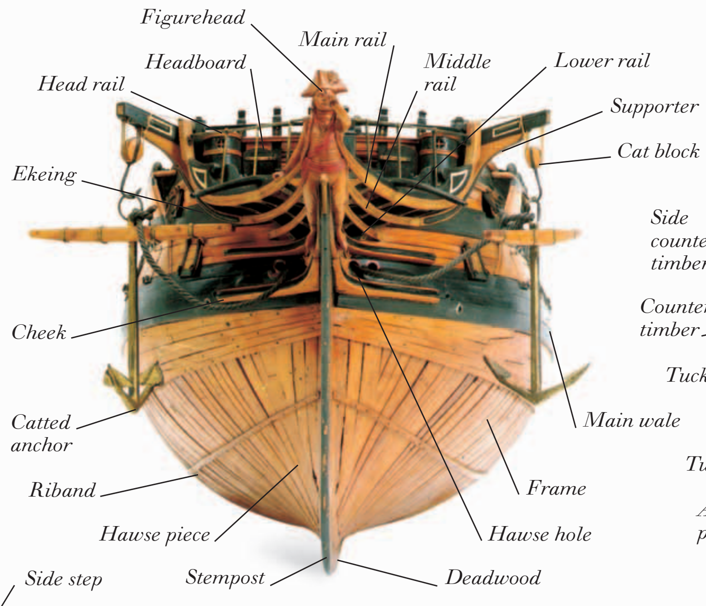
LONGBOAT



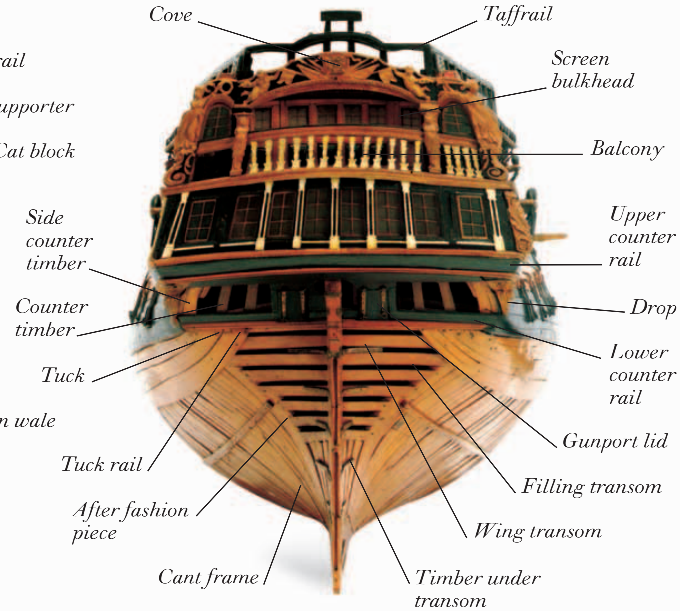
UPPER DECK OF A 74-GUN SHIP

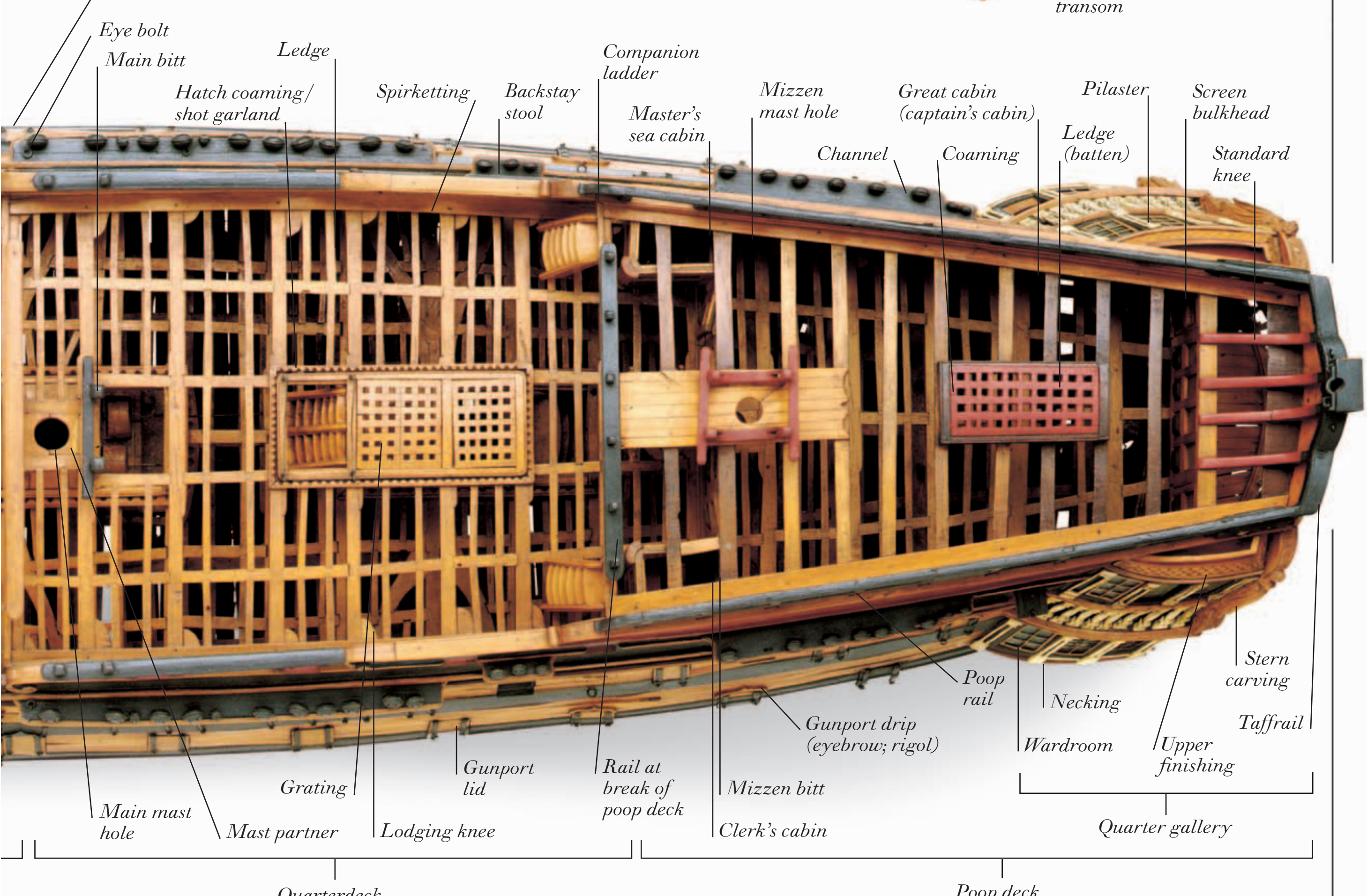


BOW


Figurehead
Main rail
Headboard
Middle rail
Lower rail
Head rail
Supporter
Cat block
Ekeing
Cheek
Catted anchor
Main wale
Riband
Frame
Hawse piece
Hawse hole
Stempost
Deadwood

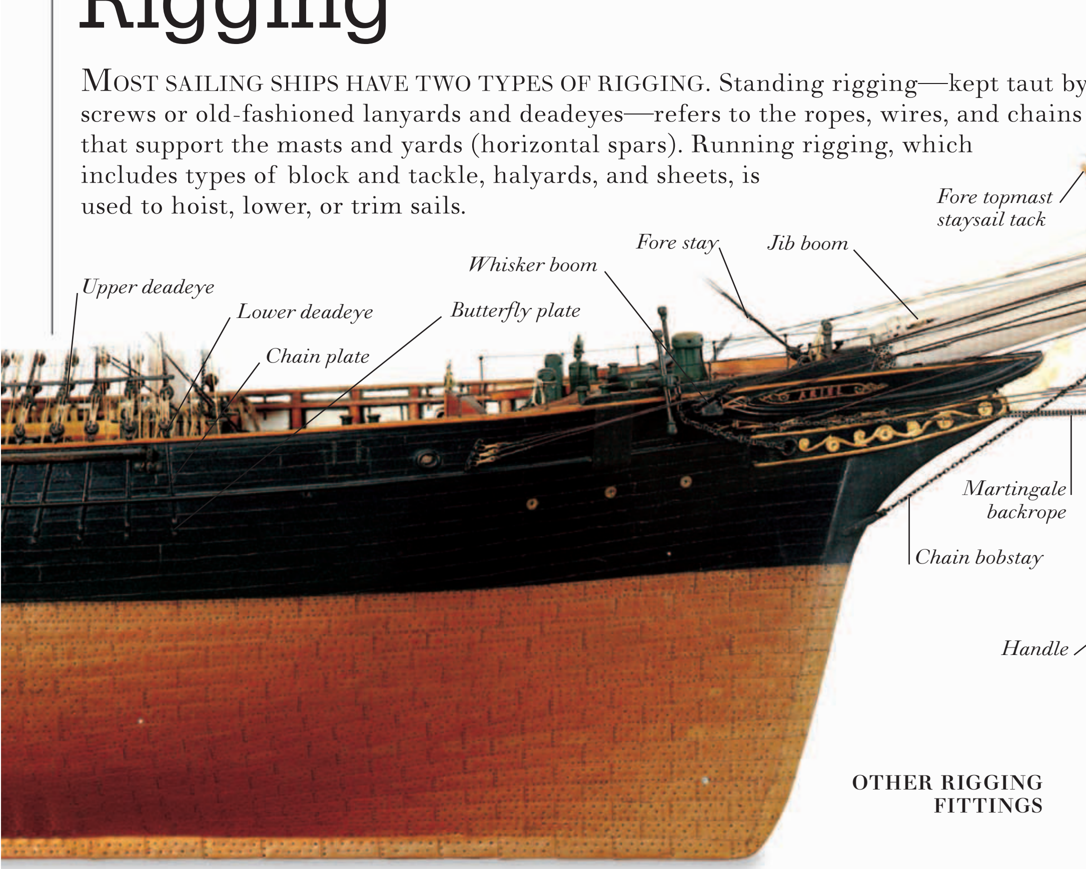
STERN


Cove
Taffrail
Screen bulkhead
Balcony
Side counter timber
Upper counter rail
Counter timber
Drop
Tuck
Lower counter rail
Gunport lid
Tuck rail
Filling transom
After fashion piece
Wing transom
Cant frame
Timber under transom


Side step
Eye bolt
Main bitt
Ledge
Hatch coaming/ shot garland
Spirketting
Backstay stool
Companion ladder
Master's sea cabin
Mizzen mast hole
Great cabin (captain's cabin)
Pilaster
Screen bulkhead
Channel
Coaming
Ledge (batten)
Standard knee
Stern carving
Poop rail
Necking
Taffrail
Gunport drip (eyebrow; rigol)
Wardroom
Upper finishing
Grating
Gunport lid
Rail at break of poop deck
Mizzen bitt
Quarter gallery
Main mast hole
Mast partner
Lodging knee
Clerk's cabin
Quarterdeck
Poop deck

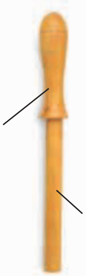
Rigging

MOST SAILING SHIPS HAVE TWO TYPES OF RIGGING. Standing rigging—kept taut by rigging screws or old-fashioned lanyards and deadeyes—refers to the ropes, wires, and chains that support the masts and yards (horizontal spars). Running rigging, which includes types of block and tackle, halyards, and sheets, is used to hoist, lower, or trim sails.



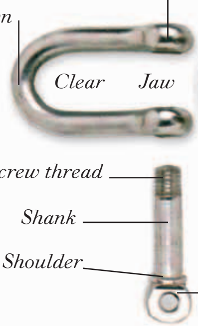
BOWSPRIT AND JIB BOOM

OTHER RIGGING FITTINGS



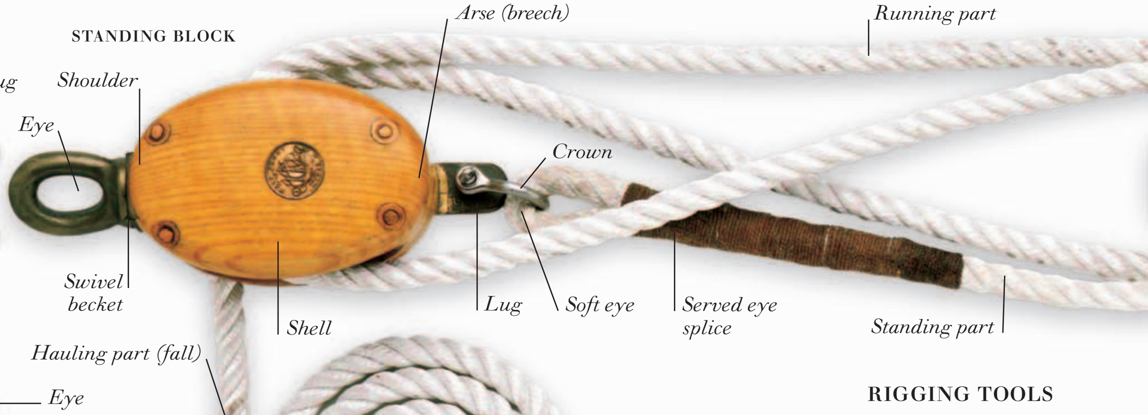
BELAYING PIN

MAST BAND



SHACKLE

SHACKLE PIN

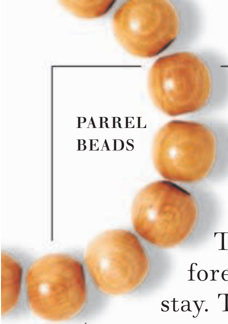


BLOCK AND TACKLE (PURCHASE)

RIGGING TOOLS

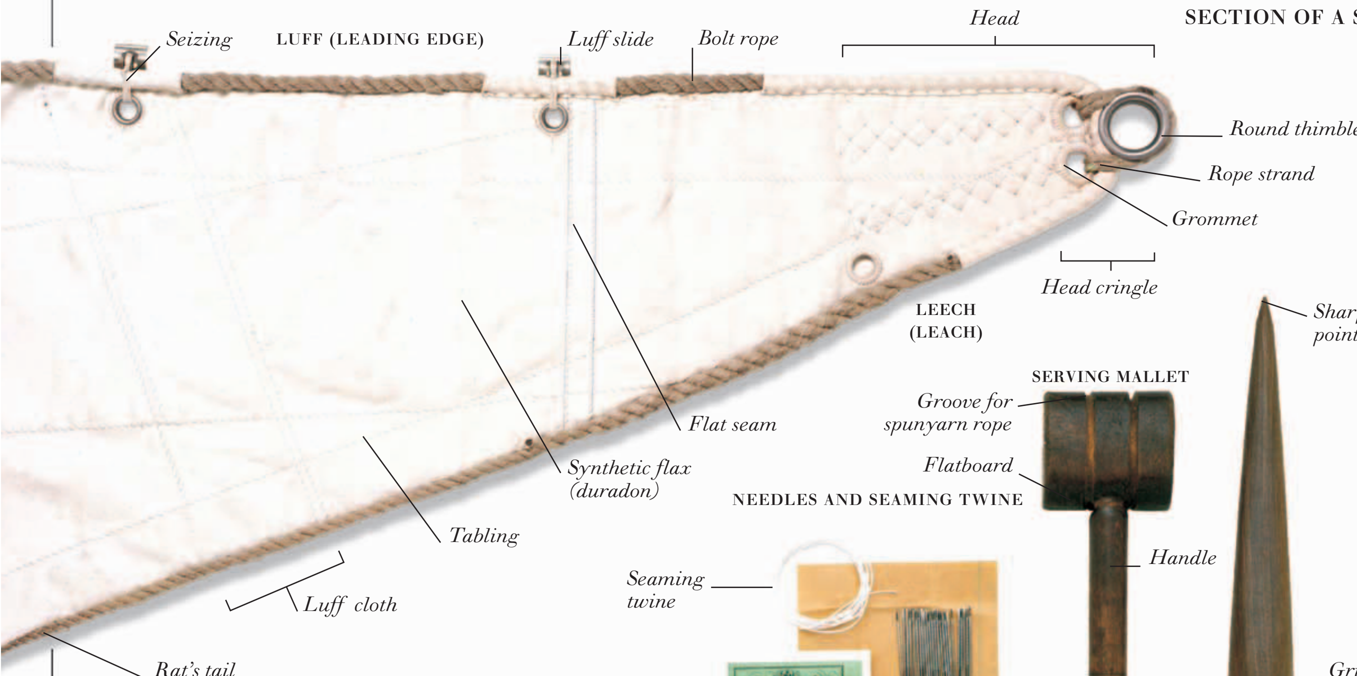
RIGGER'S GAUGE FOR MEASURING THE DIAMETER OF ROPE OR WIRE


Fore royal stay
Flying jib tack
Outer jib tack
Outer martingale stay
Middle martingale stay
Inner martingale stay
Eye
SCORED BULLSEYE FAIRLEAD
Eye
Strap
SHEET LEAD
Base
RUNNING BLOCK
Double rope becket
DUTCH TRIPLE FIDDLE BLOCK
Flat seizing
Swallow
Strop
Sheave
Shoulder
Back
Shank
HOOK
Crown
Clear
Jaw
Fixed lug
Bill
Cheek
Pin cover
ROPE SERVING MALLET
SPLICING FID
HEAVER FOR WIRE SERVING
PRICKERS
HOLLOW SPIKE FOR WIRE
MARLINSPIKE
LANYARD AND DEADEYES
Leather pointing
Turk's head
Hitched hauling end
UPPER DEADEYE
Swallow
Tail
Standing part
LANYARD
LOWER DEADEYE
Grooving
Binding
Bolt
Nut
Face
Seizing
RIGGING SCREW (TURNBUCKLE)
Shroud
Spun yarn serving
Flat wire seizing
Solid heart thimble
Cotter pin
Fork end
Right hand screw
Open body
Left hand screw
Safe working load mark
Swallow
Shoulder
Eye
Crown



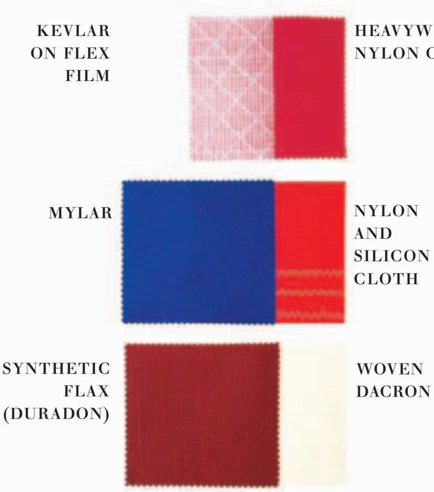
Sails

THERE ARE TWO MAIN TYPES OF SAIL, often used in combination. Square sails are driving sails. They are usually attached by parrels to yards, square to the mast to catch the following wind. On fore-and-aft sails, such as lateen and lug sails, the luff (leading edge) usually abuts a mast or a stay. The head of the sail may abut a gaff, and the foot a boom. Around the world, a great range of rigs (sail patterns), such as the ketch, lugger, and schooner, have evolved to suit local needs. Sails are made from strips of cloth, cut to give the sail a belly and strong enough to resist the most violent of winds. Cotton and flax are the traditional sail materials, but synthetic fabrics are now commonly used.



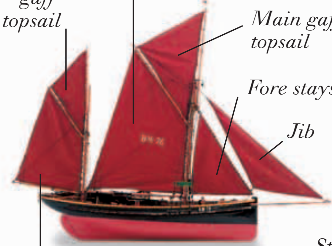
SECTION OF A SAIL

SAILCLOTHS

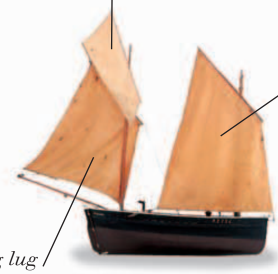


SAILMAKING TOOLS

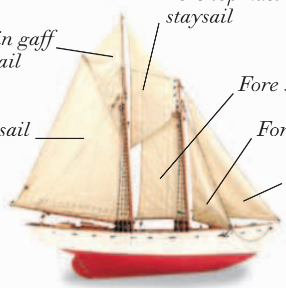
SAILING RIGS



KETCH

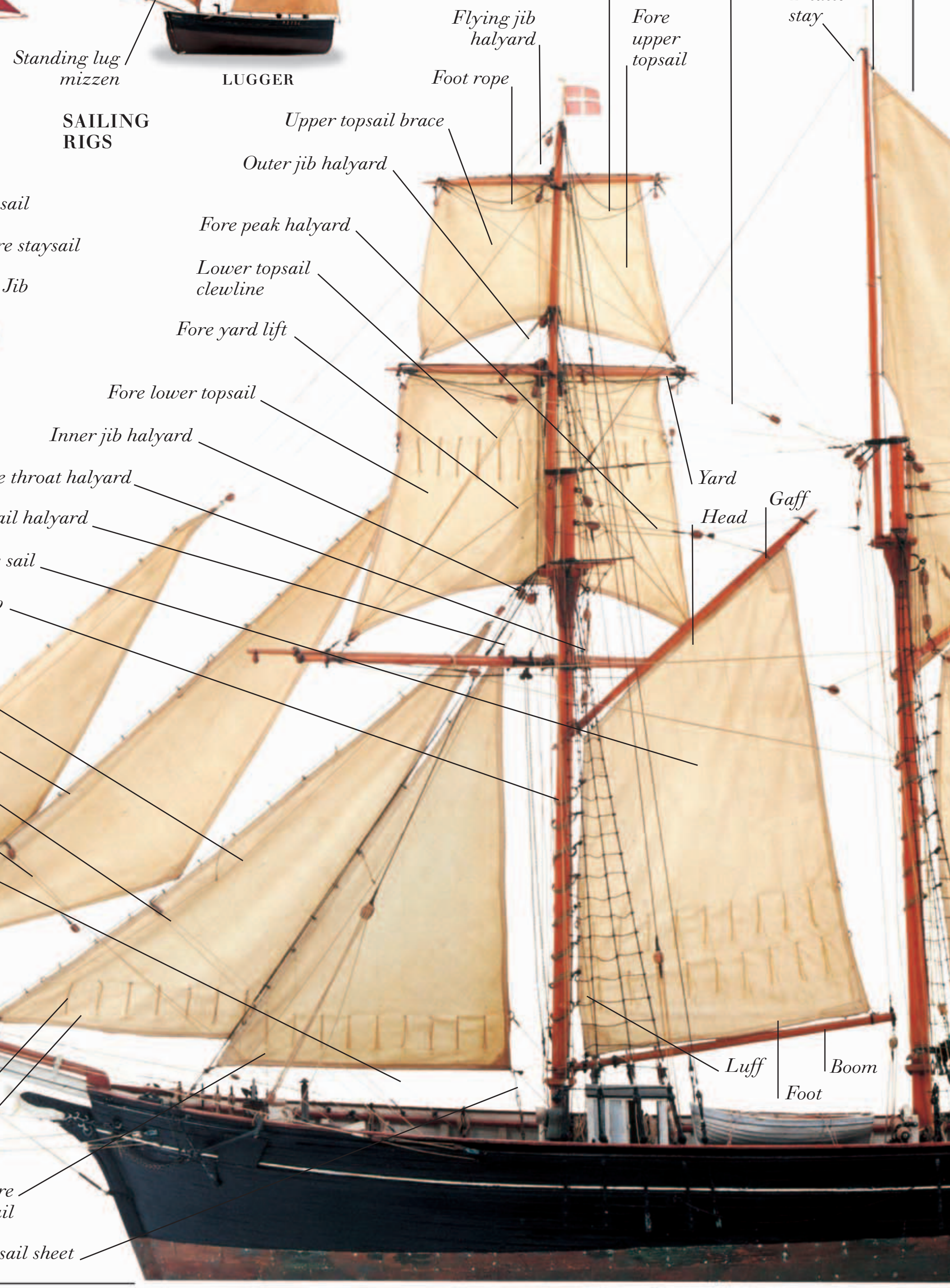


LUGGER



FISHERMAN'S SCHOONER (FORE-AND-AFT SCHOONER)

SAILS AND RUNNING RIGGING OF A DOUBLE TOPSAIL SCHOONER



Mooring and anchoring

FOR LARGE VESSELS IN OPEN WATER, ANCHORAGE IS ESSENTIAL. By holding a ship securely to the seabed, an anchor prevents the vessel from being at the mercy of wave, tide, and current. The earliest anchors were nothing more than stones. In later years, many anchors had a standard design, much like the Admiralty pattern anchor shown on this page. The Danforth anchor is somewhat different. It has particularly deep flukes to give it great holding power. On large sailing ships, anchors were worked by teams of sailors. They turned the drum of a capstan by pushing on bars slotted into the revolving cylinder. This, in turn, lifted or lowered the anchor chain. In calm harbors and estuaries, ships can moor (make fast) without using anchors. Berthing ropes can be attached to bollards both inboard and on the quayside. Berthing ropes are joined to each other by bends, like those opposite.

STONE ANCHOR (KILLICK)

TYPES OF ANCHOR

CLOSE-STOWING ANCHOR

CQR ANCHOR (SECURE ANCHOR; PLOW ANCHOR)

ADMIRALTY ANCHOR TYPE ACII

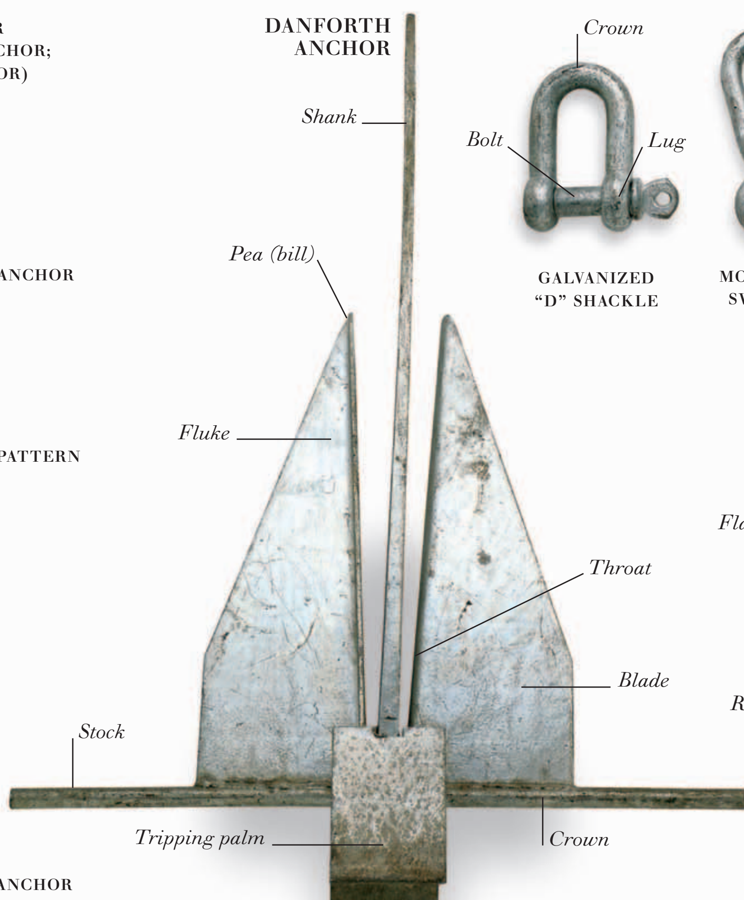
ADMIRALTY PATTERN ANCHOR

STOCKLESS ANCHOR

MUSHROOM ANCHOR (PERMANENT MOORING ANCHOR)

ANCHOR CHAIN

DANFORTH ANCHOR



SHACKLE, SWIVELS, AND LINK

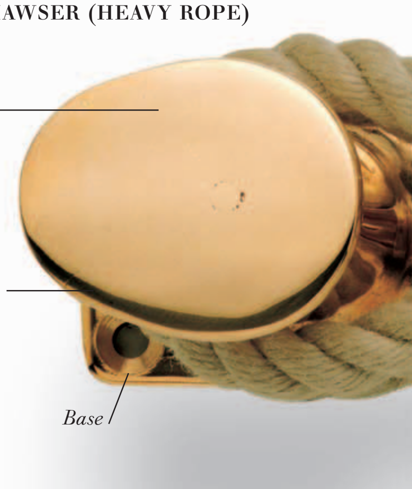
GALVANIZED "D" SHACKLE

MOORING SWIVEL

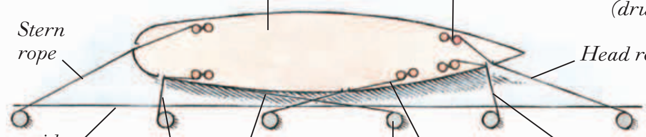
CHAIN SWIVEL

MAILLOT (SCREW LINK)

TWIN BOLLARDS WITH RAKED PILLARS AND A HAWSER (HEAVY ROPE)



BERTHING ROPES (HAWSERS)

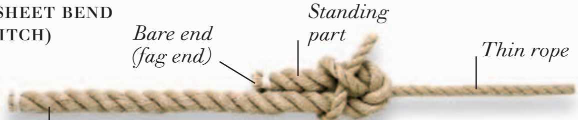


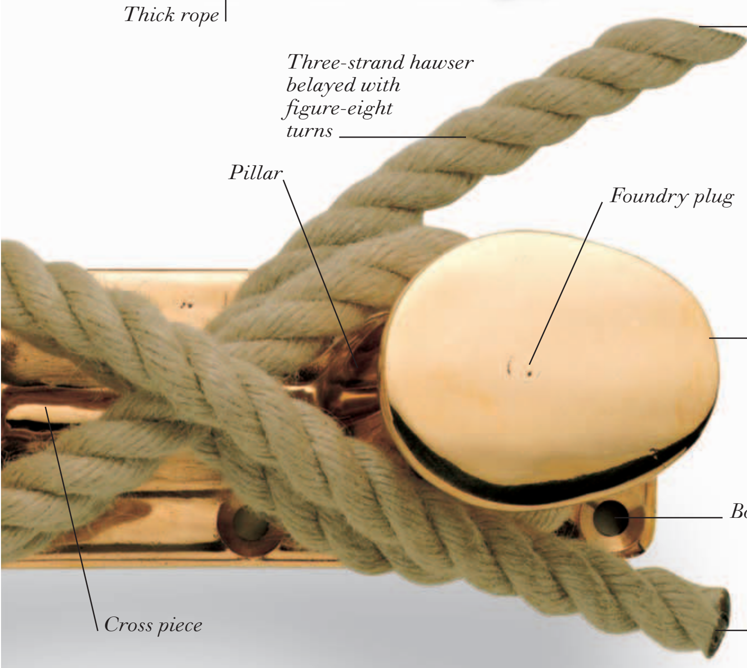
MOORING ROPE BENDS

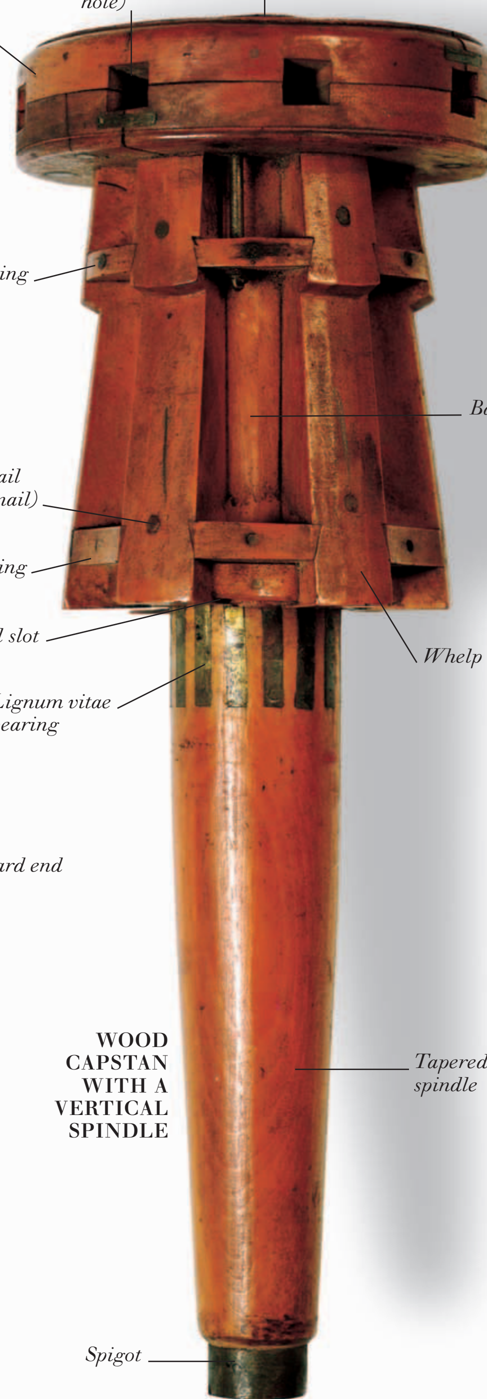
HAWSER BEND (TWO DOUBLE ROUND TURNS AND DOUBLE HALF HITCHES)

CARRICK BEND

SINGLE SHEET BEND (SWAB HITCH)





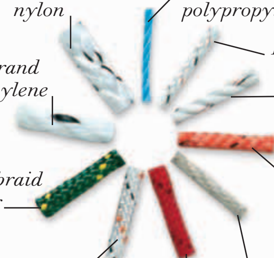


WOOD CAPSTAN WITH A VERTICAL SPINDLE

Ropes and knots

ALL KINDS OF ROPES ARE USED AT SEA, from thin twines and yarns to thick hawsers. Synthetic fibers have been developed specifically for use at sea. Nylon ropes stretch, and so are ideal for anchoring; polyester (frequently called by the trade name Dacron) has little stretch, so is ideal for halyards and sheets. Different knots have different uses. Knots that join two ropes are called bends; hitches join a rope to another object; and bowlines produce an eye (loop) in the end of a rope. Ropes can be joined by splicing (unraveling the ends and weaving them together) or seizing (lashing the ropes together side by side).

SYNTHETIC ROPES



FRENCH BOWLINE (PORTUGUESE BOWLINE)

HALF HITCH WITH SEIZING

ROPEWORK

REEF KNOT (SQUARE KNOT)

OVERHAND KNOT (HALF HITCH)

HUNTER'S BEND

ROLLING HITCH

CLOVE HITCH

MARLINSPIKE HITCH

BOWLINE


WORMING, PARCELING, AND SERVING

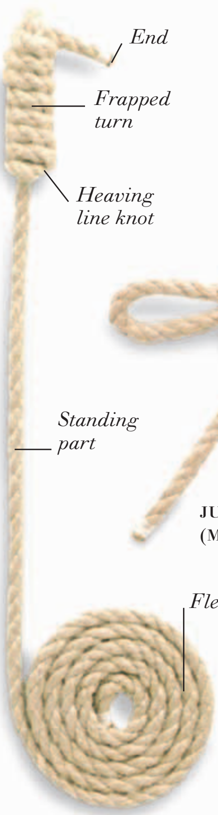
THUMB KNOT

SPANISH BOWLINE

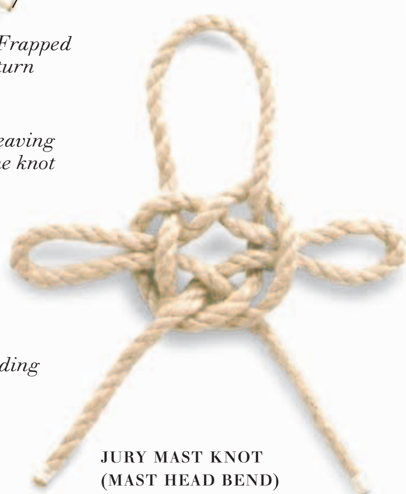
FLAT SEIZING
(ROUND SEIZING)

DOUBLE CARRICK BEND

LIGHTERMAN'S HITCH



HEAVING LINE



JURY MAST KNOT
(MAST HEAD BEND)

SHEET BEND (SWAB HITCH)

HEAVING LINE BEND

MANHARNESS KNOT
(BUTTERFLY KNOT;
ARTILLERY LOOP)

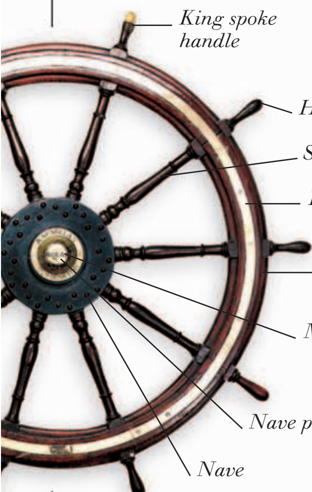
PINNED SHEEPSHANK

Hawser laid three-strand manilla rope with right-handed lay

Paddle wheels and propellers

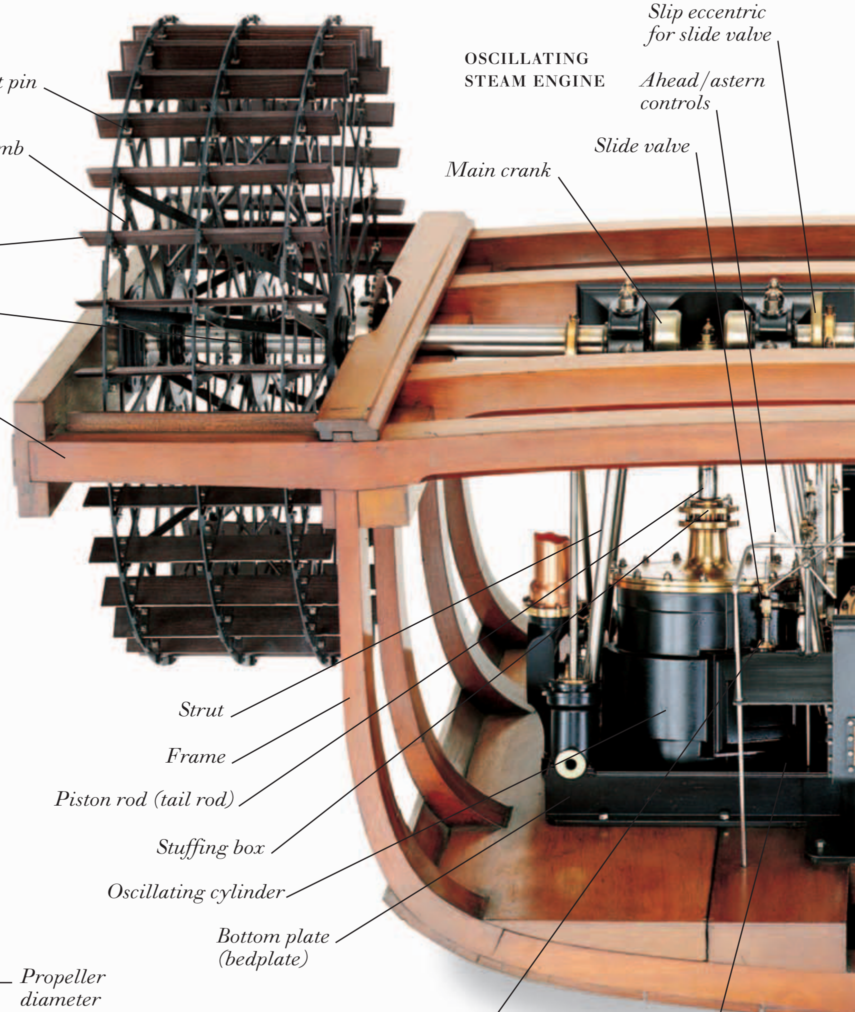
THE INVENTION OF THE STEAM ENGINE IN THE 18TH CENTURY made mechanically driven ships fitted with paddle wheels or propellers a viable alternative to sails. Paddle wheels have fixed or feathered floats, and the model shown below features both types. Feathered floats give more propulsive power than fixed floats because they are almost upright at all times in the water. Paddle wheels were superseded by the propeller on oceangoing vessels in the mid-19th century. Propellers are more efficient, work better in rough water, and are less vulnerable in collisions. The first propellers were two-bladed but later three- and four-bladed versions are more powerful; the shape and pitch of blades have also been refined over the years. At the beginning of the 18th century, tillers were superseded on many larger ships by the ship's wheel as a means of steering.

SHIP'S WHEEL

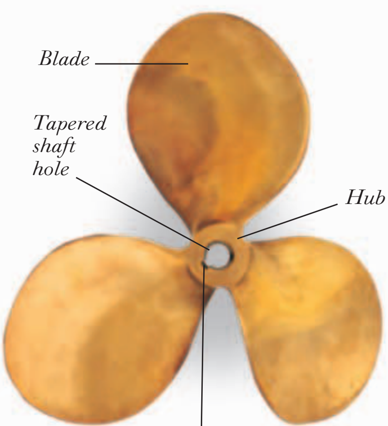


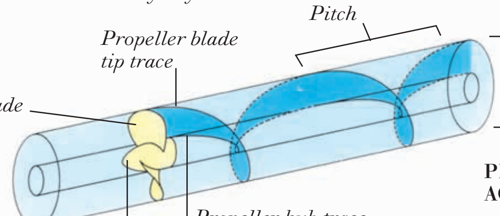
PADDLE WHEEL WITH FIXED FLOATS

OSCILLATING STEAM ENGINE



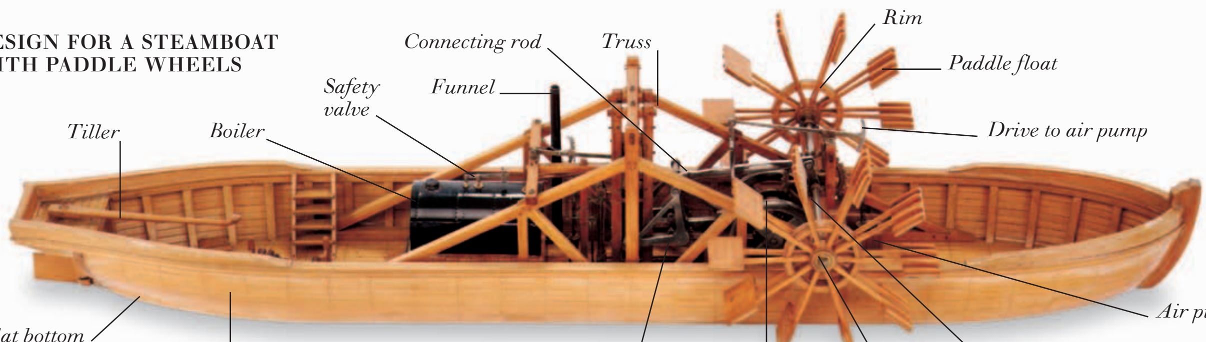
THREE-BLADED PROPELLER



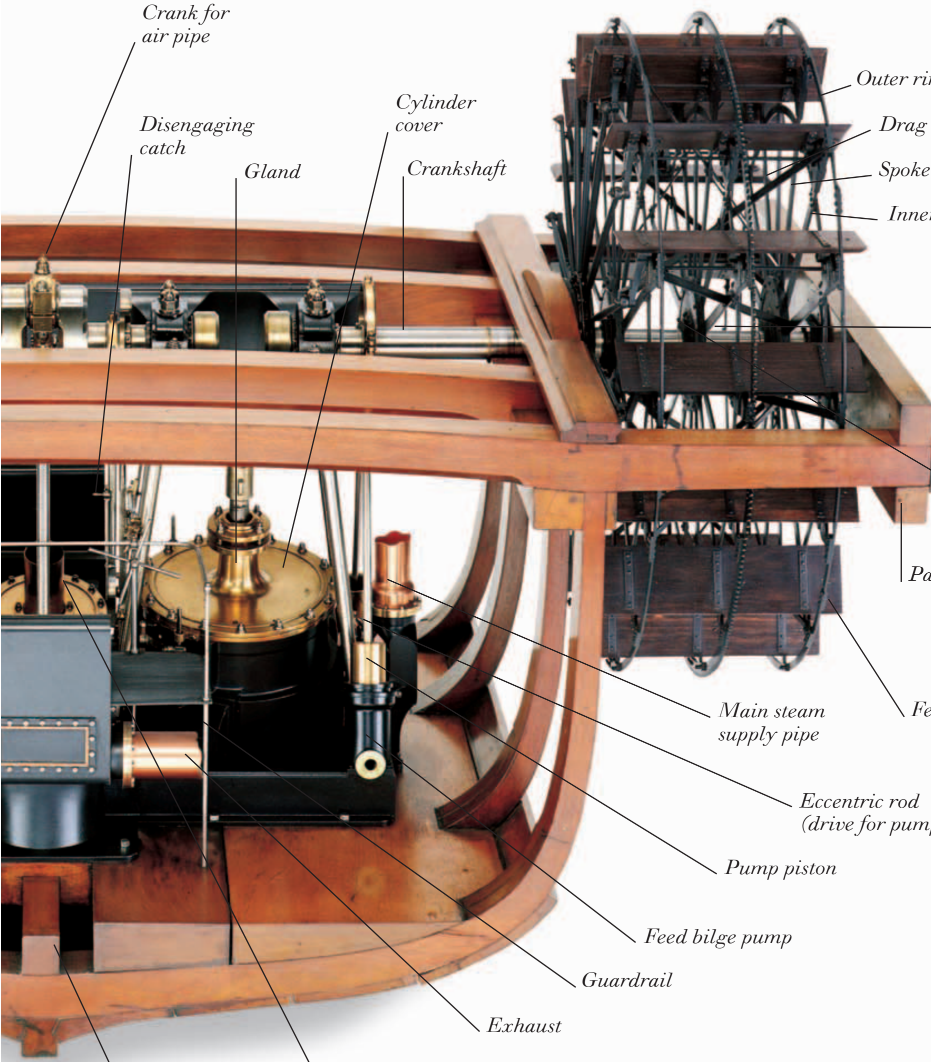


PROPELLER ACTION

DESIGN FOR A STEAMBOAT WITH PADDLE WHEELS



PADDLE WHEEL WITH FEATHERED FLOATS



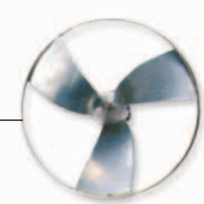
PROPULSION SYSTEM OF A 19TH CENTURY PADDLESTEAMER

TYPES OF PROPELLER

FROUDE'S EARLY TEST PROPELLER

TUG PROPELLER

THREE-BLADED PROPELLER

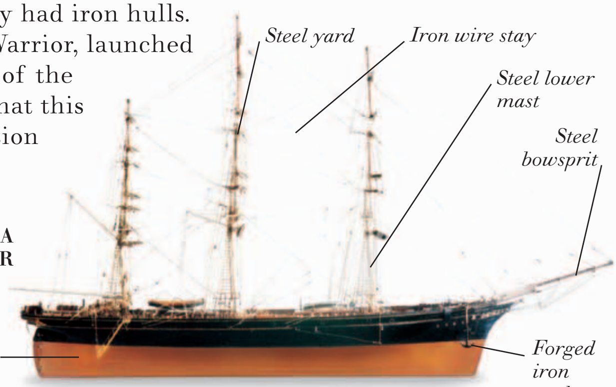


SHROUD RING PROPELLER

Anatomy of an iron ship

IRON PARTS WERE USED IN THE HULLS OF WOODEN SHIPS AS EARLY AS 1675, often in the same form as the wooden parts that they replaced. Eventually, as on the tea clipper Cutty Sark (below), iron rigging was found to be stronger than the traditional rope. The first "ironclads" were warships whose wooden hulls were protected by iron armor plates. Later ironclads actually had iron hulls. The model opposite is based on the British warship HMS Warrior, launched in 1860, the first battleship built entirely of iron. The plan of the iron paddlesteamer (bottom), built somewhat later, shows that this vessel was a sailing ship; but it also boasted a steam propulsion plant amidships that turned two side paddlewheels. Early iron hulls were made from plates that were painstakingly riveted together (as below), but by the 20th century vessels began to be welded together, whole sections at a time. The Second World War "liberty ship" was one of the first of these "production-line vessels."

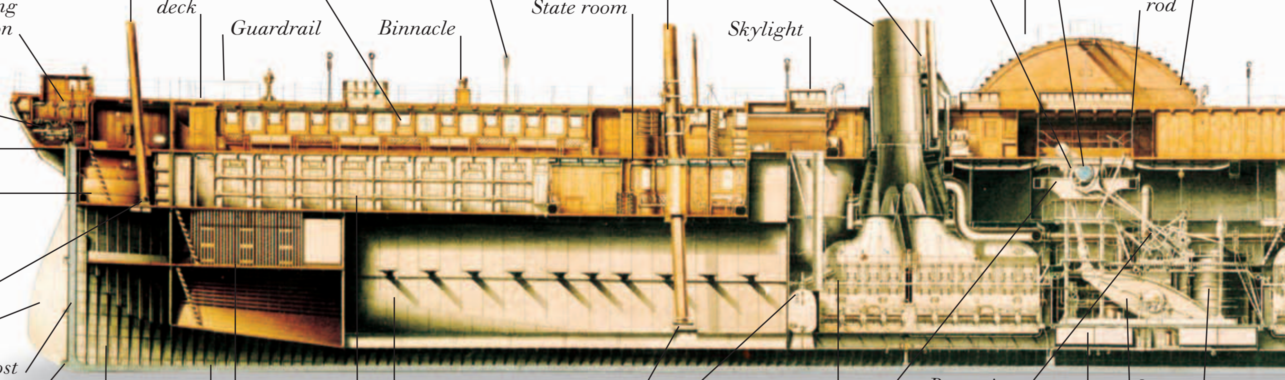
TEA CLIPPER



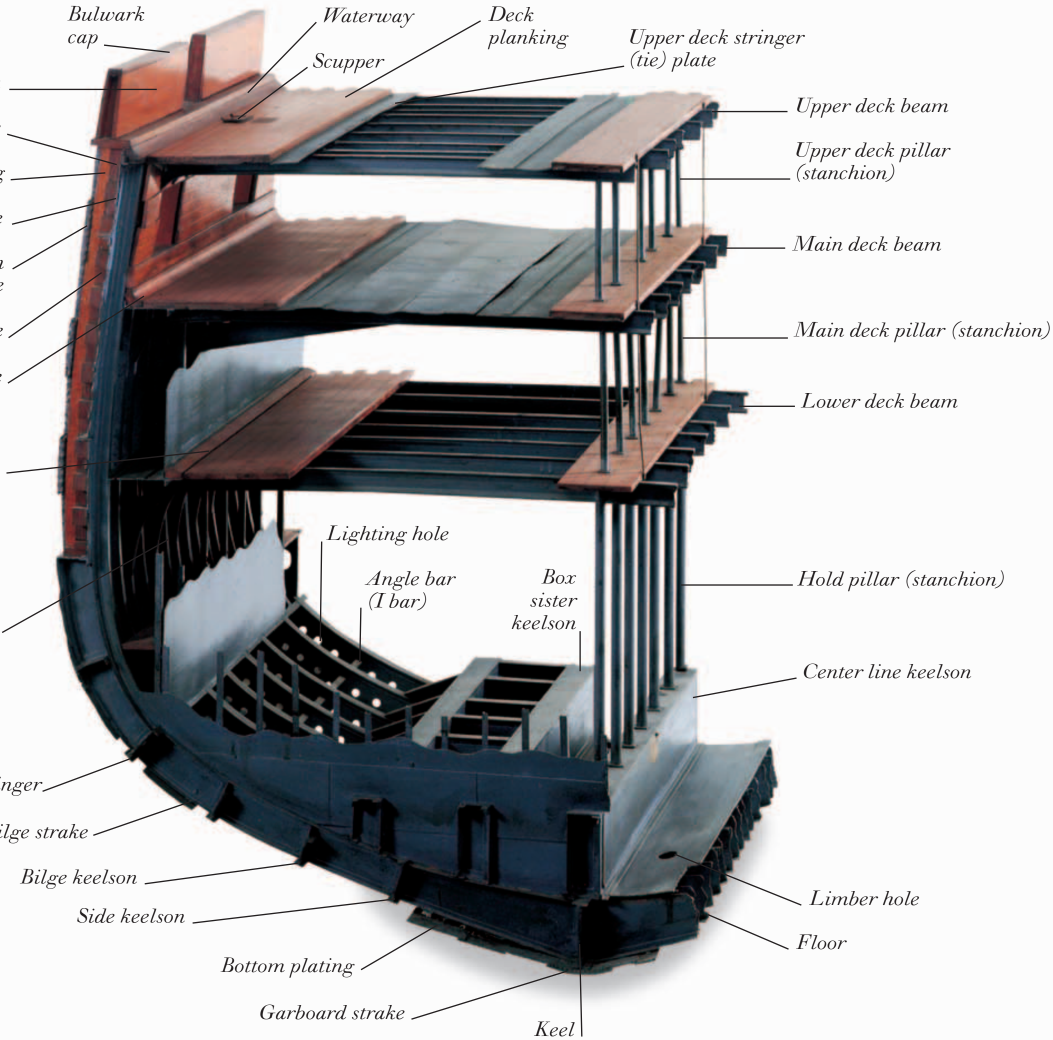
RIVETTED PLATES

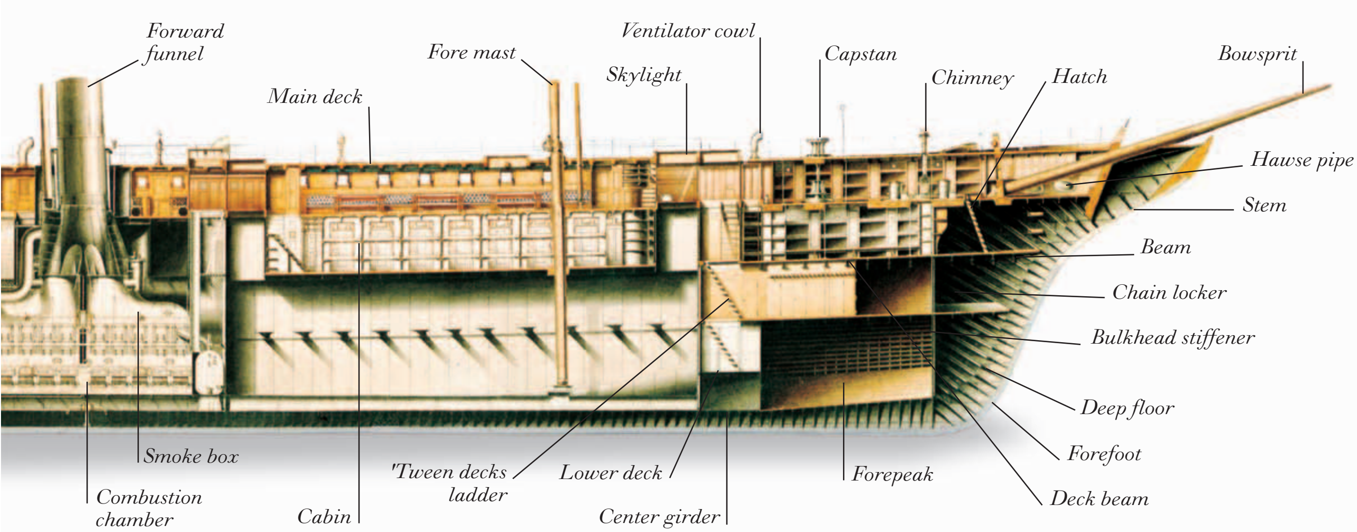
LIBERTY SHIP

PLAN OF AN IRON PADDLESTEAMER



CUTAWAY SECTION OF AN IRONCLAD



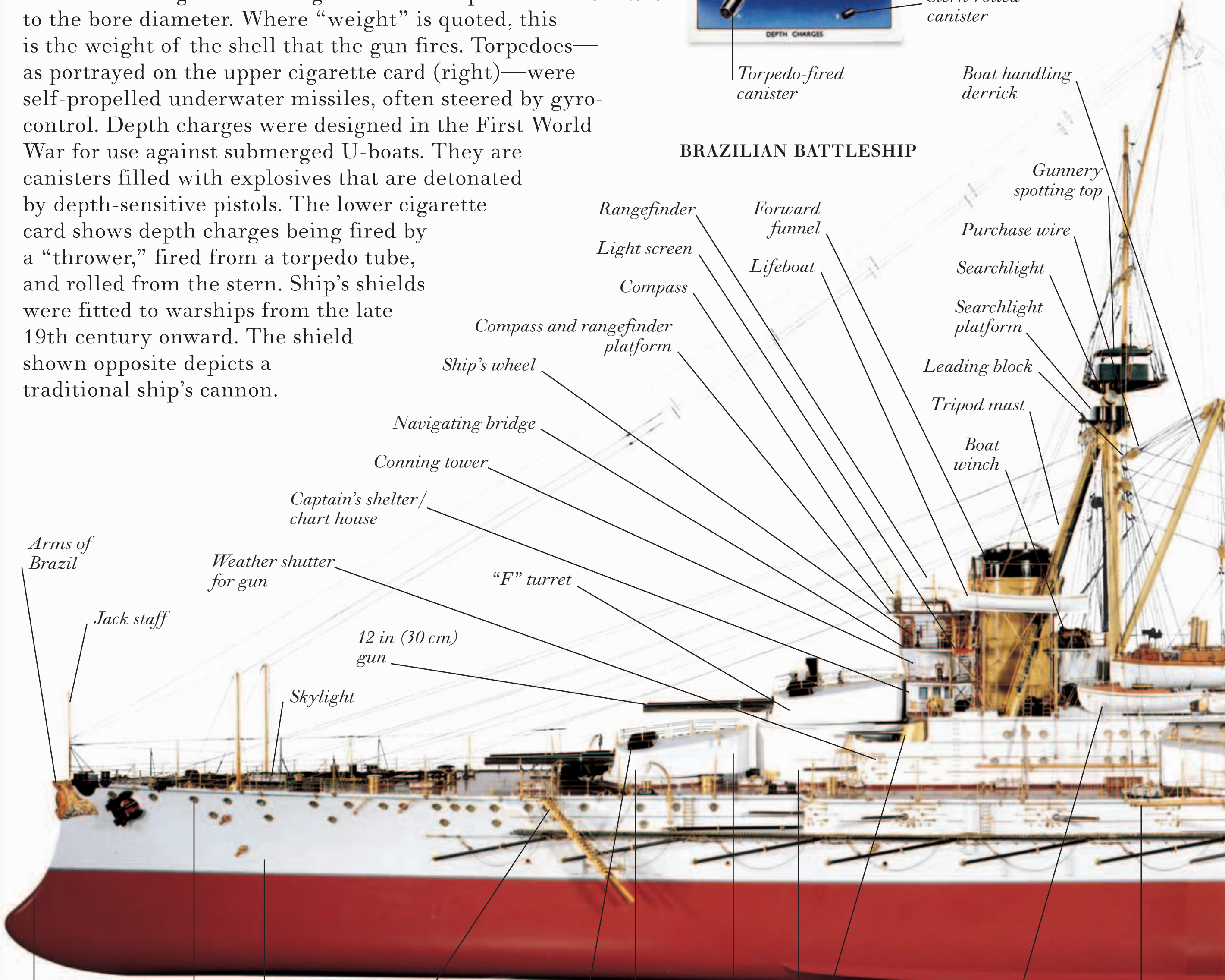


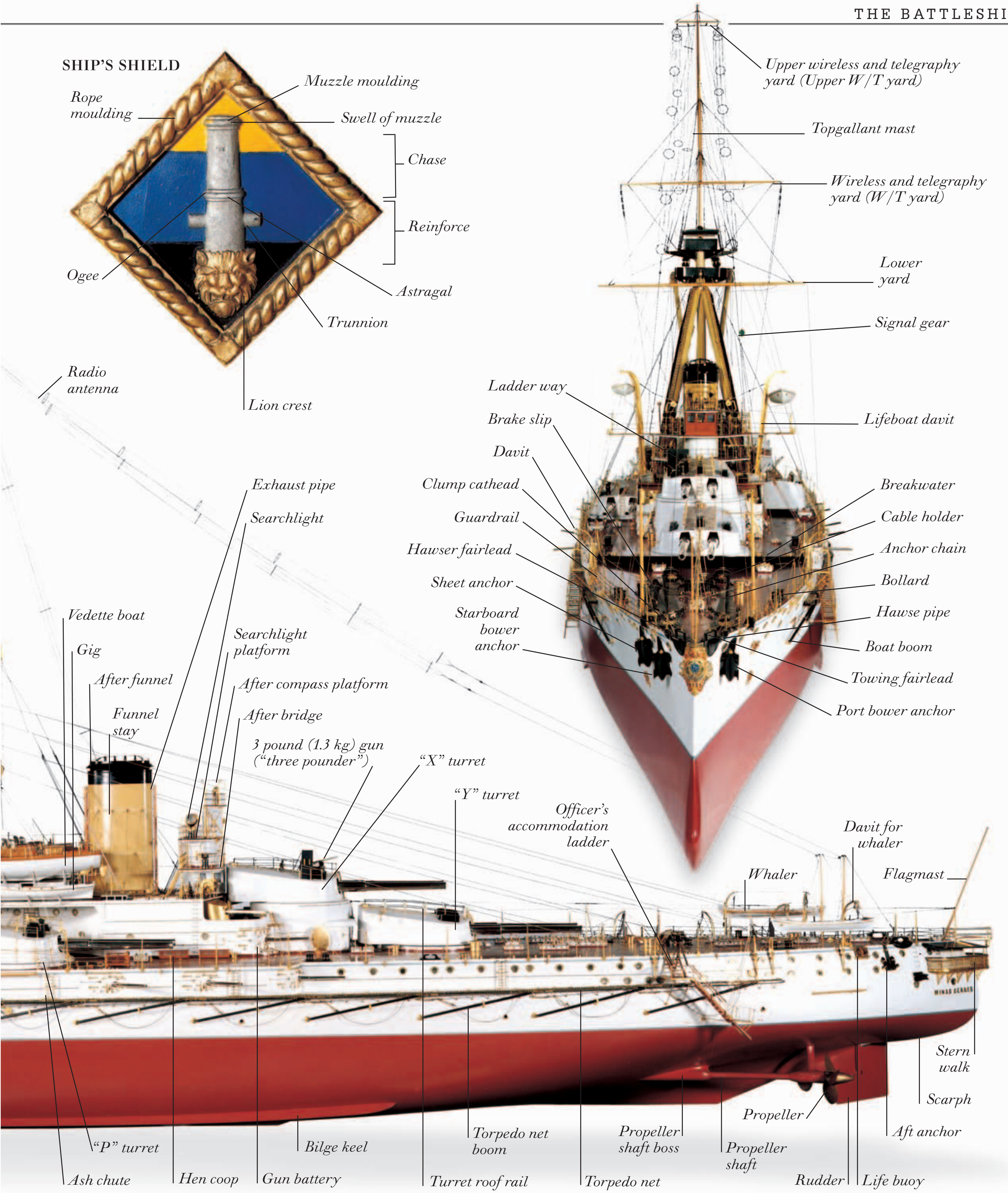
The battleship

IN THE EARLY YEARS OF THE 20TH CENTURY, sea warfare—attacking enemy vessels or defending a ship—was revolutionized by the introduction of Dreadnought-type battleships like the Brazilian vessel below. These new ships combined the latest advances in steam propulsion, gunnery, and armor plating. The gun turret was designed to fire shells over huge distances. It was protected by armor 12 in (30 cm) thick. The measurements given for the guns of this ship refer to the bore diameter. Where "weight" is quoted, this is the weight of the shell that the gun fires. Torpedoes—as portrayed on the upper cigarette card (right)—were self-propelled underwater missiles, often steered by gyro-control. Depth charges were designed in the First World War for use against submerged U-boats. They are canisters filled with explosives that are detonated by depth-sensitive pistols. The lower cigarette card shows depth charges being fired by a "thrower," fired from a torpedo tube, and rolled from the stern. Ship's shields were fitted to warships from the late 19th century onward. The shield shown opposite depicts a traditional ship's cannon.

20TH CENTURY WEAPONRY

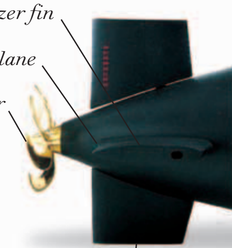
BRAZILIAN BATTLESHIP

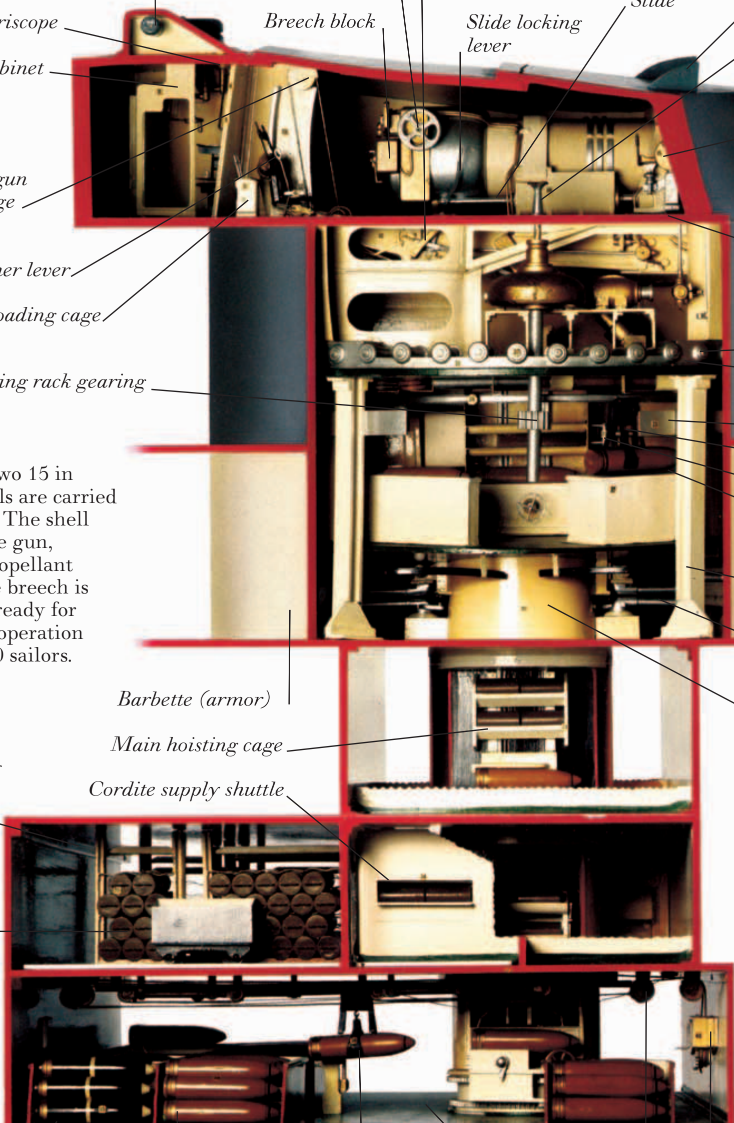



SHIP'S SHIELD
Rope moulding
Muzzle moulding
Swell of muzzle
Chase
Reinforce
Ogee
Astragal
Trunnion
Lion crest
Radio antenna
Upper wireless and telegraphy yard (Upper W/T yard)
Topgallant mast
Wireless and telegraphy yard (W/T yard)
Lower yard
Signal gear
Ladder way
Lifeboat davit
Brake slip
Davit
Clump cathead
Breakwater
Guardrail
Cable holder
Hawser fairlead
Anchor chain
Sheet anchor
Bollard
Starboard bower anchor
Hawse pipe
Boat boom
Towing fairlead
Port bower anchor
Exhaust pipe
Searchlight
Vedette boat
Gig
Searchlight platform
After funnel
After compass platform
Funnel stay
After bridge
3 pound (1.3 kg) gun ("three pounder")
"X" turret
"Y" turret
Officer's accommodation ladder
Davit for whaler
Whaler
Flagmast
Stern walk
Scarph
Propeller
Aft anchor
Propeller shaft boss
Propeller shaft
Torpedo net boom
"P" turret
Bilge keel
Ash chute
Hen coop
Gun battery
Turret roof rail
Torpedo net
Rudder
Life buoy

Frigates and submarines

FROM THE MID-19TH CENTURY, ARMORED SHIPS provided a new challenge to enemy craft. In response, huge revolving gun turrets were developed. These could fire in any direction, could be loaded from the breech very rapidly, and, instead of cannonballs, they discharged exploding shells. Modern fighting ships, like the frigate, combine heavy ship-borne armament with light helicopter weaponry. Submarines function below the surface of the sea. Their speed and ability to fire missiles from under water are their major assets. The nuclear submarine can stay under water for several years without refueling.

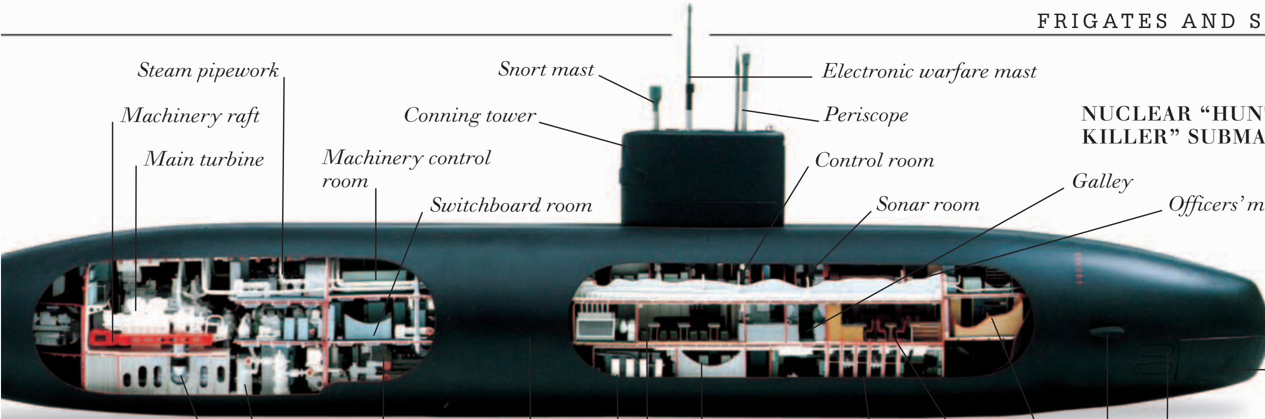




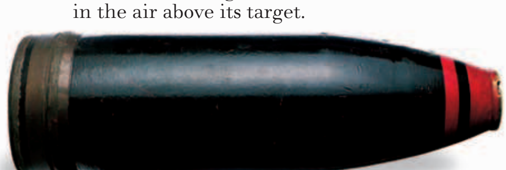
GUN TURRET
In this turret for two 15 in (37 cm) guns, shells are carried in a hoisting cage. The shell is rammed into the gun, followed by the propellant (charge). Once the breech is closed, the gun is ready for firing. The whole operation requires around 70 sailors.

FRIGATE

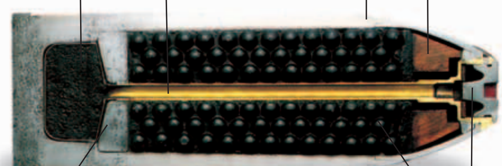
NUCLEAR "HUNTER-KILLER" SUBMARINE



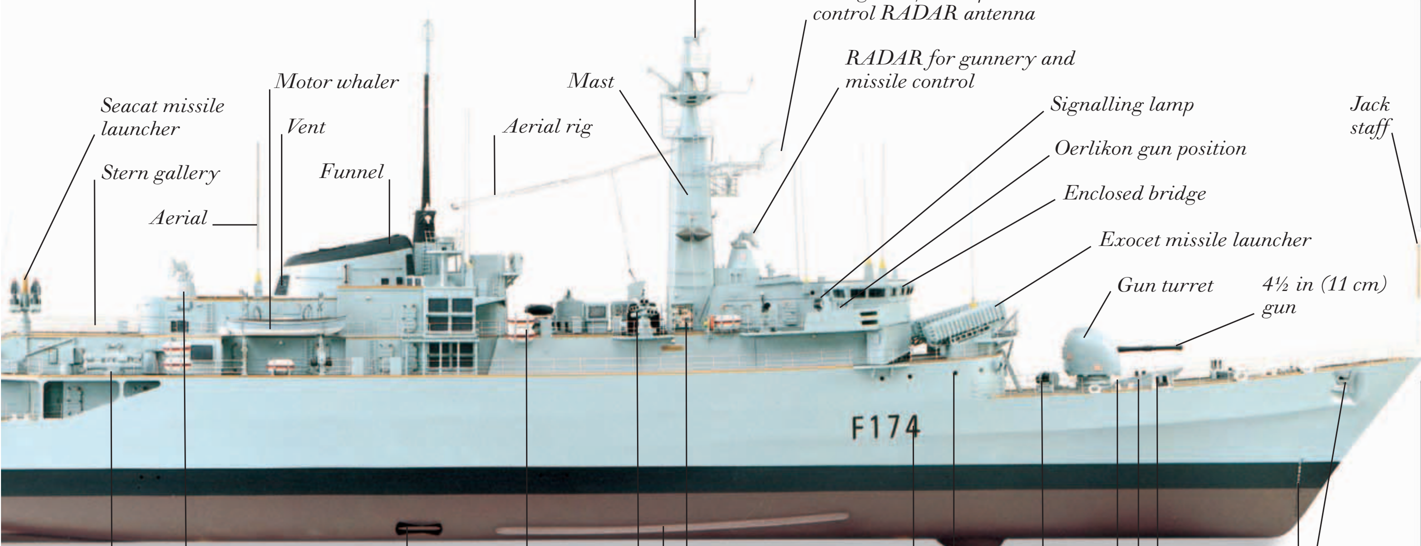
6 in (15 cm) SHELL
This shell is designed to burst in the air above its target.



SHELL CASE



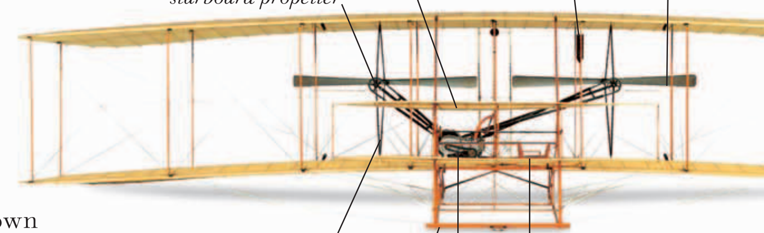
CROSS-SECTION OF THE SHELL



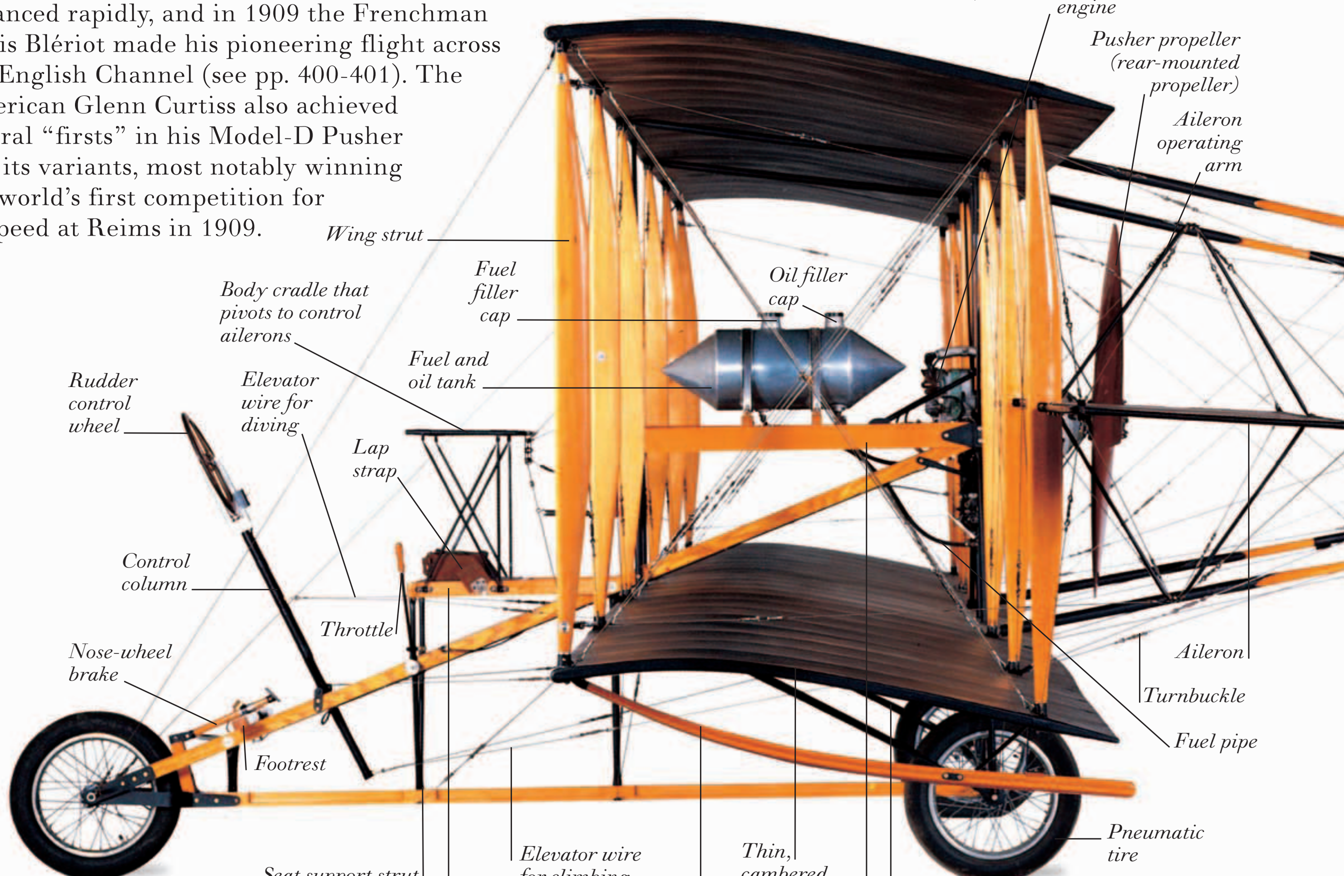
Pioneers of flight

FLIGHT HAS FASCINATED MANKIND for centuries, and countless unsuccessful flying machines have been designed. The first successful flight was made by the French Montgolfier brothers in 1783, when they flew a balloon over Paris. The next major advance was the development of gliders, notably by the Englishman Sir George Cayley, who in 1845 designed the first glider to make a sustained flight, and by the German Otto Lil ienthal, who became known as the world's first pilot because he managed to achieve controlled flights. However, powered flight did not become a practical possibility until the invention of lightweight, gas-driven internal combustion engines at the end of the 19th century. Then, in 1903, the American brothers Orville and Wilbur Wright made the first powered flight in their Wright Flyer biplane, which used a four-cylinder, gas-driven engine. Aircraft design advanced rapidly, and in 1909 the Frenchman Louis Blériot made his pioneering flight across the English Channel (see pp. 400-401). The American Glenn Curtiss also achieved several "firsts" in his Model-D Pusher and its variants, most notably winning the world's first competition for airspeed at Reims in 1909.

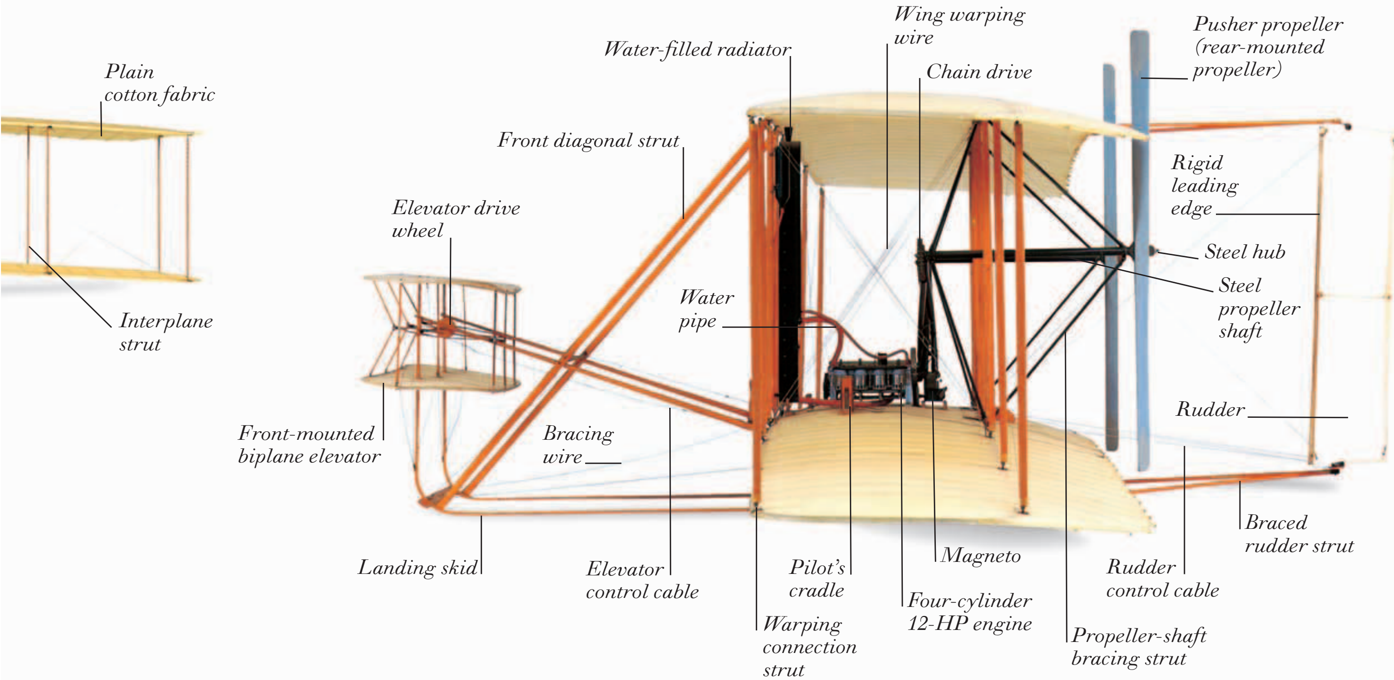
FRONT VIEW OF WRIGHT FLYER, 1903

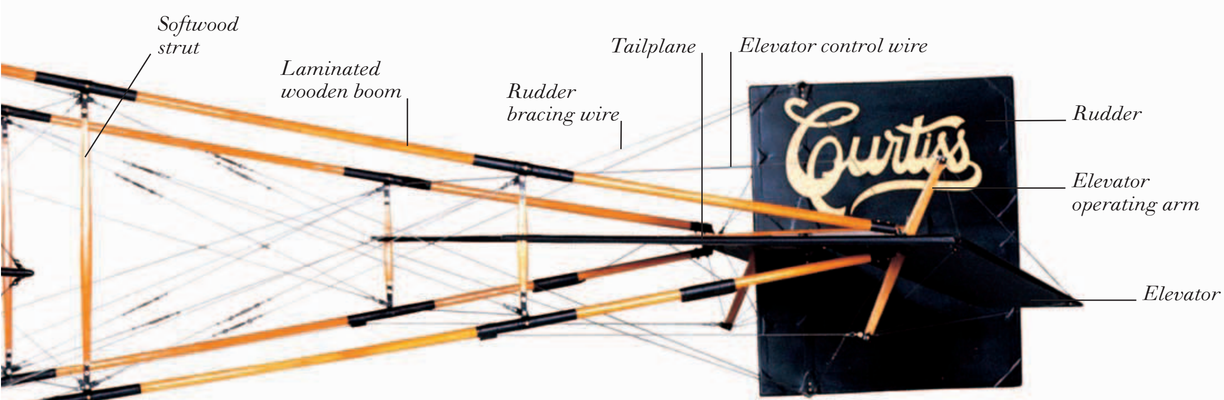


SIDE VIEW OF CURTISS MODEL-D PUSHER, 1911

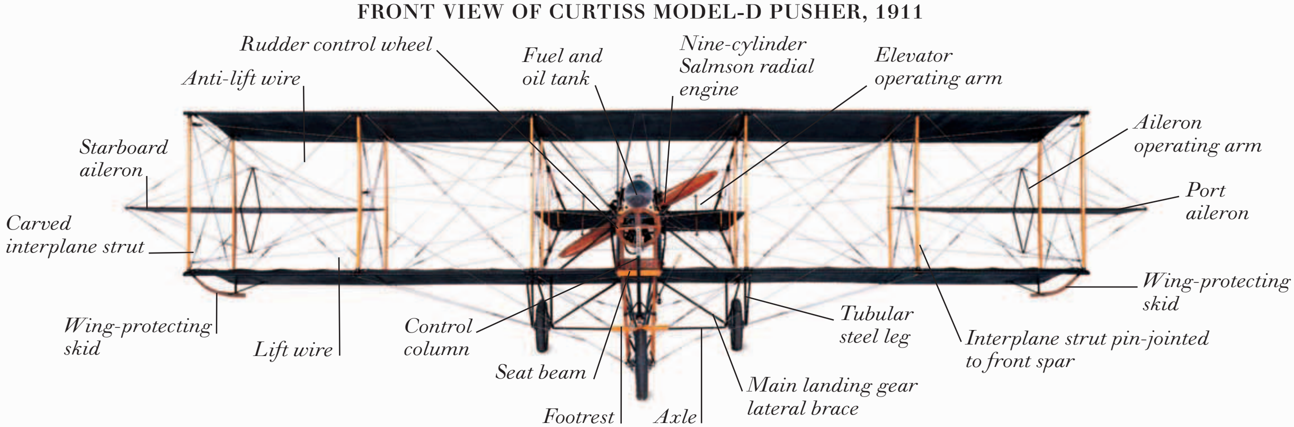


SIDE VIEW OF WRIGHT FLYER, 1903





FRONT VIEW OF CURTISS MODEL-D PUSHER, 1911

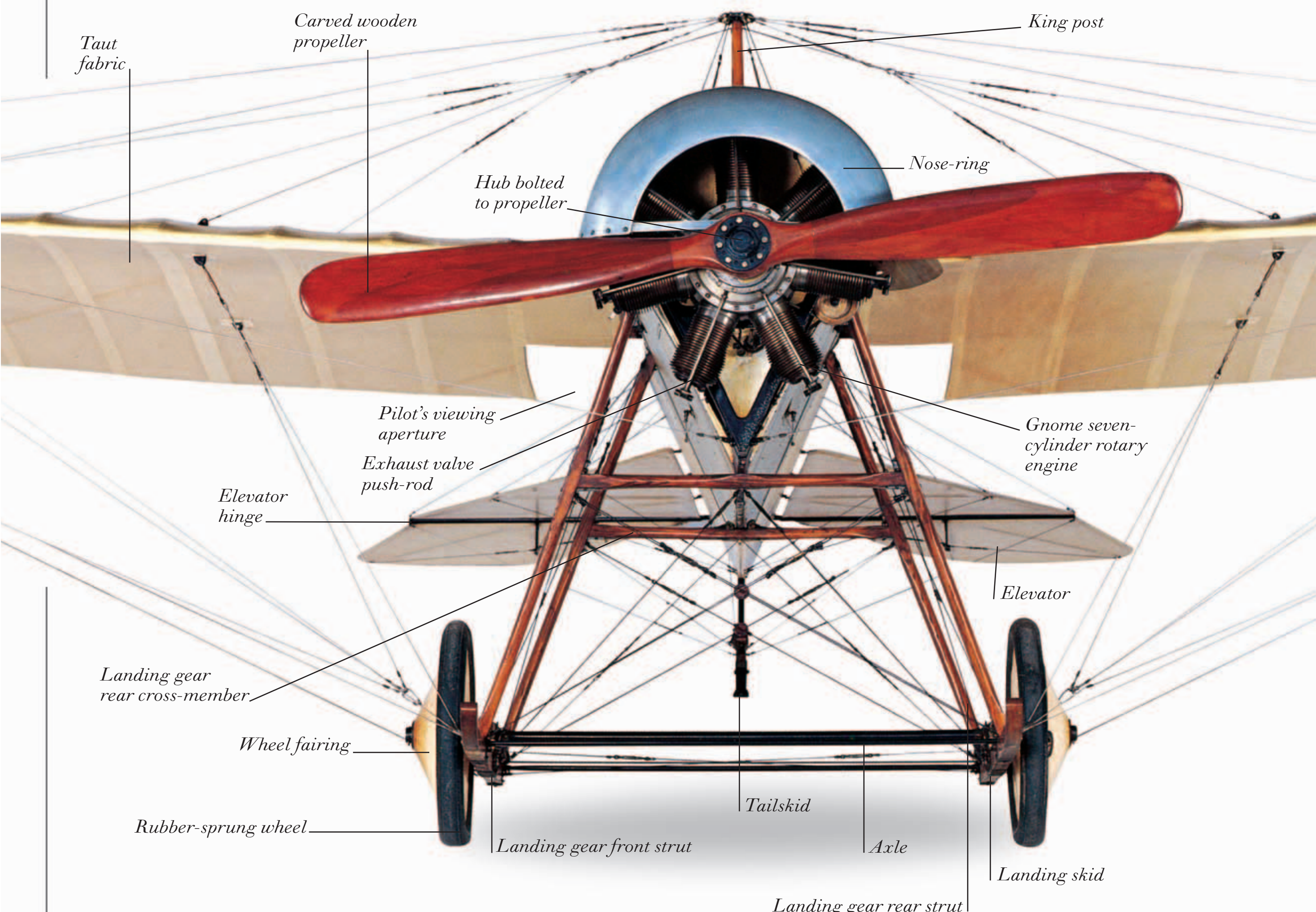


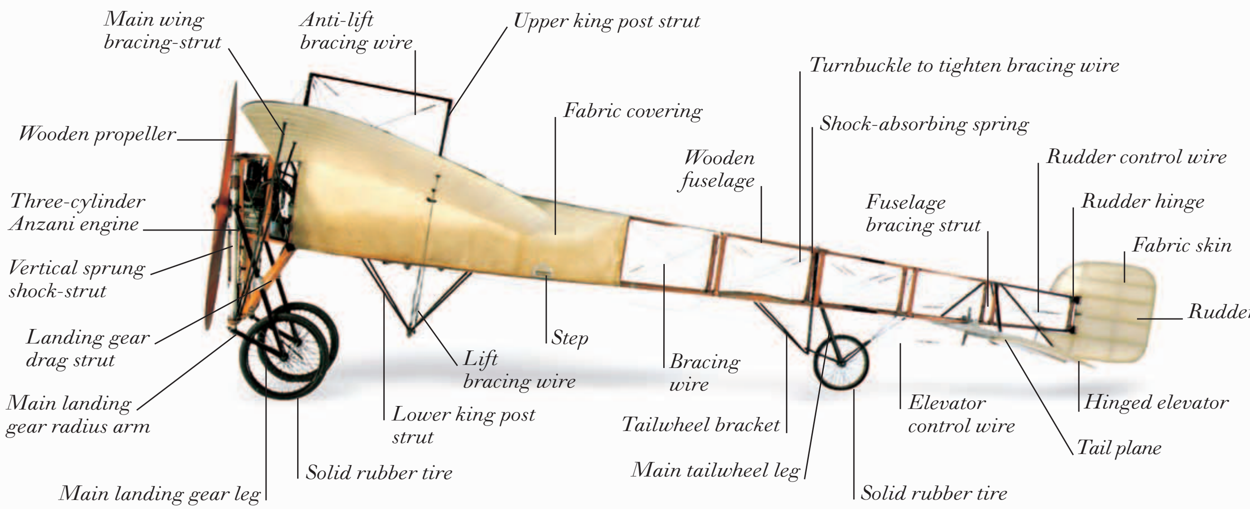
Early monoplanes

RUMPLER MONOPLANE, 1908

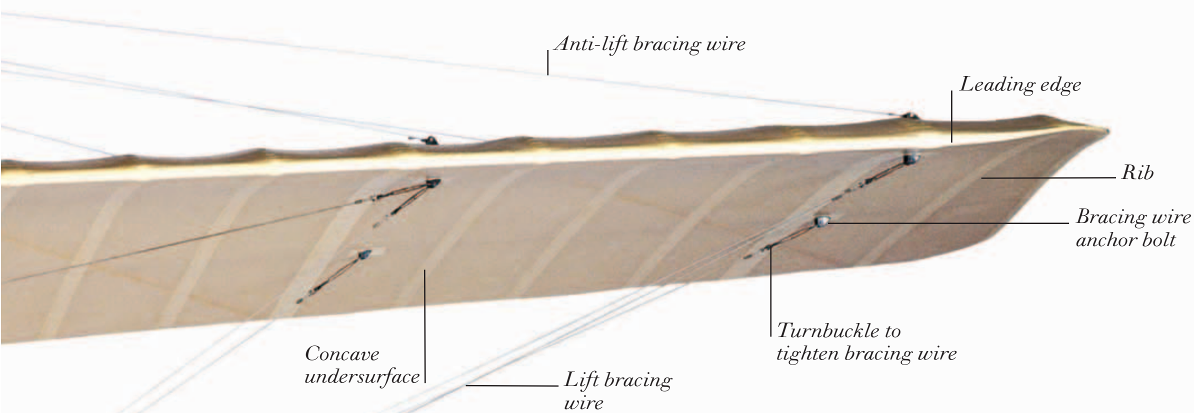
MONOPLANES HAVE ONE WING on each side of the fuselage. The principal disadvantage of this arrangement in early, wooden-framed aircraft was that single wings were weak and required strong wires to brace them to king posts above and below the fuselage. However, single wings also had advantages: they experienced less drag than multiple wings, allowing greater speed; they also made aircraft more manoeuvrable because single wings were easier to warp (twist) than double wings, and warping the wings was how pilots controlled the roll of early aircraft. By 1912, the French pilot Louis Blériot had used a monoplane to make the first flight across the English Channel, and the Briton Robert Blackburn and the Frenchman Armand Deperdussin had proved the greater speed of monoplanes. However, a spate of crashes caused by broken wings discouraged monoplane production, except in Germany, where all-metal monoplanes were developed in 1917. The wings of all-metal monoplanes did not need strengthening by struts or bracing wires, but despite this, such planes were not widely adopted until the 1930s.

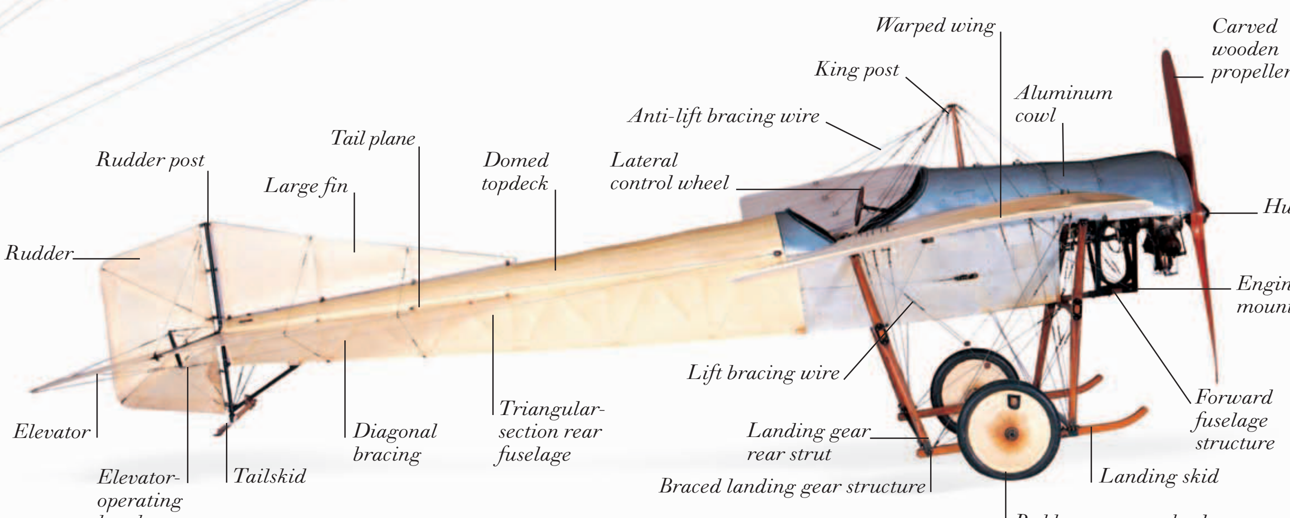
FRONT VIEW OF BLACKBURN MONOPLANE, 1912





SIDE VIEW OF BLÉRIOT XI, 1909



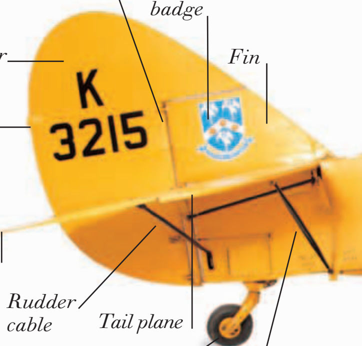


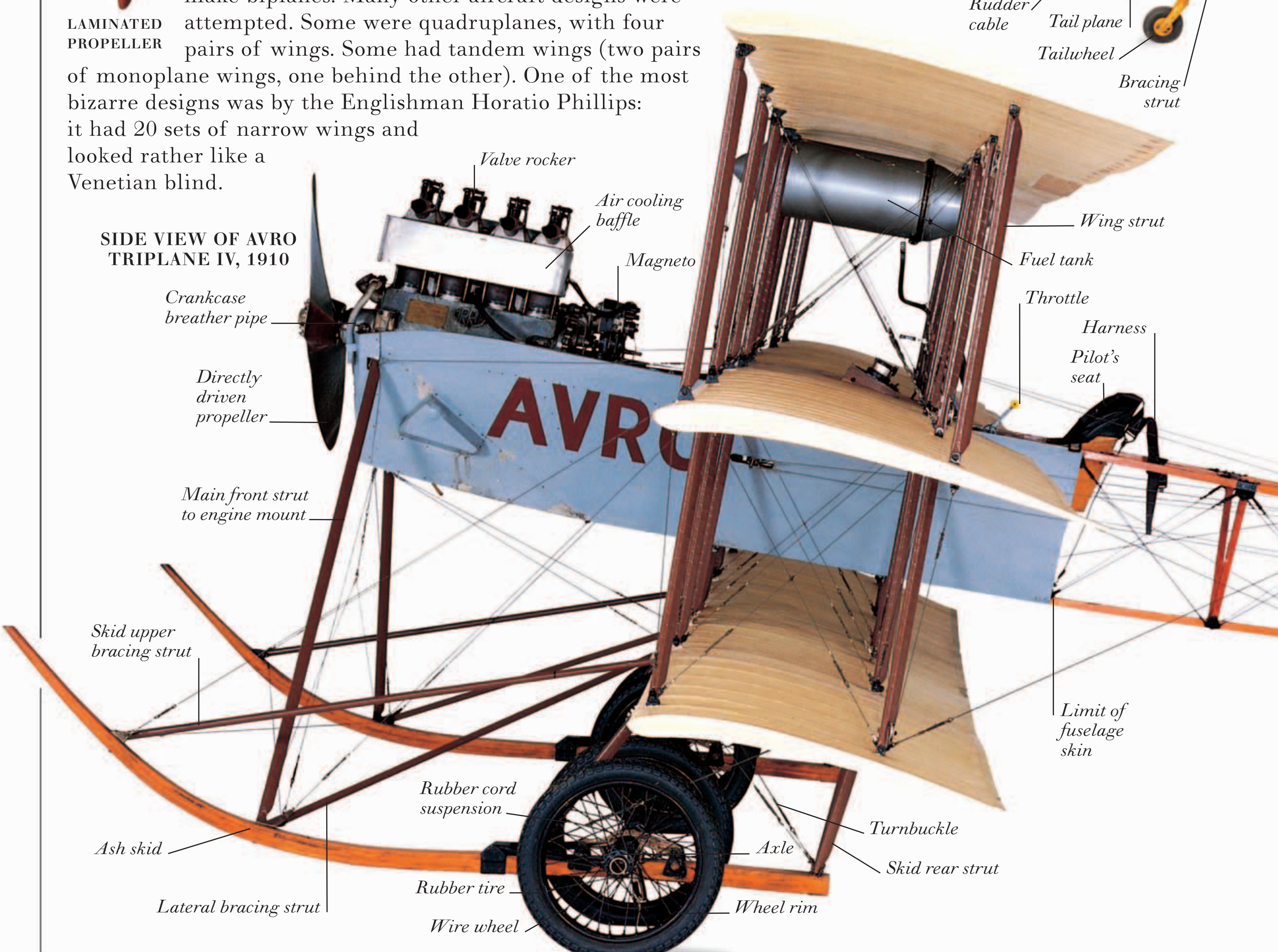
SIDE VIEW OF BLACKBURN MONOPLANE, 1912

Biplanes and triplanes

LAMINATED PROPELLER

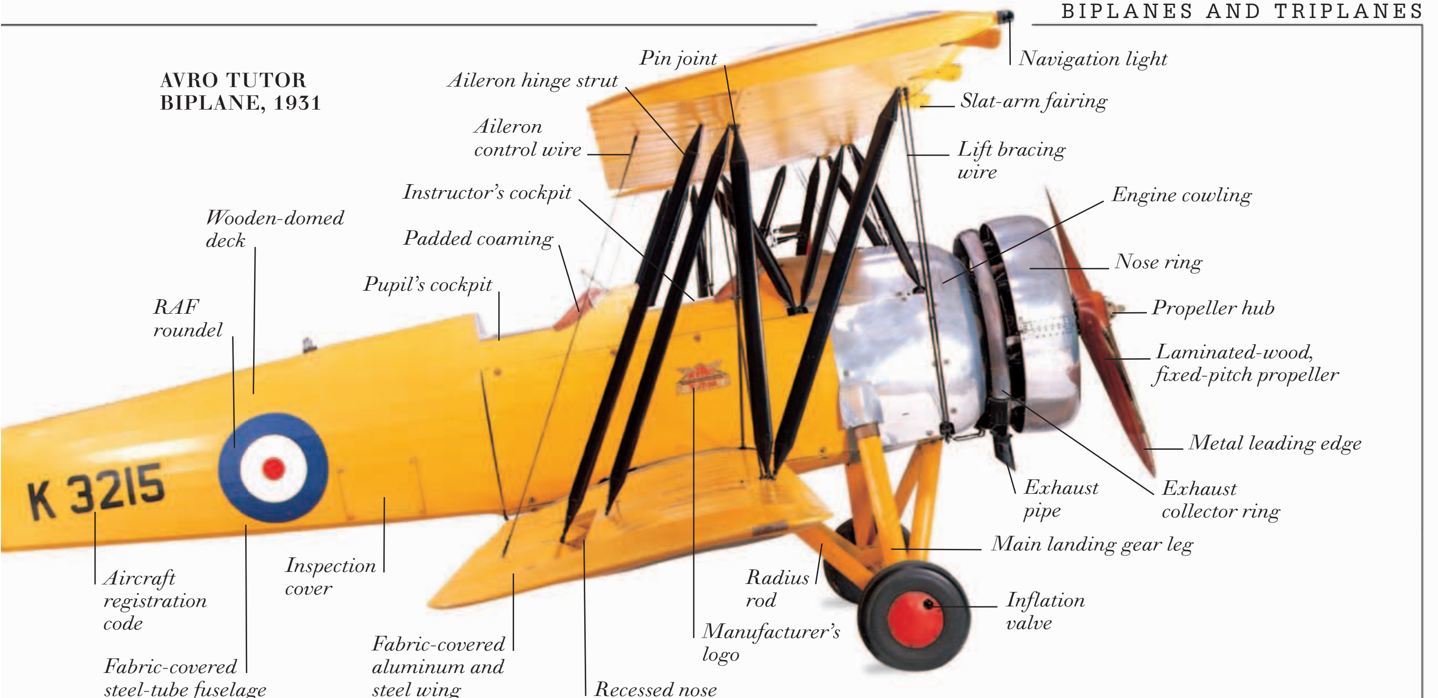
BIPLANES DOMINATED AIRCRAFT DESIGN until the 1930s, largely because some early monoplanes (see pp. 400-401) were too fragile to withstand the stresses of flight. The struts between biplanes' wings made the wings strong compared with those of early monoplanes, although the greater surface area of biplanes' wings increased drag and reduced speed. Many aircraft designers also developed triplanes, which had a particular advantage over biplanes: more wings meant a shorter wingspan to achieve the same lifting power, and a shorter wingspan gave greater manoeuvrability. Triplanes were most successful as fighters during World War I, the German Fokker triplane being a notable example. However, the greater maneuverability of triplanes was no advantage for normal flying and so most manufacturers continued to make biplanes. Many other aircraft designs were attempted. Some were quadruplanes, with four pairs of wings. Some had tandem wings (two pairs of monoplane wings, one behind the other). One of the most bizarre designs was by the Englishman Horatio Phillips: it had 20 sets of narrow wings and looked rather like a Venetian blind.



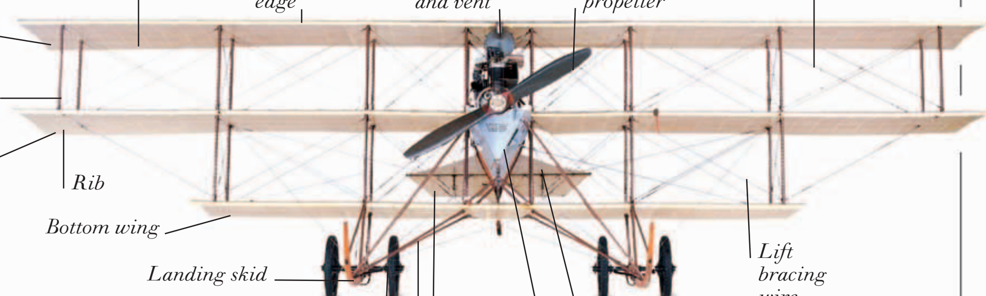


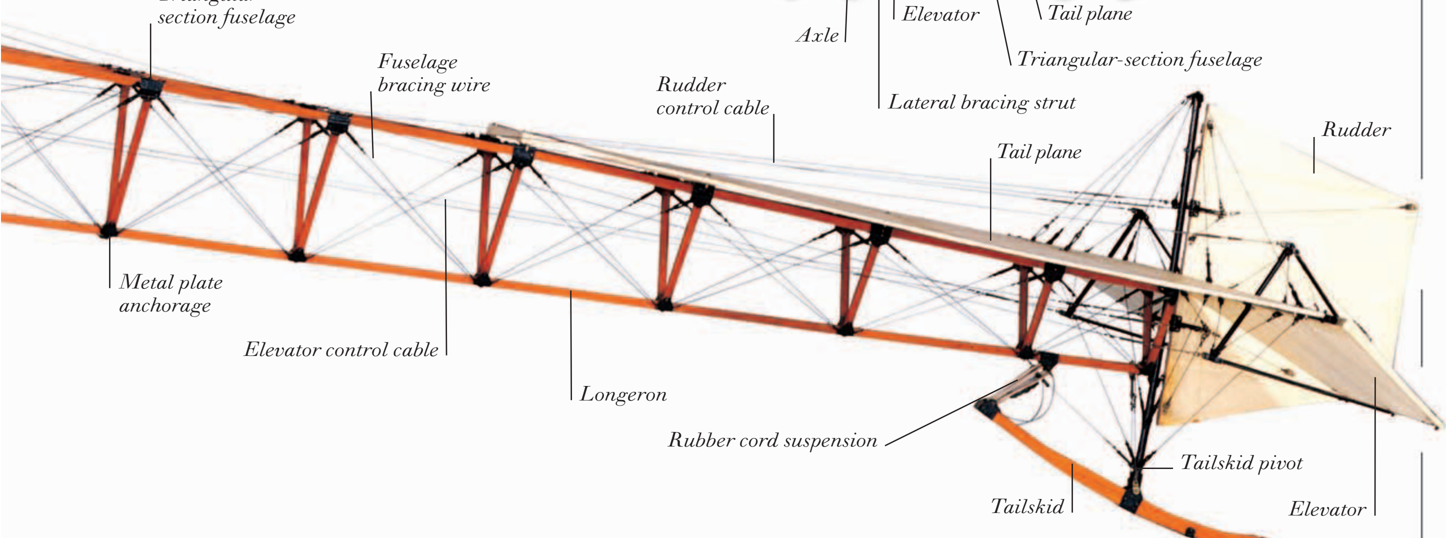
SIDE VIEW OF AVRO TRIPLANE IV, 1910

AVRO TUTOR BIPLANE, 1931



FRONT VIEW OF AVRO TRIPLANE IV, 1910



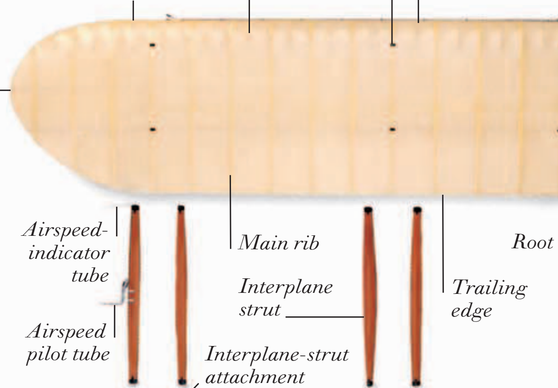


World War I aircraft

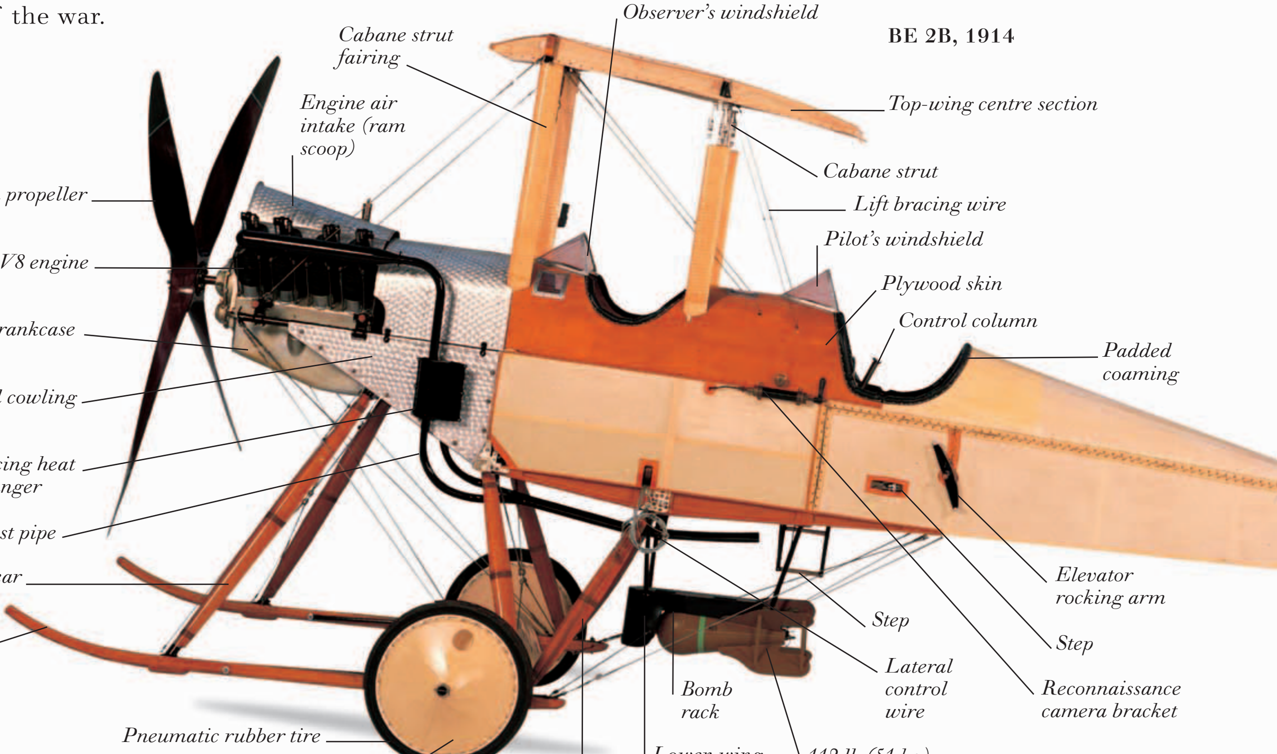
FLYING HELMET

WHEN WORLD WAR I STARTED in 1914, the main purpose of military aircraft was reconnaissance. The British-built BE 2, of which the BE 2B was a variant, was well-suited to this duty; it was very stable in flight, allowing the occupants to study the terrain, take photographs, and make notes. The BE 2 was also one of the first aircraft to drop bombs. One of the biggest problems for aircraft designers during the war was mounting machine-guns. On aircraft that had front-mounted propellers, the field of fire was restricted by the propeller and other parts of the aircraft. The problem was solved in 1915 by the Dutchman Anthony Fokker, who designed an interrupter gear that prevented a machine-gun from firing when a propeller blade passed in front of the barrel. The German LVG CVI had a forward-firing gun to the right of the engine, as well as a rear-cockpit gun, and a bombing capability. It was one of the most versatile aircraft of the war.

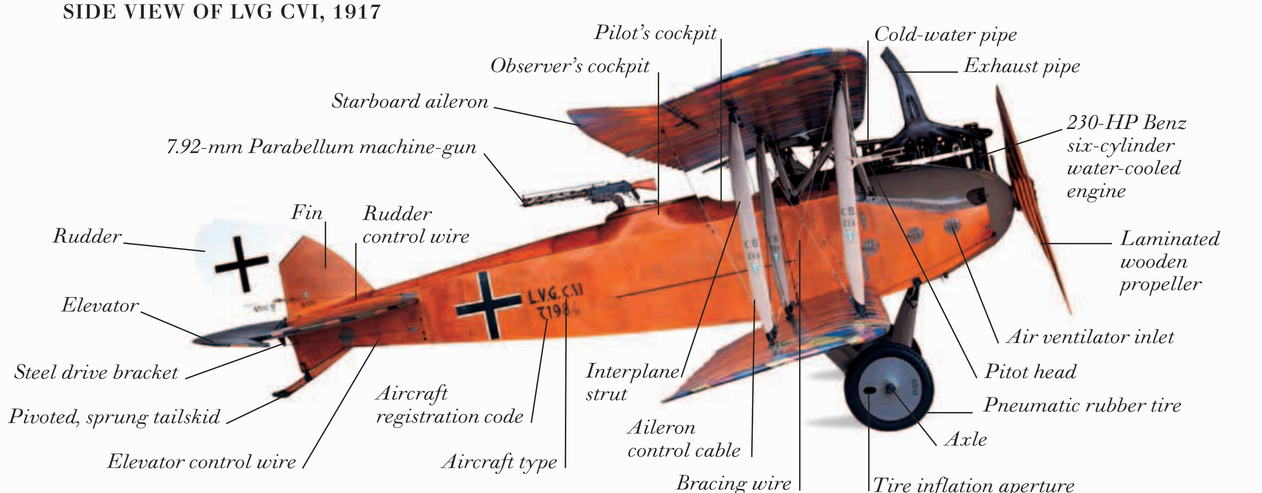
PORT WINGS FROM A BE 2B



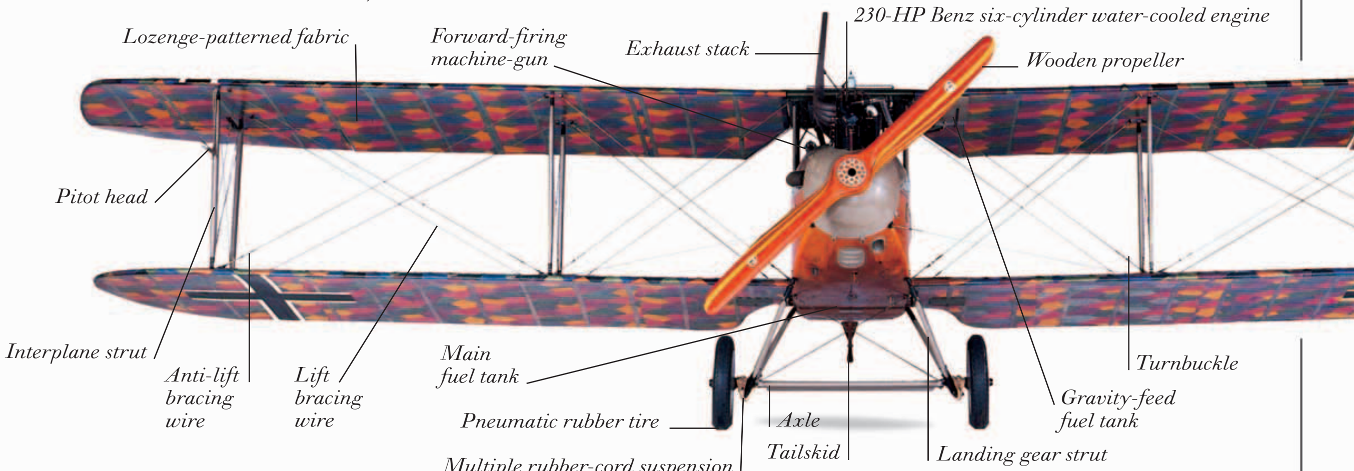
BE 2B, 1914

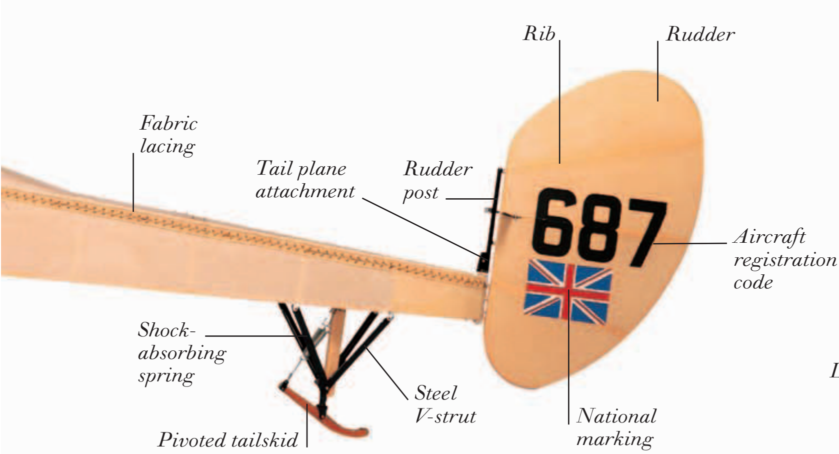


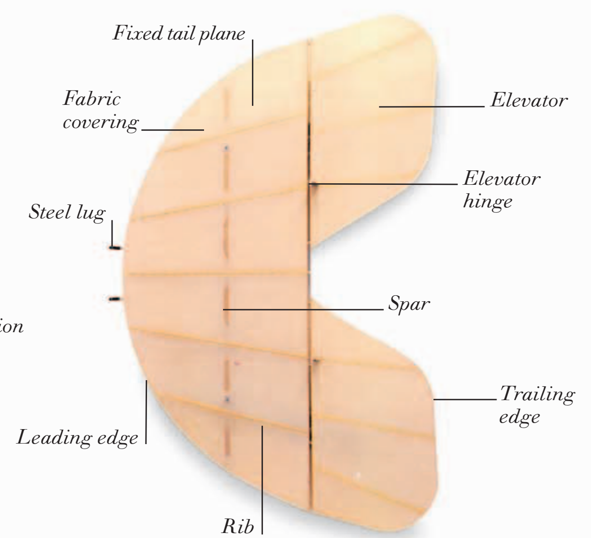
SIDE VIEW OF LVG CVI, 1917



FRONT VIEW OF LVG CVI, 1917





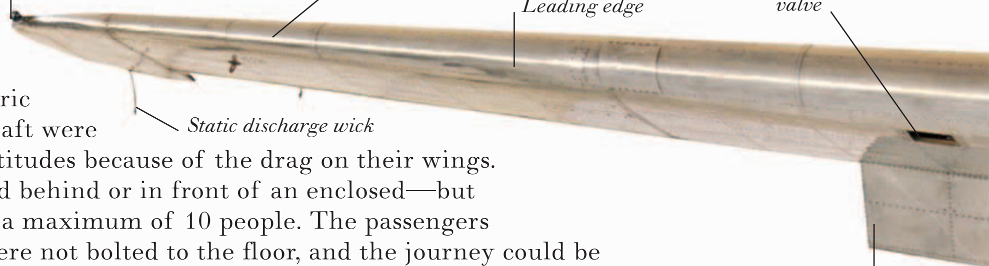


HORIZONTAL TAIL OF A BE 2B

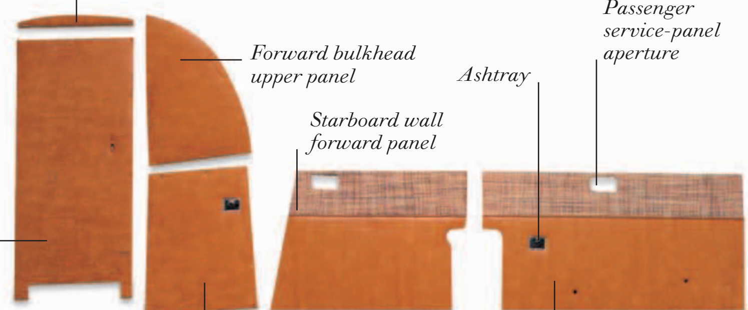
Early passenger aircraft

UNTIL THE 1930s, most passenger aircraft were biplanes, with two pairs of wings and a wooden or metal framework covered with fabric or, sometimes, plywood. Such aircraft were restricted to low speeds and low altitudes because of the drag on their wings. Many had an open cockpit, situated behind or in front of an enclosed—but unpressurized—cabin that carried a maximum of 10 people. The passengers usually sat in wicker chairs that were not bolted to the floor, and the journey could be bumpy when flying through turbulence. Warm clothing, and ear plugs to reduce the effects of prolonged noise, were often required. During the 1930s, powerful, streamlined, all-metal monoplanes, such as the Lockheed Electra shown here, became widespread. By 1939, the advent of pressurized cabins allowed fast flights at high altitudes, where there is less turbulence. Flying boats were still necessary on many routes until 1945 because of inadequate runways and the frequency of emergency sea landings. World War II, however, resulted in enough good runways being built for land-planes to become standard on all major airline routes.

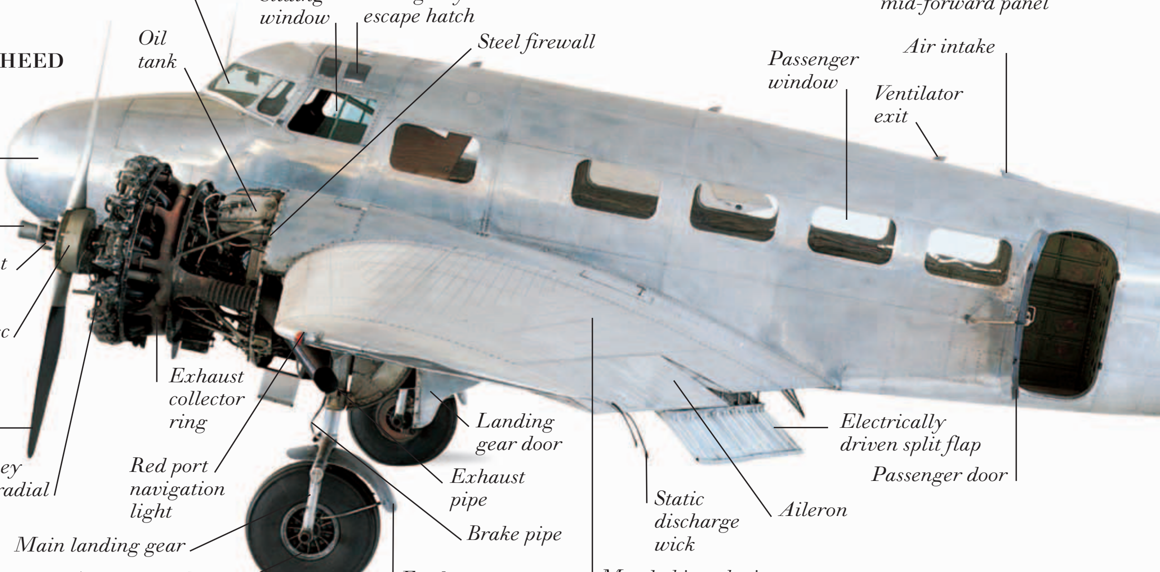
FRONT VIEW OF LOCKHEED ELECTRA, 1934

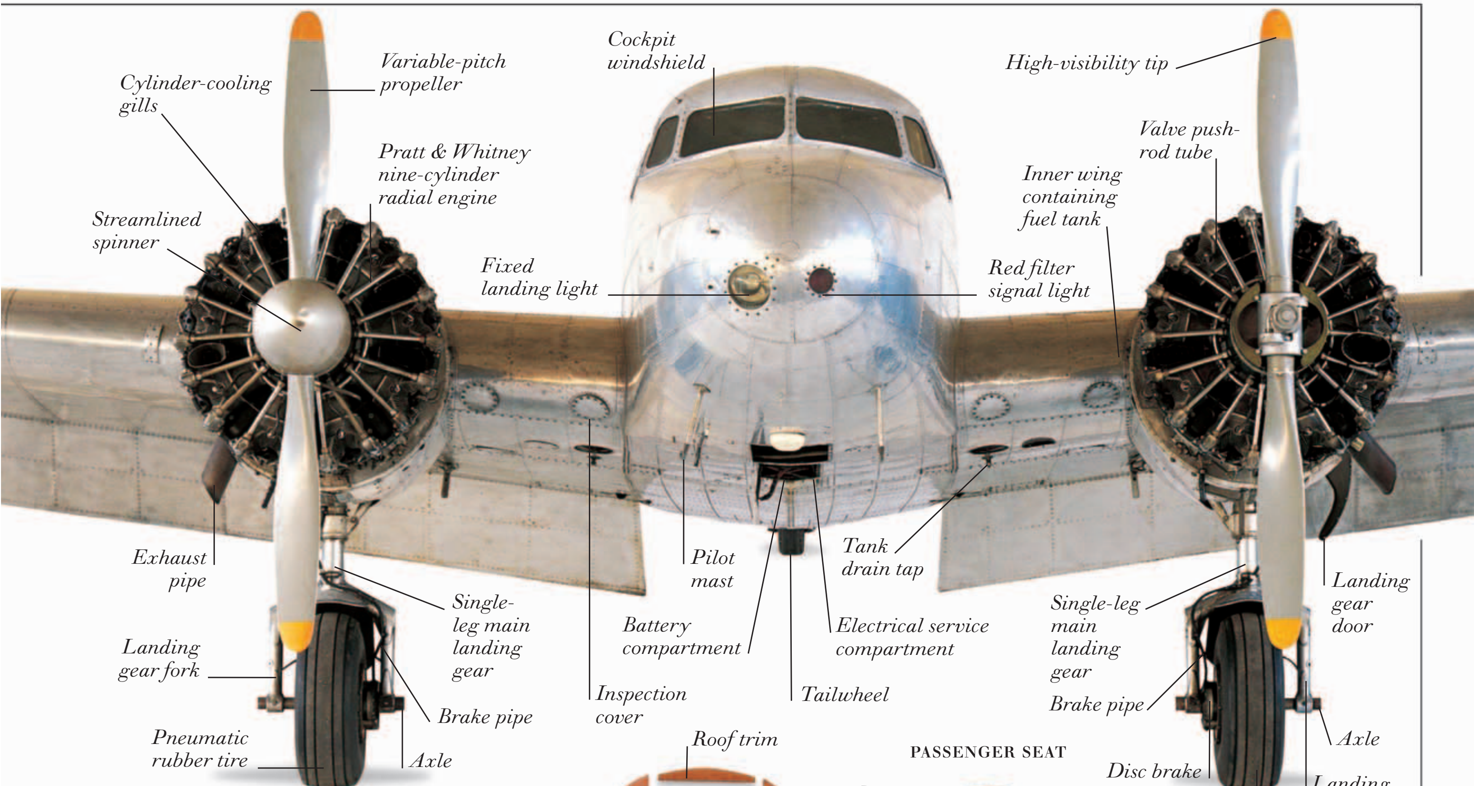


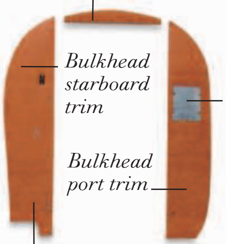
PASSENGER CABIN TRIM PANELS



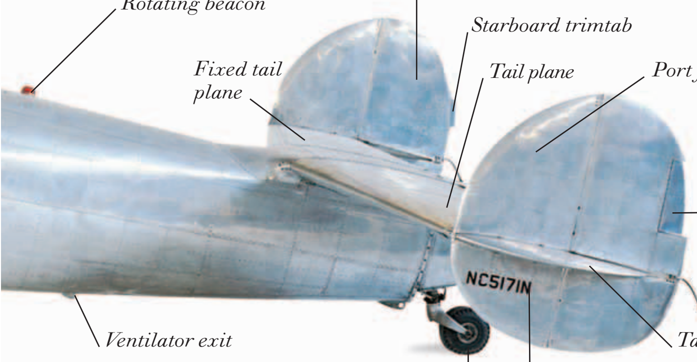
SIDE VIEW OF LOCKHEED ELECTRA, 1934



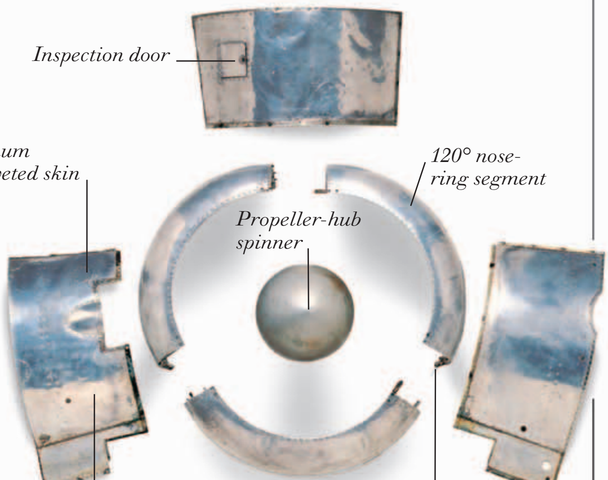




PASSENGER SEAT

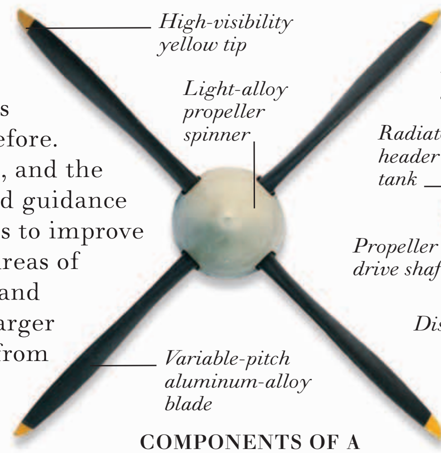


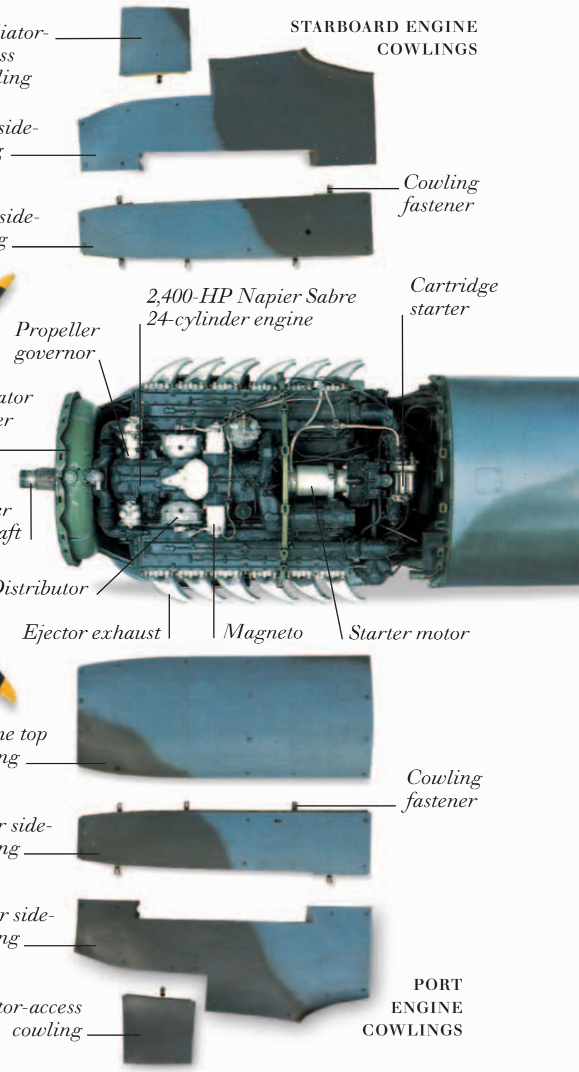
PORT ENGINE COWLINGS



World War II aircraft

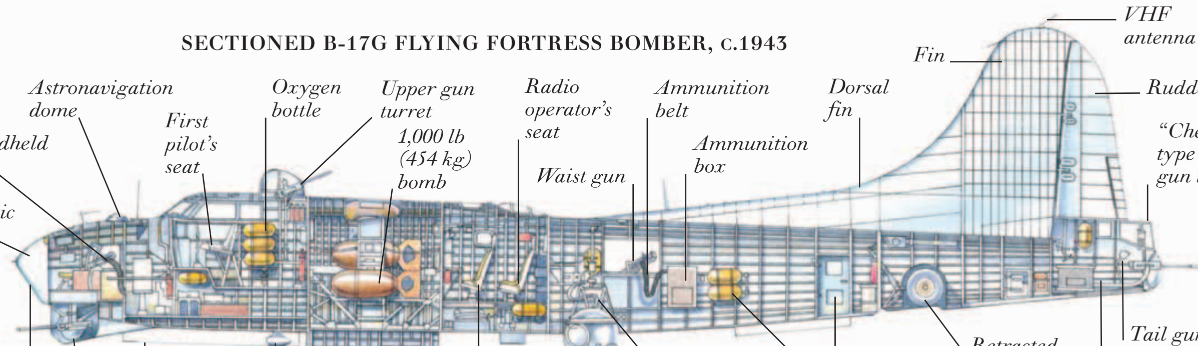
WHEN WORLD WAR II began in 1939, air forces had already replaced most of their fabric-skinned biplanes with all-metal, stressed-skin monoplanes. Aircraft played a far greater role in military operations during World War II than ever before. The wide range of aircraft duties, and the introduction of radar tracking and guidance systems, put pressure on designers to improve aircraft performance. The main areas of improvement were speed, range, and engine power. Bombers became larger and more powerful—converting from two to four engines—in order to carry a heavier bomb load; the US B-17 Flying Fortress could carry up to 6.8 tons (6.2 metric tons) of bombs over a distance of about 2,000 miles (3,200 km). Some aircraft increased their range by using drop tanks (fuel tanks that were jettisoned when empty to reduce drag). Fighters needed speed and manoeuvrability: the Hawker Tempest shown here had a maximum speed of 435 mph (700 km/h), and was one of the few Allied aircraft capable of catching the German jet-powered V1 "flying bomb." By 1944, Britain had introduced its first turbojet-powered aircraft, the Gloster Meteor fighter, and Germany had introduced the fastest fighter in the world, the turbojet-powered Me 262, which had a maximum speed of 540 mph (868 km/h).

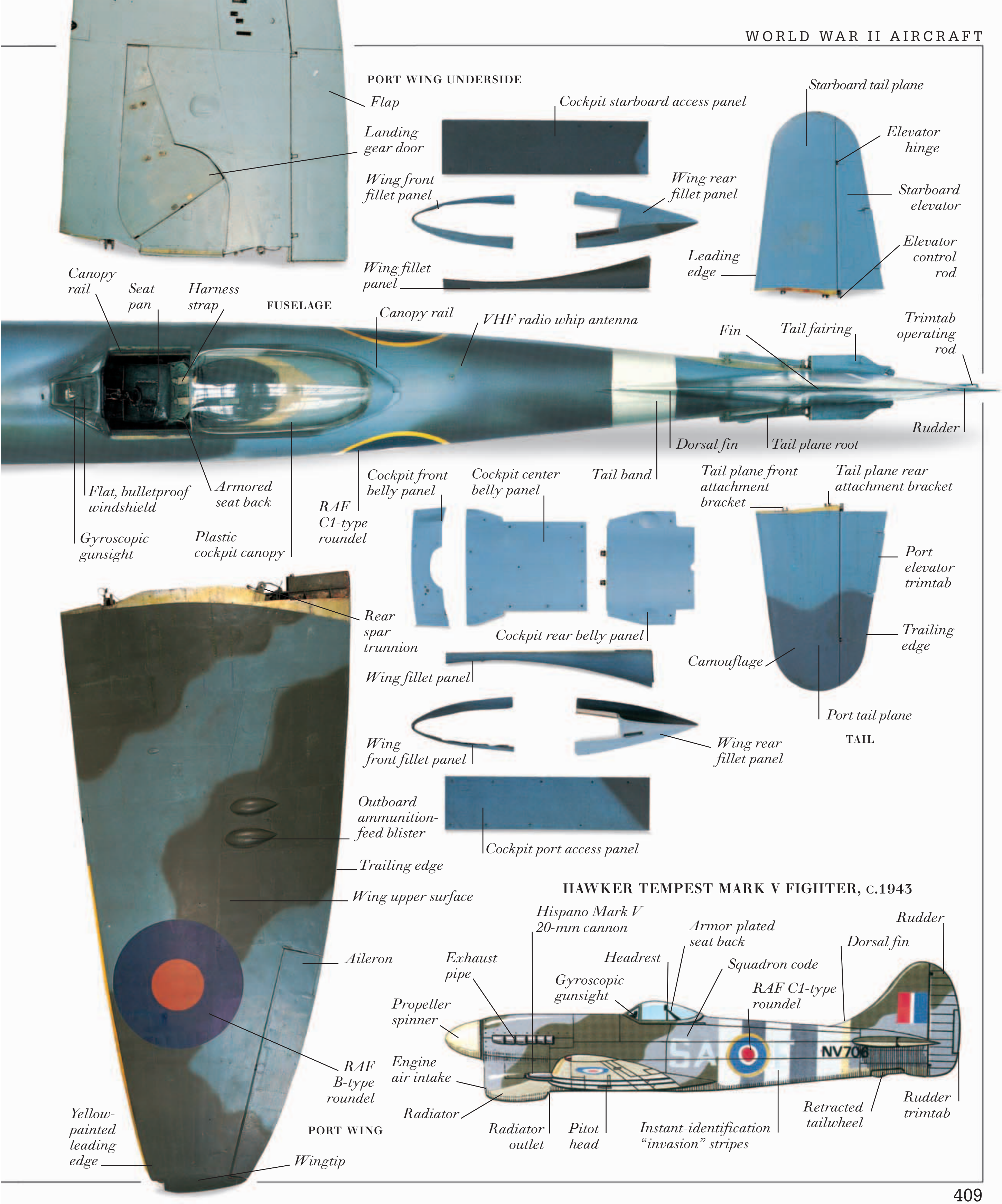




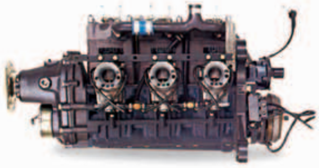
COMPONENTS OF A HAWKER TEMPEST MARK V, C.1943

SECTIONED B-17G FLYING FORTRESS BOMBER, C.1943




PORT WING UNDERSIDE
Flap
Landing gear door
Cockpit starboard access panel
Wing front fillet panel
Wing rear fillet panel
Wing fillet panel
Starboard tail plane
Elevator hinge
Starboard elevator
Leading edge
Elevator control rod
FUSELAGE
Canopy rail
Seat pan
Harness strap
Canopy rail
VHF radio whip antenna
Fin
Tail fairing
Trimtab operating rod
Rudder
Dorsal fin
Tail plane root
Flat, bulletproof windshield
Armored seat back
Gyroscopic gunsight
Plastic cockpit canopy
RAF C1-type roundel
Cockpit front belly panel
Cockpit center belly panel
Tail band
Tail plane front attachment bracket
Tail plane rear attachment bracket
Port elevator trimtab
Trailing edge
Camouflage
Port tail plane
TAIL
Rear spar trunnion
Cockpit rear belly panel
Wing fillet panel
Wing front fillet panel
Wing rear fillet panel
Outboard ammunition-feed blister
Cockpit port access panel
Trailing edge
Wing upper surface
Aileron
RAF B-type roundel
Yellow-painted leading edge
PORT WING
Wingtip
HAWKER TEMPEST MARK V FIGHTER, c.1943
Hispano Mark V 20-mm cannon
Armor-plated seat back
Rudder
Dorsal fin
Headrest
Squadron code
Exhaust pipe
Gyroscopic gunsight
RAF C1-type roundel
Propeller spinner
Engine air intake
Radiator
Radiator outlet
Pitot head
Instant-identification “invasion” stripes
Retracted tailwheel
Rudder trimtab
SA
NV706

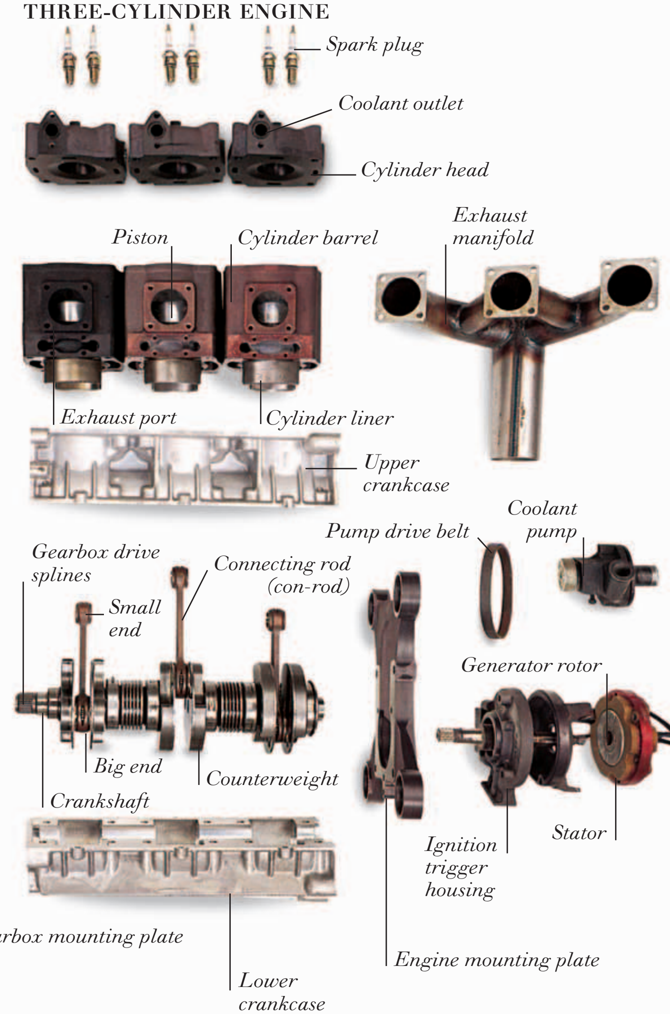
Modern piston aero-engines

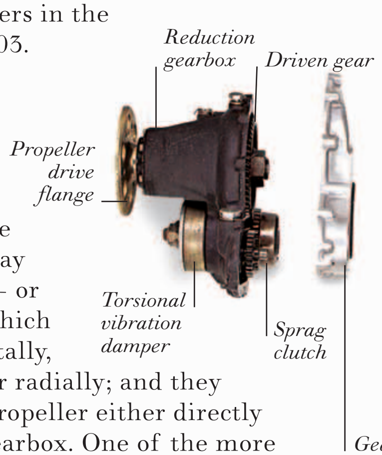


MID WEST TWO-STROKE, THREE-CYLNDER ENGINE

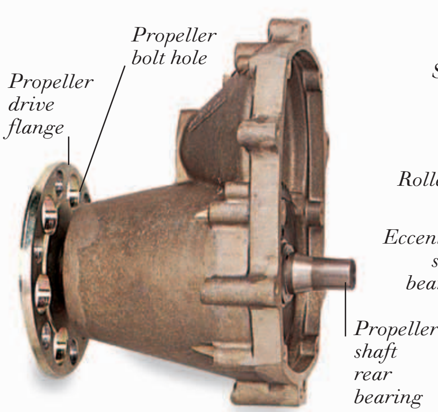
PISTON ENGINES today are used mainly to power the vast numbers of light aircraft and microlights, as well as crop-sprayers and crop-dusters, small helicopters, and fire-bombers (which dump water on large fires). Virtually all heavier aircraft are now powered by jet engines. Modern piston aero-engines work on the same basic principles as the engine used by the Wright brothers in the first powered flight in 1903. However, today's engines are more sophisticated than earlier engines. For example, modern aero-engines may use a two-stroke or a four-stroke combustion cycle; they may have from one to nine air- or water-cooled cylinders, which may be arranged horizontally, in-line, in V formation, or radially; and they may drive the aircraft's propeller either directly or through a reduction gearbox. One of the more unconventional types of modern aero-engine is the rotary engine shown here, which has a trilobate (three-sided) rotor spinning in a chamber shaped like a fat figure-eight.

MID WEST 75-HP TWO-STROKE, THREE-CYLINDER ENGINE

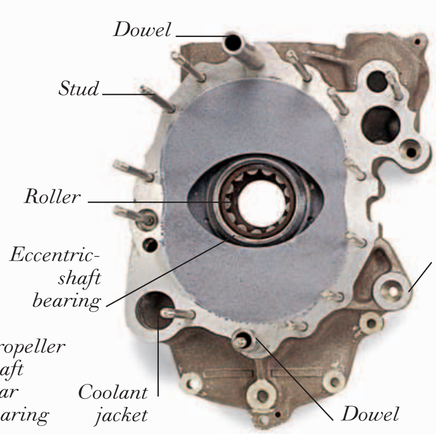




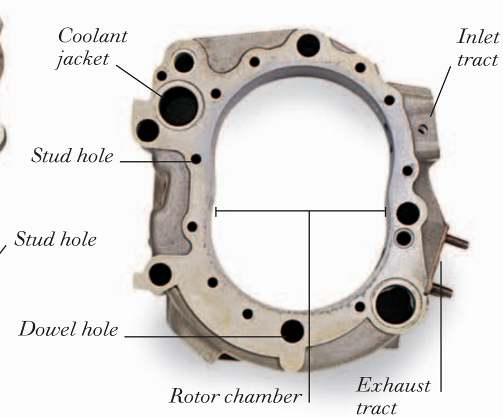
ROTOR AND HOUSINGS OF A MID WEST SINGLE-ROTOR ENGINE



GEARBOX CASE

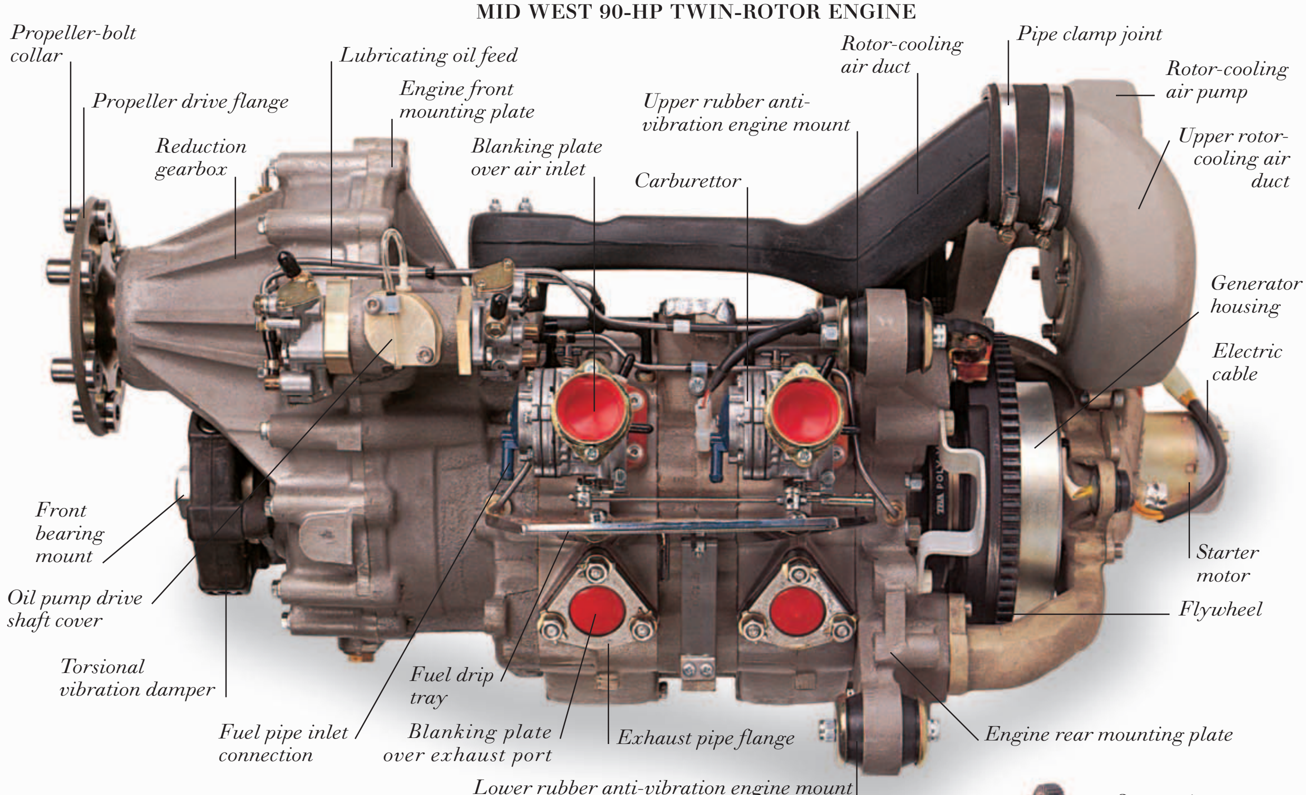


FRONT HOUSING (FRONT END-PLATE)

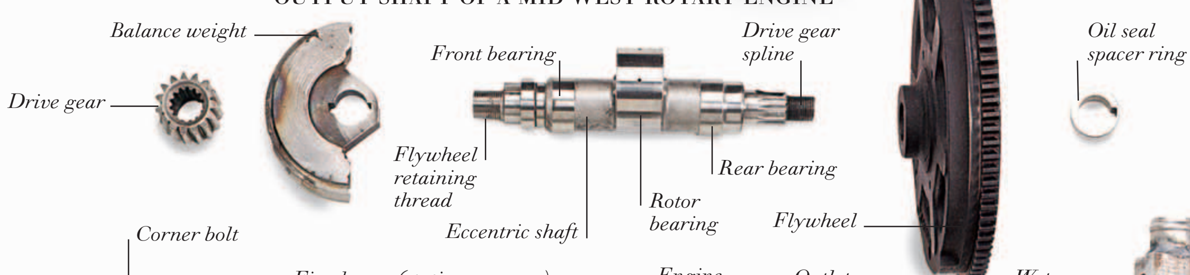


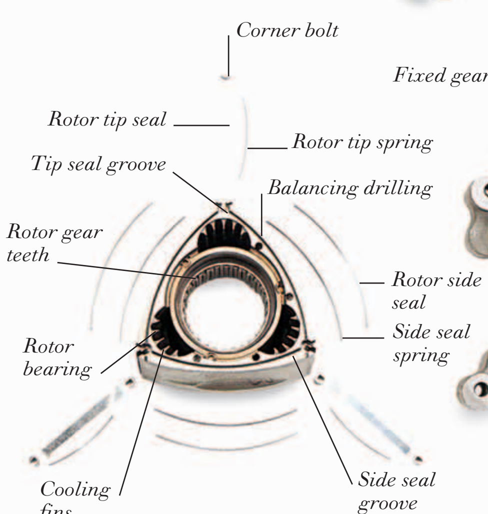
TROCHOID HOUSING

MID WEST 90-HP TWIN-ROTOR ENGINE

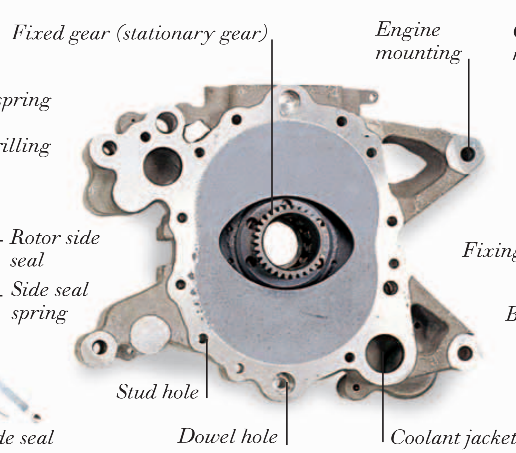


OUTPUT SHAFT OF A MID WEST ROTARY ENGINE

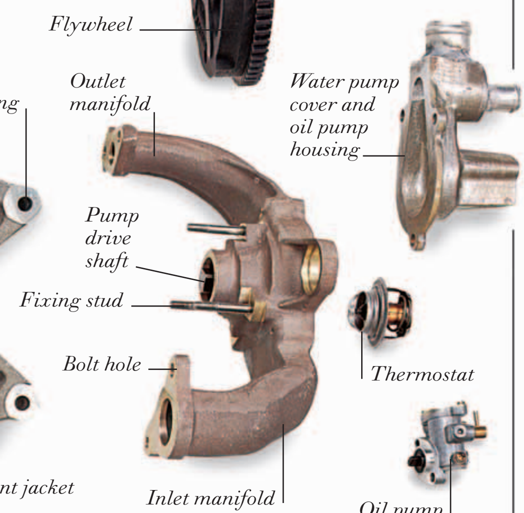




ROTOR AND SEALS



REAR HOUSING (REAR END-PLATE)

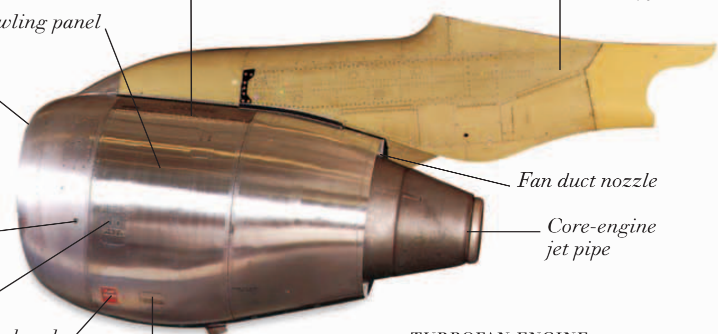


WATER PUMP HOUSING

Modern jetliners 1

BAE-146 JETLINER

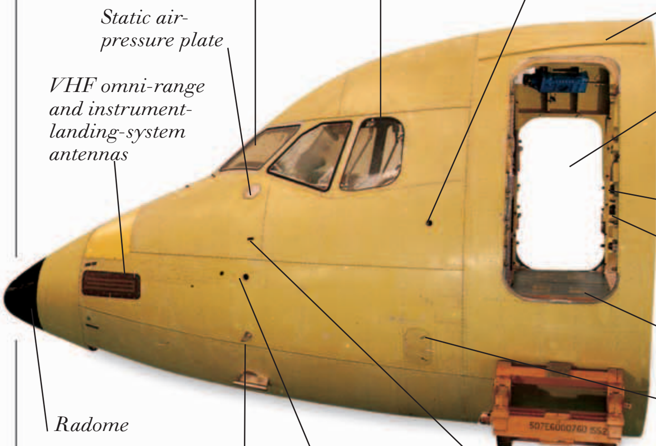
MODERN JETLINERS HAVE ENABLED ordinary people to travel to places where once only the wealthy could afford to go. Compared with the first jetliners (which were introduced in the 1940s), modern ones are much quieter, burn fuel more efficiently, and produce less air pollution. These advances are largely due to the replacement of turbojet engines with turbofan engines (see pp. 418-419). The greater power of turbofan engines at low speeds enables modern jetliners to carry more fuel and passengers than turbojet aircraft; a modern Boeing 747-400 (popularly known as a "jumbo jet") can fly 400 people for 8,500 miles (13,700 km) without needing to refuel. Jetliners fly at high altitudes, typically cruising at 26,000-36,000 ft (8000-11,000 m), where they can use fuel efficiently and usually avoid bad weather. The pilot always controls the aircraft during takeoff and landing, but at other times the aircraft is usually controlled by an autopilot. Autopilots are complex on-board mechanisms that detect deviations from an aircraft's route and make appropriate adjustments to the flight controls. Flight decks are also equipped with radars that warn pilots of approaching hazards, such as mountain ranges, bad weather, and other aircraft.

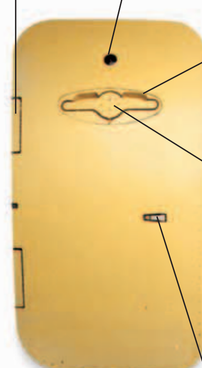


TURBOFAN ENGINE COWLING

STRUCTURAL COMPONENTS OF A BAE-146 JETLINER

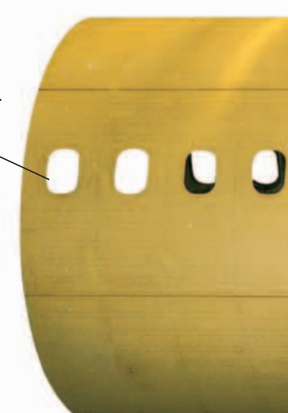
FUSELAGE NOSE-SECTION

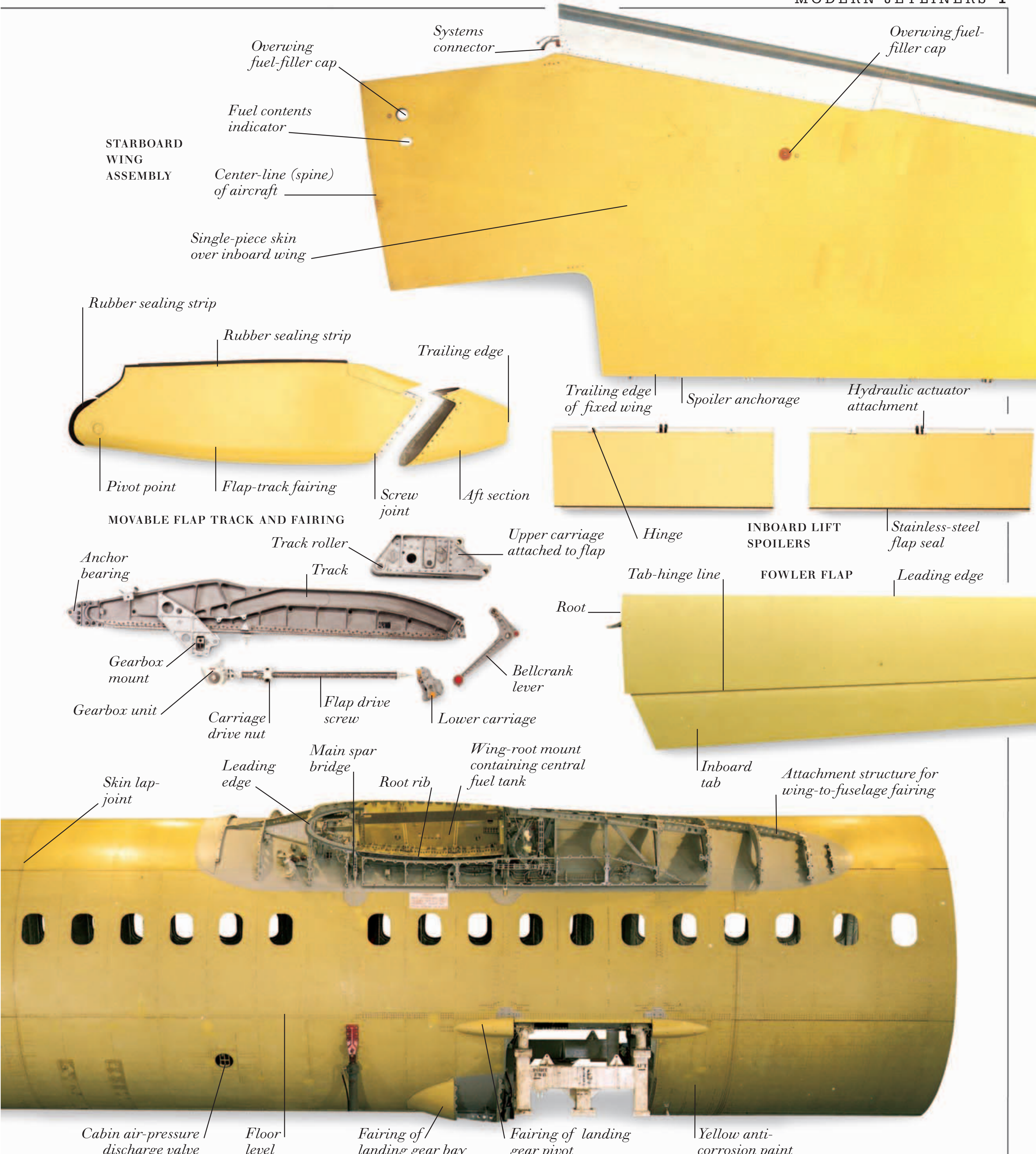




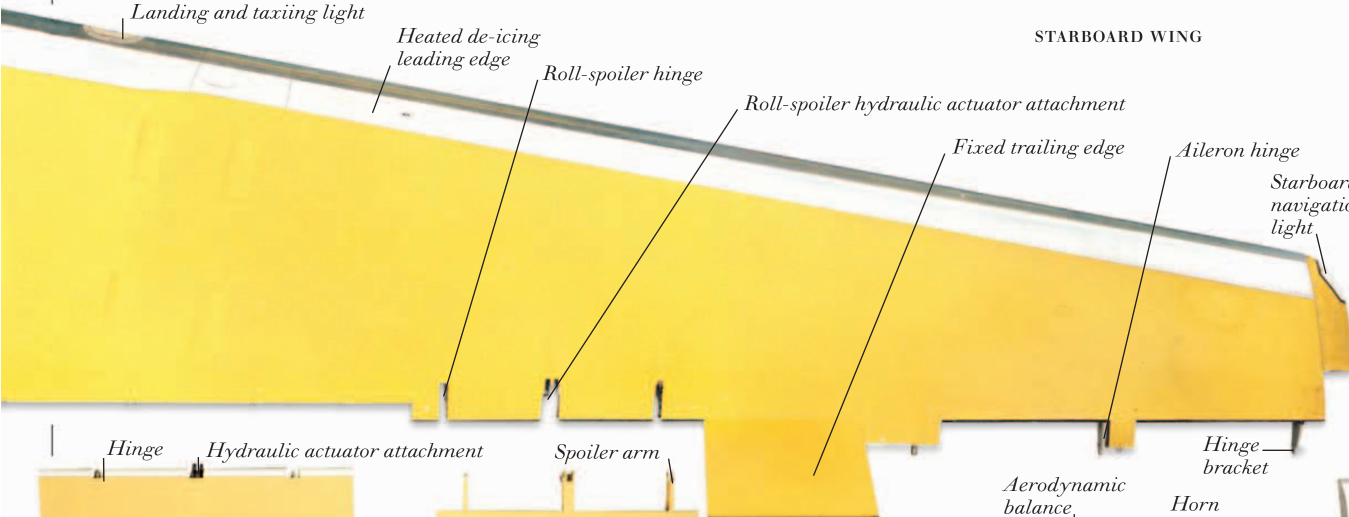
FORWARD MAIN DOOR

FUSELAGE MID-SECTION



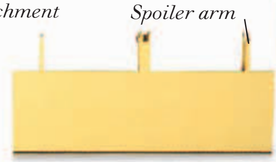

Systems connector
Overwing fuel-filler cap
Overwing fuel-filler cap
Fuel contents indicator
STARBOARD WING ASSEMBLY
Center-line (spine) of aircraft
Single-piece skin over inboard wing
Rubber sealing strip
Rubber sealing strip
Trailing edge
Trailing edge of fixed wing
Spoiler anchorage
Hydraulic actuator attachment
Pivot point
Flap-track fairing
Screw joint
Aft section
MOVABLE FLAP TRACK AND FAIRING
Hinge
INBOARD LIFT SPOILERS
Stainless-steel flap seal
Track roller
Upper carriage attached to flap
Anchor bearing
Track
Tab-hinge line
FOWLER FLAP
Leading edge
Root
Gearbox mount
Bellcrank lever
Gearbox unit
Carriage drive nut
Flap drive screw
Lower carriage
Main spar bridge
Wing-root mount containing central fuel tank
Inboard tab
Attachment structure for wing-to-fuselage fairing
Skin lap-joint
Leading edge
Root rib
Cabin air-pressure discharge valve
Floor level
Fairing of landing gear bay
Fairing of landing gear pivot
Yellow anti-corrosion paint

Modern jetliners 2

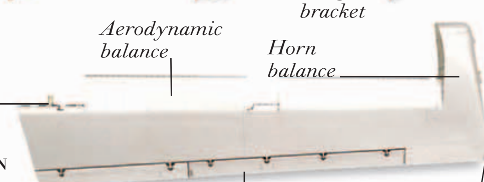


STARBOARD WING

INTERMEDIATE LIFT SPOILER

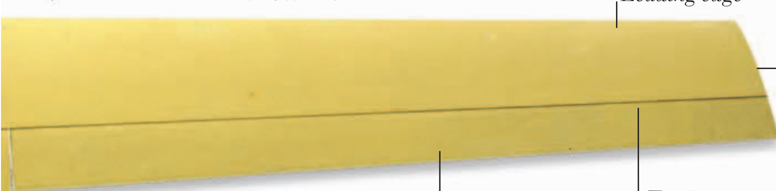


OUTBOARD ROLL SPOILER

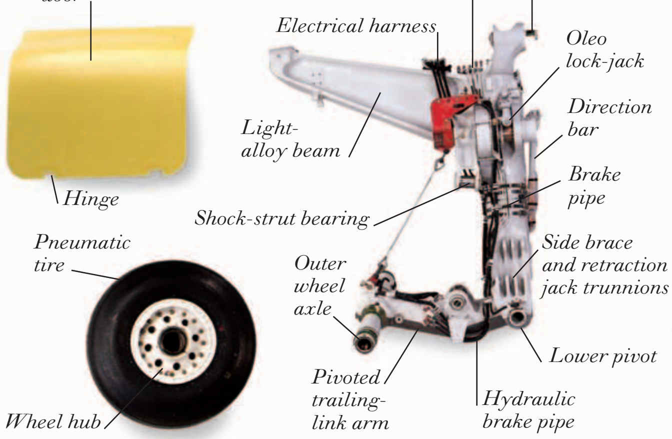


AILERON

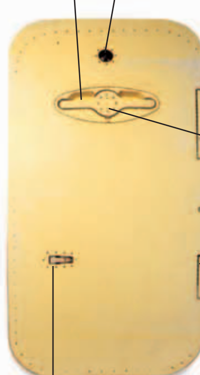
MAIN FOWLER FLAP



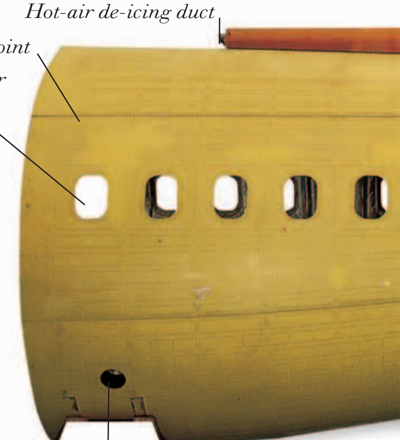
FUSELAGE SPINE FAIRING



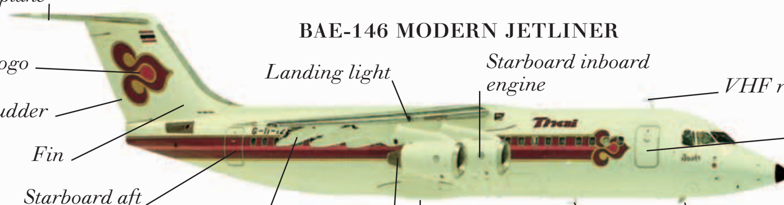
STARBOARD TWIN-WHEEL MAIN LANDING GEAR



AFT MAIN DOOR

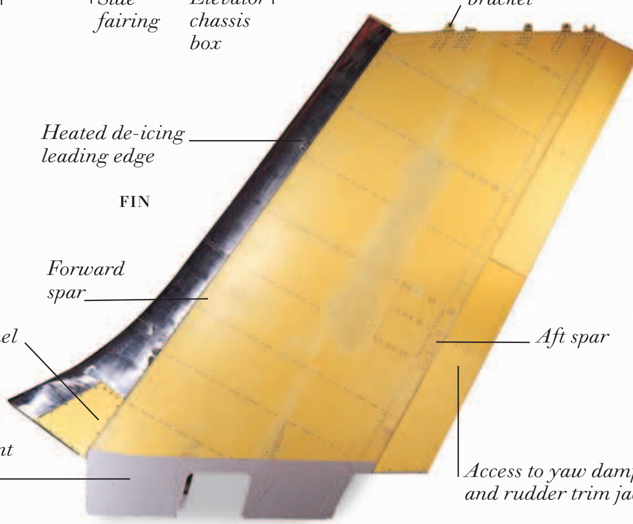


BAE-146 MODERN JETLINER

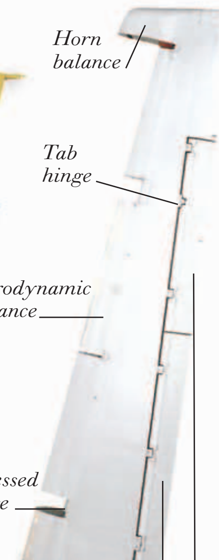


TAIL PLANE FAIRINGS

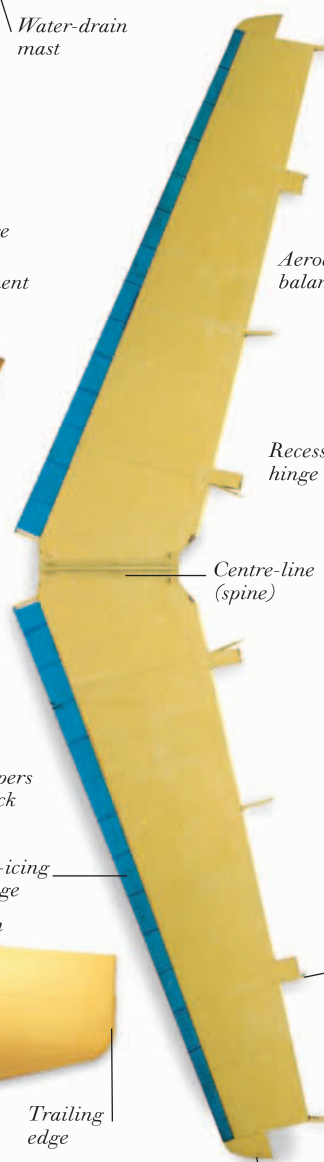
FIN



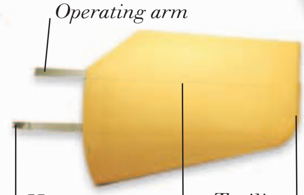
STARBOARD ELEVATOR



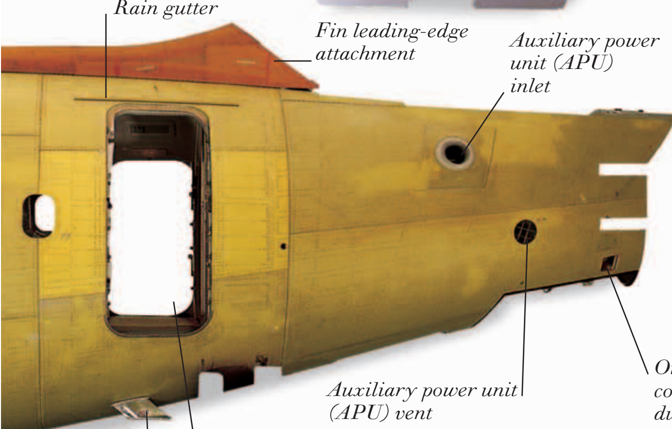
TAIL PLANE



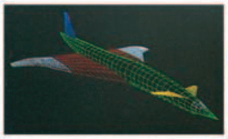
STARBOARD AIR-BRAKE



FUSELAGE TAIL-SECTION

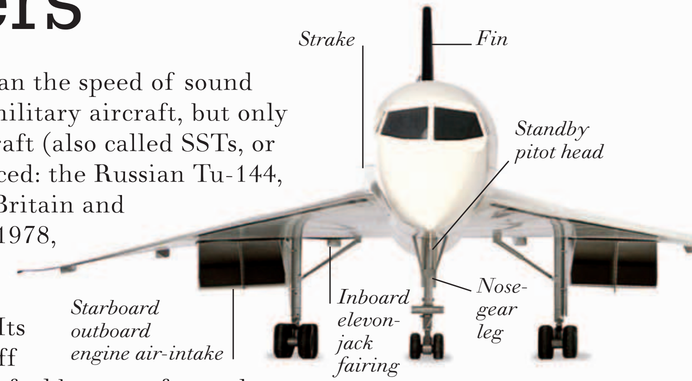


Supersonic jetliners

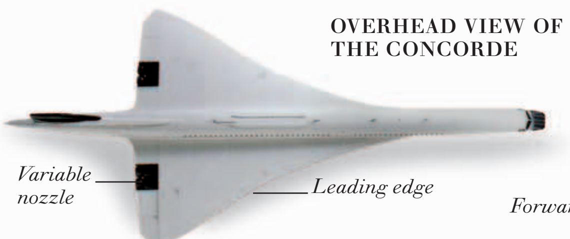


COMPUTER-DESIGNED SST

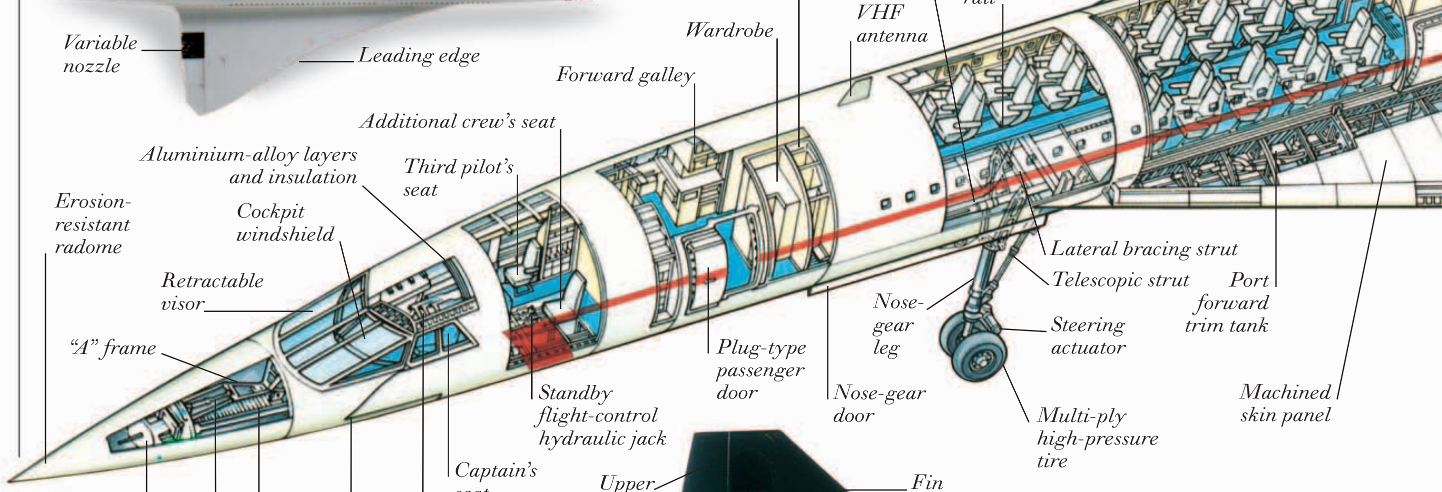
SUPERSONIC AIRCRAFT FLY FASTER than the speed of sound (Mach 1). There are many supersonic military aircraft, but only two supersonic passenger-carrying aircraft (also called SSTs, or supersonic transports) have been produced: the Russian Tu-144, and the Concorde, produced jointly by Britain and France. The Tu-144 was withdrawn in 1978, after only seven months in service. The Concorde remained in service from 1976 until 2003, with a break for modifications from July 2000 until October 2001. Its features included a droop nose, which lowered during takeoff and landing to aid visibility from the cockpit; the pumping of fuel between forward and aft trim tanks helped stabilize the aircraft. The Concorde had a narrow fuselage and shortspan wings to reduce drag during supersonic flight. Its noisy turbojet engines with afterburners enabled it to carry 100 passengers at a cruising speed of Mach 2 at 50,000-60,000 ft (15,000-18,000 m). Once an aircraft is flying faster than Mach 1, it produces a continuous air-pressure wave, which is heard as a "sonic boom."

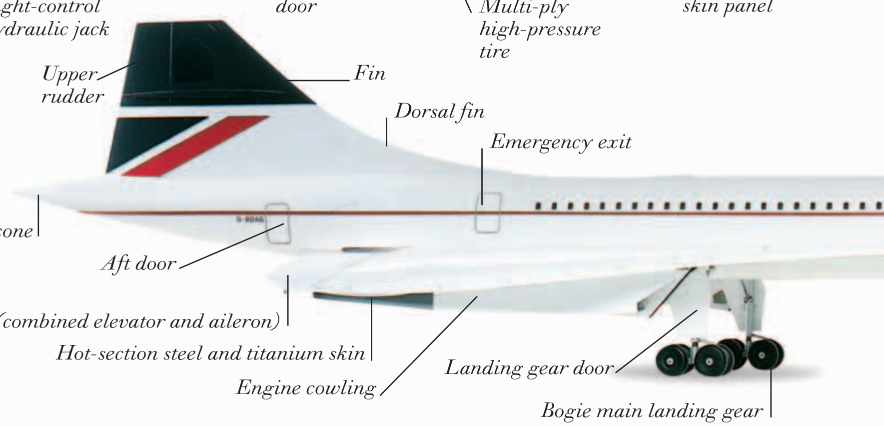


FRONT OF THE CONCORDE

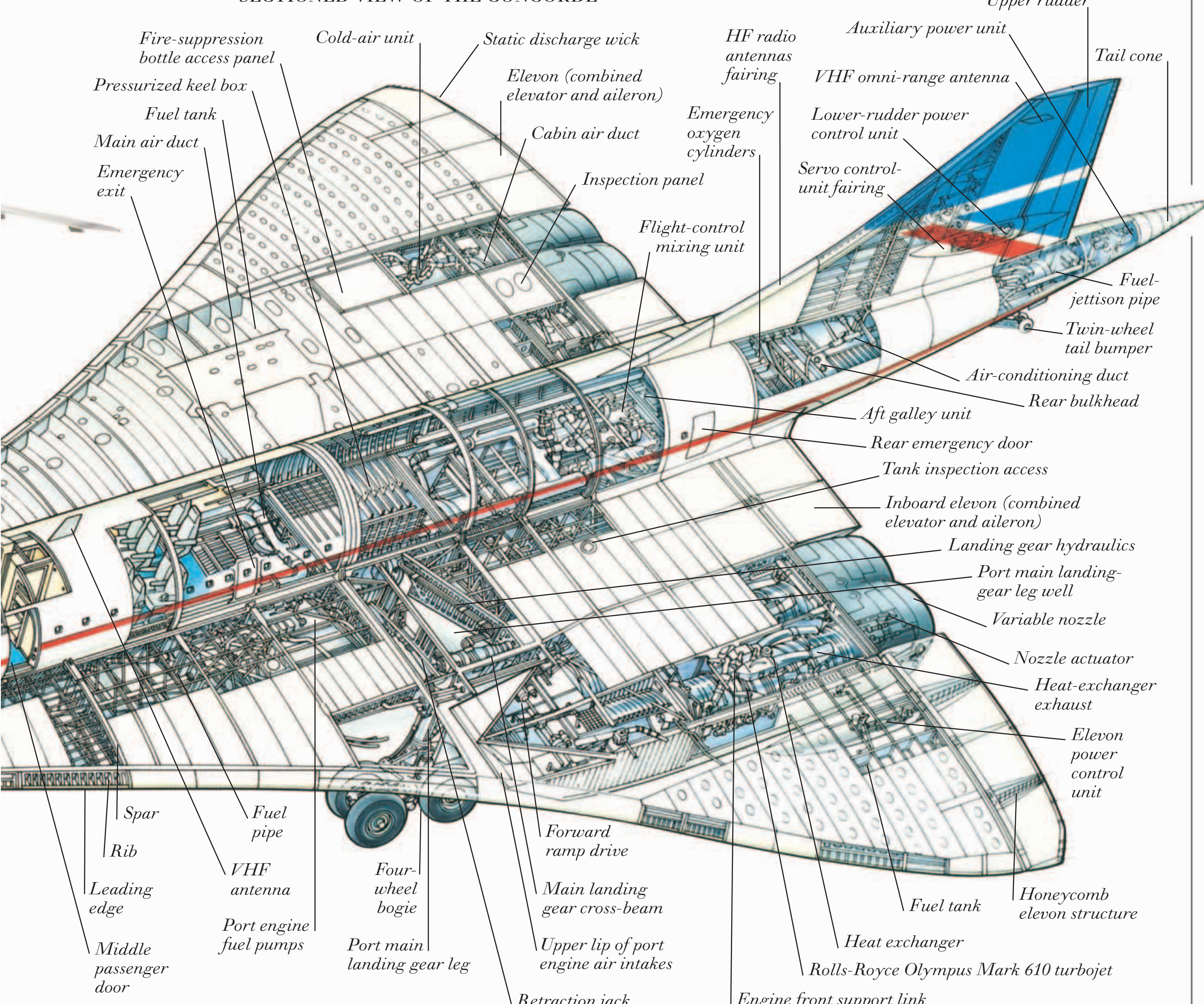


OVERHEAD VIEW OF THE CONCORDE

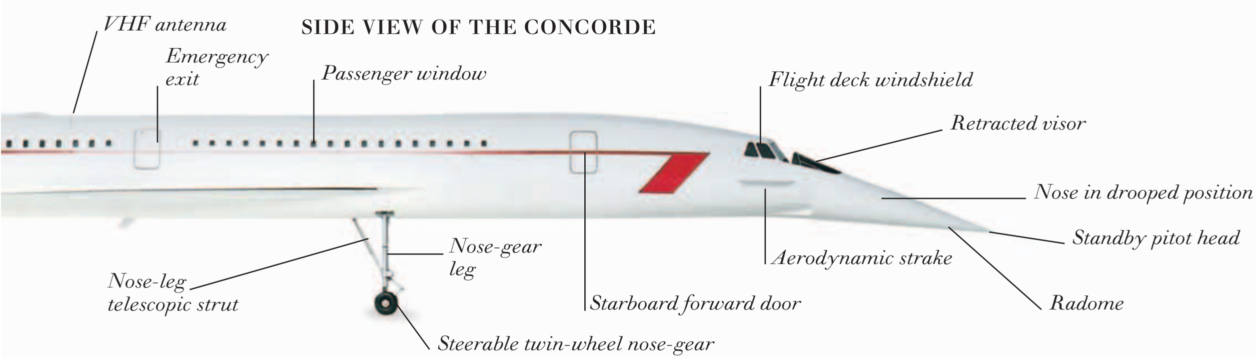




SECTIONED VIEW OF THE CONCORDE



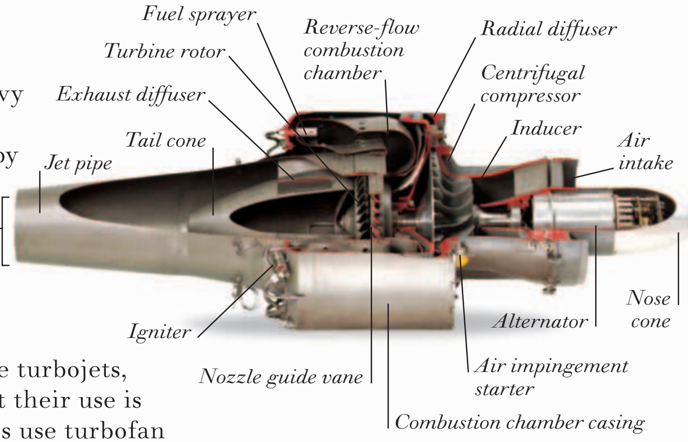
SIDE VIEW OF THE CONCORDE

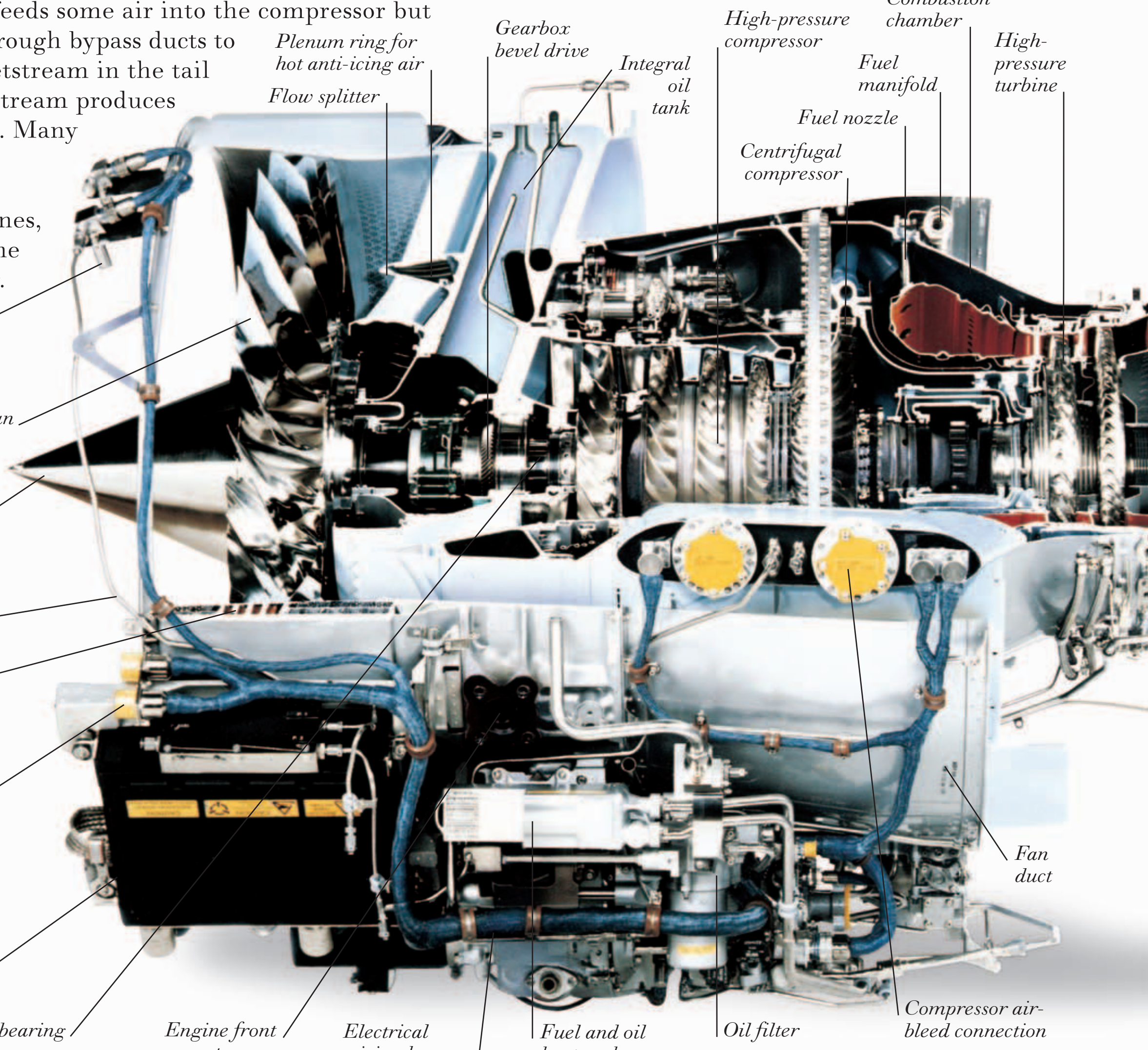


Jet engines

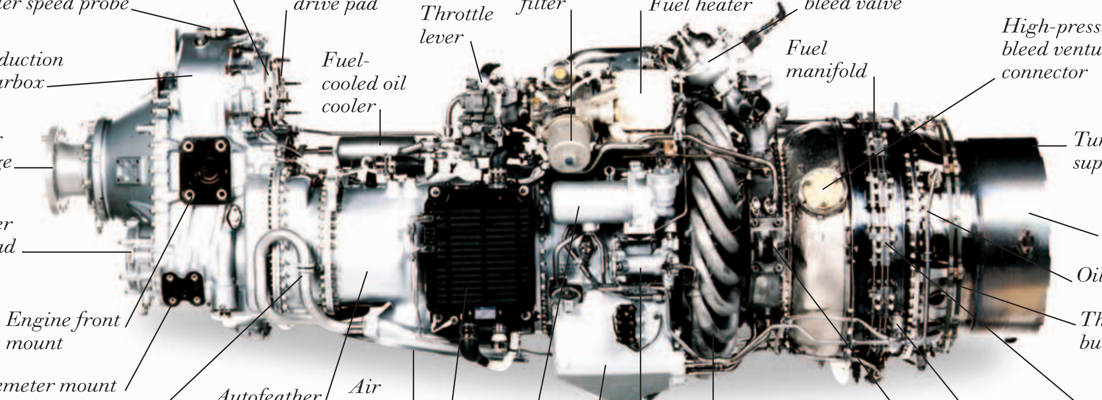
JET ENGINES ARE USED BY MOST MILITARY and heavy aircraft, and by many helicopters. The simplest type of jet engine, or gas turbine, is the turbojet. It works by continuously burning a mixture of fuel and air in a combustion chamber to produce a jet of hot exhaust gas that is expelled through a nozzle to produce thrust. The hot gas also spins turbine blades, which, in turn, spin the blades of an air compressor; the compressor forces air into the combustion chamber. Many of the fastest aircraft use turbojets, with additional booster units called afterburners, but their use is restricted by their high noise emission. Most jetliners use turbofan jet engines, which are quieter. An enormous fan, driven by a low-pressure turbine, feeds some air into the compressor but feeds most of it through bypass ducts to join the exhaust jetstream in the tail cone. The bypass stream produces most of the thrust. Many smaller, propeller-driven aircraft use turboprop jet engines, in which the engine powers a propeller.

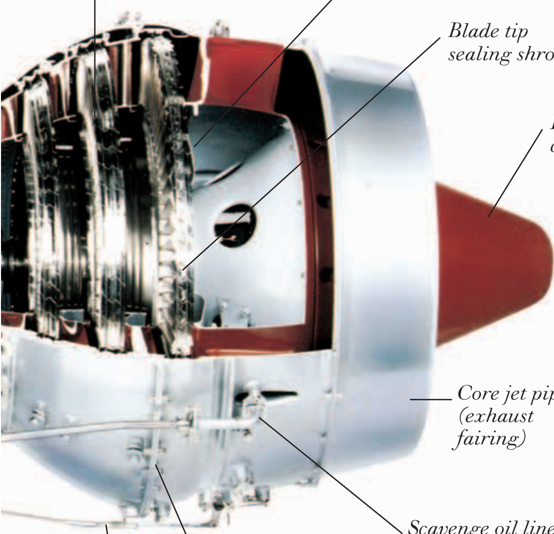
NPT 301 MODERN TURBOJET





PRATT & WHITNEY CANADA PW120 SERIES MODERN TURBOPROP

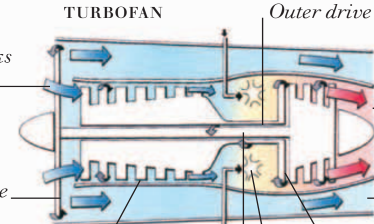




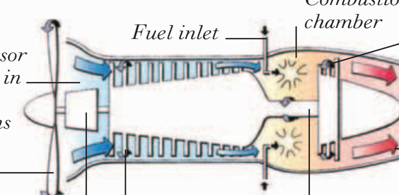
SECTIONED PRATT & WHITNEY CANADA PW305 MODERN TURBOFAN

HOW JET ENGINES WORK

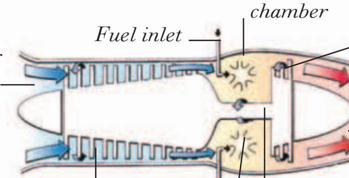
TURBOFAN



TURBOPROP



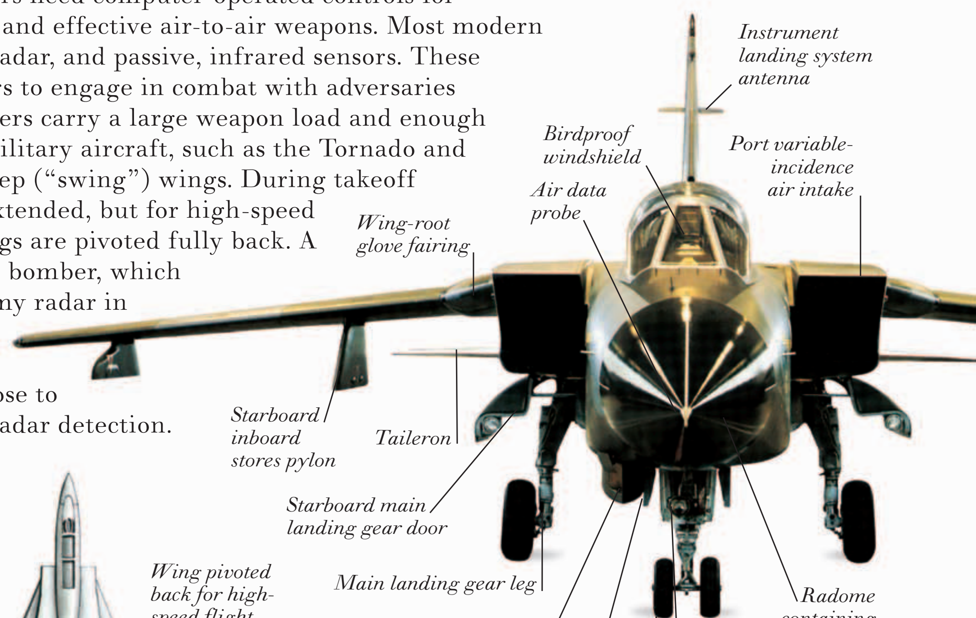
TURBOJET

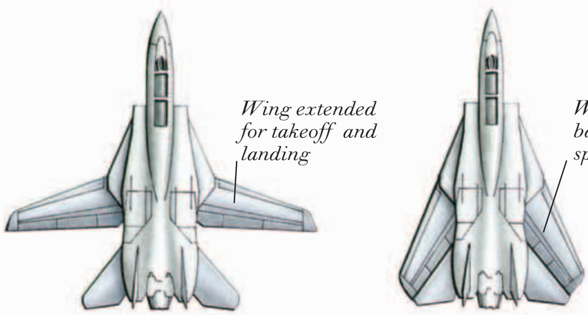


Modern military aircraft

MODERN MILITARY AIRCRAFT ARE AMONG THE MOST SOPHISTICATED and expensive products of the 21st century. Fighters need computer-operated controls for maneuverability, powerful engines, and effective air-to-air weapons. Most modern fighters also have guided missiles, radar, and passive, infrared sensors. These developments enable today's fighters to engage in combat with adversaries that are outside visual range. Bombers carry a large weapon load and enough fuel for long-range flights. A few military aircraft, such as the Tornado and the F-14 Tomcat, have variable-sweep ("swing") wings. During takeoff and landing their wings are fully extended, but for high-speed flight and low-level attacks the wings are pivoted fully back. A recent development is the "stealth" bomber, which is designed to absorb or deflect enemy radar in order to remain undetected. Earlier bombers, such as the Tornado, use terrain-following radars to fly so close to the ground that they avoid enemy radar detection.

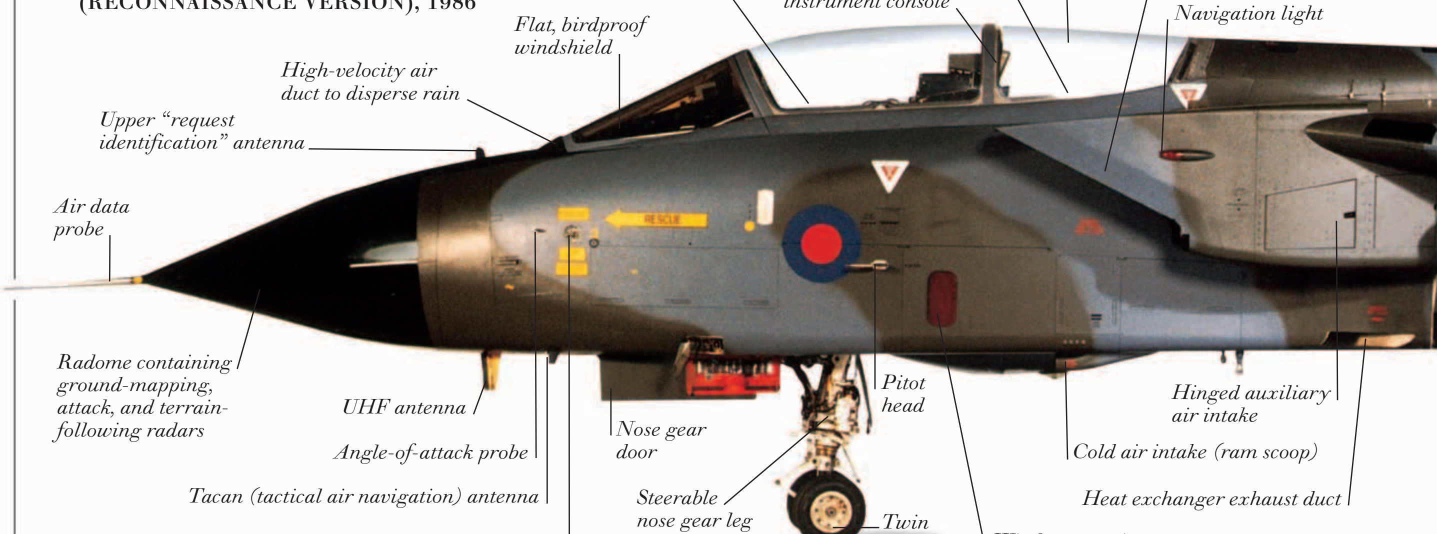
FRONT VIEW OF A PANAVIA TORNADO



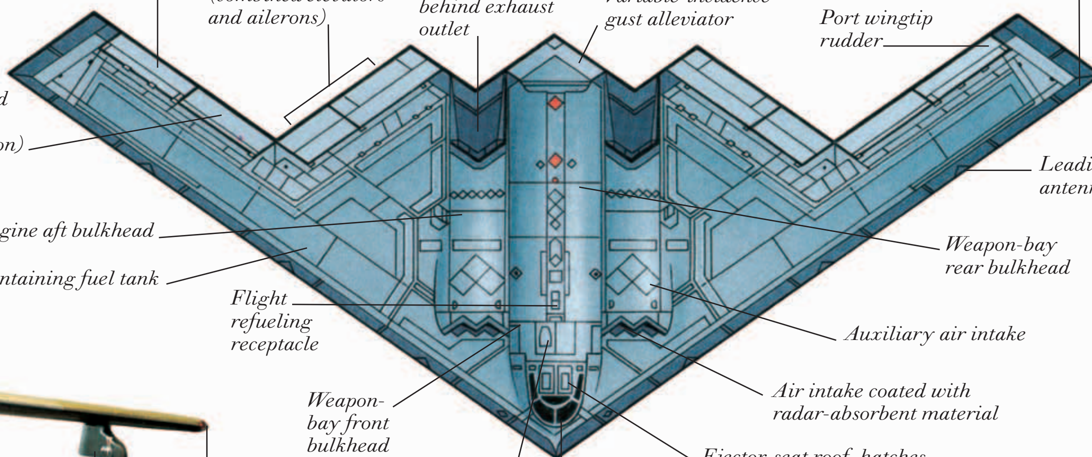


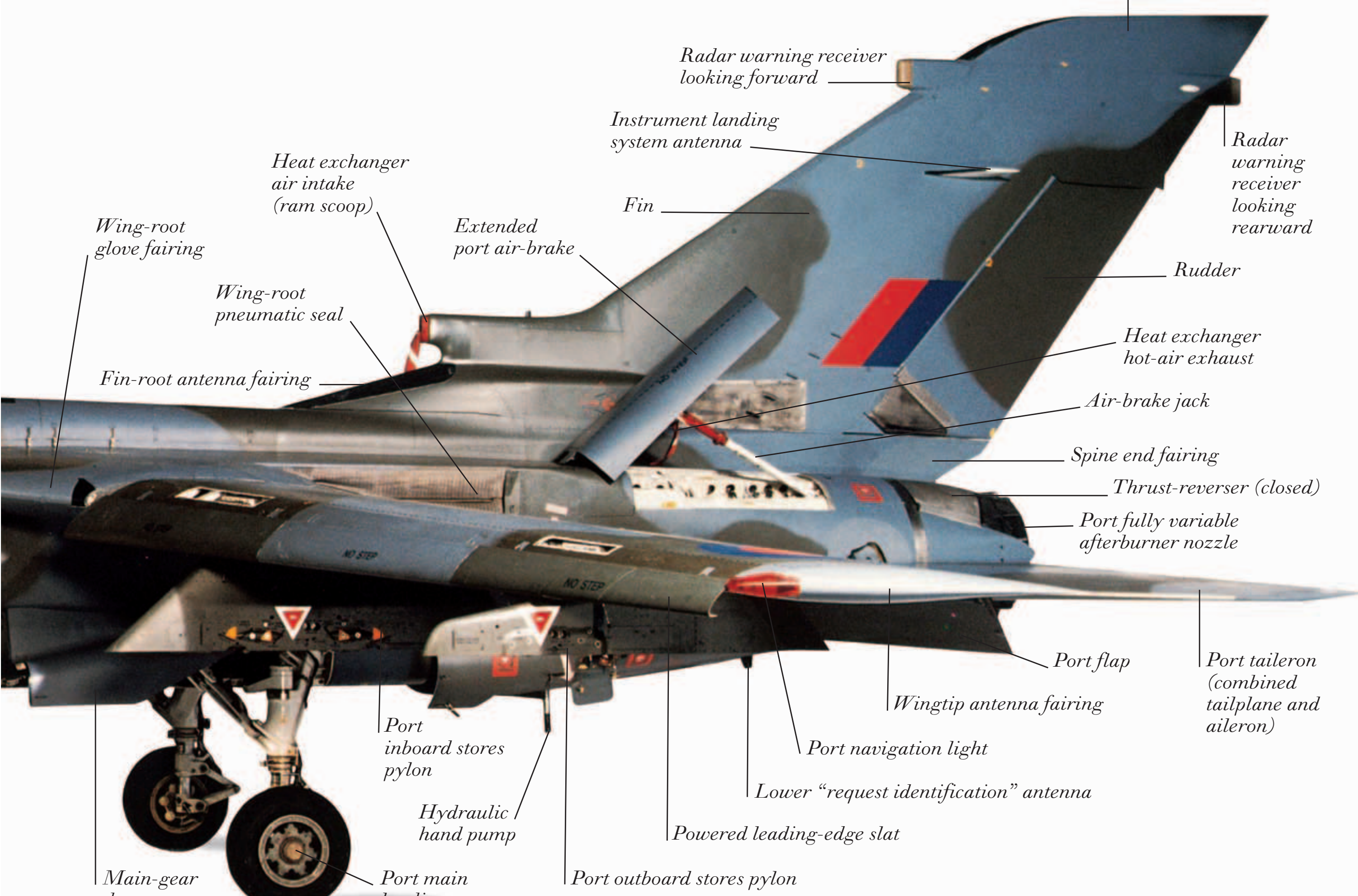
SWING-WING F-14 TOMCAT FIGHTER

SIDE VIEW OF A PANAVIA TORNADO GR1A (RECONNAISSANCE VERSION), 1986

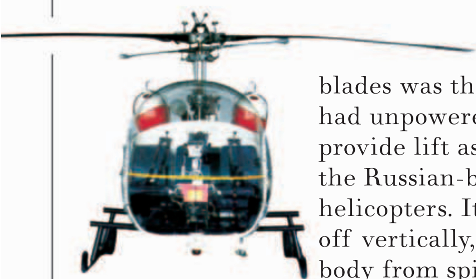


NORTHROP B-2 ("STEALTH" BOMBER), 1989



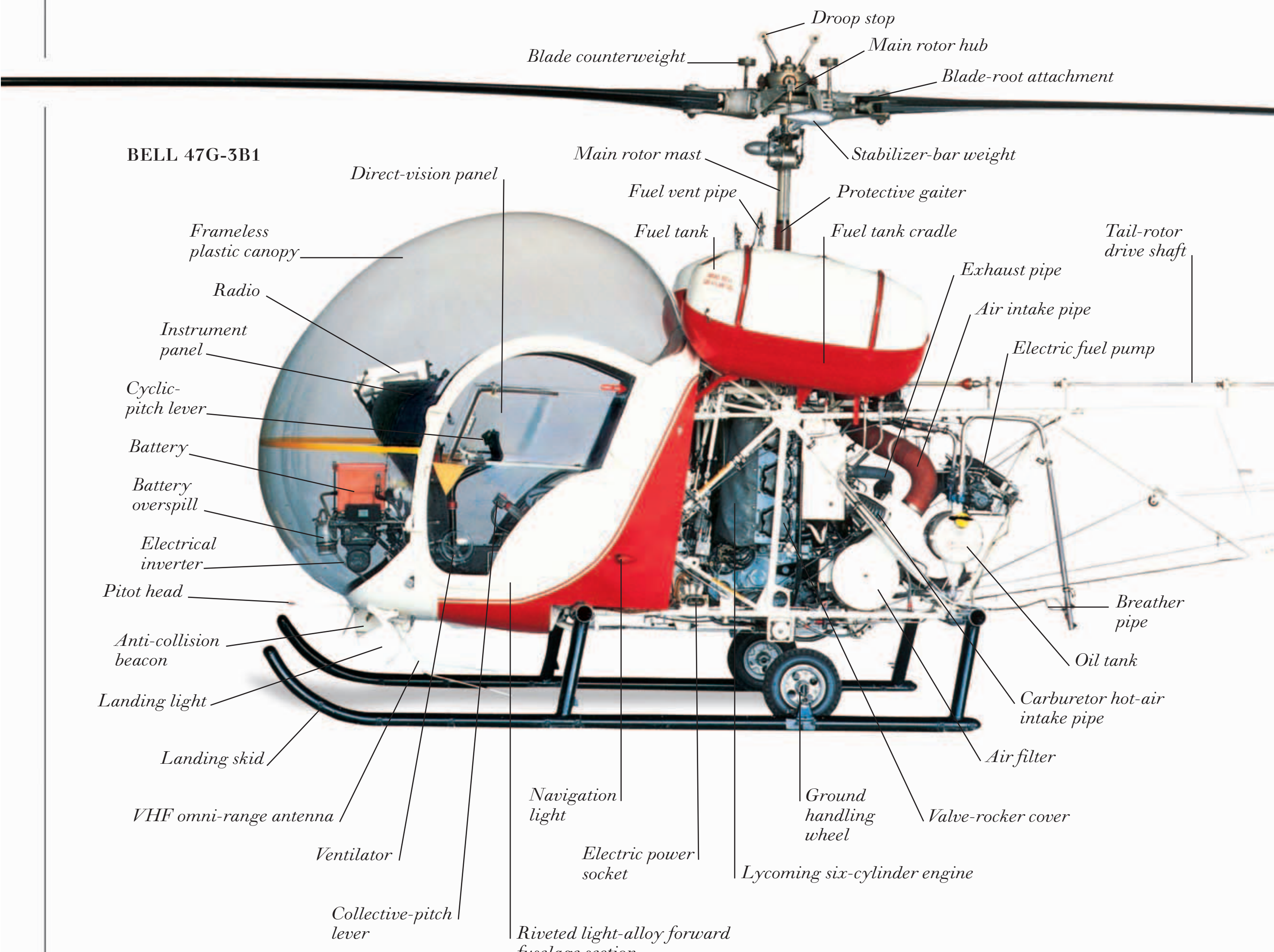


Helicopters

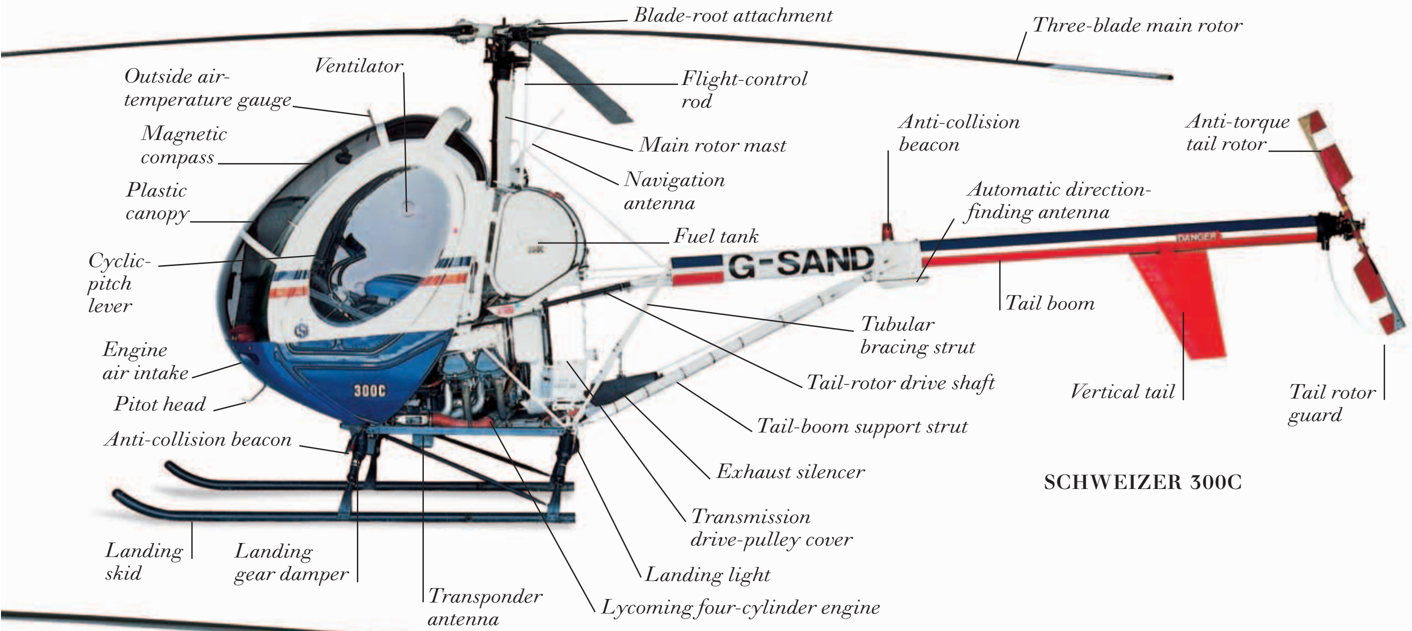


BELL 47G-3B1

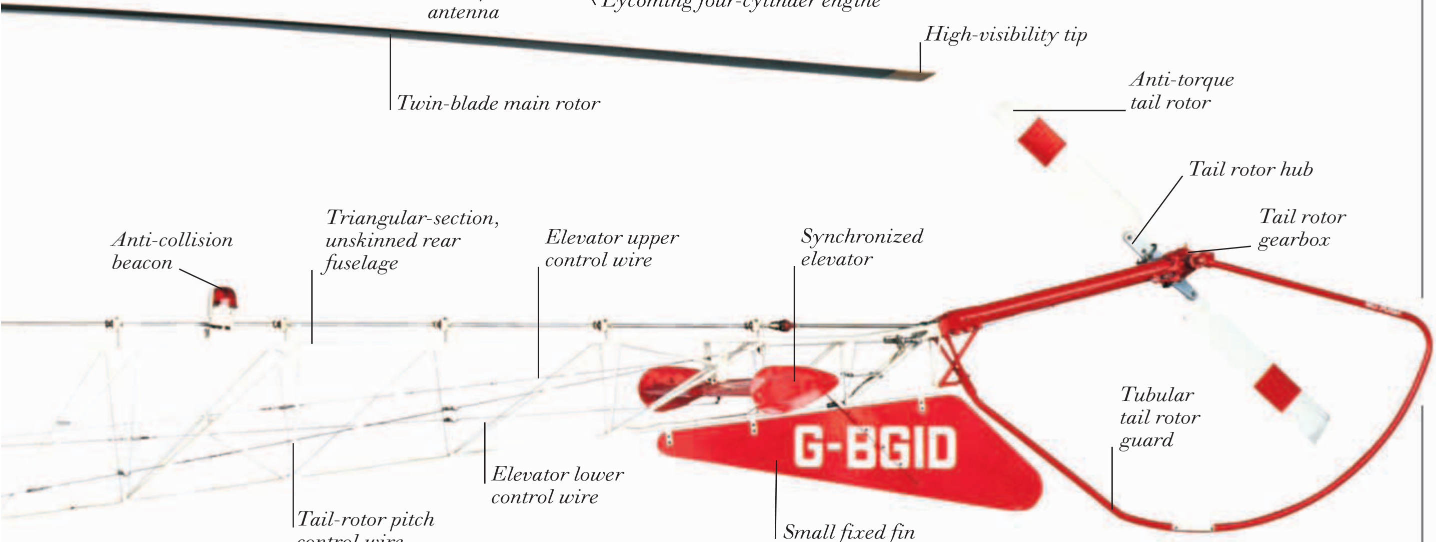
HELICOPTERS USE ROTATING BLADES for lift, propulsion, and steering. The first machine to achieve sustained, controlled flight using rotating blades was the autogiro built in the 1920s by the Spaniard Juan de la Cierva. His machine had unpowered blades above the fuselage that relied on the flow of air to rotate them and provide lift as the autogiro was driven forward by a conventional propeller. Then, in 1939, the Russian-born American Igor Sikorsky produced his VS-300, the forerunner of modern helicopters. Its engine-driven blades provided lift, propulsion, and steering. It could take off vertically, hover, and fly in any direction, and had a tail rotor to prevent the helicopter body from spinning. The introduction of gas turbine jet engines to helicopters in 1955 produced quieter, safer, and more powerful machines. Because of their versatility in flight, helicopters are today used for many purposes, including crop spraying, traffic surveillance, and transporting crews to deep-sea oil rigs, as well as acting as gunships, air ambulances, and air taxis.

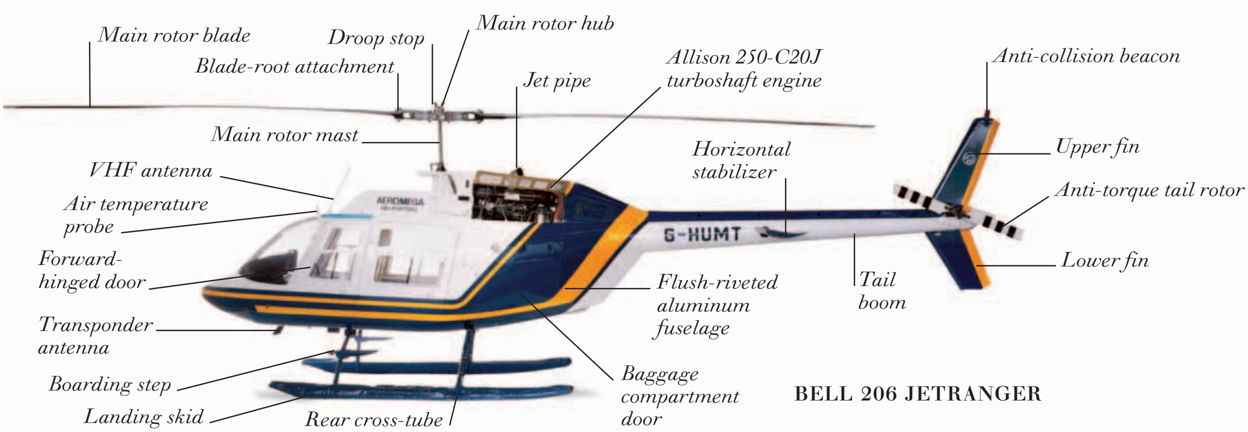


BELL 47G-3B1



SCHWEIZER 300C

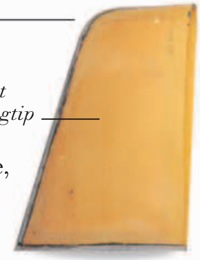


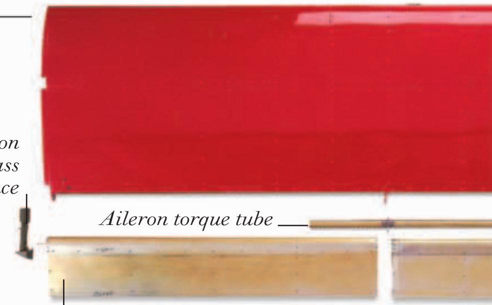


BELL 206 JETRANGER

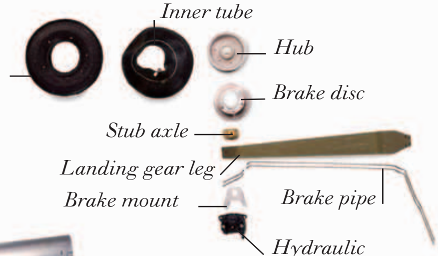
Light aircraft

LIGHT AIRCRAFT, SUCH AS THE ARV SUPER 2 shown here, are small, lightweight, and of simple construction. More than a million have been built since World War I, mainly for recreational use by private owners. Virtually all light aircraft have piston engines, most of which are air-cooled, although some are liquid-cooled. Open cockpits, almost universal in the 1920s, have today been replaced by enclosed cabins. The cabins of high-wing aircraft have one or two doors, whereas those of low-wing aircraft usually have a sliding or hinged canopy. Most modern light aircraft are made of aluminum alloy, although some are made of wood or of fiber-reinforced materials. Light aircraft today also usually have navigational instruments, an electrical system, cabin heating, wheel brakes, and a two-way radio.

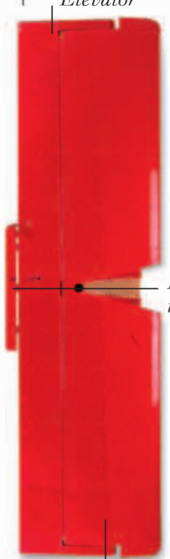


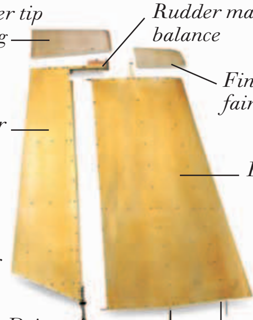


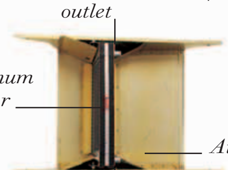
PORT MAIN LANDING GEAR

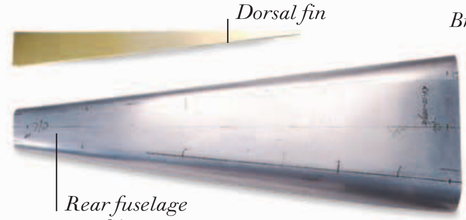


TAILPLANE AND RUDDER



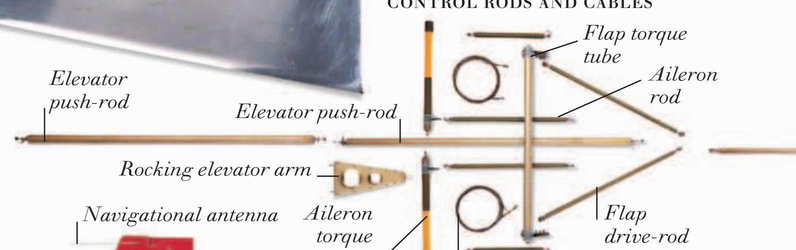






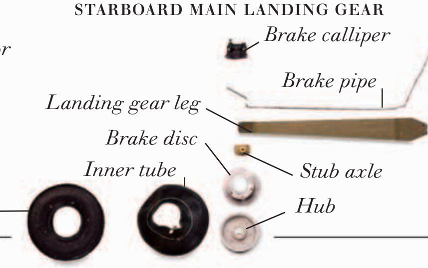
REAR FUSELAGE

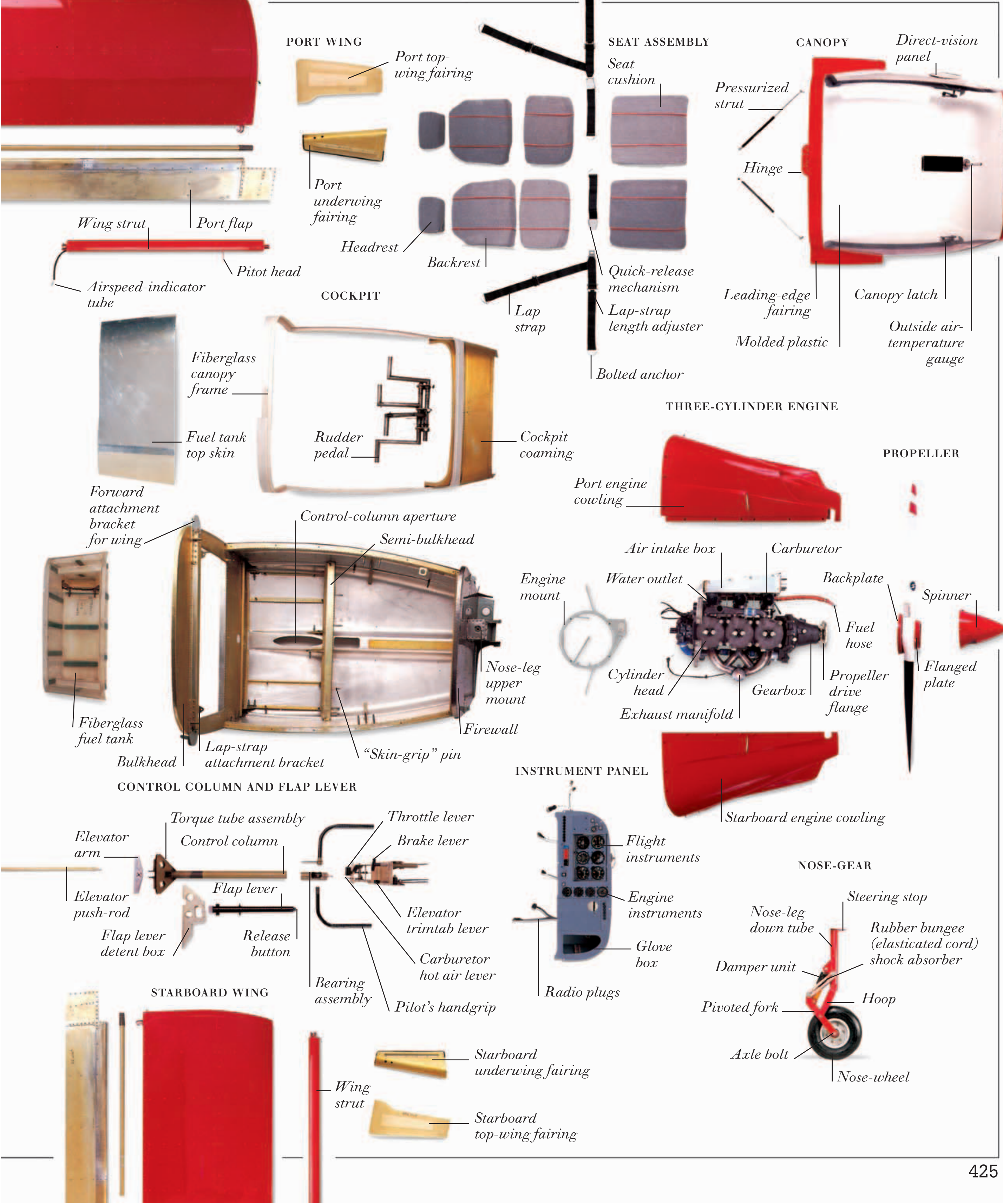
CONTROL RODS AND CABLES



SIDE VIEW OF ARV SUPER 2

STARBOARD MAIN LANDING GEAR



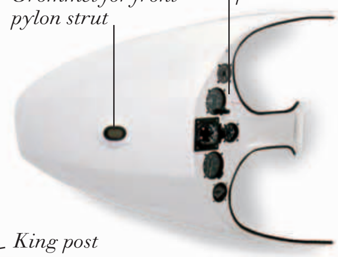

PORT WING
Port top-wing fairing
Port underwing fairing
Wing strut
Port flap
Pitot head
Airspeed-indicator tube
SEAT ASSEMBLY
Seat cushion
Headrest
Backrest
Quick-release mechanism
Lap strap
Lap-strap length adjuster
Bolted anchor
CANOPY
Direct-vision panel
Pressurized strut
Hinge
Leading-edge fairing
Molded plastic
Canopy latch
Outside air-temperature gauge
COCKPIT
Fiberglass canopy frame
Fuel tank top skin
Rudder pedal
Cockpit coaming
Forward attachment bracket for wing
Control-column aperture
Semi-bulkhead
Nose-leg upper mount
Firewall
"Skin-grip" pin
Lap-strap attachment bracket
Bulkhead
Fiberglass fuel tank
THREE-CYLINDER ENGINE
Port engine cowling
Air intake box
Carburetor
Engine mount
Water outlet
Fuel hose
Cylinder head
Gearbox
Propeller drive flange
Exhaust manifold
Starboard engine cowling
PROPELLER
Backplate
Spinner
Flanged plate
CONTROL COLUMN AND FLAP LEVER
Torque tube assembly
Elevator arm
Control column
Elevator push-rod
Flap lever
Flap lever detent box
Release button
Throttle lever
Brake lever
Elevator trimtab lever
Carburetor hot air lever
Bearing assembly
Pilot's handgrip
INSTRUMENT PANEL
Flight instruments
Engine instruments
Glove box
Radio plugs
NOSE-GEAR
Steering stop
Nose-leg down tube
Rubber bungee (elasticated cord) shock absorber
Damper unit
Hoop
Pivoted fork
Axle bolt
Nose-wheel
STARBOARD WING
Wing strut
Starboard underwing fairing
Starboard top-wing fairing

Gliders, hang-gliders, and ultralights

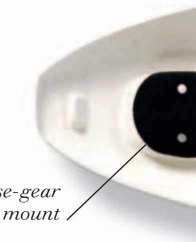
HANG-GLIDER

MODERN GLIDERS ARE AMONG the most graceful and aerodynamically efficient of all aircraft. Unpowered but with a large wingspan (up to about 82 ft, or 25 m), gliders use currents of hot, rising air (thermals) to stay aloft, and a rudder, elevators, and ailerons for control. Modern gliders have achieved flights of more than 900 miles (1,450 km) and altitudes above 49,000 ft (15,000 m). Hang-gliders consist of a simple frame across which rigid or flexible material is stretched to form the wings. The pilot is suspended below the wings in a harness or body bag and, gripping a triangular A-frame, steers by shifting weight from side to side. Like gliders, hang-gliders rely on thermals for lift. Ultralights are basically powered hang-gliders. A small engine and an open fiberglass car (trike), which can hold a crew of two, are suspended beneath a stronger version of a hang-glider frame; the frame may have rigid or flexible wings. Ultralight pilots, like hang-glider pilots, steer by shifting their weight against an A-frame. Ultralights can reach speeds of up to 100 mph (160 kph).

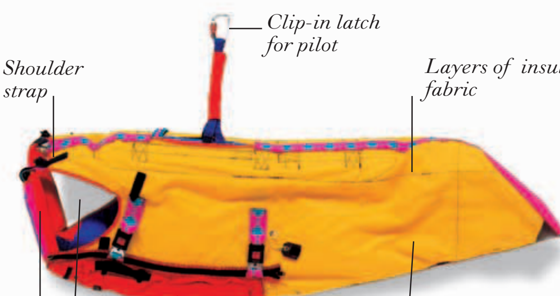
NOSE SHELL

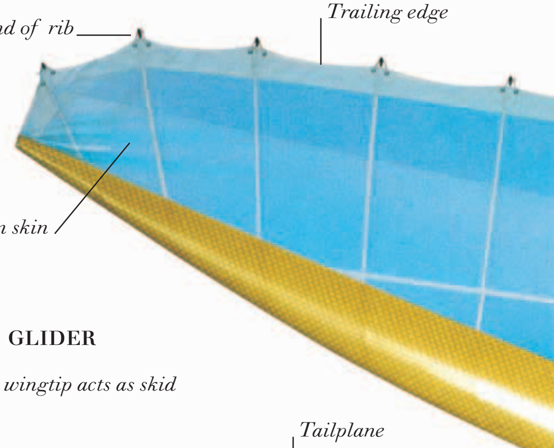


PEGASUS XL SE ULTRALIGHT

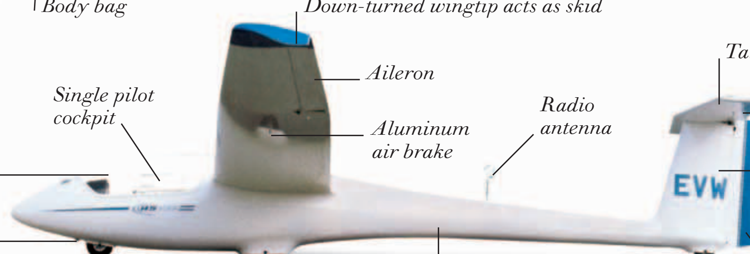


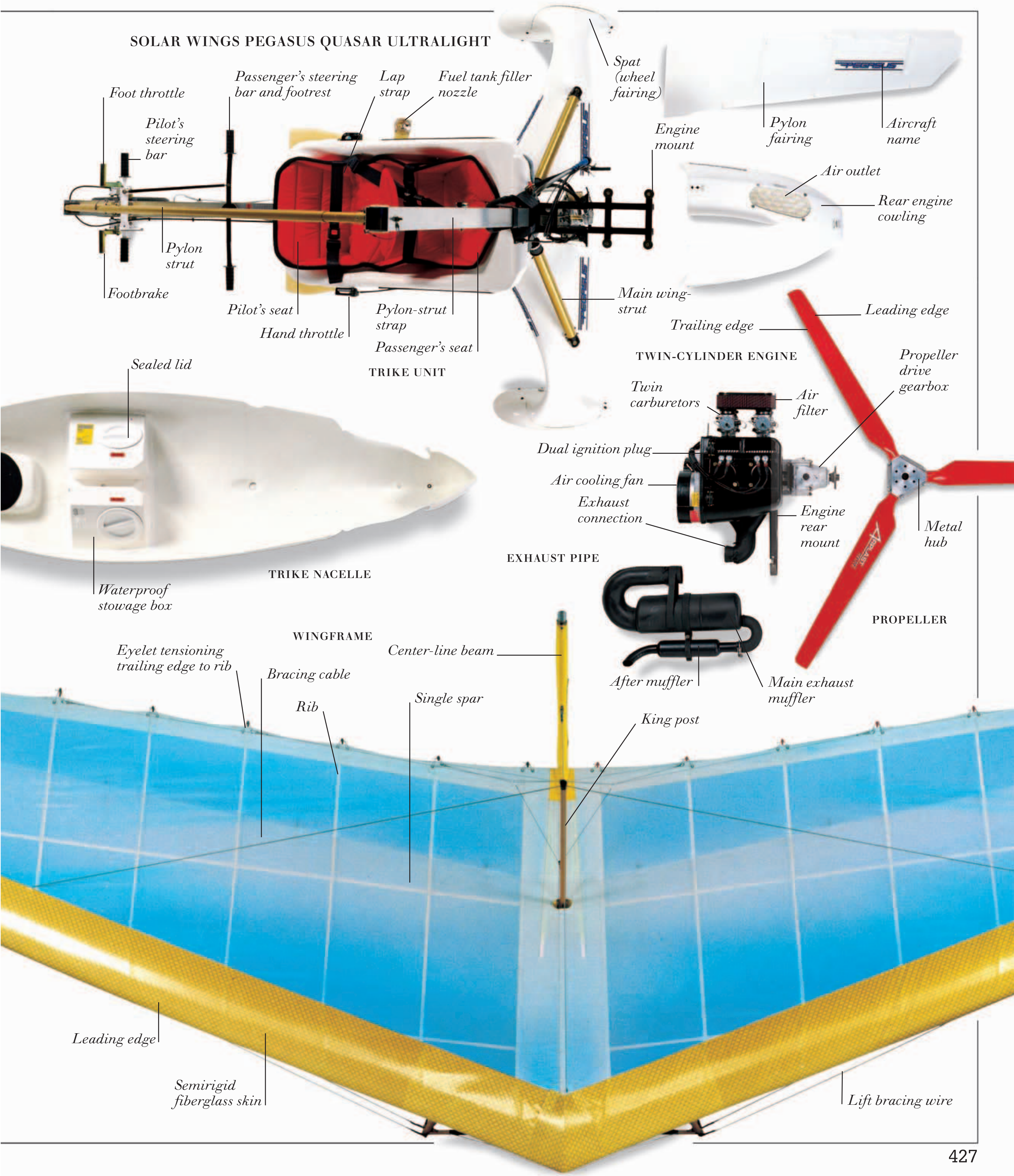
HANG-GLIDER BODY BAG



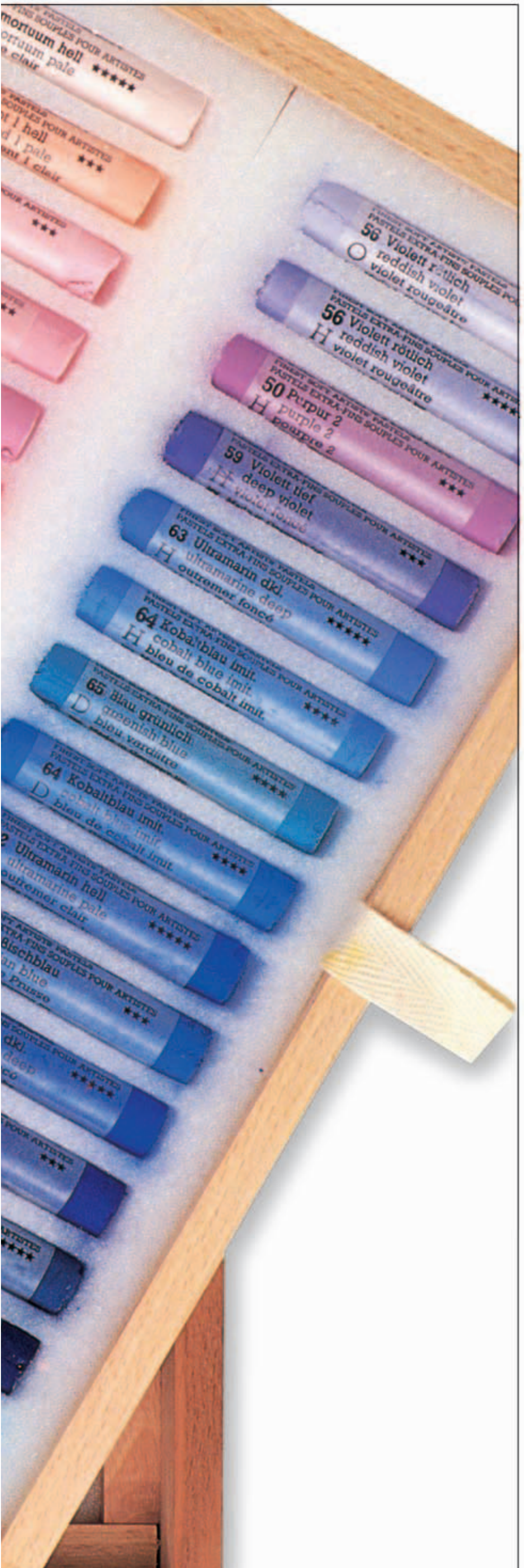


SCHLEICHER K23 GLIDER




SOLAR WINGS PEGASUS QUASAR ULTRALIGHT
Foot throttle
Passenger's steering bar and footrest
Lap strap
Fuel tank filler nozzle
Spat (wheel fairing)
Pylon fairing
Aircraft name
Pilot's steering bar
Engine mount
Air outlet
Rear engine cowling
Pylon strut
Footbrake
Pilot's seat
Hand throttle
Pylon-strut strap
Passenger's seat
Main wing-strut
Trailing edge
Leading edge
TRIKE UNIT
TWIN-CYLINDER ENGINE
Propeller drive gearbox
Sealed lid
Twin carburetors
Air filter
Dual ignition plug
Air cooling fan
Exhaust connection
Engine rear mount
Metal hub
TRIKE NACELLE
EXHAUST PIPE
Waterproof stowage box
PROPELLER
WINGFRAME
Eyelet tensioning trailing edge to rib
Center-line beam
Bracing cable
After muffler
Main exhaust muffler
Rib
Single spar
King post
Leading edge
Semirigid fiberglass skin
Lift bracing wire

75 Moosgrün 1
moss green 1
vert de mousse 1
85 Olivengrün 1
olive green 1
03 Echtgelb 2 hell
sunproof yellow 2 light
jaune solide 2 clair
04 Echtgelb 3 dkl.
sunproof yellow 3 deep
jaune solide 3 foncé
05 Echtorange 1
sunproof orange 1
orange solide 1
42 Permanentrot 1 hell
permanent red 1 pale
rouge permanent 1 clair
47 Krapprosa
rose madder
45 Krapplack
madder lake
laque de garance
49 Purpur 1
purple 1
pourpre 1
46 Karminrot
carmine red
rouge carmin
44 Permanentrot 3 dkl.
permanent red 3 deep
rouge permanent 3 foncé
91 Graublau 1
grey blue 1
gris bleu 1
64 Kobaltblau imit.
cobalt blue imit.
bleu de cobalt imit.
66 Preußischblau
Prussian blue
bleu de Prusse
57 Violett bläulich
bluish violet
violet bleuâtre
63 Ultramarin dkl.
59 Violett tief
68 Grün bläulich
bluish green
vert bleuâtre
76 Moosgrün 2
moss green 2
vert de mousse 2
71 Hellgrün
light green
vert clair
73 Laubgrün 2
leaf green 2
vert d'herbe 2
80 Kaltgrün 1
cold green 1
vert cru 1
30 Umbra grün
greenish umber
terre d'ombre verte
24 Caput mortuum dkl.
caput mortuum deep
tête morte foncé
23 Caput mortuum hell
caput mortuum pale
tête morte clair
FINEST SOFT ARTISTS' PASTELS
PASTELS EXTRA-FINS SOUPLES POUR ARTISTES



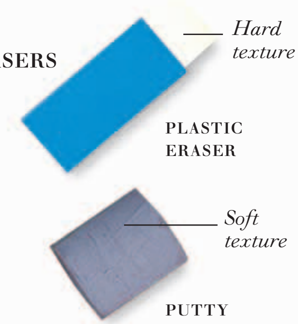
The Visual Arts

Drawing

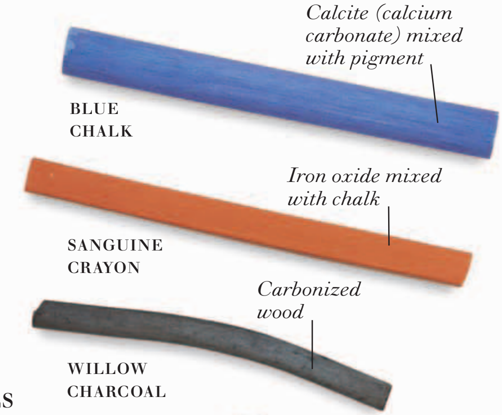
DRAWINGS CAN BE FINISHED WORKS OF ART, or preparatory studies for paintings and other visual arts. They can be made using a wide variety of drawing instruments such as pencils, graphite sticks, chalks, charcoal, pens and inks, and silver wires. The most common drawing instrument is the graphite pencil. A graphite pencil consists of a thin rod of graphite mixed with clay, encased in wood. Charcoal is one of the oldest drawing instruments. It is produced by firing twigs of willow, vine, or other woods at high temperatures in airtight containers. Erasers can be used to rub out marks made by drawing materials such as graphite pencils or charcoal, or to achieve a particular effect—such as smudging. Fixative is often applied—using a mouth diffuser or aerosol spray fixative—to prevent smudging once a drawing is finished. Silver lines can be produced by drawing silver wire across specially prepared paper—a technique known as silverpoint. The lines are permanent and cannot be erased. In time, the silver lines oxidize and turn brown.

FIXATIVE AND MOUTH DIFFUSER

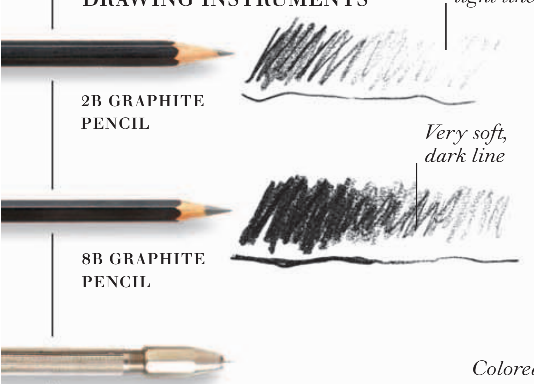
ERASERS



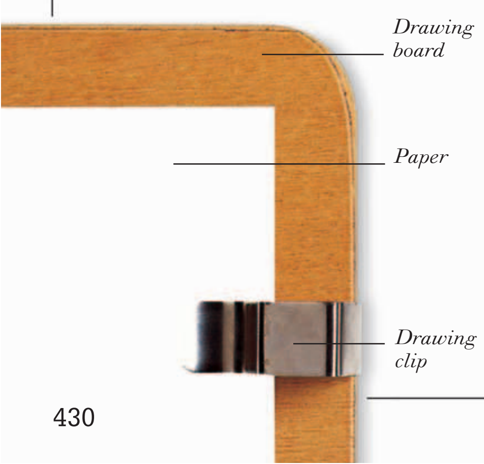
CHALK, CRAYON, AND CHARCOAL



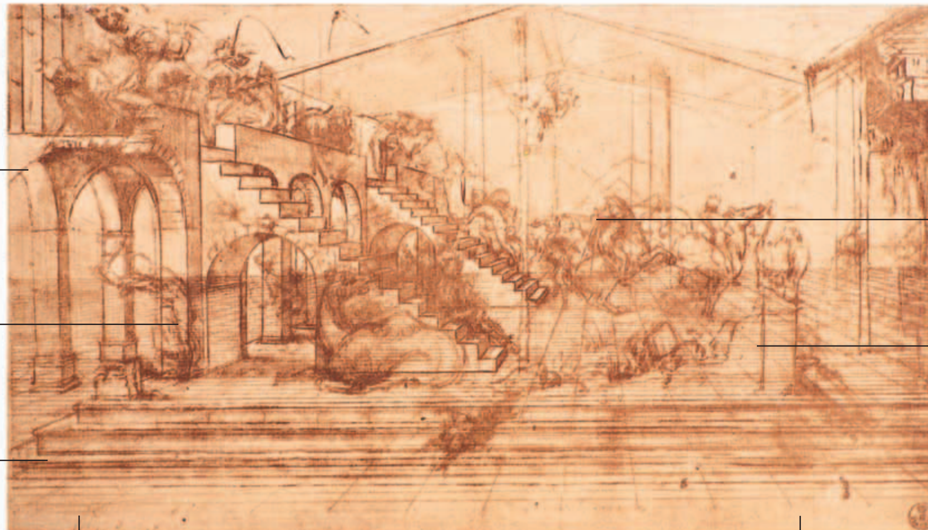
DRAWING INSTRUMENTS



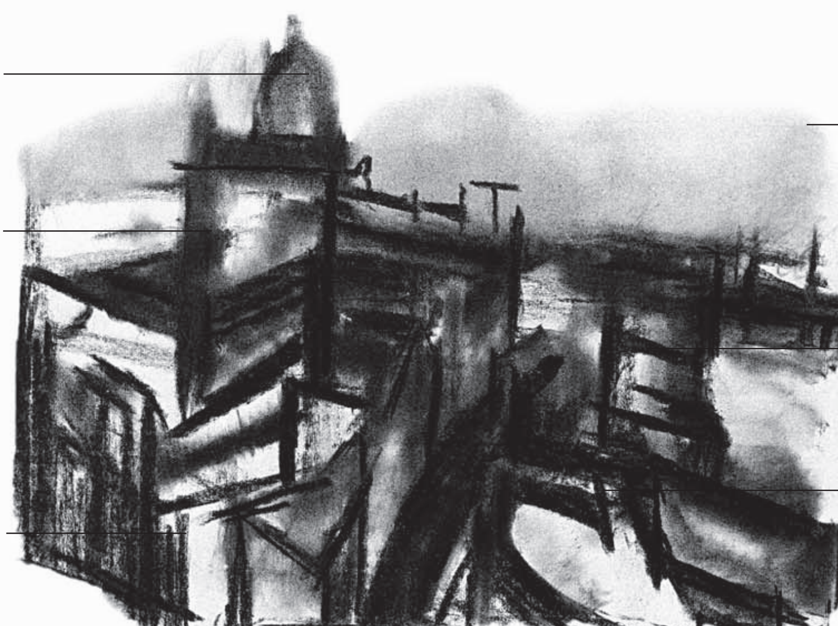
DRAWING BOARD



DRAWING MATERIALS



EXAMPLE OF A SILVERPOINT DRAWING
The Adoration of the Magi, Leonardo da Vinci, 1481
Pen and ink over silverpoint on paper
6½ × 11½ in (16.5 × 29.2 cm)



EXAMPLE OF A CHARCOAL DRAWING
St. Paul's and the River, David Bomberg, 1945
Charcoal on paper
20 × 25⅞ in (50.8 × 65.8 cm)

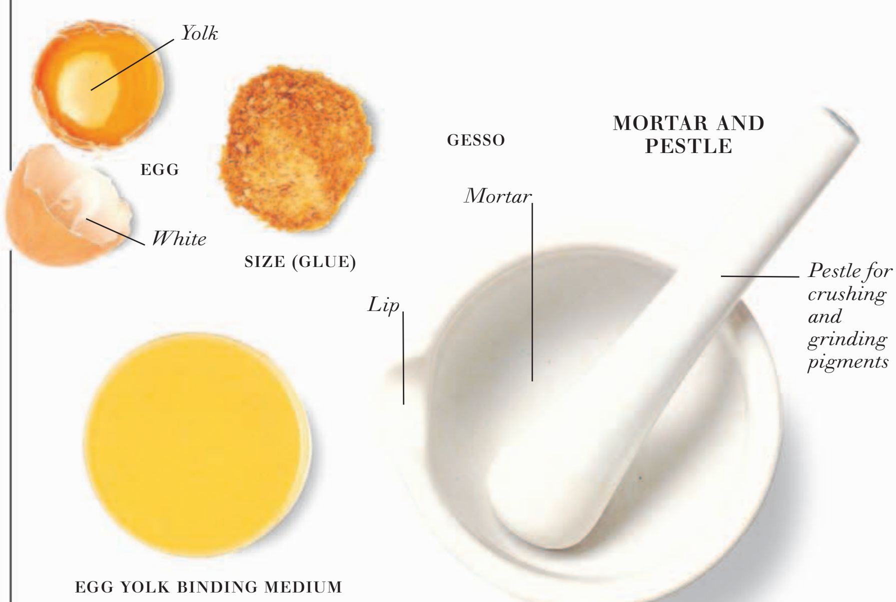
Tempera

ILLUMINATED MANUSCRIPT

THE TERM TEMPERA is applied to any paint in which pigment is tempered (mixed) with a water-based binding medium—usually egg yolk. Egg tempera is applied to a smooth surface such as vellum (for illuminated manuscripts) or more commonly to hardwood panels prepared with gesso—a mixture of chalk and size (glue). Hog hair brushes are used to apply the gesso. A layer of gesso grosso (coarse gesso) is followed by successive layers of gesso sotile (fine gesso) that are sanded between coats to provide a smooth, yet absorbent ground. The paint is applied with fine sable brushes in thin layers, using light brushstrokes. Tempera dries quickly to form a tough skin with a satin sheen. The luminous white surface of the gesso combined with the overlaid paint produces the brilliant crispness and rich colors particular to this medium. Egg tempera paintings are frequently gilded with gold. Leaves of finely beaten gold are applied to a bole (reddish-brown clay) base and polished by burnishing.

MATERIALS FOR GILDING

MATERIALS FOR TEMPERA PANEL PAINTING



EXAMPLES OF BRUSHES

EXAMPLE OF A TEMPERA PAINTING

Presentation in the Temple, Ambrogio Lorenzetti, 1342
Tempera on wood, 8 ft 5⅛ in × 5 ft 6 ⅛in (257 × 168 cm)

PIGMENTS FOR FLESH-COLOR PAINTING

VERDACCIO

VERMILION AND LEAD WHITE

VERMILION

RED EARTH (IRON OXIDE)

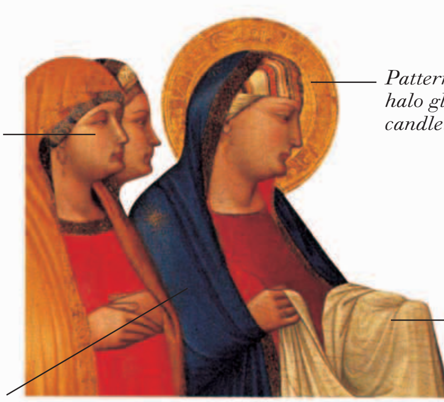
EXAMPLES OF PIGMENTS

MALACHITE

ULTRAMARINE LAPIS LAZULI

VINE BLACK

LEAD TIN YELLOW



DETAIL FROM "PRESENTATION IN THE TEMPLE"

Fresco

FRESCO IS A METHOD OF WALL PAINTING. In buon fresco (true fresco), pigments are mixed with water and applied to an intonaco (layer of fresh, damp lime-plaster). The intonaco absorbs and binds the pigments as it dries making the picture a permanent part of the wall surface. The intonaco is applied in sections called giornate (daily sections). The size of each giornata depends on the artist's estimate of how much can be painted before the plaster sets. The junctions between giornate are sometimes visible on a finished fresco. The range of colors used in buon fresco are limited to lime-resistant pigments such as earth colors (below). Slaked lime (burnt lime mixed with water), bianco di San Giovanni (slaked lime that has been partly exposed to air), and chalk can be used to produce fresco whites. In fresco secco (dry fresco), pigments are mixed with a binding medium and applied to dry plaster. The pigments are not completely absorbed into the plaster and may flake off over time.

CROSS-SECTION SHOWING FRESCO LAYERS

EXAMPLES OF EARTH COLOR PIGMENTS


RAW UMBER


RED EARTH (IRON OXIDE)


GREEN EARTH


RAW SIENNA

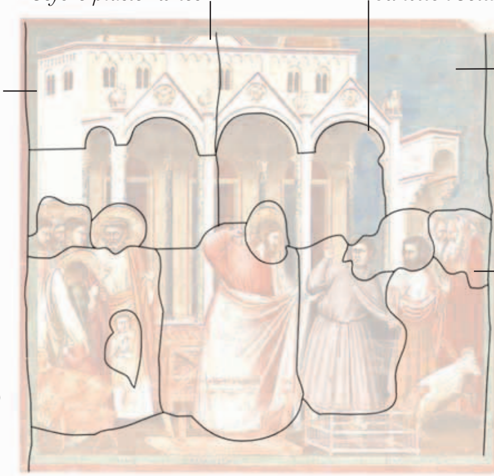
EXAMPLES OF FRESCO BRUSHES

INGREDIENTS FOR FRESCO WHITES

EXAMPLE OF A FRESCO

The Expulsion of the Merchants from the Temple, Giotto, c.1306
Fresco, 78 × 72 in (200 × 185 cm)

DETAIL FROM "THE EXPULSION"



GIORNATE (DAILY SECTIONS) IN "THE EXPULSION"

Oils

KIDNEY-SHAPED PALETTE

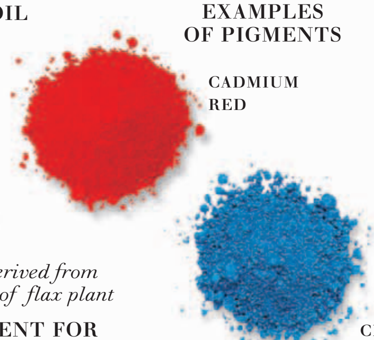
OIL PAINTS ARE MADE BY MIXING and grinding pigment with a drying vegetable oil such as linseed oil. The paint can be applied to many different surfaces and textures—the most common being canvas. Before painting, the canvas is stretched on a wooden frame and its surface is prepared with layers of size (glue) and primer. The two main types of brushes used in oil painting are stiff hog hair bristle brushes—generally used for covering large areas; and soft hair brushes made from sable or synthetic material—generally used for fine detail. Other tools, including painting knives, can also be used to achieve different effects. Oil paint can be applied thickly (a technique known as impasto), or can be thinned down using a solvent—such as turpentine. Varnishes are sometimes applied to finished paintings to protect their surface and to give them a matte or gloss finish.

DAMMAR RESIN VARNISH

COMMERCIAL OIL PAINTS

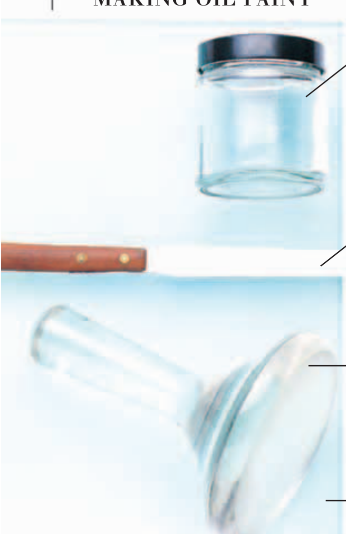
LINSEED OIL

EXAMPLES OF PIGMENTS

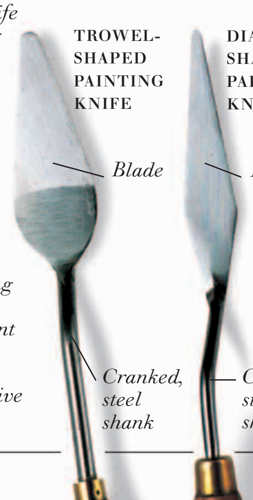


DOUBLE DIPPER (PALETTE ATTACHMENT)

EQUIPMENT FOR MAKING OIL PAINT



PAINTING KNIVES

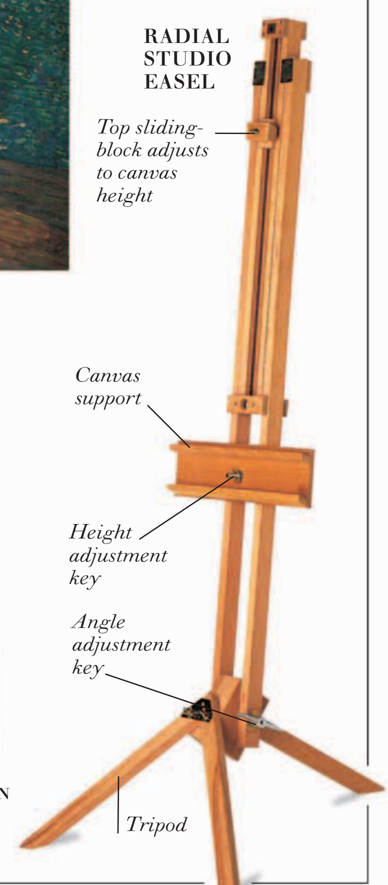


EXAMPLES OF BRUSHES

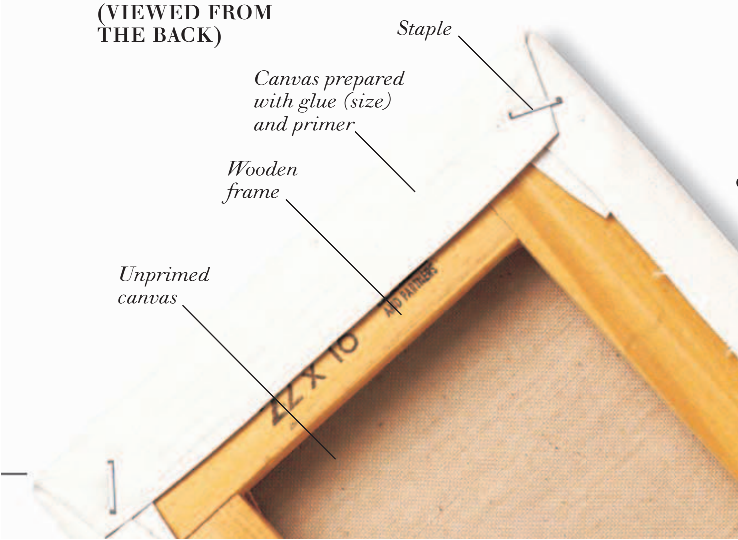
EXAMPLE OF AN OIL PAINTING

Fritillarias, Vincent van Gogh, 1886 Oil on canvas, 29 × 24 in (73.5 × 60.5 cm)

RADIAL STUDIO EASEL



CANVAS STRETCHED ON WOODEN FRAME (VIEWED FROM THE BACK)



EXAMPLES OF CANVASES

COTTON DUCK

FINE LINEN

COARSE LINEN

Watercolor

WATERCOLOR PAINT IS MADE OF GROUND PIGMENT mixed with a watersoluble binding medium, usually gum arabic. It is usually applied to paper using soft hair brushes such as sable, goat hair, squirrel, and synthetic brushes. Watercolors are often diluted and applied as overlaying washes (thin, transparent layers) to build up depth of color. Washes can be laid in a variety of ways to create a range of different effects. For example, a wet-in-wet wash can be achieved by laying a wash on top of another wet wash. The two washes blend together to give a fused effect. Sponges are used to modify washes by soaking up paint so that areas of pigment are lightened or removed from the paper. Watercolors can also be applied undiluted—a technique known as dry brush—to create a broken-color effect. Watercolors are generally transparent and allow light to reflect from the surface of the paper through the layers of paint to give a luminous effect. They can be thickened and made opaque by adding body color (Chinese white).

GUM ARABIC

NATURAL SPONGE

ANATOMY OF A SABLE BRUSH

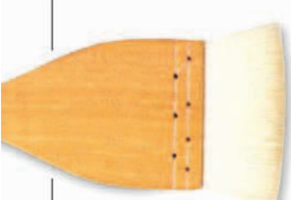
SOFT HAIR BRUSHES

ROUND SABLE BRUSH (NO. 6)

ROUND SABLE BRUSH (NO. 1)

SYNTHETIC WASH BRUSH

SQUIRREL MOP WASH BRUSH



LARGE GOAT HAKE WASH BRUSH

TUBES OF WATERCOLOR PAINT

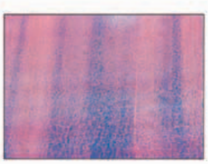
PORTABLE BOX OF WATERCOLOR PAINTS

EXAMPLE OF A WATERCOLOR

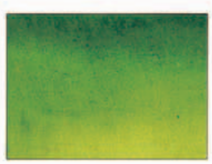
Burning of the Houses of Parliament, Turner, 1834
Watercolor on paper, 11½ × 17½ in (29.2 × 44.5 cm)

EXAMPLES OF WATERCOLOR PAPERS

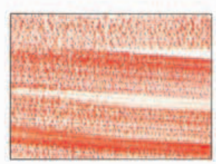
EXAMPLES OF WASHES



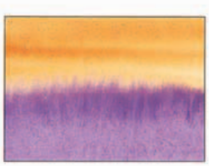
WASH OVER DRY BRUSH
Wash laid over paint applied with dry brush gives two-tone effect



GRADED WASH
Strong wash applied to tilted paper gives graded effect



DRY BRUSH
Undiluted paint dragged across surface of paper gives broken effect



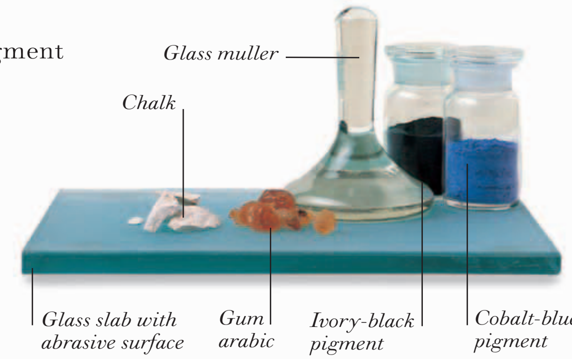
WET-IN-WET
Two diluted washes left to run together to give fused effect

COLOR WHEEL OF WATERCOLOR PAINTS

Pastels

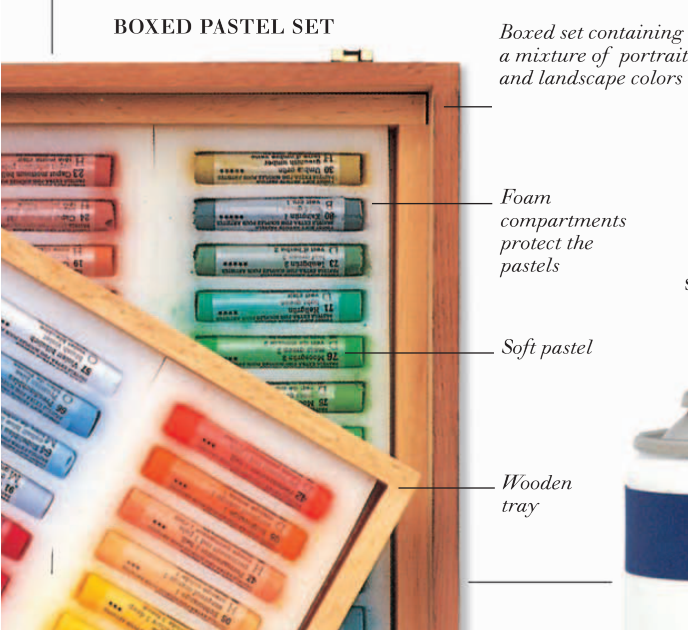
PASTELS ARE STICKS OF PIGMENT made by mixing ground pigment with chalk and a binding medium, such as gum arabic. They vary in hardness depending on the proportion of the binding medium to the chalk. Soft pastel—the most common form of pastel—contains just enough binding medium to hold the pigment in stick form. Pastels can be applied directly to any support (surface) with sufficient tooth (texture). When a pastel is drawn over a textured surface, the pigment crumbles and lodges in the fibers of the support. Pastel marks have a particular soft, matte quality and are suitable for techniques such as blending, scumbling, and feathering. Blending is a technique of rubbing and fusing two or more colors on the support using fingers or various tools such as tortillons (paper stumps), soft hair brushes, putty erasers, and soft bread. Scumbling is a technique of building up layers of pastel colors. The side or blunted tip of a soft pastel is lightly drawn over an underpainted area so that patches of the color beneath show through. Feathering is a technique of applying parallel strokes of color with the point of a pastel, usually over an existing layer of pastel color. A thin spray of fixative can be applied—using a mouth diffuser (see pp. 430-431) or aerosol spray fixative—to a finished pastel painting, or in between layers of color, to prevent smudging.

EQUIPMENT FOR MAKING PASTELS



EXAMPLES OF SOFT PASTELS

BOXED PASTEL SET



EQUIPMENT USED WITH PASTELS

EXAMPLE OF A PASTEL PAINTING

Woman Drying her Neck, Edgar Degas, c.1898
Pastel on cardboard, 24½ x 25½ in (62.5 x 65.5 cm)

DETAIL FROM "WOMAN DRYING HER NECK"

EXAMPLES OF TEXTURED PAPERS AND PASTEL BOARDS


WATERCOLOR PAPER (ROUGH TEXTURE)


GLASS PAPER

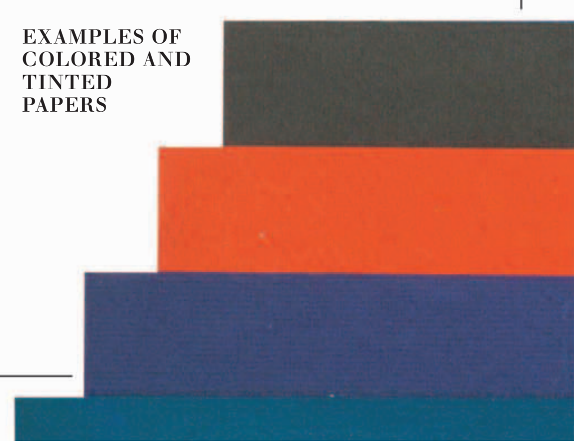

WATERCOLOR PAPER (MEDIUM TEXTURE)


INGRES PAPER


FLOCKED PASTEL BOARD


CANSON PAPER

EXAMPLES OF COLORED AND TINTED PAPERS

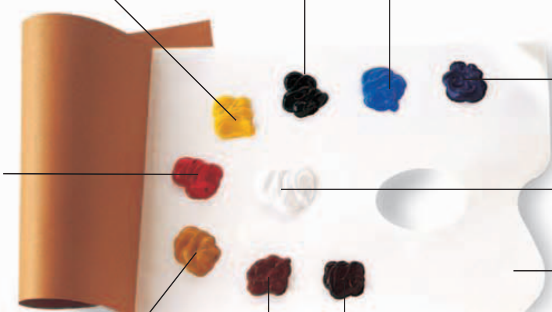


Acrylics

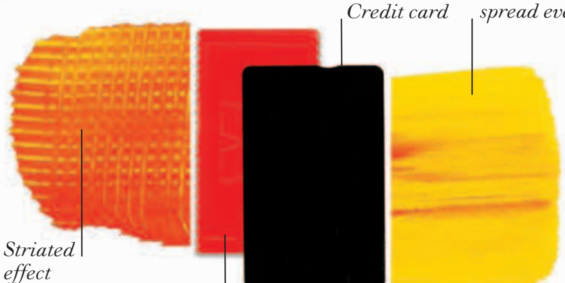
ACRYLIC PAINT IS MADE BY MIXING PIGMENT with a synthetic resin. It can be thinned with water but dries to become water insoluble. Acrylics are applied to many surfaces, such as paper and acrylic-primed board and canvas. A variety of brushes, painting knives, rollers, air-brushes, plastic scrapers, and other tools are used in acrylic painting. The versatility of acrylics makes them suitable for a wide range of techniques. They can be used opaquely or—by adding water—in a transparent, watercolor style. Acrylic mediums can be added to the paint to adjust its consistency for special effects such as glazing and impasto (ridges of paint applied in thick strokes) or to make it more matt or glossy. Acrylics are quick-drying, which allows layers of paint to be applied on top of each other almost immediately.

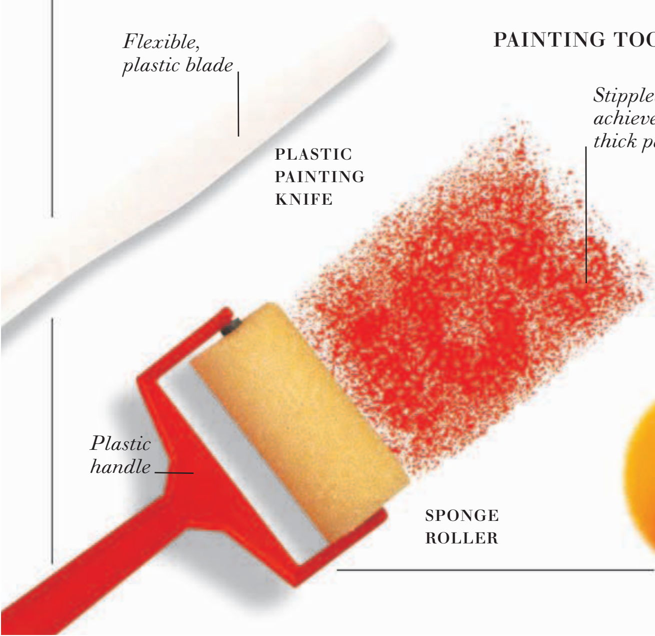
EXAMPLES OF BRUSHES

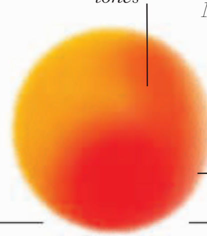
EXAMPLES OF PAINTS USED IN ACRYLICS

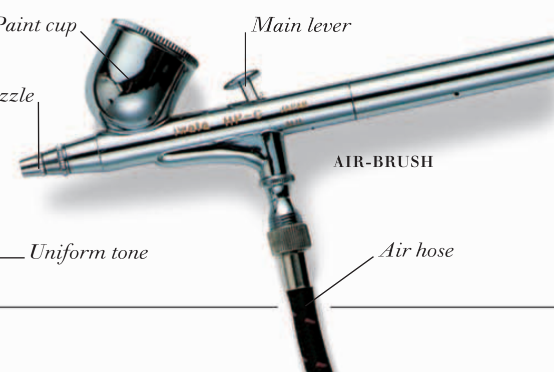


PAINTING TOOLS









EXAMPLE OF AN ACRYLIC PAINTING
A Bigger Splash, David Hockney, 1967
Acrylic on canvas, 95½ x 96 in (242.5 x 243.8 cm)

EXAMPLES OF ACRYLIC PAINTS AND TECHNIQUES

Calligraphy

CALLIGRAPHY IS BEAUTIFULLY FORMED LETTERING. The term applies to written text and illumination (the decoration of manuscripts using gold leaf and color). The essential materials needed to practice calligraphy are a writing tool, ink, and a writing surface. Quills are among the oldest writing tools. They are usually made from goose or turkey feathers, and are noted for their flexibility and ability to produce fine lines. A quill point, however, is not very durable and constant recutting and trimming is required. The most commonly used writing instrument in Western calligraphy is a detachable, metal nib held in a penholder. The metal nib is very durable, and there are a wide range of different types. Particular types of nibs—such as copperplate, speedball, and round-hand nibs—are used for specific styles of lettering. Some nibs have integral ink reservoirs and others have reservoirs that are detachable. Brushes are also used for writing, and for filling in outlined letters and painting decoration. Other writing tools used in calligraphy are fountain pens, felt-tip pens, rotring pens, and reed pens. Calligraphy inks may come in liquid form, or as a solid ink stick. Ink sticks are ground down in distilled water to form a liquid ink. The most common writing surfaces for calligraphy are good quality, smooth -surfaced papers. To achieve the best writing position, the calligrapher places the paper on a drawing board set at an angle.

EQUIPMENT USED IN BRUSH LETTERING

BRUSHES AND BRUSH REST

INK STICK AND STONE

PENS, NIBS, AND BRUSHES USED IN CALLIGRAPHY


PENHOLDER


COPPERPLATE NIB

SPEEDBALL NIB


FELT-TIP PEN


ROUND-HAND NIB AND DETACHABLE INK RESERVOIR


AUTOMATIC PEN


REED PEN


SQUARE SABLE BRUSH

POINTED SABLE BRUSH

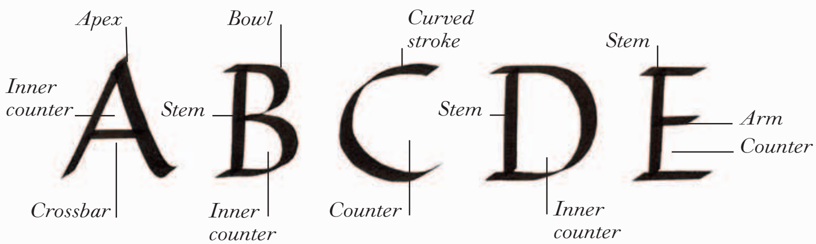
GOOSE-FEATHER QUILL


GOAT HAIR BRUSH

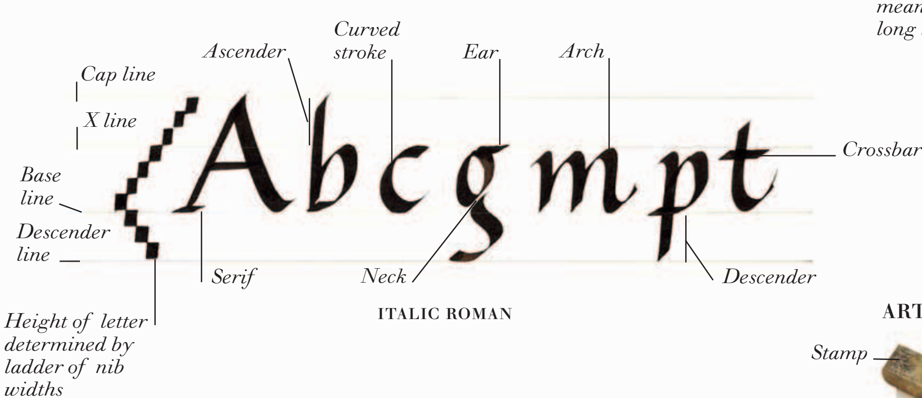

WOLF HAIR BRUSH

FOUNTAIN PEN AND INK

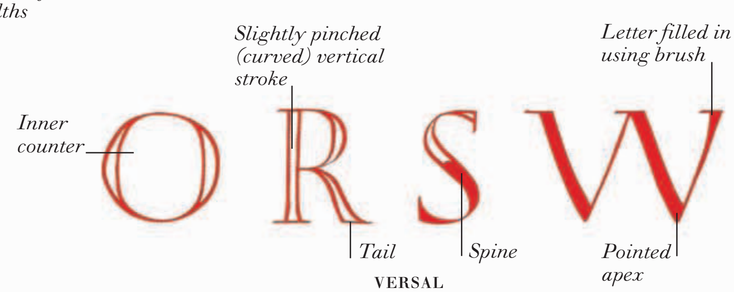
EXAMPLES OF LETTERING STYLES



ROMAN CAPITALS

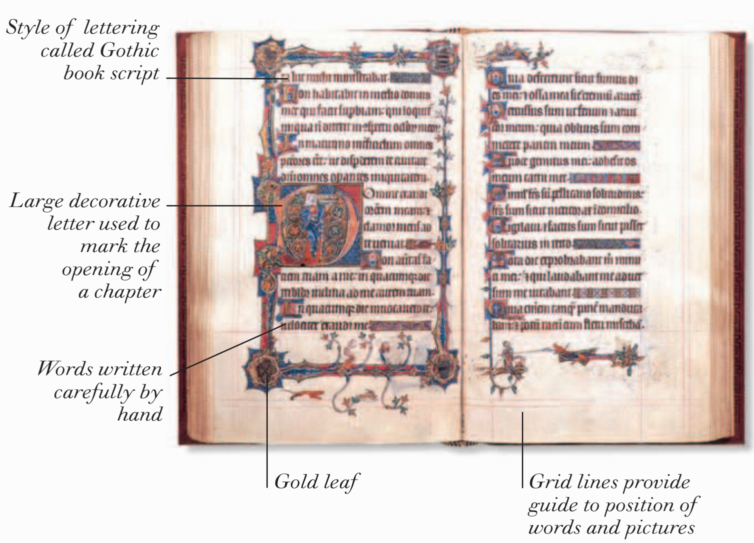


ITALIC ROMAN



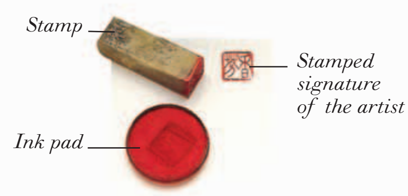
VERSAL

AN ILLUMINATED MANUSCRIPT

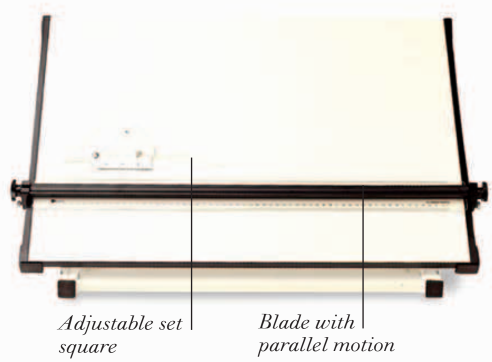


CHINESE LETTERING

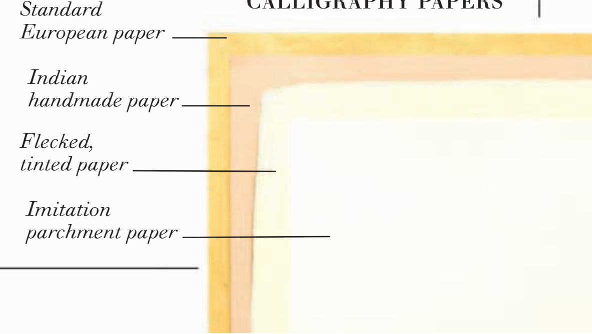
ARTIST'S STAMP



DRAWING BOARD



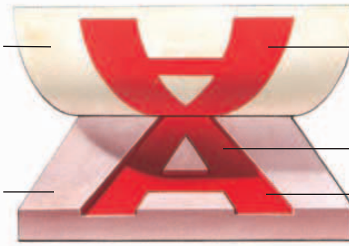
EXAMPLES OF CALLIGRAPHY PAPERS



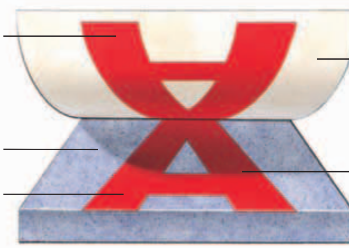
Printmaking 1

PRINTS ARE MADE BY FOUR BASIC printing processes—intaglio, lithographic, relief, and screen. In intaglio printing, lines are engraved or etched into the surface of a metal plate. Lines are engraved by hand using sharp metal tools. They are etched by corroding the metal plate with acid, using acid-resistant ground to protect the areas not to be etched. The plate is then inked and wiped, leaving the grooves filled with ink and the surface clean. Dampened paper is laid over the plate, and both paper and plate are passed through the rollers of an etching press. The pressure of the rollers forces the paper into the grooves, so that it takes up the ink, leaving an impression on the paper. Lithographic printing is based on the antipathy between grease and water. An image is drawn on a surface—usually a stone or metal plate—with a greasy medium, such as tusche (lihographic ink). The greasy drawing is fixed on to the plate by applying an acidic solution, such as gum arabic. The surface is then dampened and rolled with ink. The ink adheres only to the greasy areas and is repelled by the water. Paper is laid on the plate and pressure is applied by means of a press. In relief printing, the nonprinting areas of a wood or linoleum block are cut away using gouges, knives, and other tools. The printing areas are left raised in relief and are rolled with ink. Paper is laid on the inked block and pressure is applied by means of a press or by burnishing (rubbing) the back of the paper. The most common forms of relief printing are woodcut, wood engraving, and linocut. In screen printing, the printing surface is a mesh stretched across a wooden frame. A stencil is applied to the mesh to seal the nonprinting areas and ink is scraped through the mesh to produce an image.

THE FOUR MAIN PRINTING PROCESSES

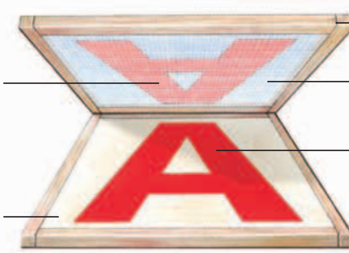


INTAGLIO



LITHOGRAPHIC

RELIEF



SCREEN

LEATHER INK DABBER

EQUIPMENT USED IN INTAGLIO PRINTING

ROCKER

SCRIBER

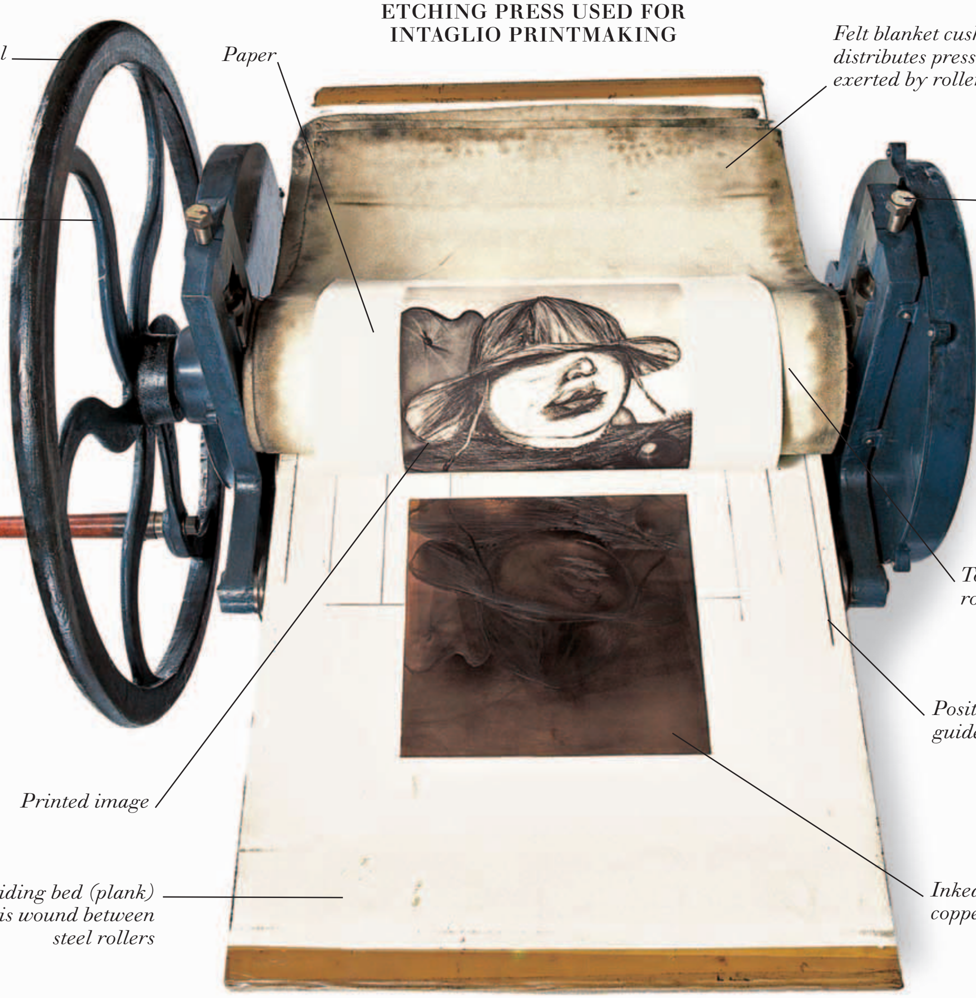
ROULETTE

SCRAPER

BURNISHER

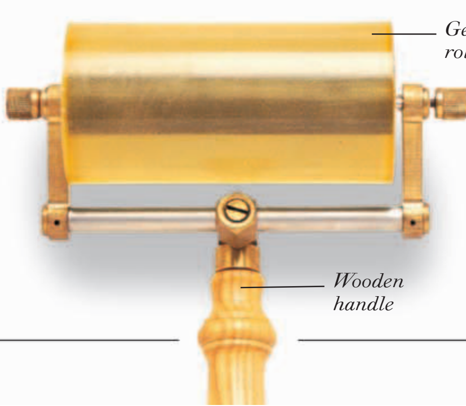
CLAMP

ETCHING PRESS USED FOR INTAGLIO PRINTMAKING



GROUND

GROUND ROLLER



EXAMPLE OF AN INTAGLIO PRINT
Annie with a Sun Hat, Jock McFadyen, 1993
Etched copper plate, 16 × 15¾ in (41 × 40 cm)

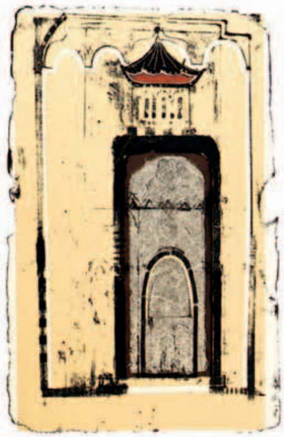
EXAMPLES OF PRINTING PAPERS

Printmaking 2

EXAMPLE OF A LITHOGRAPHIC STONE AND PRINT

Crown Gateway 2, Mandy Bonnell, 1987
Lithograph, 19½ × 15¾ in (50 × 40 cm)

IMAGE DRAWN ON STONE

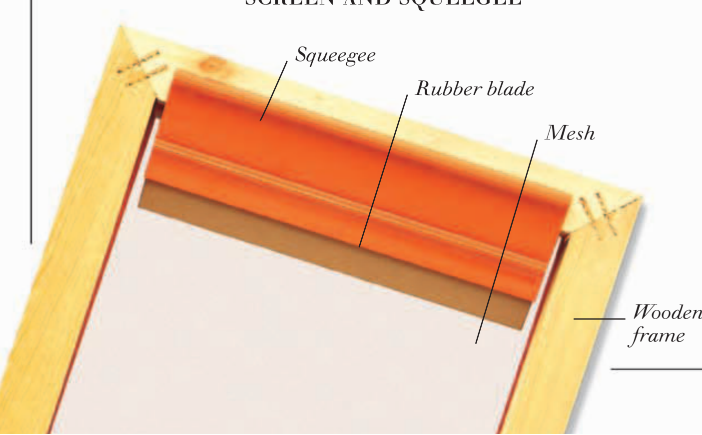


LITHOGRAPIC PRINT

EXAMPLE OF A SCREEN PRINT

Sea Change, Patrick Hughes, 1992
Screen print, 30 × 37 in (77 × 94.5 cm)

SCREEN AND SQUEEGEE



EQUIPMENT USED IN LITHOGRAPHIC PRINTING

CRAYON AND HOLDER

LITHOGRAPHIC PENCIL

TUSCHE (LITHOGRAPHIC INK) PEN

ERASING STICK

EXPANDABLE SPONGE

TUSCHE (LITHOGRAPHIC INK) STICK

RUBBING INK

INK ROLLER

MILD ACIDIC SOLUTION

GUM ARABIC SOLUTION

WATER-BASED SCREEN PRINTING INKS

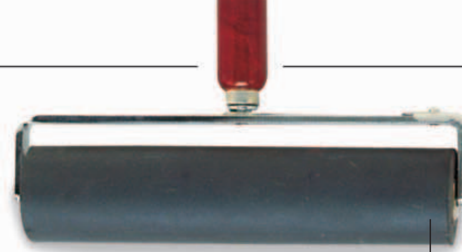
BLUE ACRYLIC INK

RED ACRYLIC INK

BROWN TEXTILE INK

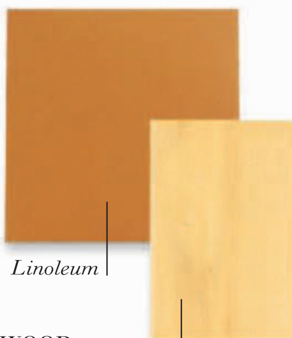
EQUIPMENT USED IN RELIEF PRINTING

V-SHAPED GOUGE



INK ROLLER

LINOLEUM AND WOODCUT BLOCK



U-SHAPED GOUGE

GRAVER

KNIFE

SCORPER

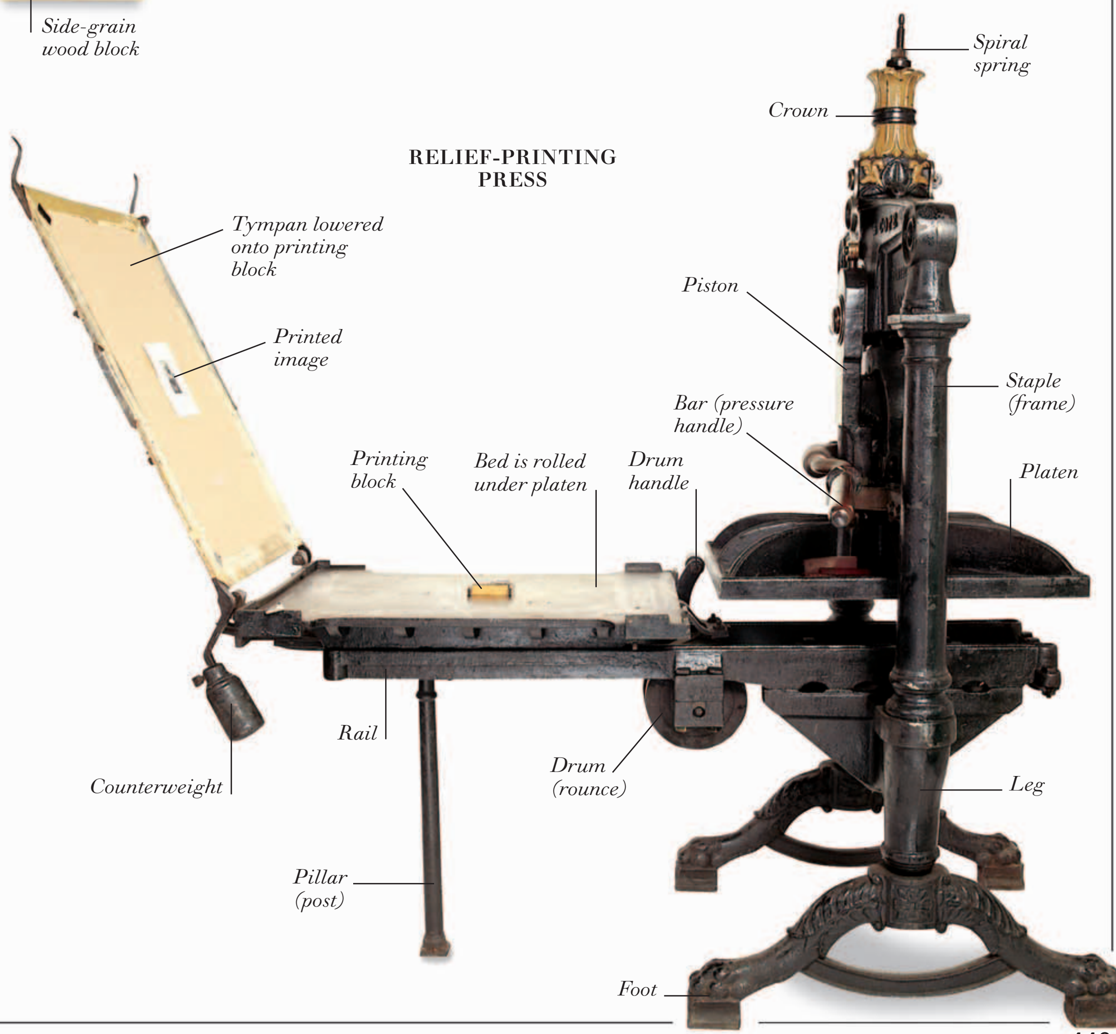
WOOD ENGRAVING

END-GRAIN WOOD BLOCK

INKED-UP ENGRAVED BLOCK

WOOD ENGRAVING PRINT

RELIEF-PRINTING PRESS



Mosaic

MOSAIC IS THE ART OF MAKING patterns and pictures from tesserae (small, colored pieces of glass, marble, and other materials). Different materials are cut into tesserae using different tools. Smalti (glass enamel) and marble are cut into pieces using a hammer and a hardy (a pointed blade) embedded in a log. Vitreous glass is cut into pieces using a pair of pliers. Mosaics can be made using a direct or indirect method. In the direct method, the tesserae are laid directly into a bed of cement-based adhesive. In the indirect method, the design is drawn in reverse on paper or cloth. The tesserae are then stuck face-down on the paper or cloth using water-soluble glue. Adhesive is spread with a trowel on to a solid surface—such as a wall—and the back of the mosaic is laid into the adhesive. Finally, the paper or cloth is soaked off to reveal the mosaic. Gaps between tesserae can be filled with grout. Grout is forced into gaps by dragging a grouting squeegee across the face of the mosaic. Mosaics are usually used to decorate walls and floors, but they can also be applied to smaller objects.

EQUIPMENT FOR BREAKING MARBLE

PLIERS

MOSAIC TOOLS

CEMENT-BASED ADHESIVE

GROUT

SMALTI (GLASS ENAMEL)

RED SMALTI

YELLOW SMALTI

BLUE SMALTI

EXAMPLE OF A MOSAIC (DIRECT METHOD)
Seascape, Tessa Hunkin, 1993
Smalti mosaic on board
31½ in (80 cm) diameter

TROWEL

GROUTING SQUEEGEE

STAGES IN THE CREATION OF A MOSAIC (INDIRECT METHOD)

COLOR SKETCH
A color sketch is drawn in oil pastel to give a clear impression of how the finished mosaic will look.

REVERSE IMAGE
Tesserae are glued face-down on reverse image on paper. Mosaic is then attached to solid surface and paper is removed.

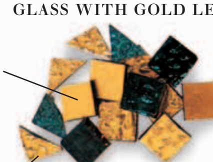
FINISHED MOSAIC
Goldfish, Tessa Hunkin, 1993
Vitreous glass mosaic on board
14 × 10 in (35.5 × 25.5 cm)

MOSAIC POT

MOSAIC MOSQUE DESIGN

VITREOUS GLASS

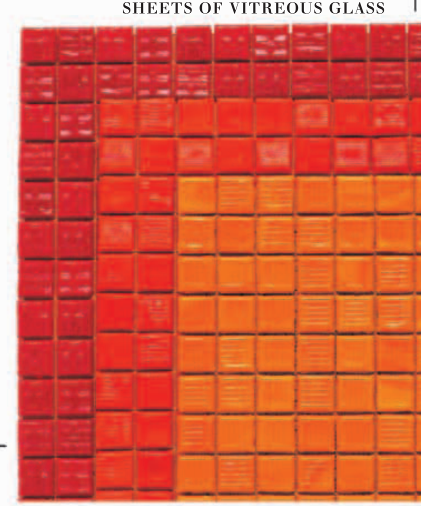
GREEN VITREOUS GLASS WITH GOLD LEAF



RED VITREOUS GLASS

BLUE VITREOUS GLASS

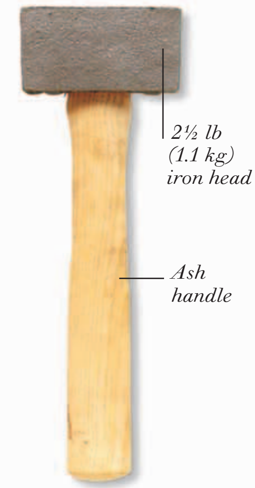
SHEETS OF VITREOUS GLASS



Sculpture 1

THE TWO TRADITIONAL METHODS OF MAKING SCULPTURE are carving and modeling. A carved sculpture is made by cutting away the surplus from a block of hard material such as stone, marble, or wood. The tools used for carving vary according to the material being carved. Heavy steel points, claws, and chisels that are struck with a lump hammer are generally used for stone and marble. Sharp gouges and chisels that are struck with a wooden mallet are used for wood. Sculptures formed from hard materials are generally finished by filing with rasps, rifflers, and other abrasive implements. Modeling is a process by which shapes are built up, using malleable materials such as clay, plaster, and wax. The material is cut with wire-ended tools and modeled with the fingers or a variety of hardwood and metal implements. For large or intricate modeled sculptures an armature (frame), made from metal or wood, is used to provide internal support. Sculptures formed in soft materials may harden naturally or can be made more durable by firing in a kiln. Modeled sculptures are often first designed in wax or another material to be cast later in a metal (see pp. 454-455) such as bronze. The development of many new materials in the 20th century has enabled sculptors to experiment with new techniques such as construction (joining preformed pieces of material such as machine components, mirrors, and furniture) and kinetic (mobile) sculpture.

EXAMPLES OF MARBLE CARVING TOOLS



LUMP HAMMER

WIDE MARBLE CLAW

NARROW MARBLE CLAW

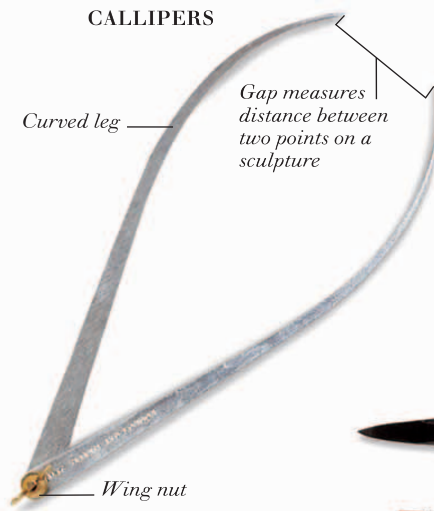
POINT

FLAT CHISEL

BULLNOSE CHISEL

DIAMOND WHETSTONE

CALLIPERS



EXAMPLES OF WOOD-CARVING TOOLS

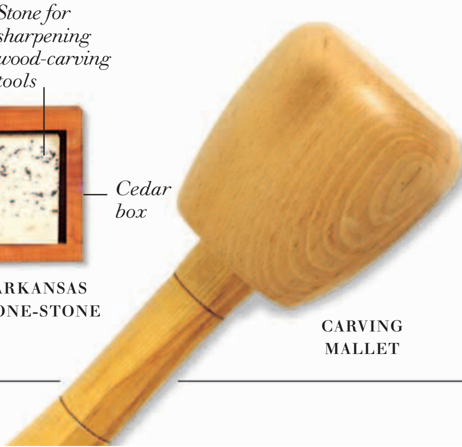
CABINET RASP

STRAIGHT GOUGE

SALMON BEND GOUGE

CHISEL

ARKANSAS HONE-STONE



CARVING MALLET

EXAMPLES OF RIFFLERS (FOR STONE, MARBLE, AND WOOD)

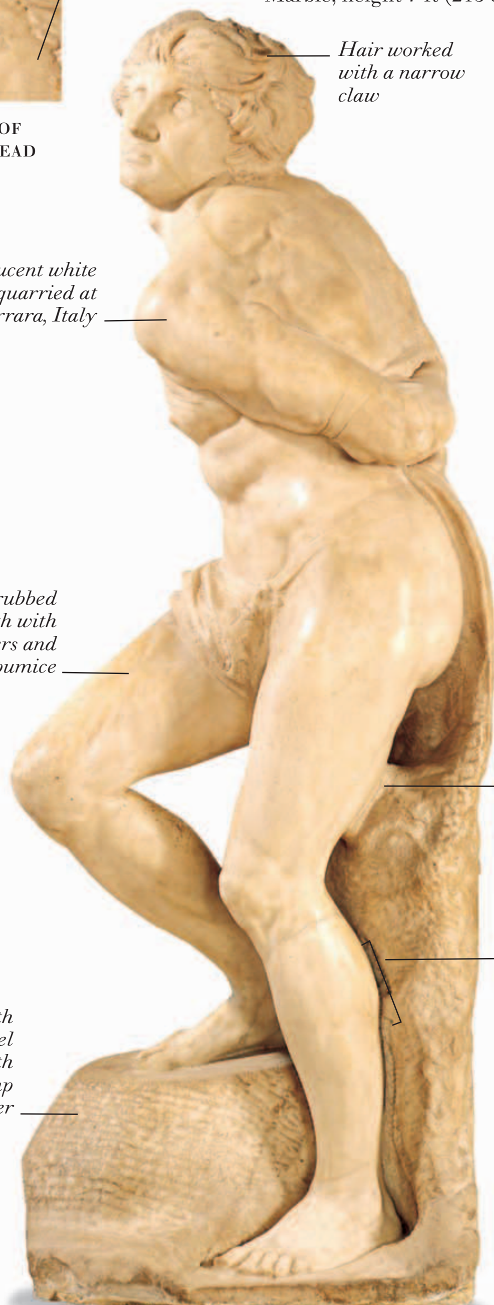
12 IN (30 CM) RIFFLER

6 IN (15 CM) RIFFLER

DETAIL OF SLAVE'S HEAD

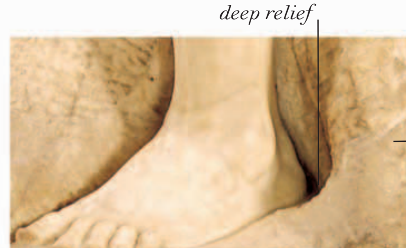
EXAMPLE OF A CARVED MARBLE SCULPTURE

The Rebel Slave, Michelangelo, 1513-1516
Marble, height 7 ft (213 cm)



EXAMPLE OF A CARVED WOOD SCULPTURE

Mary Magdalene, Donatello, 1454-1455
Poplar wood, height 6 ft 2 in (188 cm)



DETAIL OF SLAVE'S FOOT

Sculpture 2

EXAMPLES OF MODELING TOOLS

WIRE-ENDED CUTTING TOOL

CURVED MOLDING TOOL

SPATULA-ENDED WAX MODELING TOOL

ROUNDED WAX MODELING TOOL

EXAMPLES OF BRONZE FINISHING TOOLS

HOOKED RIFFLER

POINTED RIFFLER

SPIRIT LAMP (FOR HEATING WAX MODELING TOOLS)

STAGES IN THE LOST-WAX METHOD OF CASTING

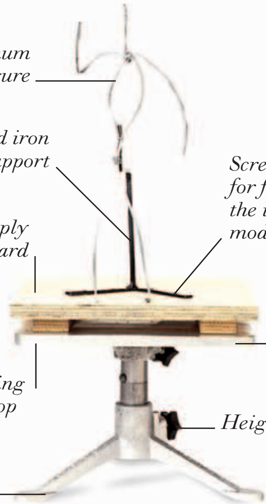
Based on Mars, Giambologna, c.1546

ORIGINAL MODEL
An original, solid wax model is made and preserved so that numerous replicas can be cast.

HOLLOW WAX FIGURE IS CAST
A new, hollow wax model is cast from the original model. It is filled with a plaster core that is held in place with nails. Wax runners and risers are attached.

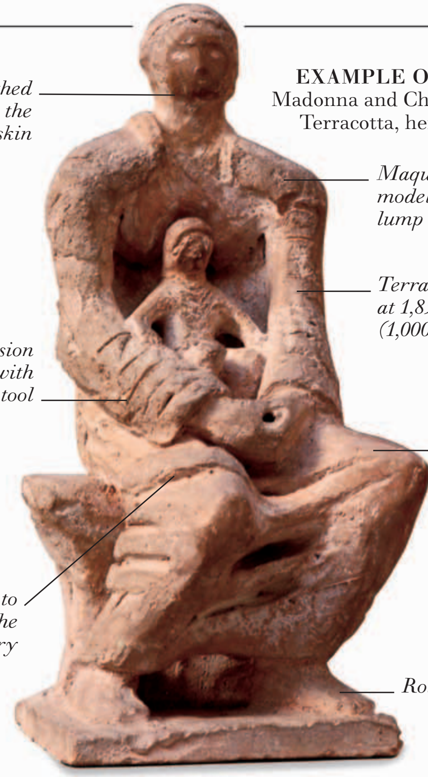
FIGURE IS BAKED IN CASTING MOLD
The model is encased in clay and baked. The wax melts away (through the channels made by the wax rods) and is replaced by molten bronze.

MODELING STAND AND ARMATURE



EXAMPLE OF A CLAY MODEL

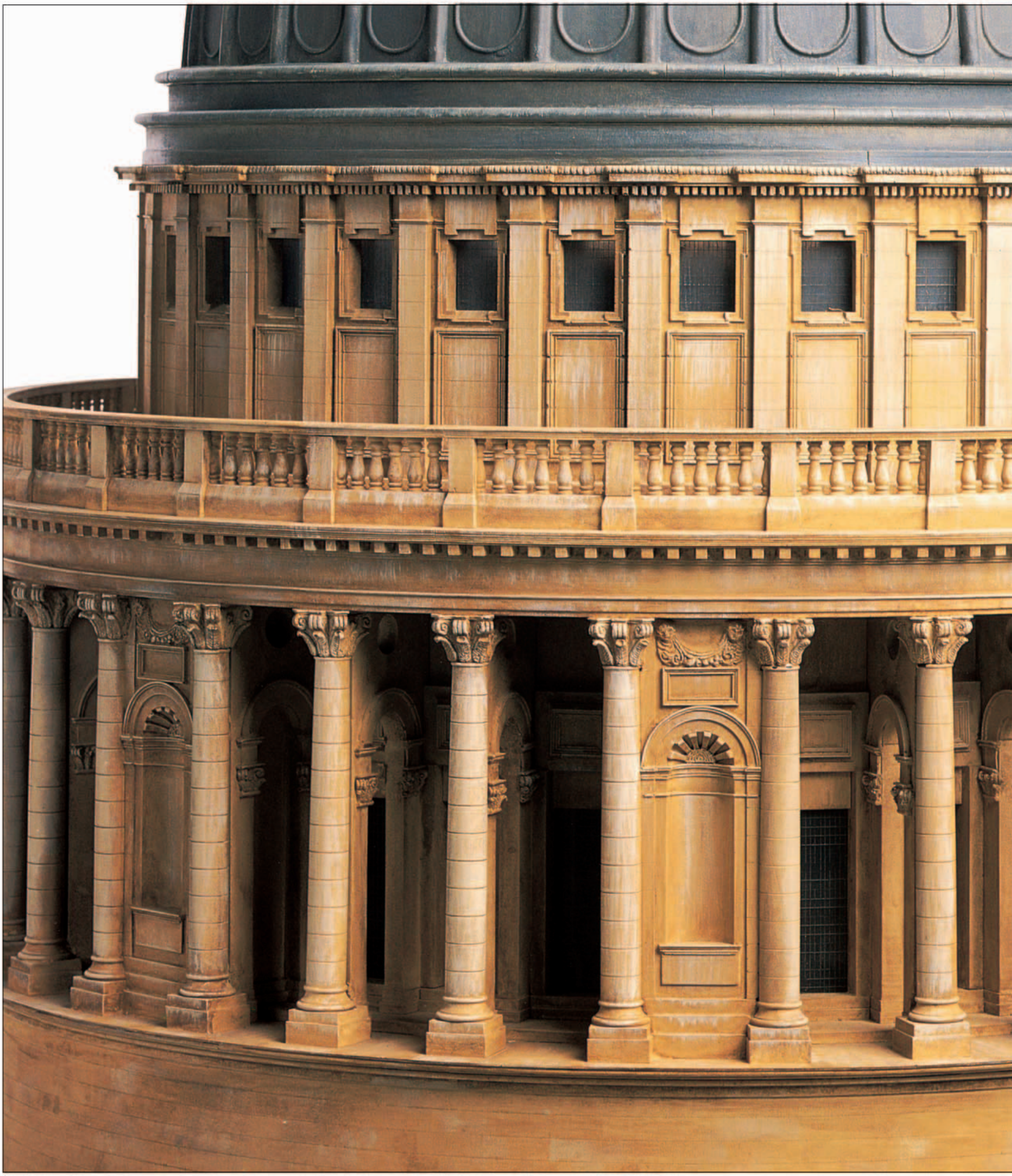
Madonna and Child, Henry Moore, 1943
Terracotta, height 7¼ in (18.4 cm)



STATUE IS STRIPPED OF CLAY
When the bronze has cooled, the clay mold is broken open to reveal the bronze statue with solid metal runners and risers.

STATUE IS FINISHED
The nails are pulled out and a large hole is made to remove the plaster core. When the metal rods have been sawn off, the sculpture is filed to refine the surface.

STATUE IS CLEANED
Finally, the work is cleaned and polished. An artificial patina (coloring) is achieved by treating the surface with chemicals.



Architecture

Ancient Egypt

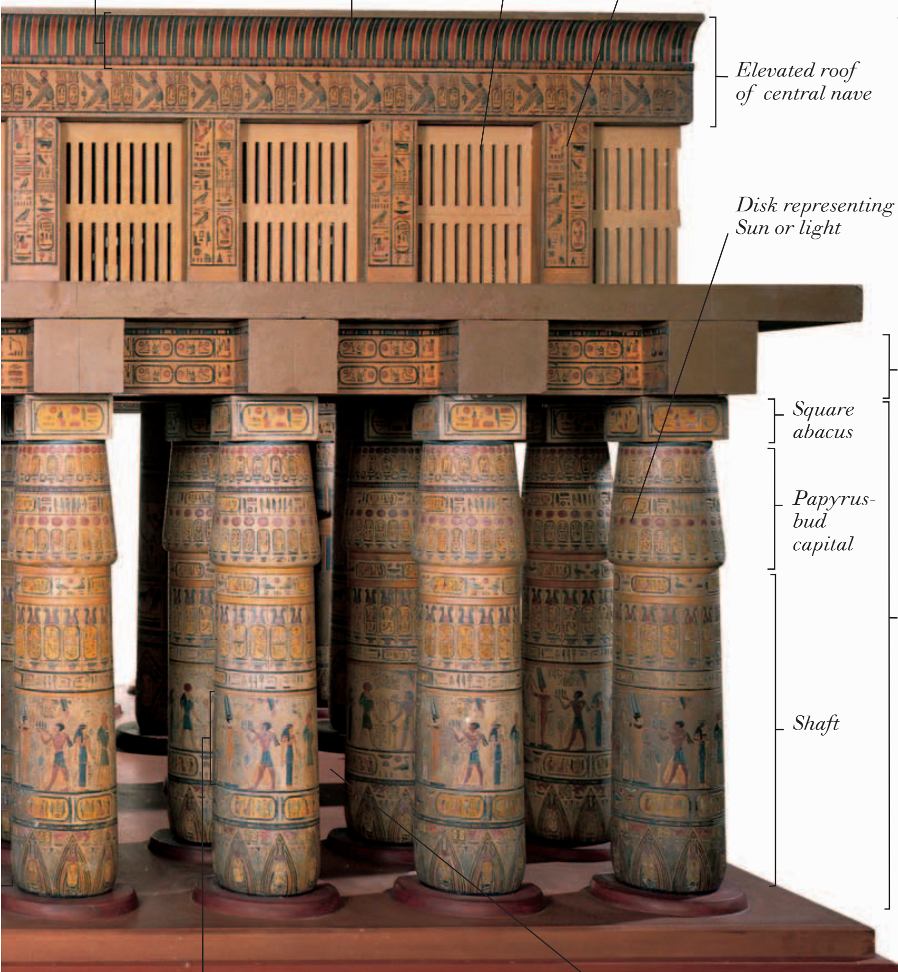
THE CIVILIZATION OF THE ANCIENT EGYPTIANS (which lasted from about 3100 BC until it was finally absorbed into the Roman Empire in 30 BC) is famous for its temples and tombs. Egyptian temples were often huge and geometric, like the Temple of Amon-Re (below and right). They were usually decorated with hieroglyphs (sacred characters used for picture-writing) and painted reliefs depicting gods, Pharaohs (kings), and queens. Tombs were particularly important to the Egyptians, who believed that the dead were resurrected in the afterlife. The tombs were often decorated—as, for example, the surround of the false door opposite—in order to give comfort to the dead. The best-known ancient Egyptian tombs are the pyramids, which were designed to symbolize the rays of the Sun. Many of the architectural forms used by the ancient Egyptians were later adopted by other civilizations; for example, columns and capitals were later used by the ancient Greeks (see pp. 460-461) and ancient Romans (see pp. 462-465).

FRONT VIEW OF HYPOSTYLE HALL, TEMPLE OF AMON-RE

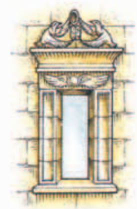
SIDE VIEW OF HYPOSTYLE HALL, TEMPLE OF AMON-RE, KARNAK, EGYPT, c. 1290 BC

LIMESTONE FALSE DOOR WITH HIEROGLYPHS, TOMB OF KING TJETJI, GIZA, EGYPT, c.2400 BC

PLANT CAPITAL OF THE PTOLEMAIC-ROMAN PERIOD, EGYPT, 332-30 BC



ANCIENT EGYPTIAN BUILDING DECORATION



DECORATED WINDOW, MEDINET HABU, EGYPT, c.1198 BC

ROPE AND PATERAE DECORATION

CAPITAL WITH THE HEAD OF THE SKY-GODDESS HATHOR, TEMPLE OF ISIS, PHILAE, EGYPT, 283-47 BC

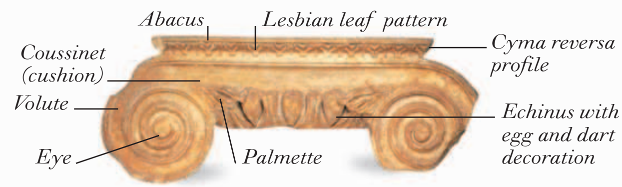
LOTUS AND PAPYRUS FRIEZE DECORATION

Ancient Greece

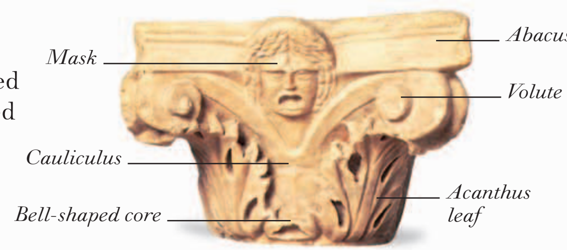
THE CLASSICAL TEMPLES OF ANCIENT GREECE were built according to the belief that certain forms and proportions were pleasing to the gods. There were three main ancient Greek architectural orders (styles), which can be distinguished by the decoration and proportions of their columns, capitals (column tops), and entablatures (structures resting on the capitals). The oldest is the Doric order, which dates from the seventh century BC and was used mainly on the Greek mainland and in the western colonies, such as Sicily and southern Italy. The Temple of Neptune, shown here, is a classic example of this order. It is hypaethral (roofless) and peripteral (surrounded by a single row of columns). About a century later, the more decorative Ionic order developed on the Aegean Islands. Features of this order include volutes (spiral scrolls) on capitals and acroteria (pediment ornaments). The Corinthian order was invented in Athens in the fifth century BC and is typically identified by an acanthus leaf on the capitals. This order was later widely used in ancient Roman architecture.

CAPITALS OF THE THREE ORDERS OF ANCIENT GREEK ARCHITECTURE

DORIC CAPITAL, THE PROPYLAEUM (GATEWAY), THE ACROPOLIS, ATHENS, GREECE, 449 BC

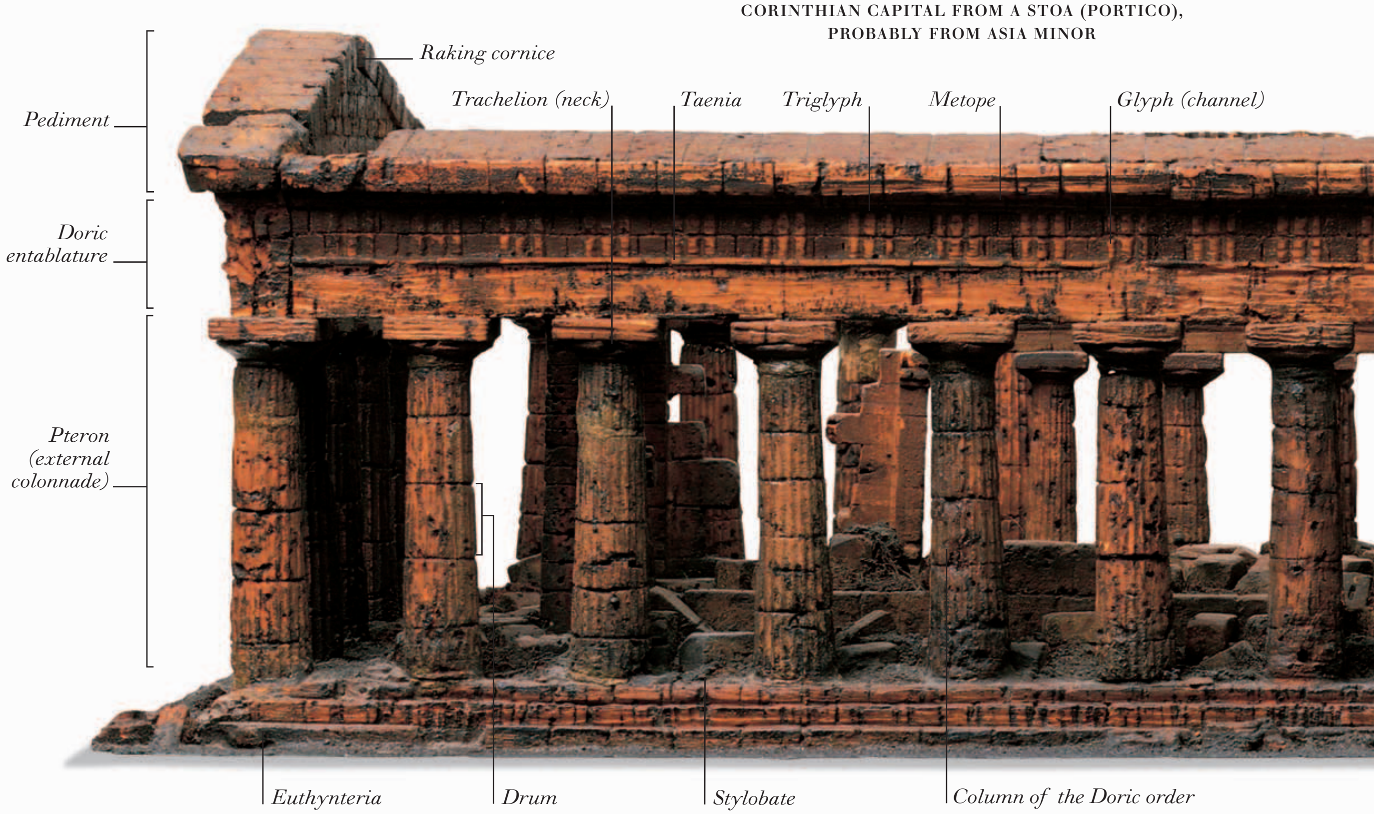


IONIC CAPITAL, THE PROPYLAEUM (GATEWAY), TEMPLE OF ATHENA POLIAS, PRIENE, GREECE, c.334 BC



CORINTHIAN CAPITAL FROM A STOA (PORTICO), PROBABLY FROM ASIA MINOR

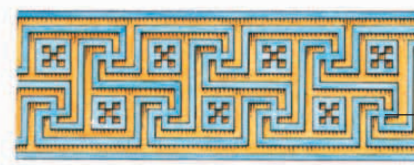
TEMPLE OF NEPTUNE, PAESTUM, ITALY, c.460 BC



PLAN OF THE TEMPLE OF NEPTUNE, PAESTUM

ANCIENT GREEK BUILDING DECORATION

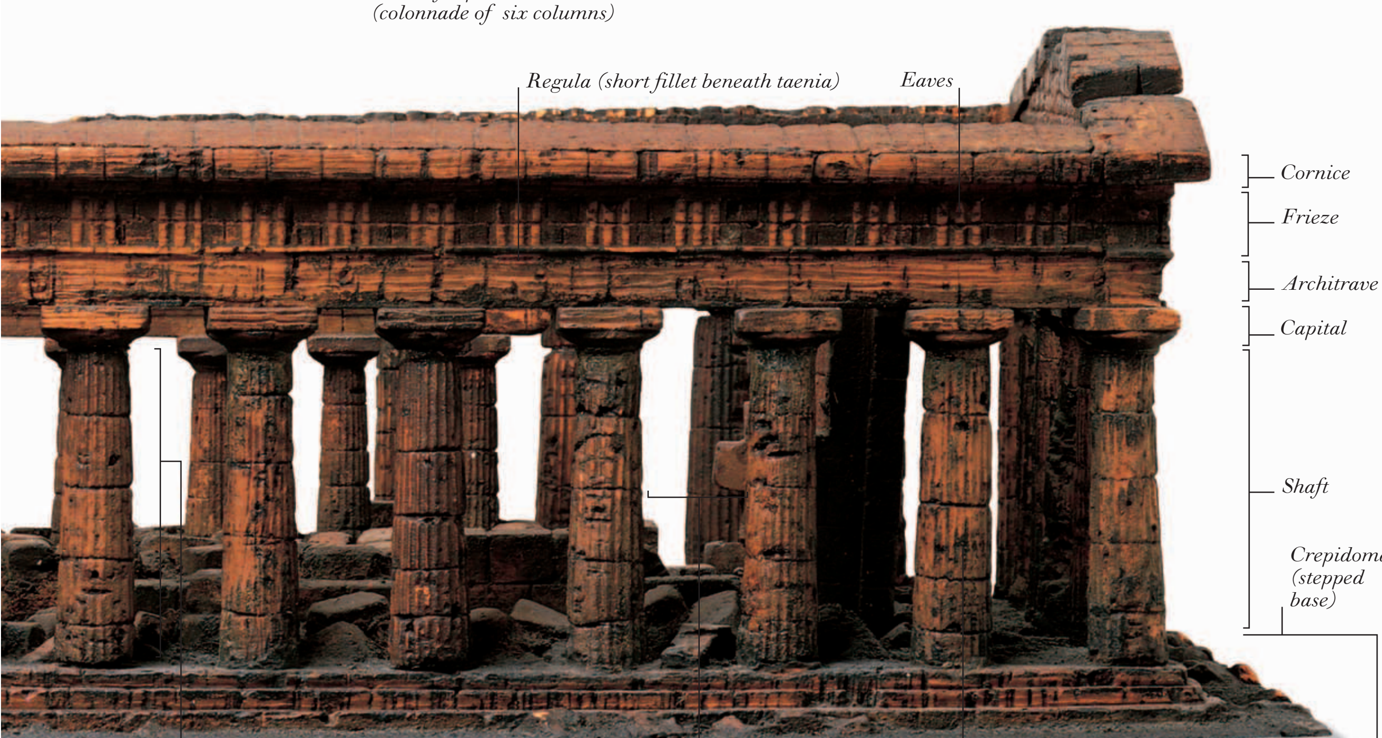
FACADE, TREASURY OF ATREUS, MYCENAE, GREECE, 1350-1250 BC



FRETWORK, PARTHENON, ATHENS, GREECE, 447-436 BC

ACROTERION, TEMPLE OF APHAIA, AEGINA, GREECE, 490 BC

ANTEFIXA, TEMPLE OF APHAIA, AEGINA, GREECE, 490 BC



Ancient Rome 1

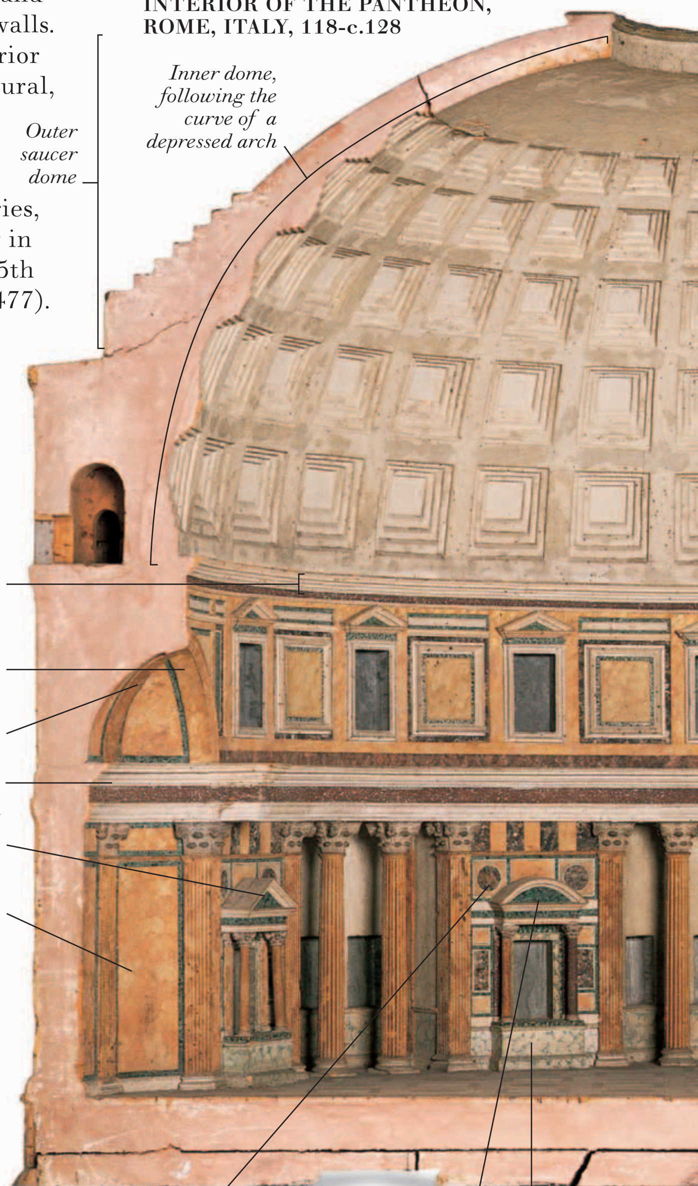
IN THE EARLY PERIOD OF THE ROMAN EMPIRE extensive use was made of ancient Greek architectural ideas, particularly those of the Corinthian order (see pp. 460-461). As a result, many early Roman buildings—such as the Temple of Vesta (opposite)—closely resemble ancient Greek buildings. A distinctive Roman style began to evolve in the first century AD. This style developed the interiors of buildings (the Greeks had concentrated on the exterior) by using arches, vaults, and domes inside the buildings, and by ornamenting internal walls. Many of these features can be seen in the Pantheon. Exterior columns were often used for decorative, rather than structural, purposes, as in the Colosseum and the Porta Nigra (see pp. 464-465). Smaller buildings had timber frames with wattle-and-daub walls, as in the mill (see pp. 464-465). Roman architecture remained influential for many centuries, with some of its principles being used in the 11th century in Romanesque buildings (see pp. 468-469) and also in the 15th and 16th centuries in Renaissance buildings (see pp. 474-477).

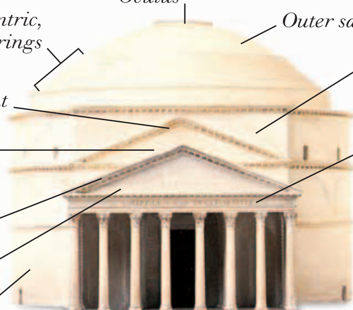
ANCIENT ROMAN BUILDING DECORATION

FESTOON, TEMPLE OF VESTA, TIVOLI, ITALY, C.80 BC

RICHLY DECORATED ROMAN OVUM

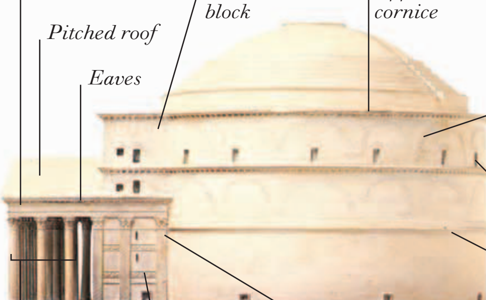
INTERIOR OF THE PANTHEON, ROME, ITALY, 118-c.128





FRONT VIEW OF THE PANTHEON

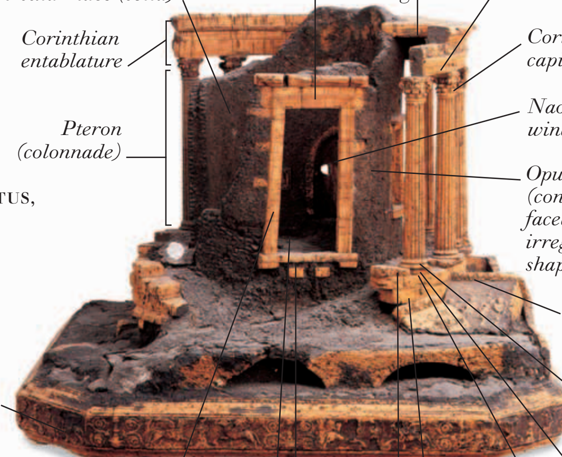
SIDE VIEW OF THE PANTHEON

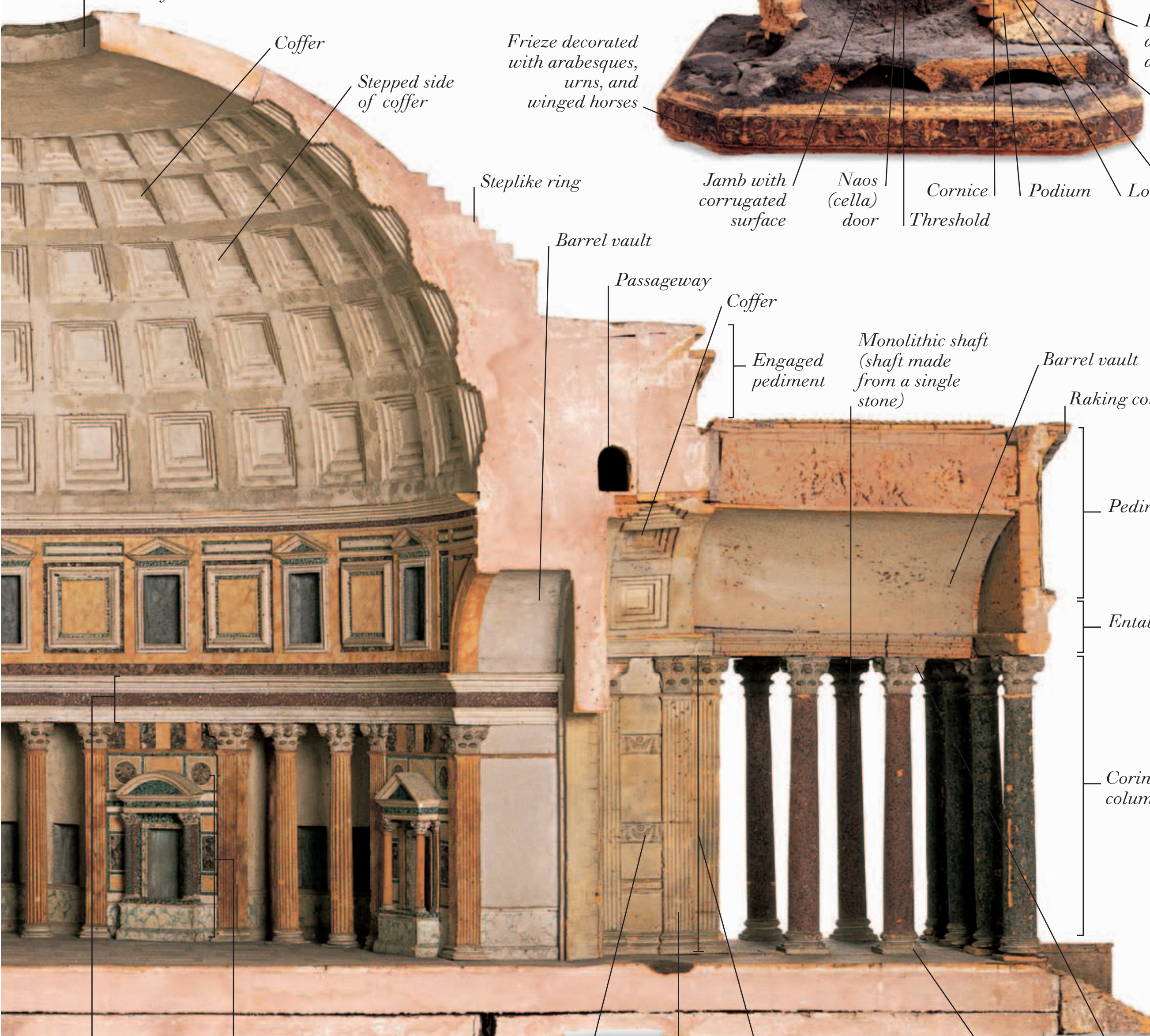


FRIEZE, FORUM OF TRAJAN, ROME, ITALY, 98-113

KEYSTONE, ARCH OF TITUS, ROME, ITALY, 81

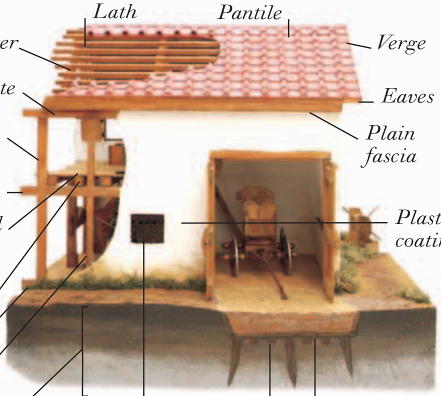
TEMPLE OF VESTA, TIVOLI, ITALY, c.80 BC



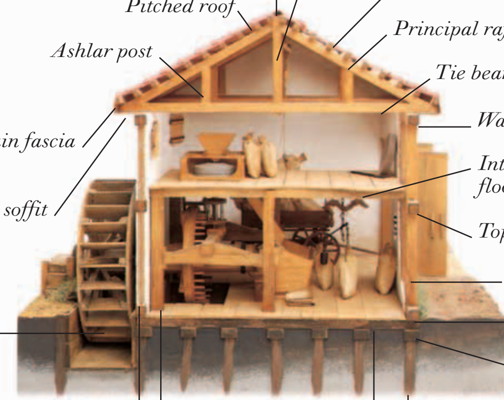


Ancient Rome 2

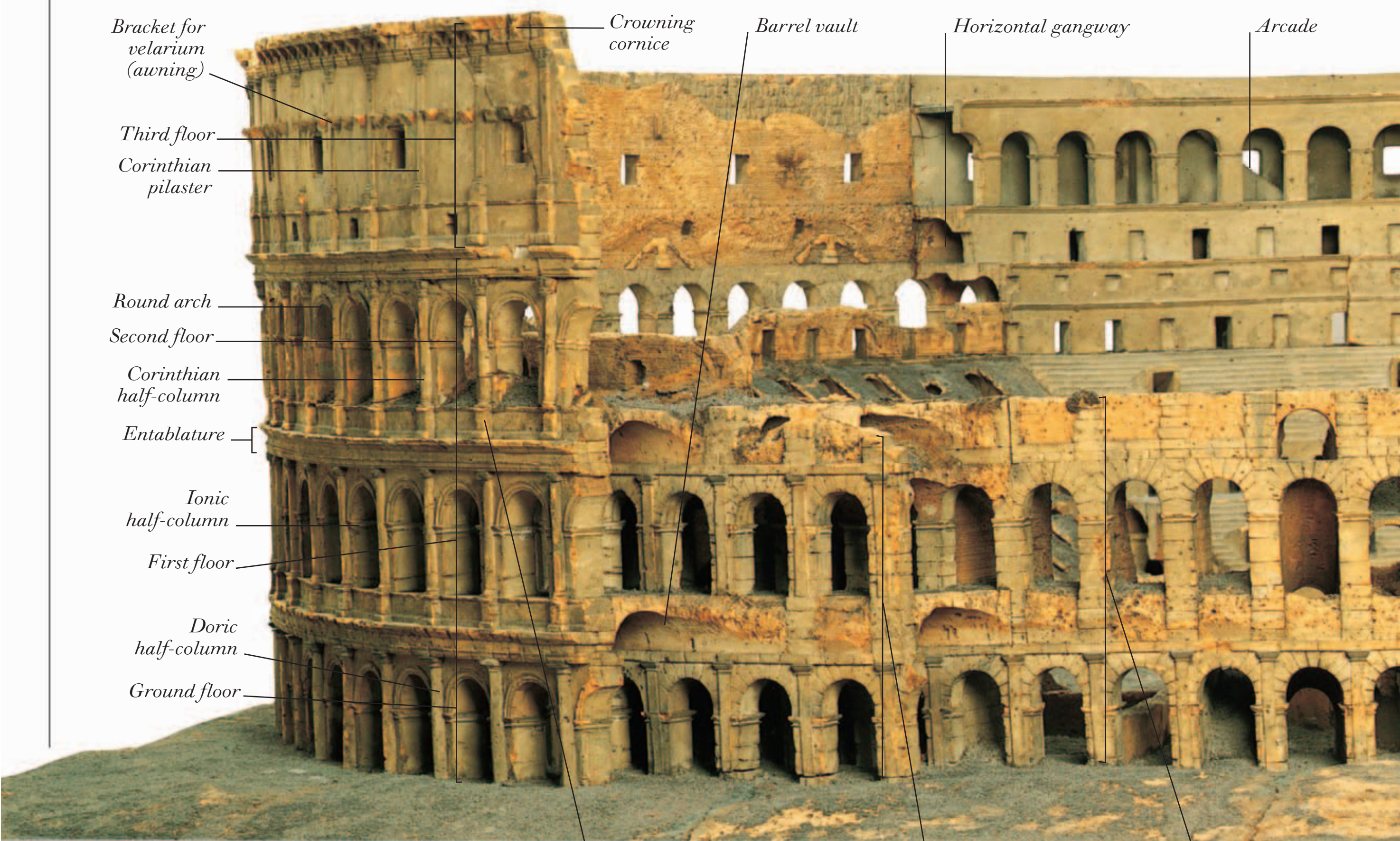
SIDE VIEW OF A ROMAN MILL



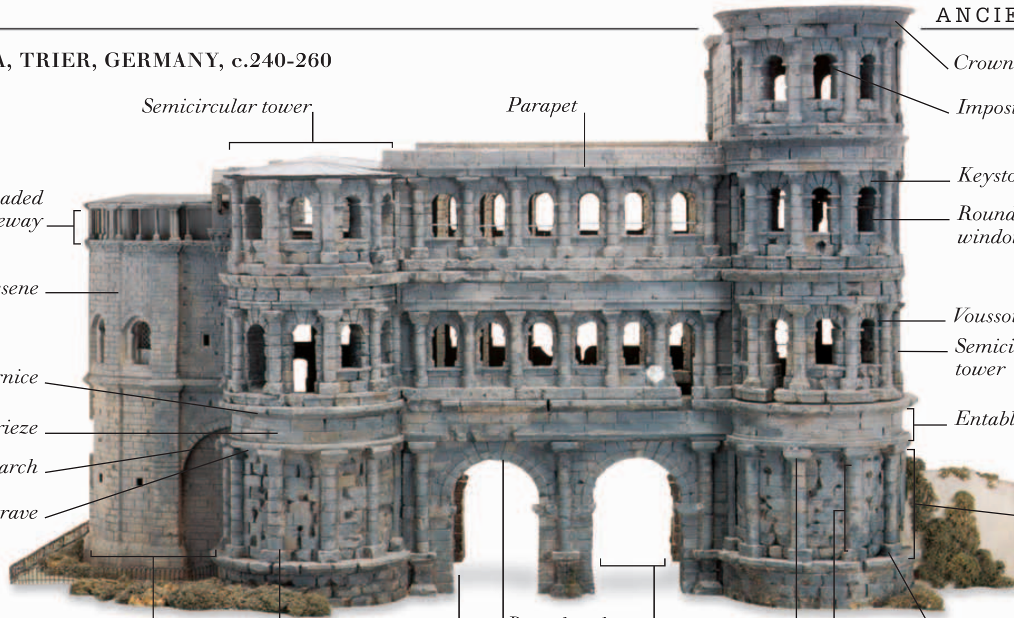
FRONT VIEW OF A ROMAN MILL, 1ST CENTURY BC



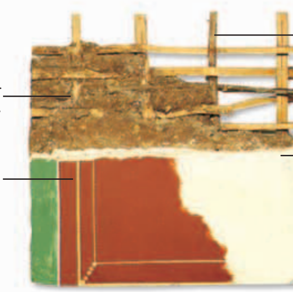
THE COLOSSEUM (FLAVIAN AMPHITHEATRE), ROME, ITALY, 70-82

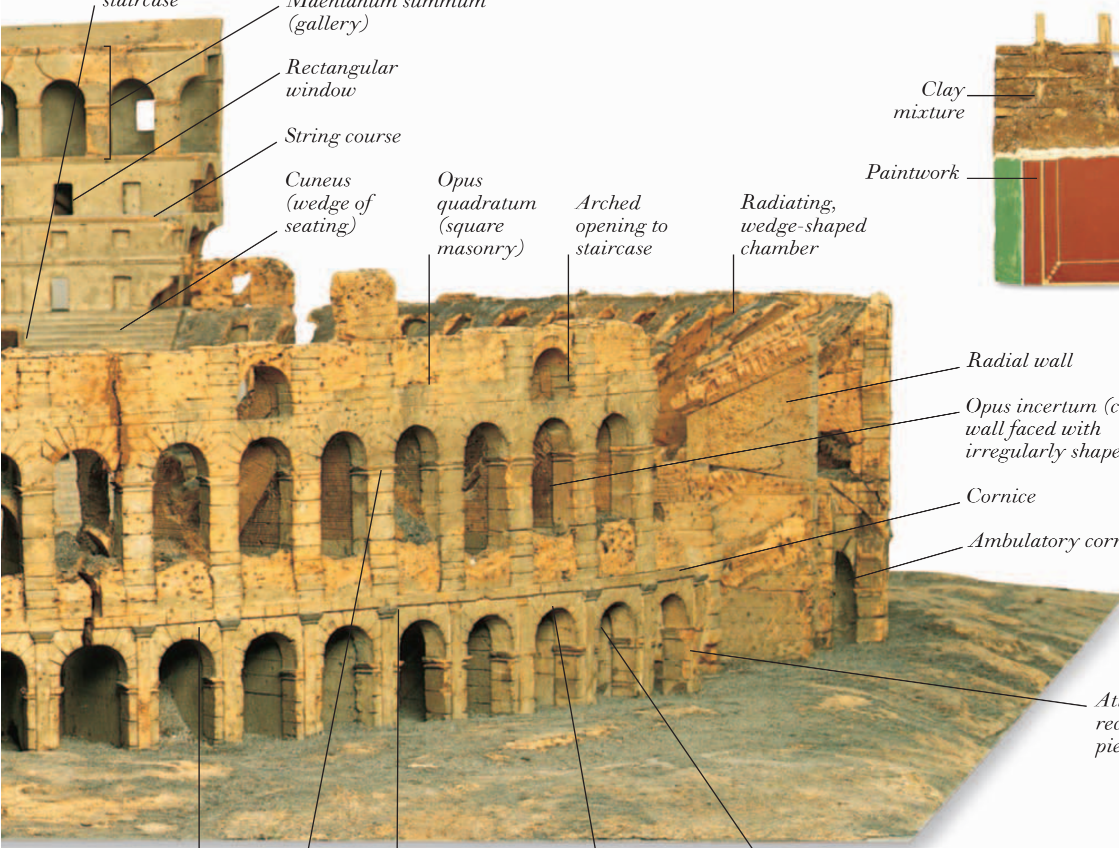


PORTA NIGRA, TRIER, GERMANY, c.240-260



ROMAN WATTLE-AND-DAUB WALL, 1ST CENTURY BC

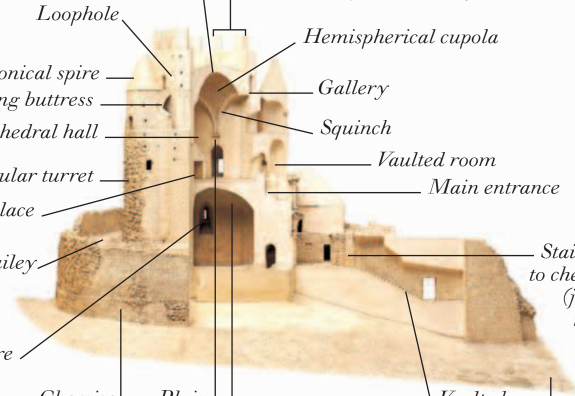


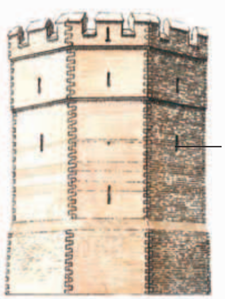


Medieval castles and houses

WARFARE WAS COMMON IN EUROPE in the Middle Ages, and many monarchs and nobles built castles as a form of defense. Typical medieval castles have outer walls surrounding a moat. Inside the moat is a bailey (courtyard), protected by a chemise (jacket wall). The innermost and strongest part of a medieval castle is the keep. There are two main types of keep: towers called donjons, such as the Tour de César and Coucy-le-Château, and rectangular keeps ("hall-keeps"), such as the Tower of London. Castles were often guarded by salients (projecting fortifications), like those of the Bastille. Medieval houses typically had timber cruck (tentlike) frames, wattle-and-daub walls, and pitched roofs, like those on medieval London Bridge (opposite).

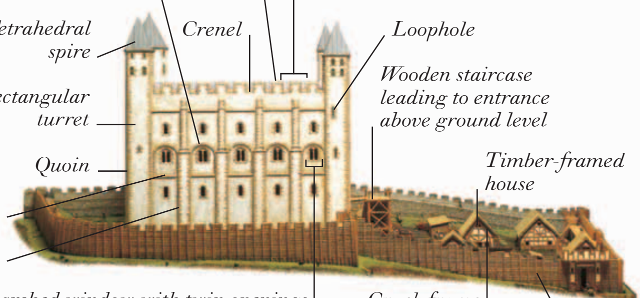
DONJON, TOUR DE CESAR, PROVINS, FRANCE, 12TH CENTURY



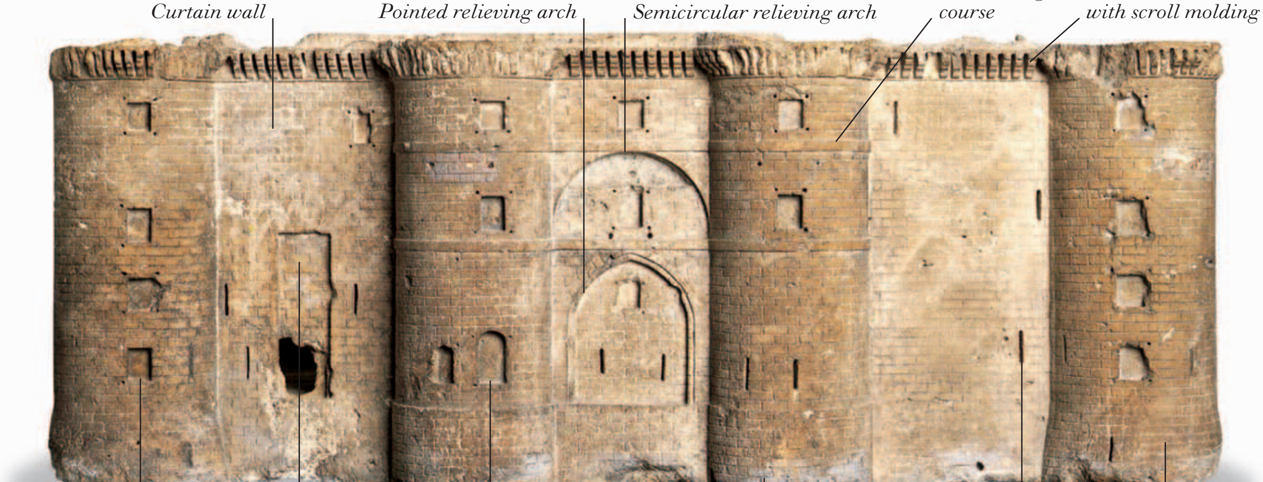


SALIENT, CAERNARVON CASTLE, BRITAIN, 1283-1323

CRUCK-FRAMED HOUSE, BRITAIN, c.1200

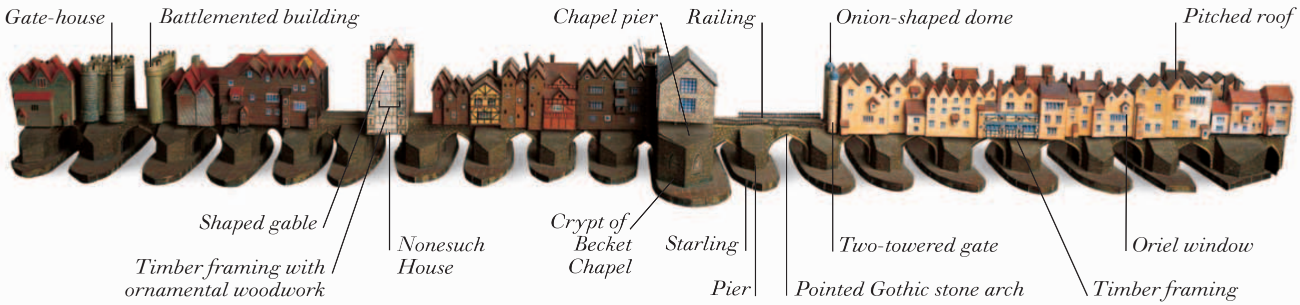


TOWER OF LONDON, BRITAIN, FROM 1070

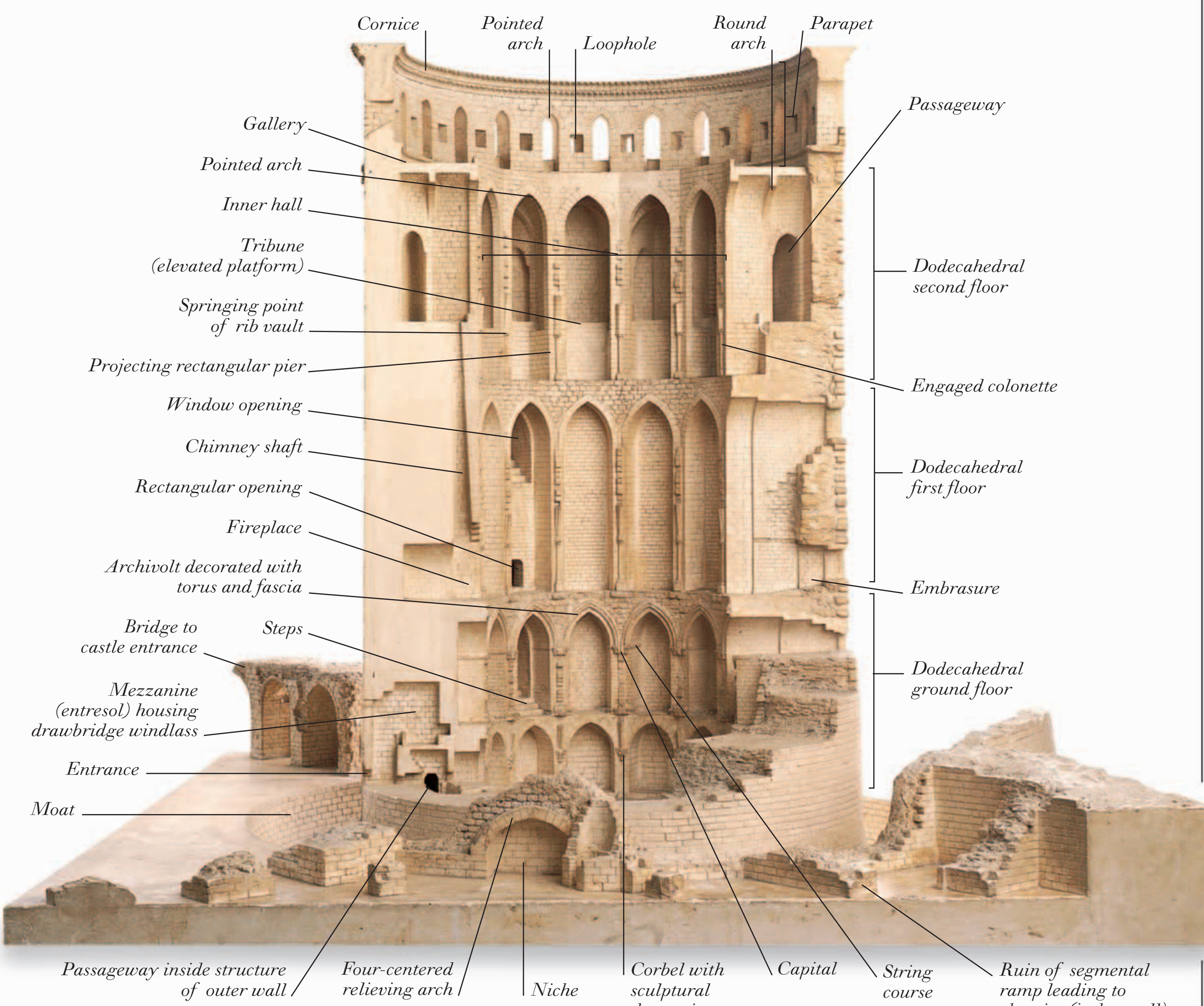


THE BASTILLE, PARIS, FRANCE, 14TH CENTURY

MEDIEVAL LONDON BRIDGE, BRITAIN, 1176 (WITH 14TH-CENTURY BATTLEMENTED BUILDING, NONESUCH HOUSE, AND TWO-TOWERED GATE)



DONJON, COUCY-LE-CHATEAU, AISNE, FRANCE, 1225-1245



Medieval churches

DURING THE MIDDLE AGES, large numbers of churches were built in Europe. European churches of this period typically have high vaults supported by massive piers and columns. In the 10th century, the Romanesque style developed. Romanesque architects adopted many Roman or early Christian architectural ideas, such as cross-shaped ground-plans—like that of Angoulême Cathedral (opposite)—and the basilican system of a nave with a central vessel and side aisles. In the mid-12th century, flying buttresses and pointed vaults appeared. These features later became widely used in Gothic architecture (see pp. 470-471). Bagneux Church (opposite) has both styles: a Romanesque tower, and a Gothic nave and choir.

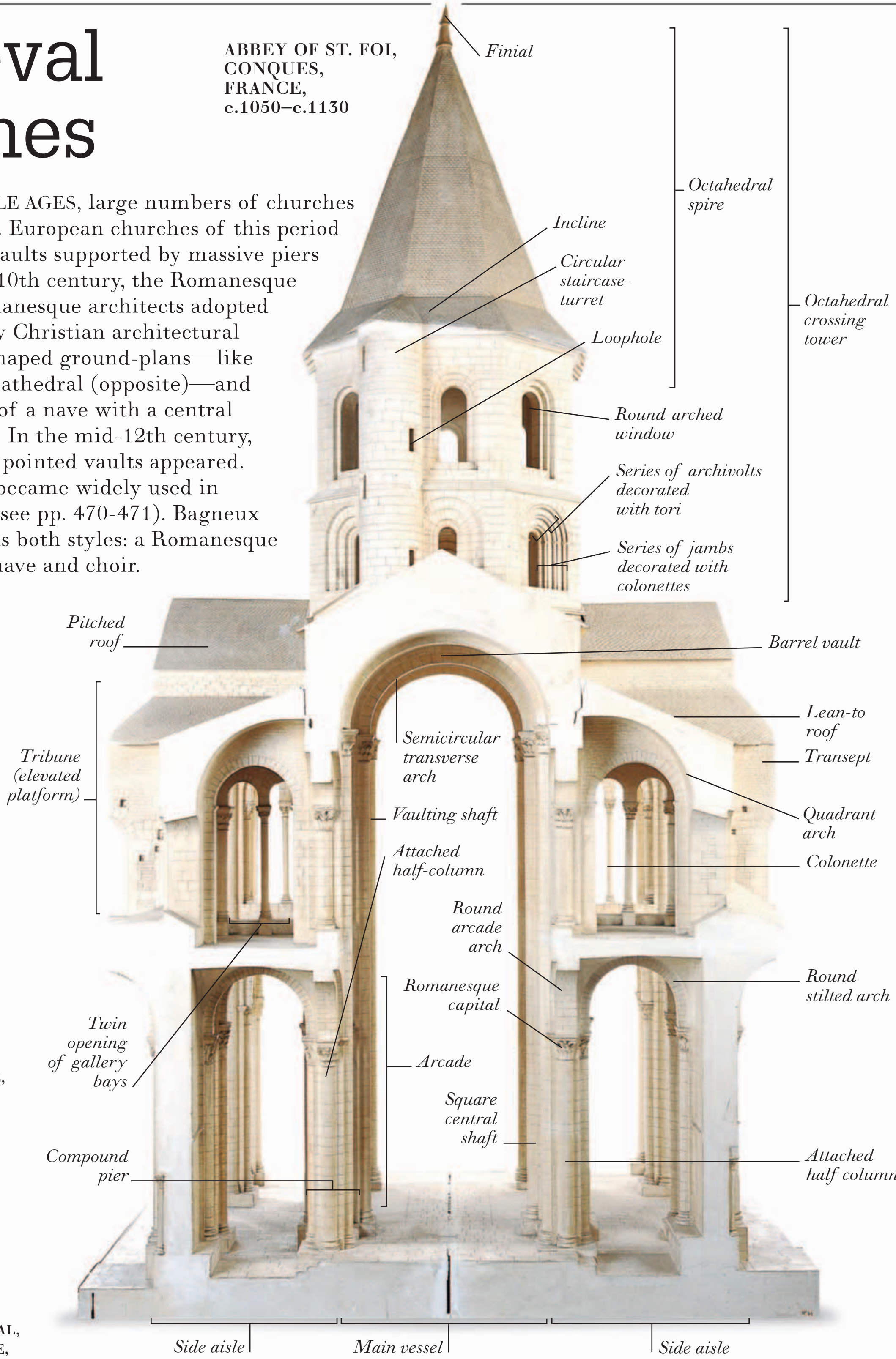
CHURCH-ROOF BOSS, BRITAIN

ROMANESQUE CAPITALS

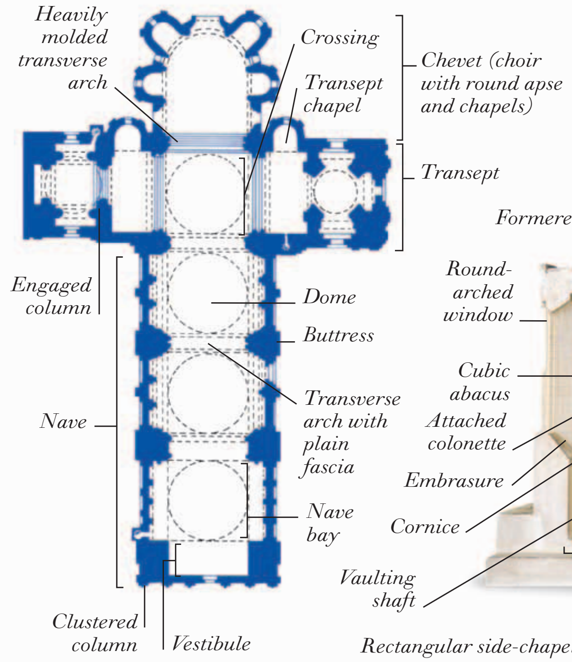
"THE FLIGHT INTO EGYPT" CAPITAL, CATHEDRAL OF ST. LAZARE, AUTUN, FRANCE, 1120-1130

"CHRIST IN MAJESTY" CAPITAL, BASILICA OF ST. MADELEINE, VEZELAY, FRANCE, 1120-1140

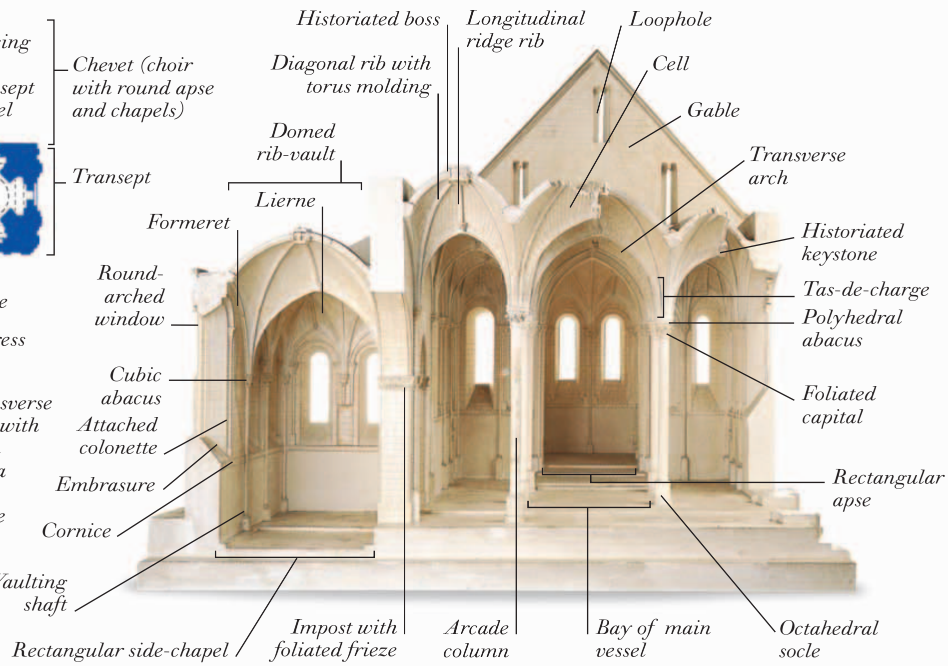
ABBEY OF ST. FOI, CONQUES, FRANCE, c.1050–c.1130



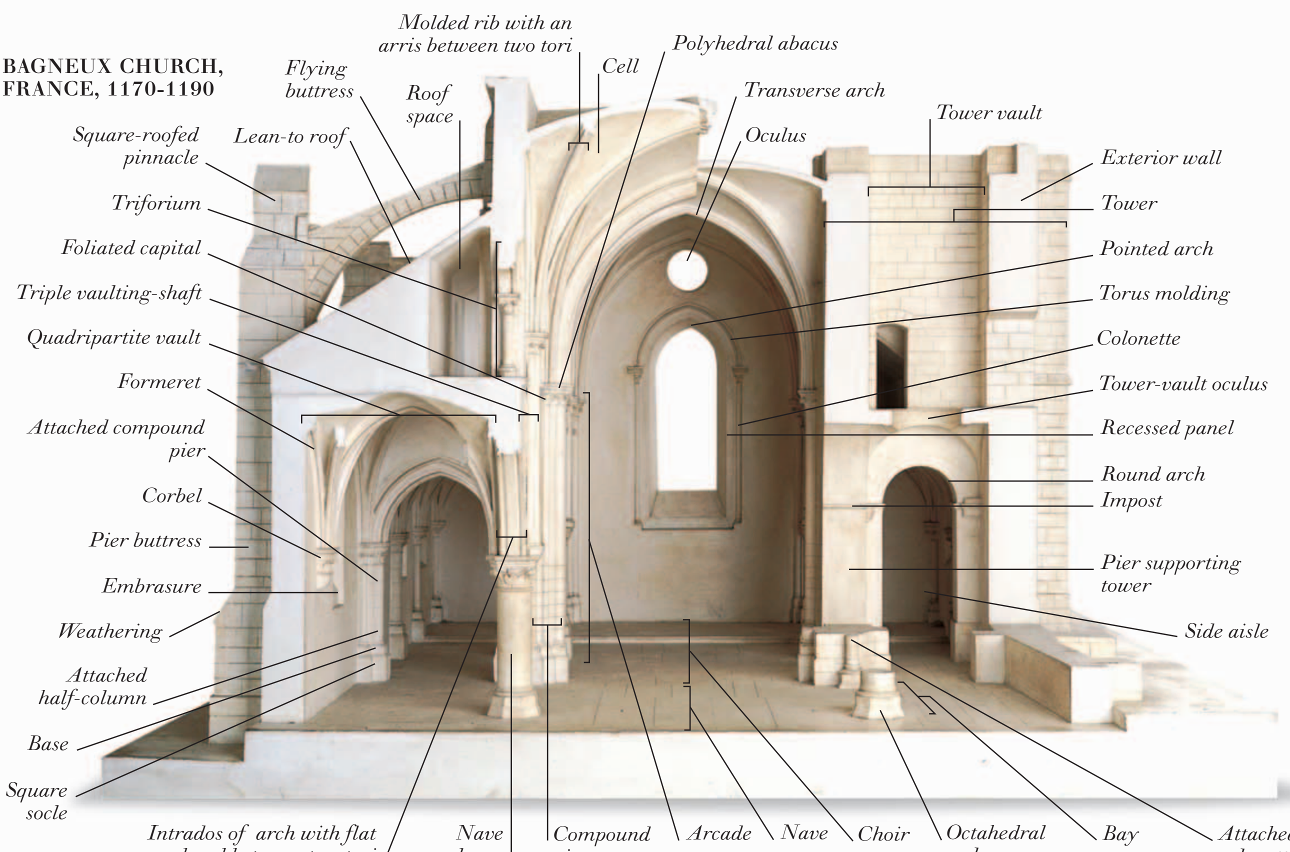
GROUND-PLAN OF ANGOULEME CATHEDRAL, FRANCE, FROM c.1105



CHOIR, CHURCH OF ST. SERGE, ANGERS, FRANCE, c.1215-1220



BAGNEUX CHURCH, FRANCE, 1170-1190

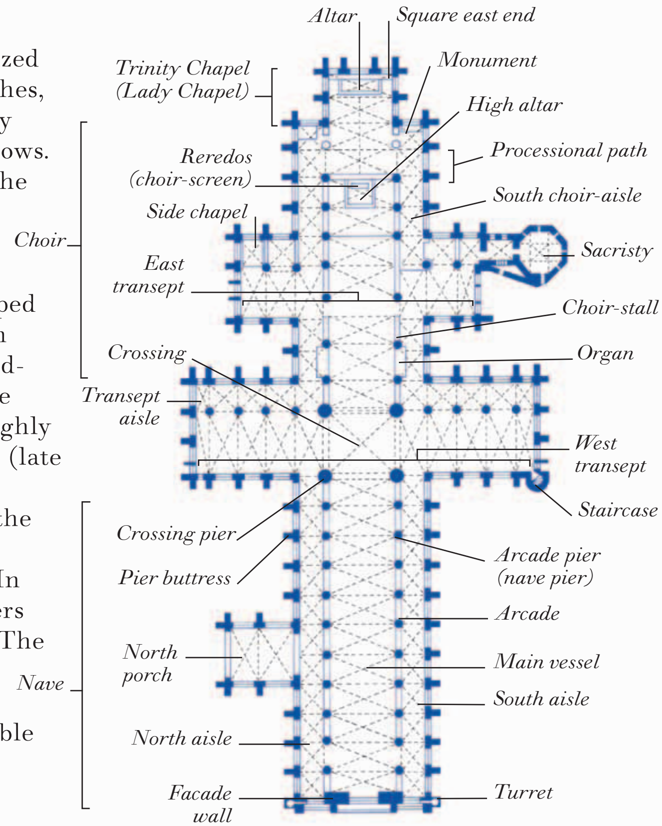


Gothic 1

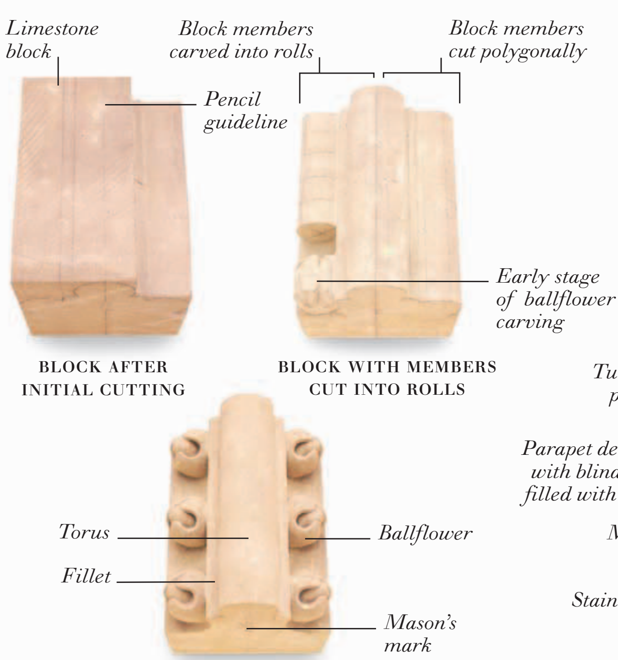
GOTHIC STAINED GLASS WITH FOLIATED SCROLL MOTIF, ON WOODEN FORM

GOTHIC BUILDINGS are characterized by rib vaults, pointed or lancet arches, flying buttresses, decorative tracery and gables, and stained-glass windows. Typical Gothic buildings include the Cathedrals of Salisbury and old St. Paul's in England, and Notre Dame de Paris in France (see pp. 472-473). The Gothic style developed out of Romanesque architecture in France (see pp. 468-469) in the mid-12th century, and then spread throughout Europe. The decorative elements of Gothic architecture became highly developed in buildings of the English Decorated style (late 13th-14th century) and the French Flamboyant style (15th-16th century). These styles are exemplified by the tower of Salisbury Cathedral and the staircase in the Church of St. Maclou (see pp. 472-473), respectively. In both of these styles, embellishments such as ballflowers and curvilinear (flowing) tracery were used liberally. The English Perpendicular style (late 14th-15th century), which followed the Decorated style, emphasized the vertical and horizontal elements of a building. A notable feature of this style is the hammer-beam roof.

GROUND-PLAN OF SALISBURY CATHEDRAL



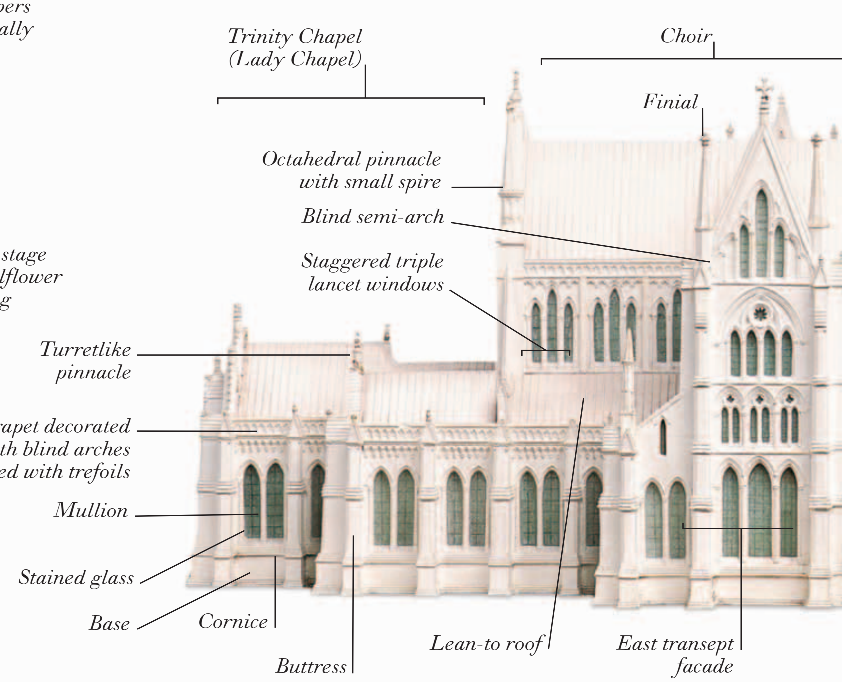
GOTHIC TORUS WITH BALLFLOWERS



BLOCK AFTER INITIAL CUTTING

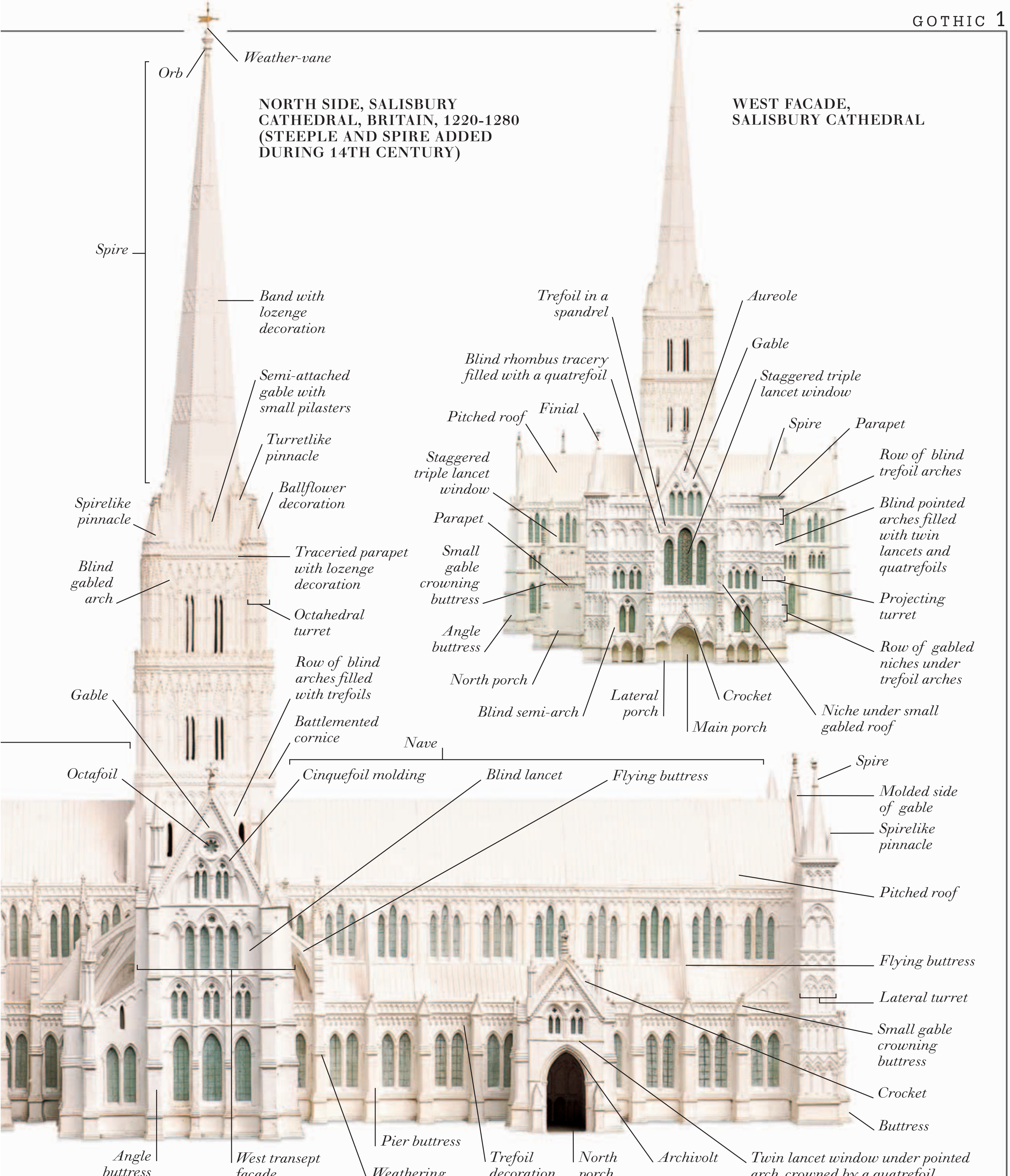
BLOCK WITH MEMBERS CUT INTO ROLLS

FINISHED BLOCK



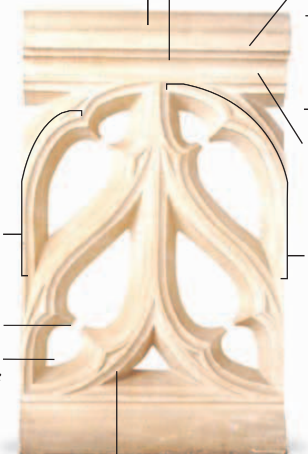
NORTH SIDE, SALISBURY CATHEDRAL, BRITAIN, 1220-1280 (STEEPLE AND SPIRE ADDED DURING 14TH CENTURY)

WEST FACADE, SALISBURY CATHEDRAL

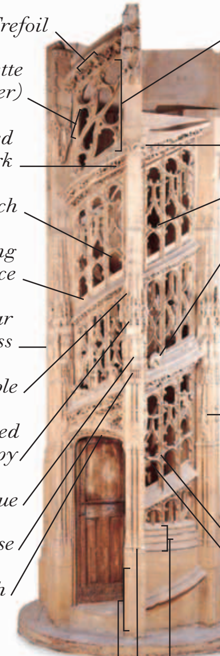


Gothic 2

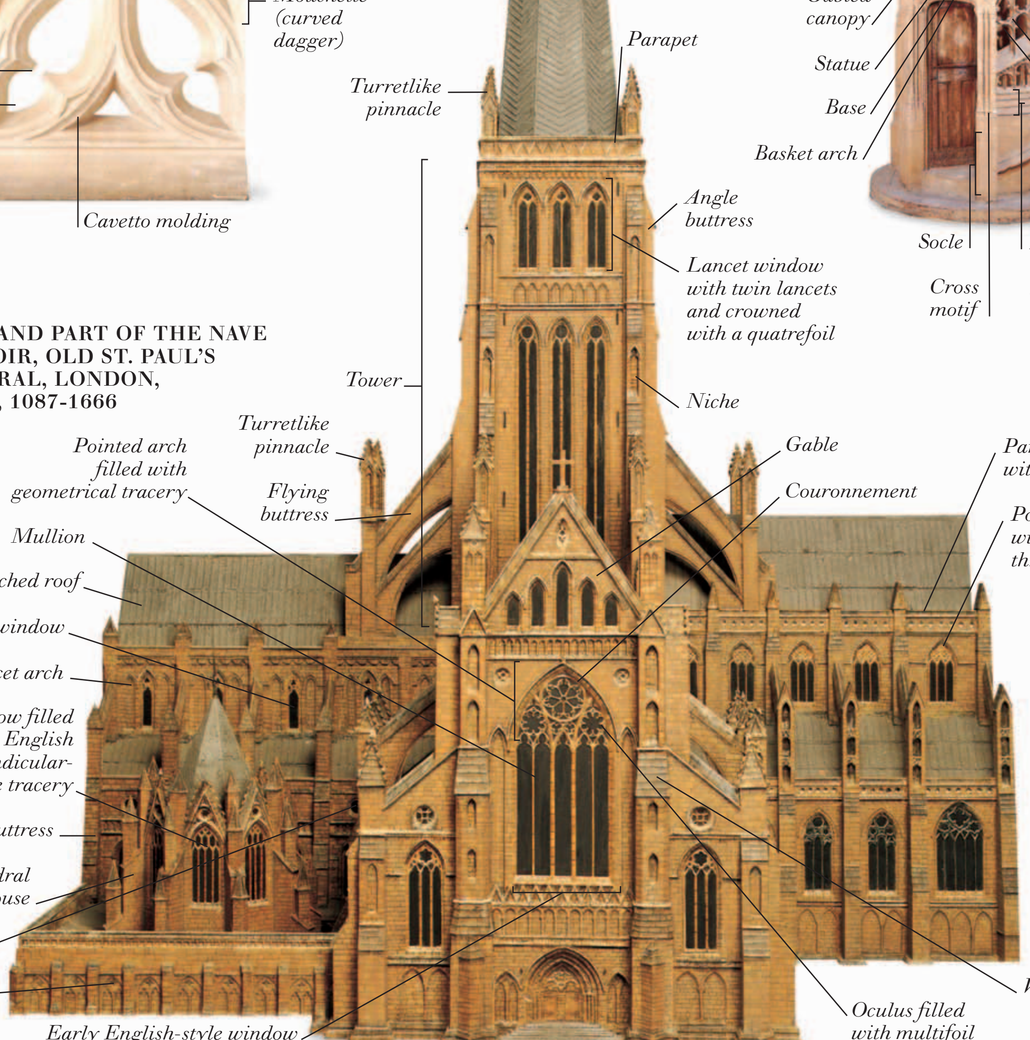
CURVILINEAR (FLOWING) TRACERY FROM A BALUSTRADE, 14TH OR 15TH CENTURY

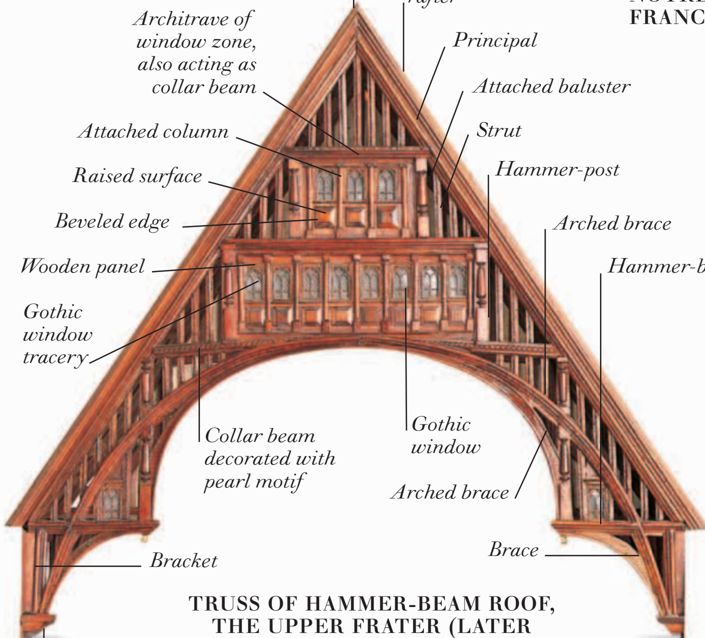


SPIRAL STAIRCASE TO ORGAN, CHURCH OF ST. MACLOU, ROUEN, FRANCE, c.1519



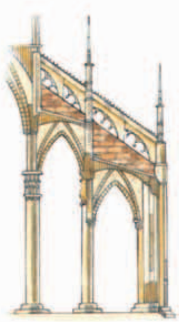
TOWER AND PART OF THE NAVE AND CHOIR, OLD ST. PAUL'S CATHEDRAL, LONDON, BRITAIN, 1087-1666





TRUSS OF HAMMER-BEAM ROOF, THE UPPER FRATER (LATER BLACKFRIARS' PLAYHOUSE), LONDON, BRITAIN, PROBABLY 14TH CENTURY

TYPICAL GOTHIC FEATURES

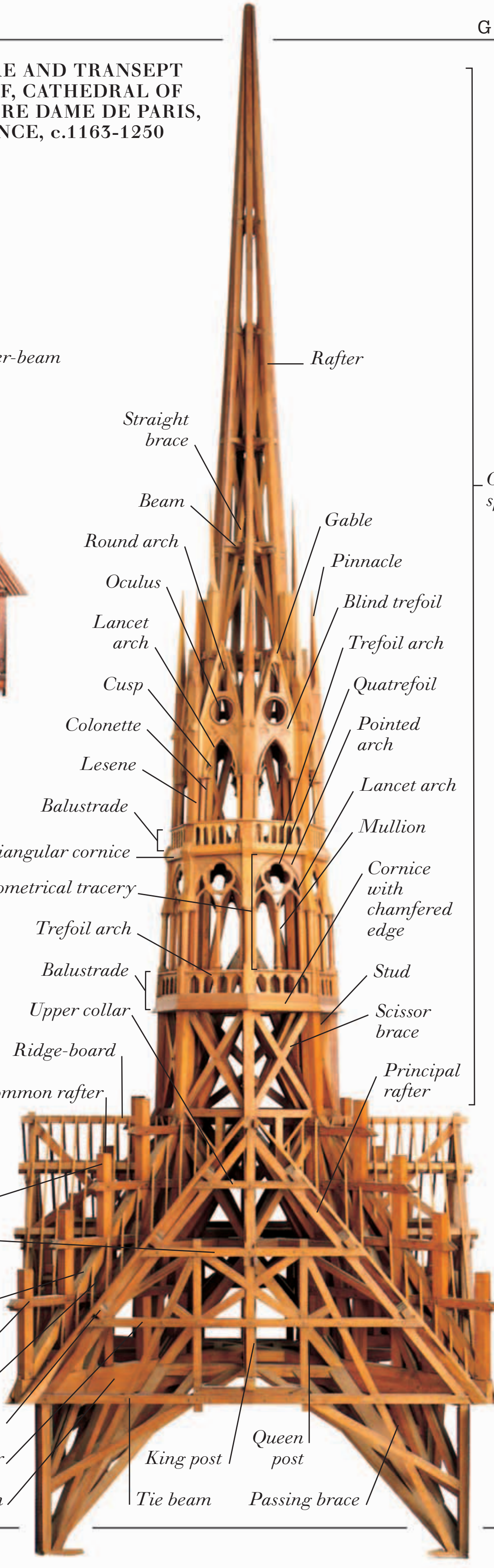


FLYING BUTTRESS OVER SIDE AISLES, MILAN CATHEDRAL, ITALY, c.1385-1485

GARGOYLE, HORSLEY CHURCH, DERBYSHIRE, BRITAIN, c.1450

HAMMER-BEAM ROOF, CHURCH OF ST. BOTOLPH, TRUNCH, NORFOLK, BRITAIN, 1360-1380

SPIRE AND TRANSEPT ROOF, CATHEDRAL OF NOTRE DAME DE PARIS, FRANCE, c.1163-1250



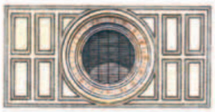
Renaissance 1

THE RENAISSANCE was a European movement—lasting roughly from the 14th century to the mid-17th century—in which the arts and sciences underwent great changes. In architecture, these changes were marked by a return to the classical forms and proportions of ancient Roman buildings. The Renaissance originated in Italy, and the buildings most characteristic of its style can be found there, such as the Palazzo Strozzi shown here. Mannerism is a branch of the Renaissance style that distorts the classical forms; an example is the Laurentian Library staircase. As the Renaissance style spread to other European countries, many of its features were incorporated into the local architecture; for example, the Château de Montal in France (see pp. 476-477) incorporates aedicules (tabernacles).

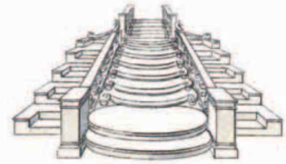
FACADE ON TO PIAZZA, PALAZZO STROZZI

SIDE VIEW OF PALAZZO STROZZI, FLORENCE, ITALY, 1489 (BY G. DA SANGALLO, B. DA MAIANO, AND CRONACA)

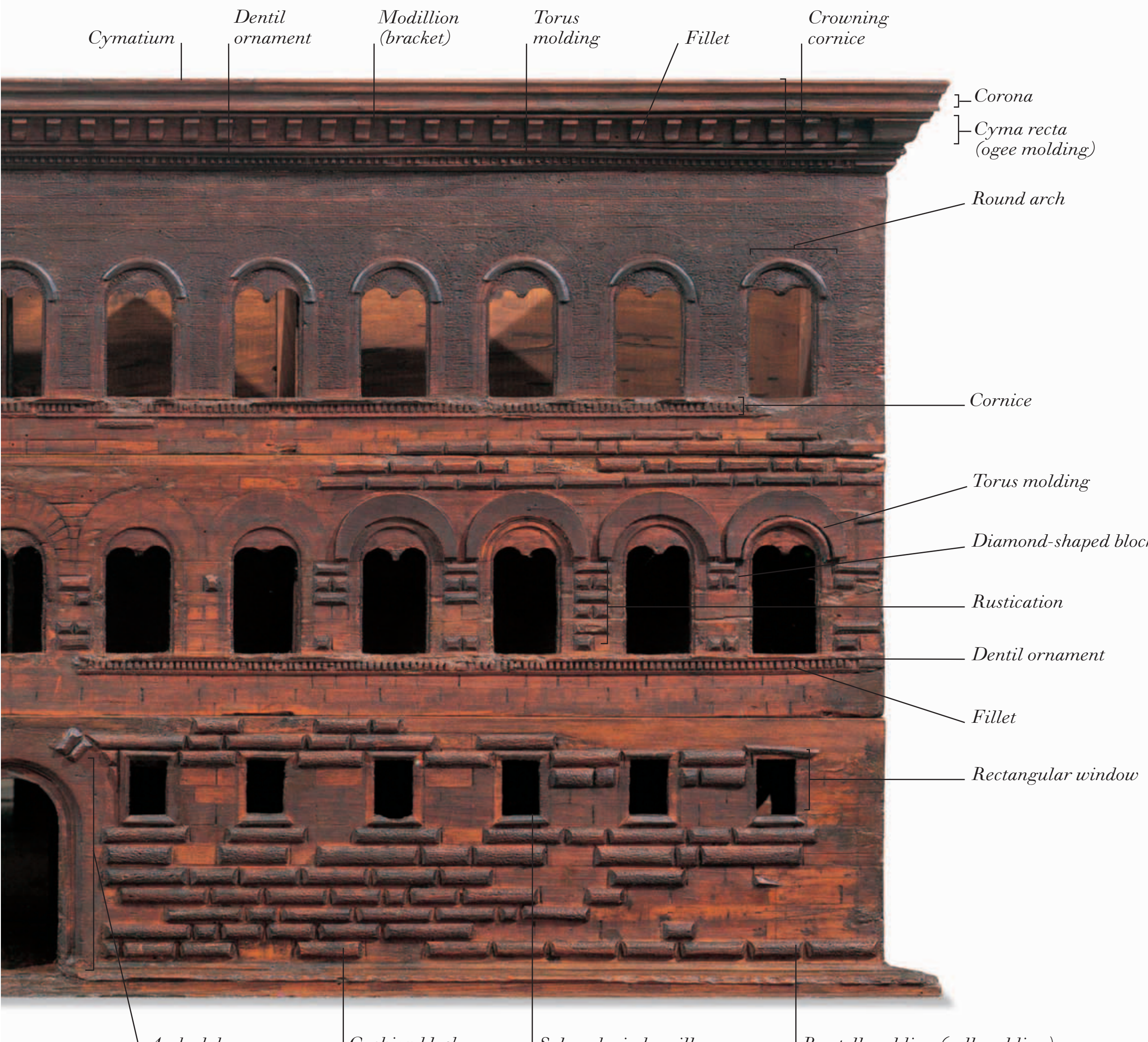
DETAILS FROM ITALIAN RENAISSANCE BUILDINGS


PANEL FROM DRUM OF DOME, FLORENCE CATHEDRAL, 1420-1436


COFFERING IN DOME, PAZZI CHAPEL, FLORENCE, 1429-1461


STAIRCASE, LAURENTIAN LIBRARY, FLORENCE, 1559


PORTICO, VILLA ROTUNDA, VICENZA, 1567-1569



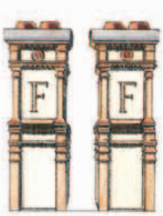
Renaissance 2

DETAILS FROM EUROPEAN RENAISSANCE BUILDINGS

STONE WALL, QUOINS, AND SHELL DECORATION, CASA DE LAS CONCHAS, SALAMANCA, SPAIN, 1475-1483

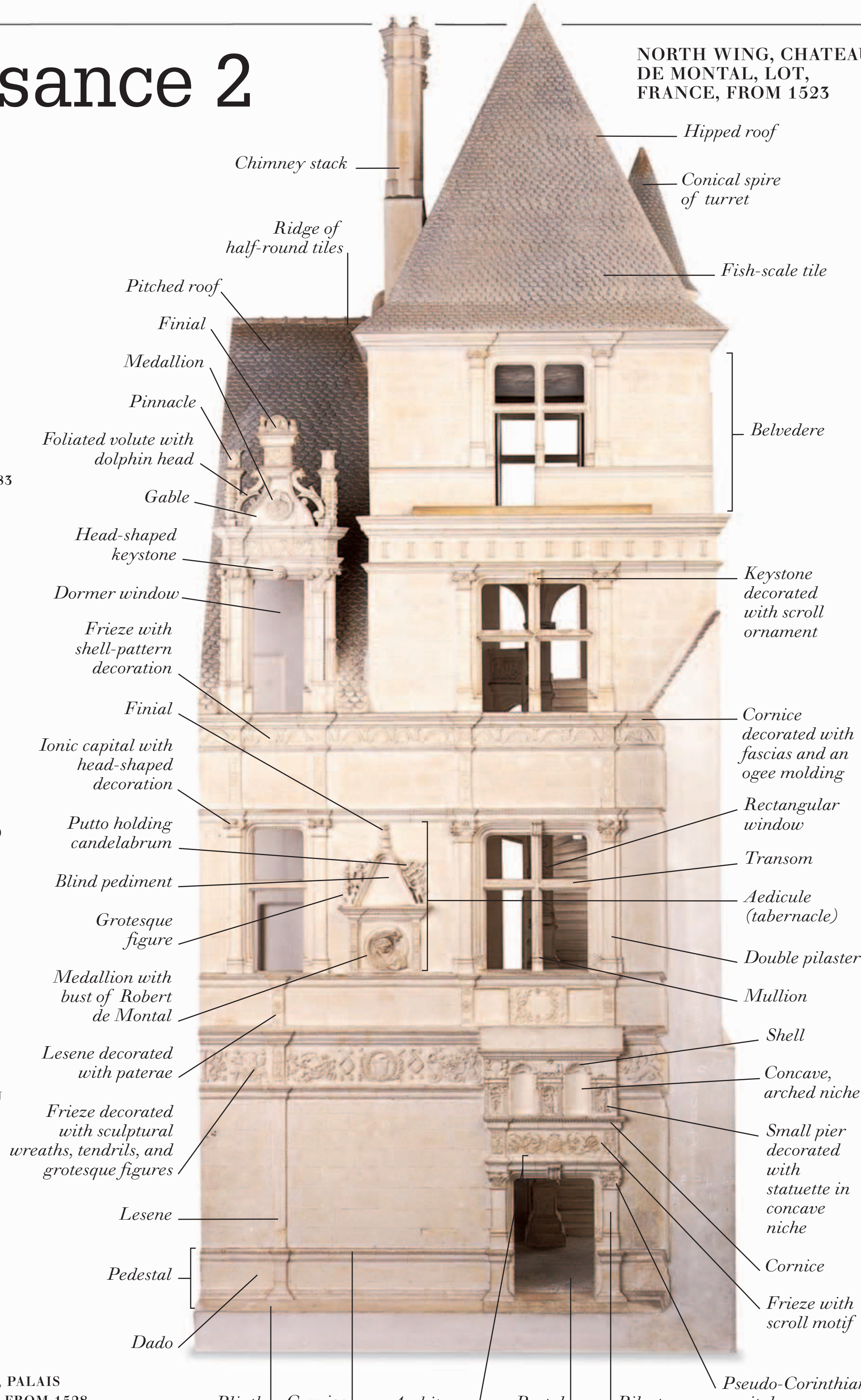
SPIRAL-STAIRCASE TOWER, CHATEAU DE BLOIS, FRANCE, 1514-1530

CONICAL DOME, CHATEAU DE CHAMBORD, FRANCE, 1519-1547

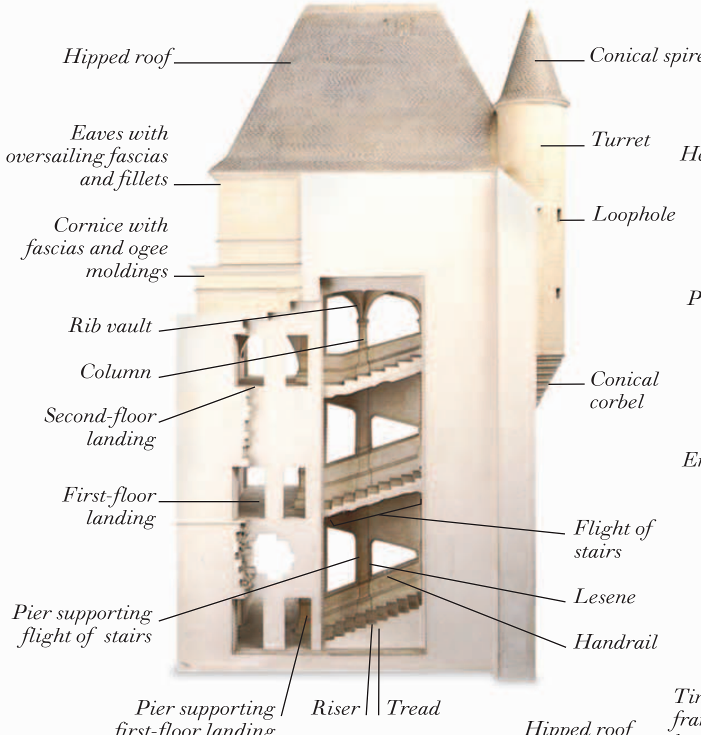


PAIR OF CHIMNEY-STACKS, PALAIS DE FONTAINEBLEAU, FRANCE, FROM 1528

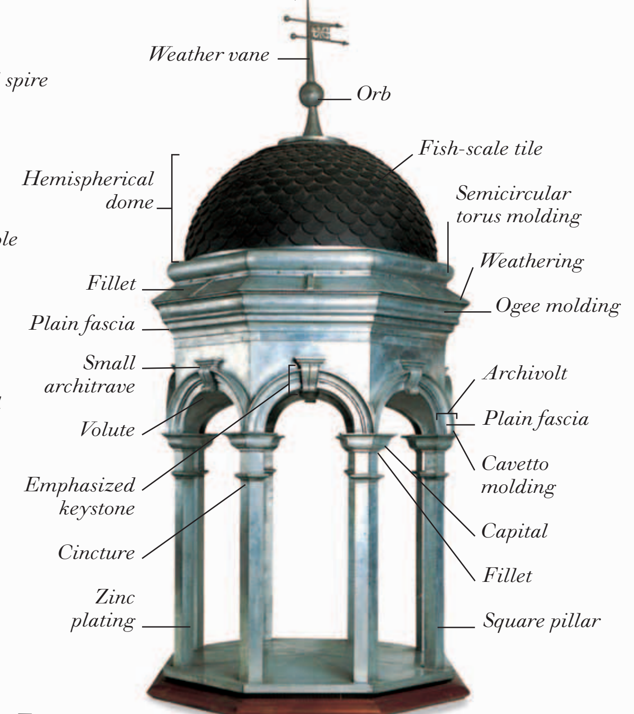
NORTH WING, CHATEAU DE MONTAL, LOT, FRANCE, FROM 1523



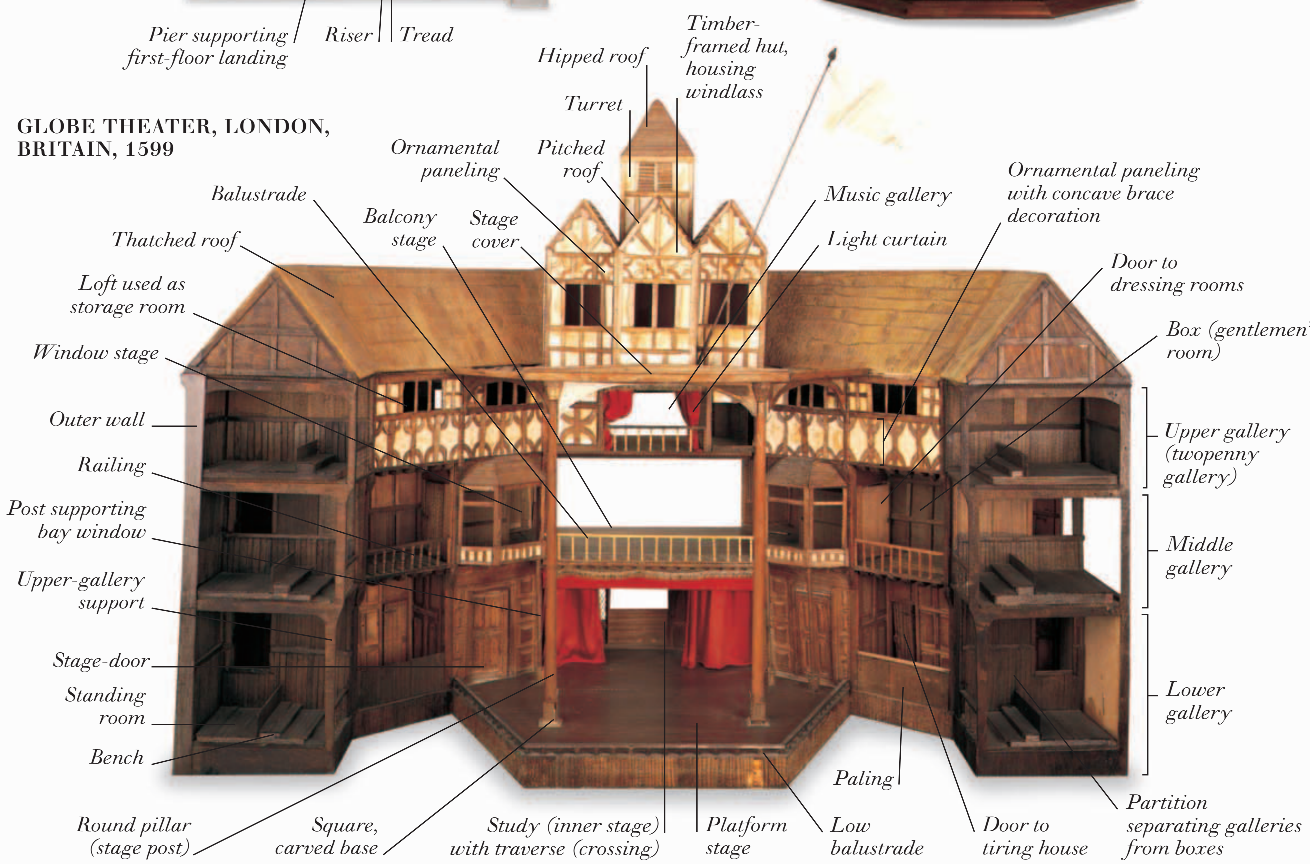
NORTH-WING STAIRCASE, CHATEAU DE MONTAL



CAMPANILE, CHURCH OF ST. EUSTACHE, PARIS, FRANCE, 1532-1640



GLOBE THEATER, LONDON, BRITAIN, 1599



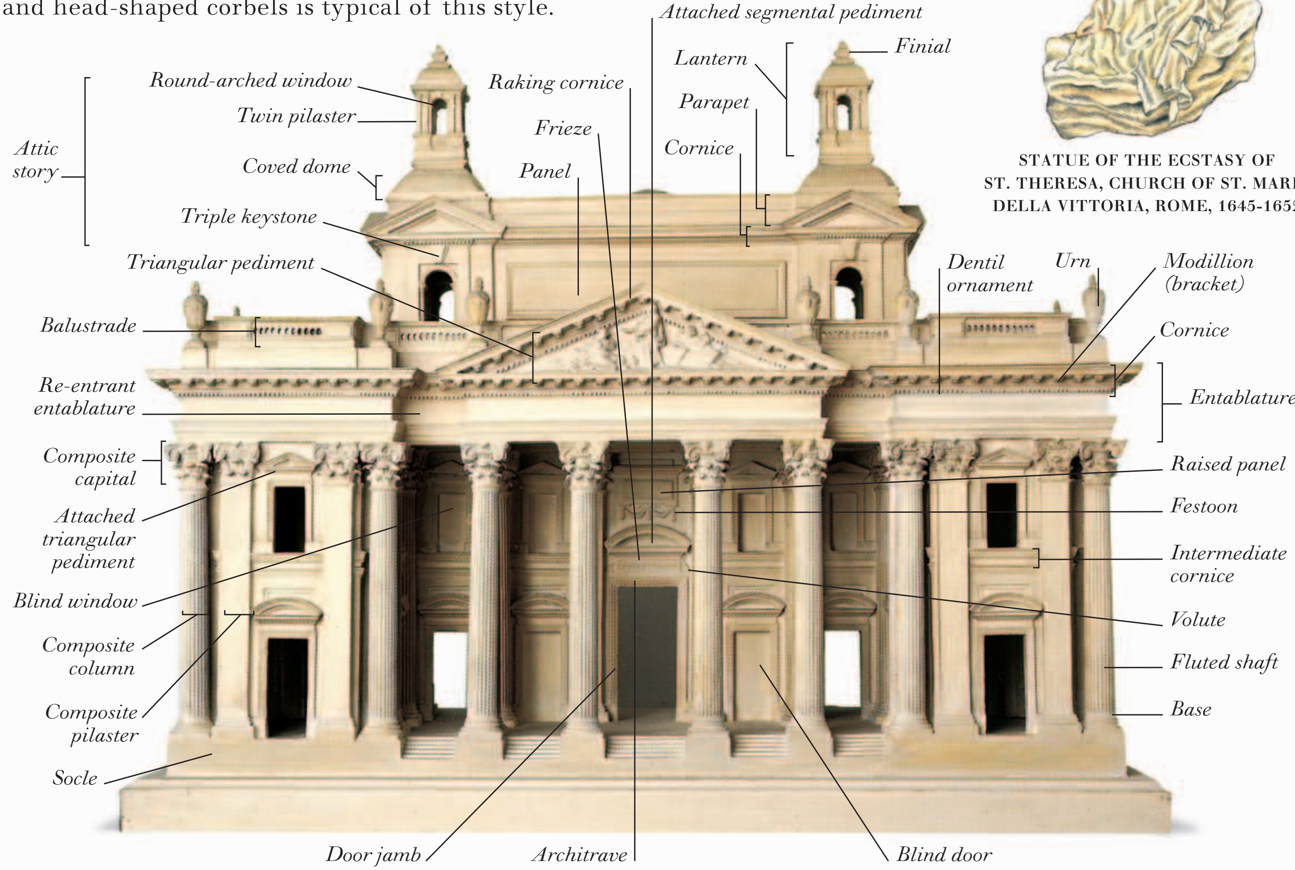
Baroque and neoclassical 1

THE BAROQUE STYLE EVOLVED IN THE EARLY 17TH CENTURY in Rome. It is characterized by curved outlines and ostentatious decoration, as can be seen in the Italian church details (right). The baroque style was particularly widely favored in Italy, Spain, and Germany. It was also adopted in Britain and France, but with adaptations. The British architects Sir Christopher Wren and Nicholas Hawksmoor, for example, used baroque features—such as the concave walls of St. Paul's Cathedral and the curved buttresses of the Church of St. George in the East (see pp. 480-481)—but they did so with restraint. Similarly, the curved buttresses and volutes of the Parisian Church of St. Paul-St. Louis are relatively plain. In the second half of the 17th century, a distinct classical style (known as neoclassicism) developed in northern Europe as a reaction to the excesses of baroque. Typical of this new style were churches such as the Madeleine (a proposed facade is shown below), as well as secular buildings such as the Cirque Napoleon (opposite) and the buildings of the British architect Sir John Soane (see pp. 482-483). In early 18th-century France, an extremely lavish form of baroque developed, known as rococo. The balcony from Nantes (see pp. 482-483) with its twisted ironwork and head-shaped corbels is typical of this style.

DETAILS FROM ITALIAN BAROQUE CHURCHES

SCROLLED BUTTRESS, CHURCH OF ST. MARIA DELLA SALUTE, VENICE, 1631-1682

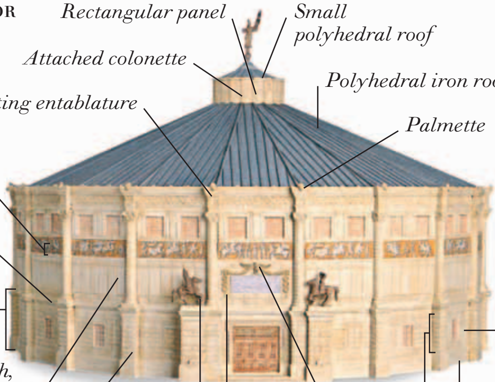
STATUE OF THE ECSTASY OF ST. THERESA, CHURCH OF ST. MARIA DELLA VITTORIA, ROME, 1645-1652



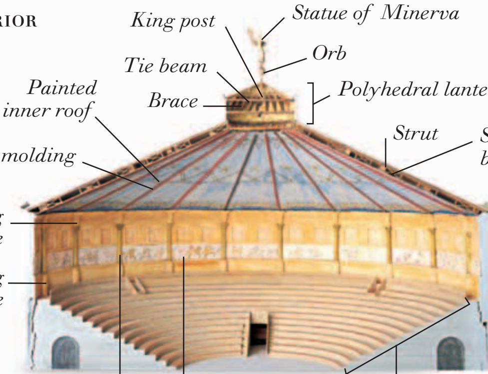
PROPOSED FACADE, THE MADELEINE (NEOCLASSICAL), PARIS, FRANCE, 1764 (BY P. CONTANT D'IVRY)

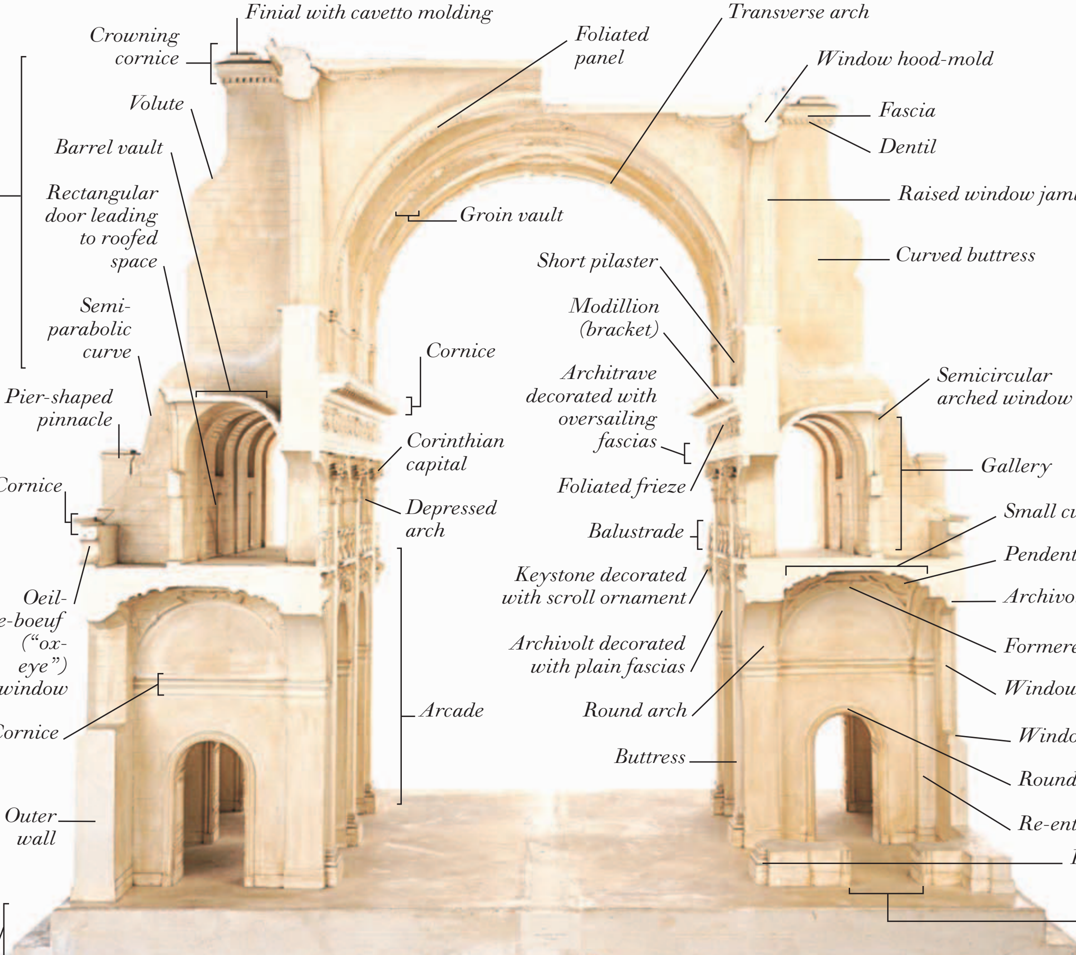
CIRQUE NAPOLEON (NEOCLASSICAL), PARIS, FRANCE, 1852 (BY J. I. HITTORFF)

EXTERIOR



INTERIOR

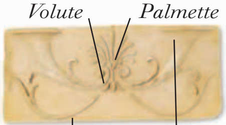




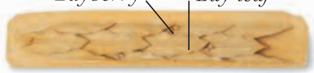
NAVE, CHURCH OF ST. PAUL-ST. LOUIS (FRENCH BAROQUE), PARIS, FRANCE, FROM 1627 (BY E. MARTELLANGE)

Baroque and neoclassical 2

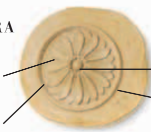
ARABESQUE



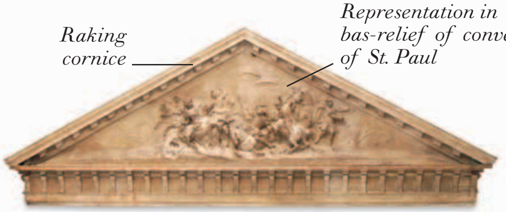
BAY-LEAF GARLAND



PATERA

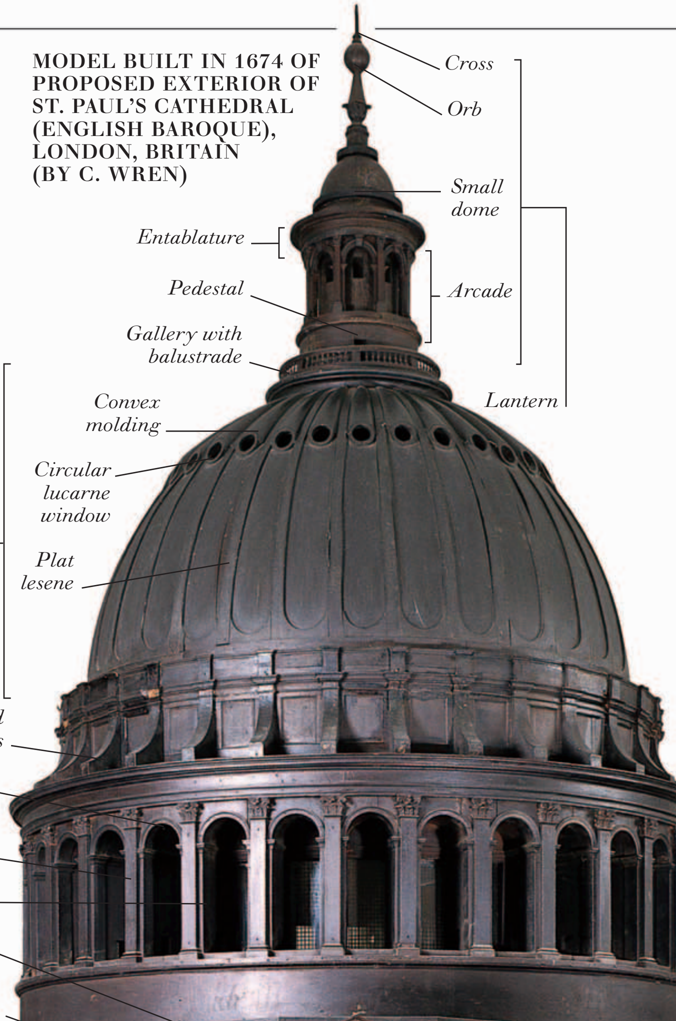


DECORATIVE MOLDINGS FROM ENGLISH NEOCLASSICAL BUILDINGS



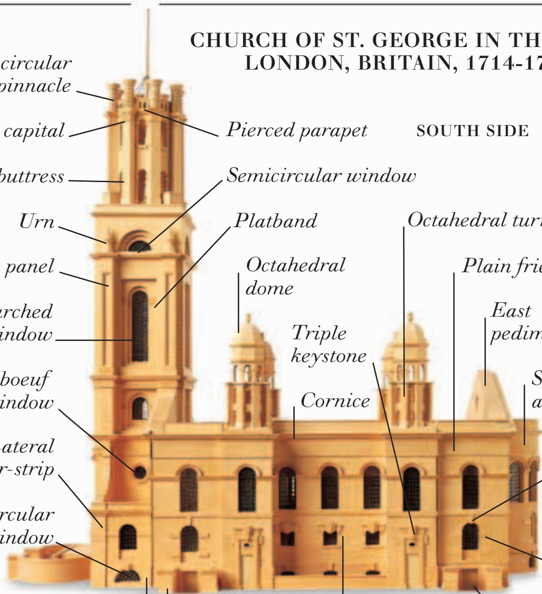
TRIANGULAR PEDIMENT, WEST FACADE, ST. PAUL'S CATHEDRAL

MODEL BUILT IN 1674 OF PROPOSED EXTERIOR OF ST. PAUL'S CATHEDRAL (ENGLISH BAROQUE), LONDON, BRITAIN (BY C. WREN)

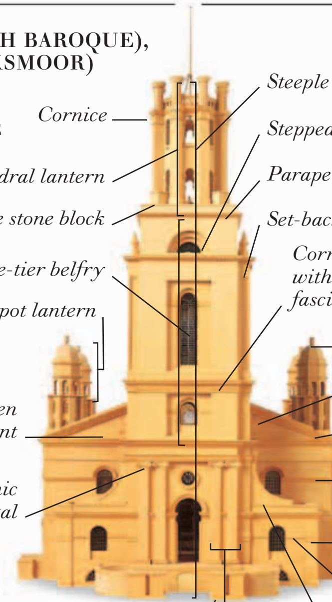


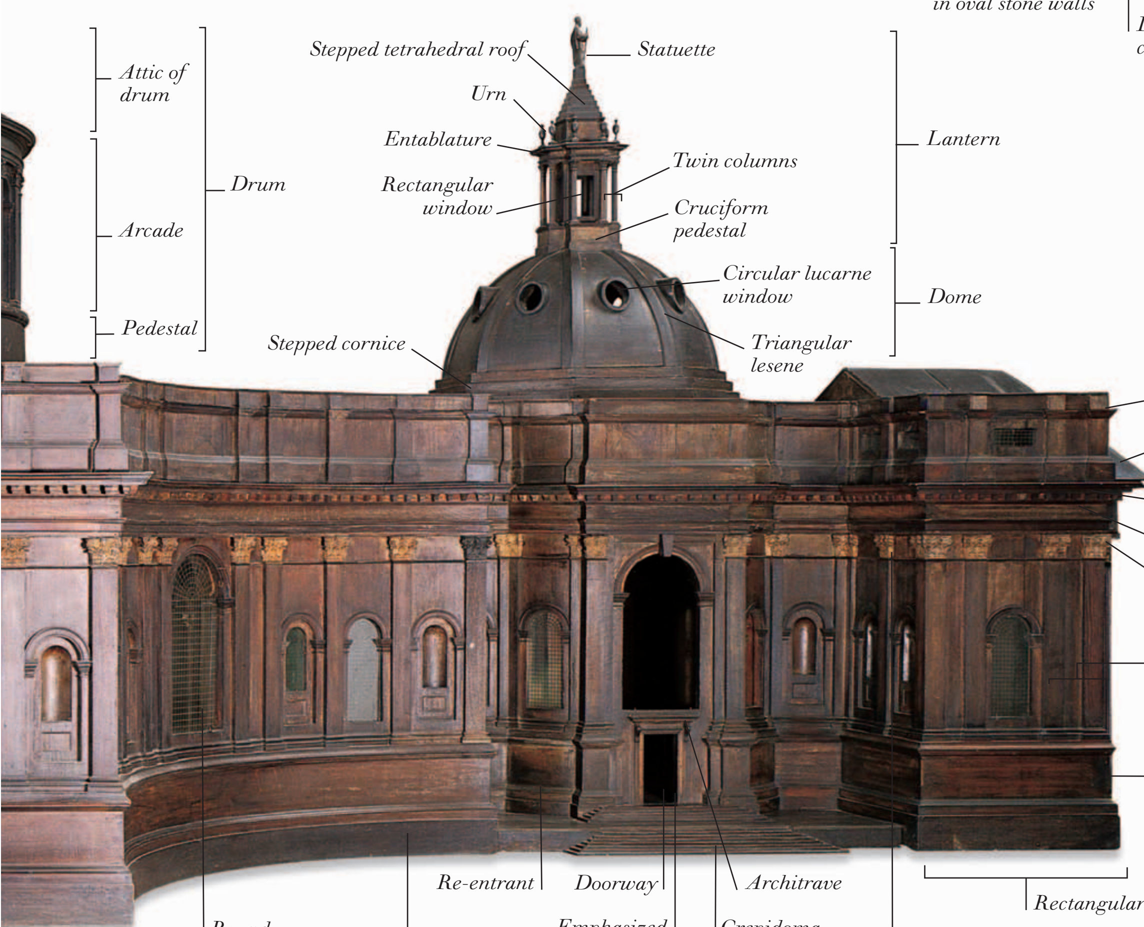

CHURCH OF ST. GEORGE IN THE EAST (ENGLISH BAROQUE), LONDON, BRITAIN, 1714-1734 (BY N. HAWKSMOOR)

SOUTH SIDE



WEST FACADE

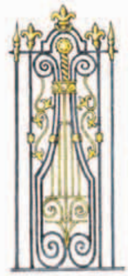




Baroque and neoclassical 3

DETAILS FROM BAROQUE, NEOCLASSICAL, AND ROCOCO BUILDINGS

PORTICO, THE VYNE, HAMPSHIRE, BRITAIN, 1654 (NEOCLASSICAL)



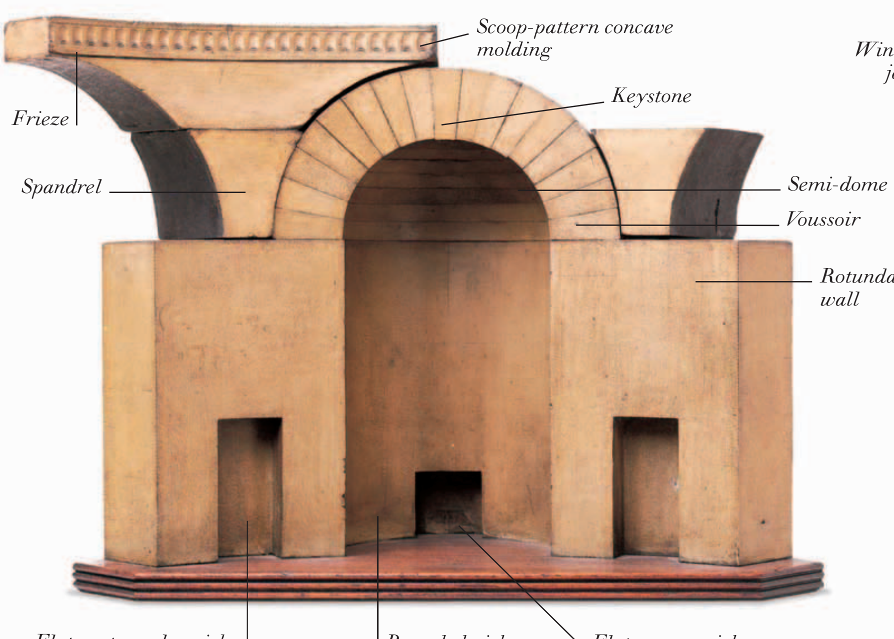
GILT IRONWORK FROM SCREEN, PALAIS DE VERSAILLES, FRANCE, 1669-1674 (FRENCH BAROQUE)

WINDOW, PALAZZO STANGA, CREMONA, ITALY, EARLY 18TH CENTURY (ROCOCO)

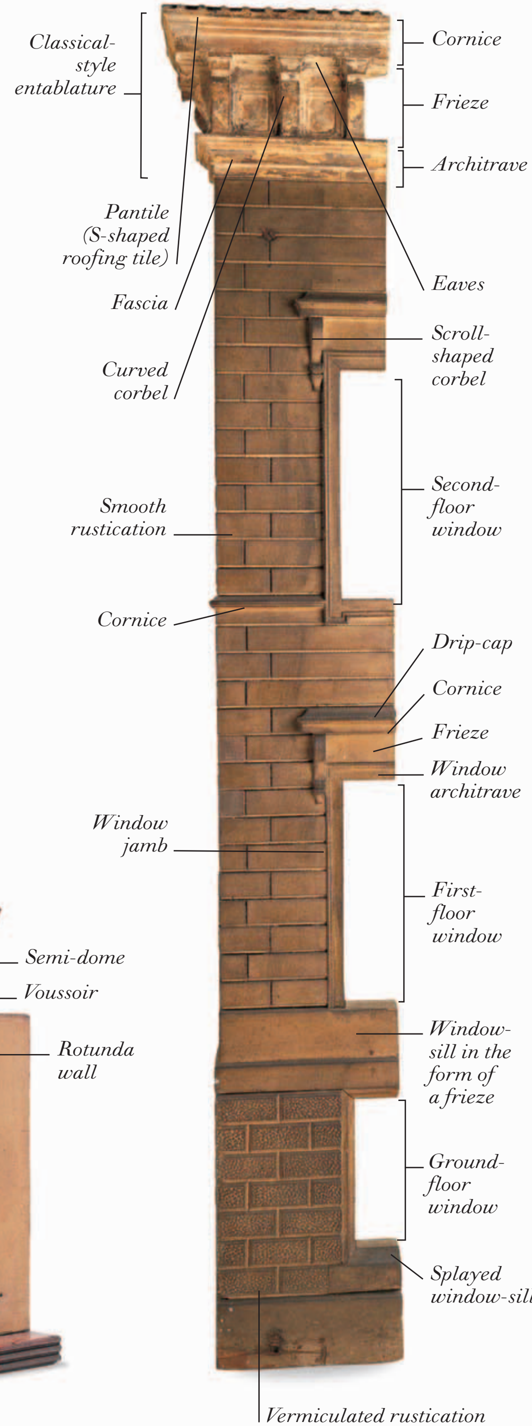
ATLAS (MALE CARYATID), UPPER BELVEDERE, VIENNA, AUSTRIA, 1721 (GERMAN-STYLE BAROQUE)

BALCONY, NANTES, FRANCE, 1730-1740 (ROCOCO)

MASONRY OF A NICHE IN THE ROTUNDA (NEOCLASSICAL), BANK OF ENGLAND, LONDON, BRITAIN, 1794 (BY J. SOANE)

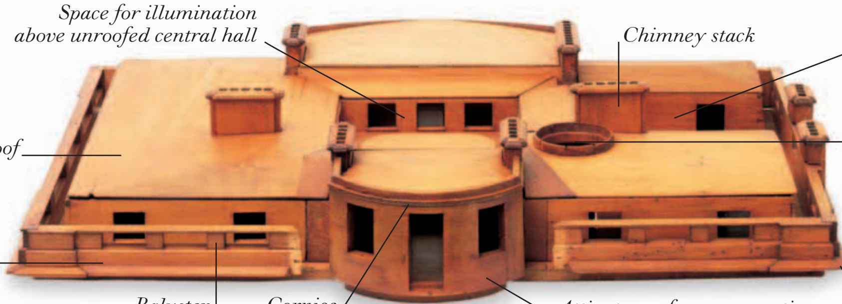


CORNER OF THE NEW STATE PAPER OFFICE (NEOCLASSICAL), LONDON, BRITAIN, 1830-1831 (BY J. SOANE)

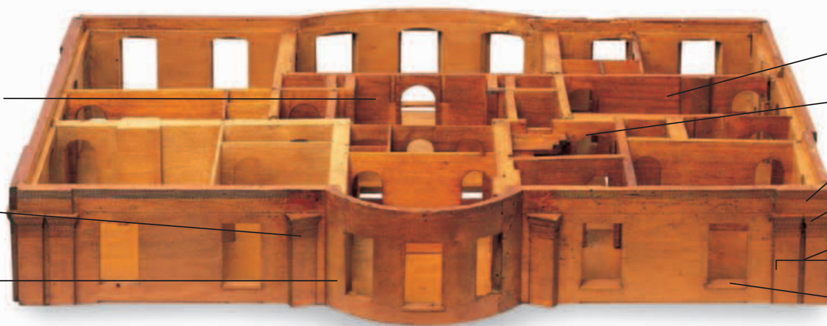


TYRINGHAM HOUSE (NEOCLASSICAL), BUCKINGHAMSHIRE, BRITAIN, 1793-1797 (BY J. SOANE)

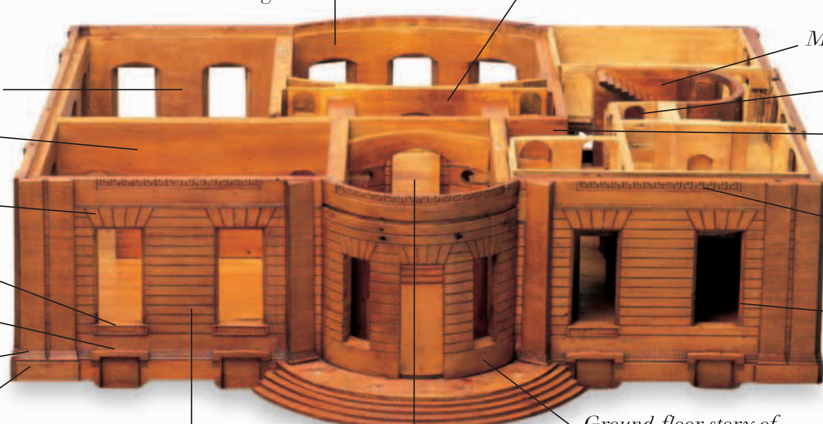
ROOF LEVEL (ATTIC LEVEL)



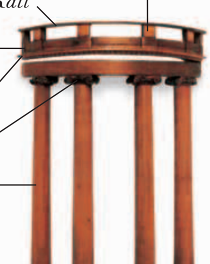
FIRST-FLOOR LEVEL (CHAMRER FLOOR)



GROUND-FLOOR LEVEL (PRINCIPAL FLOOR)



FACADE OF TYRINGHAM HOUSE

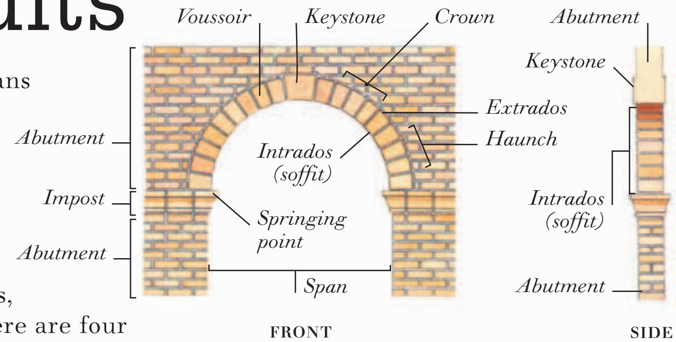


PROSTYLE COLONNADE

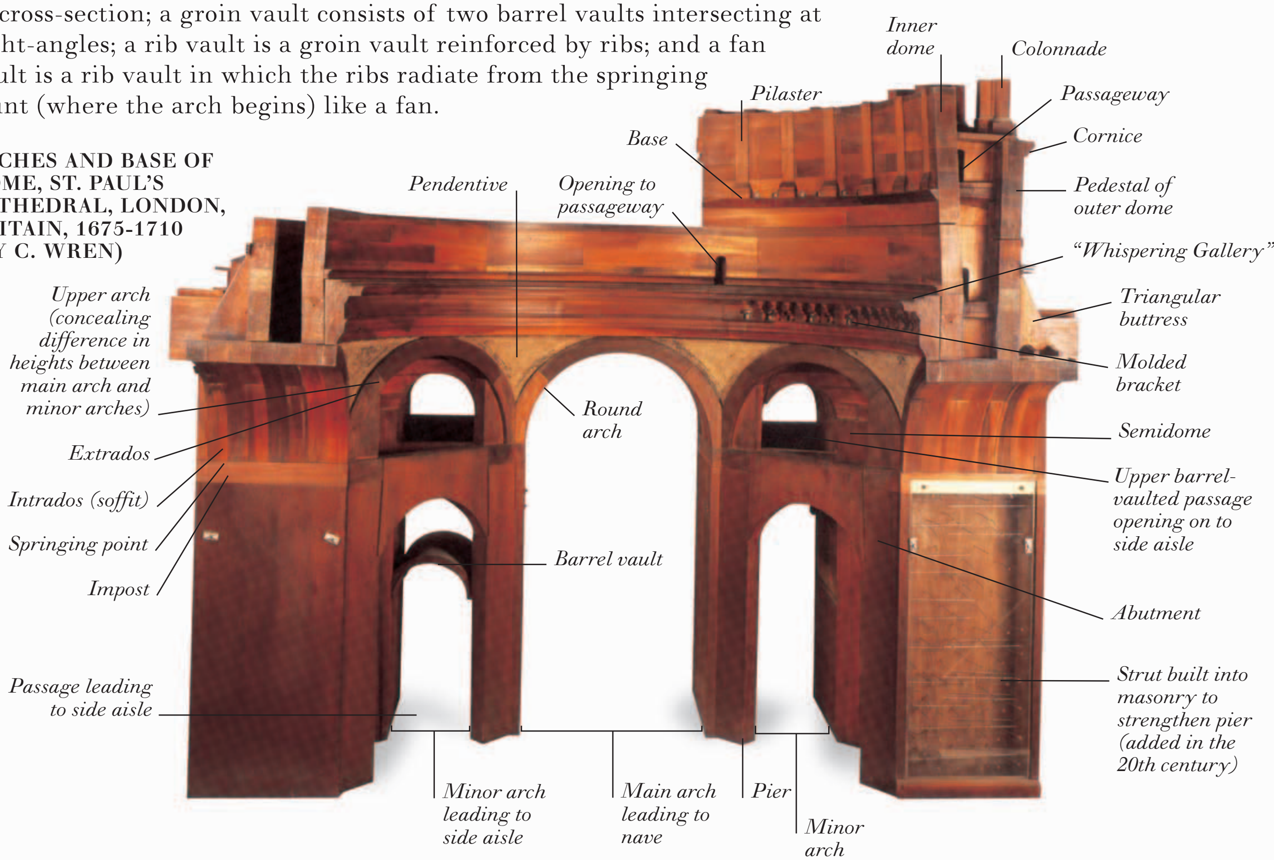
Arches and vaults

ARCHES ARE CURVED STRUCTURES used to bridge spans and to support the weight of upper parts of buildings, such as domes, as in St. Paul's Cathedral (below) and the antique temple (opposite). The voussoirs (wedge-shaped blocks) that form an arch (right) support each other and convert the downward force of the weight of the building into an outward force. This outward force is in turn transferred to buttresses, piers, or abutments. A vault is an arched roof or ceiling. There are four main types of vault (opposite). A barrel vault is a single vault, semicircular in cross-section; a groin vault consists of two barrel vaults intersecting at right-angles; a rib vault is a groin vault reinforced by ribs; and a fan vault is a rib vault in which the ribs radiate from the springing point (where the arch begins) like a fan.

PARTS OF AN ARCH

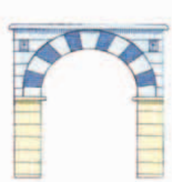


ARCHES AND BASE OF DOME, ST. PAUL'S CATHEDRAL, LONDON, BRITAIN, 1675-1710 (BY C. WREN)

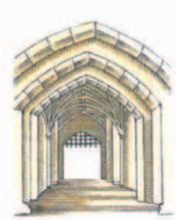


TYPES OF ARCH

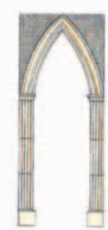
HORSESHOE ARCH (MOORISH ARCH), GREAT MOSQUE, CORDORA, SPAIN, 785



BASKET ARCH (SEMI-ELLIPTICAL ARCH), PALATINE CHAPEL, AIX-LA-CHAPELLE, FRANCE, 790-798



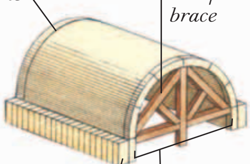
TUDOR ARCH, TOWER OF LONDON, BRITAIN, c.1086-1097



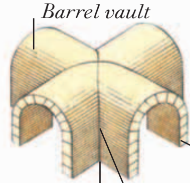
LANCET ARCH, WESTMINSTER ABBEY, LONDON, BRITAIN, 1503-1519

TREFOIL ARCH, BEVERLEY MINSTER, YORKSHIRE, BRITAIN, c.1300

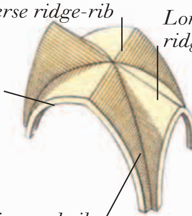
TYPES OF VAULT



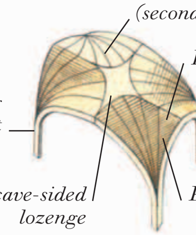
BARREL VAULT (TUNNEL VAULT; WAGON VAULT)



GROIN VAULT

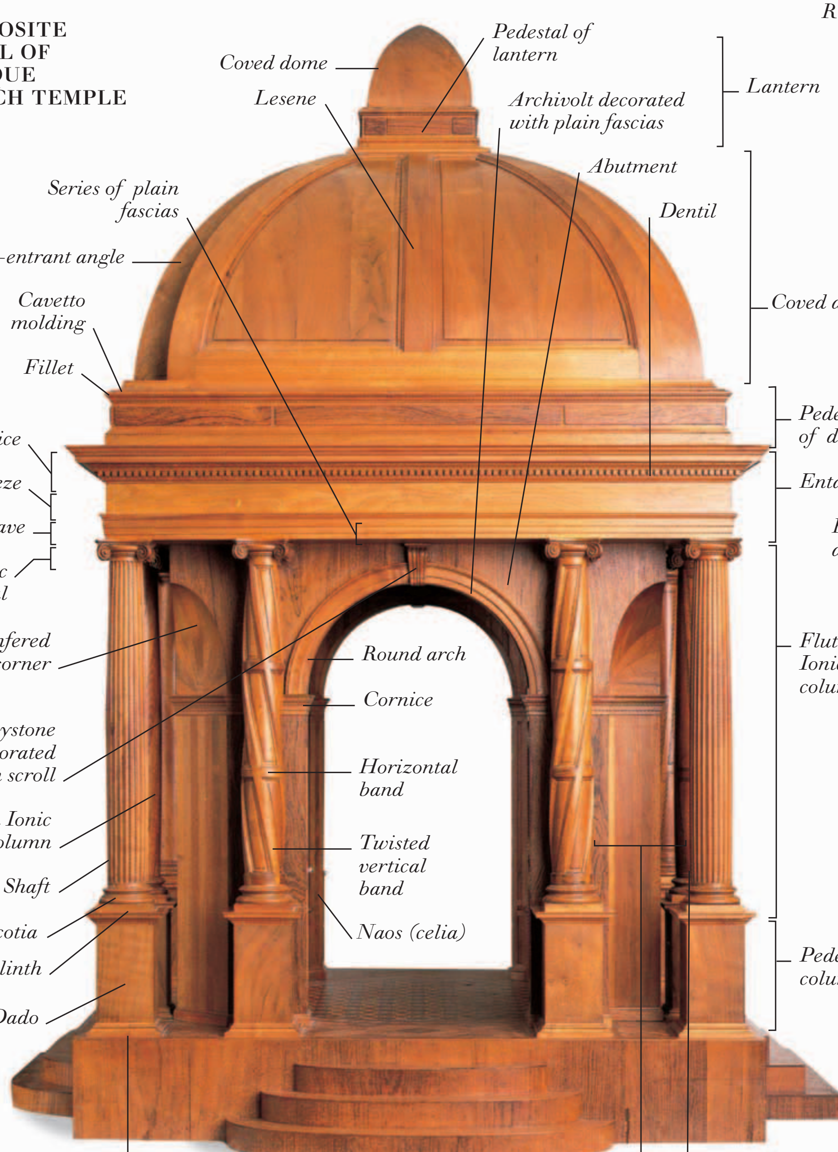


RIB VAULT

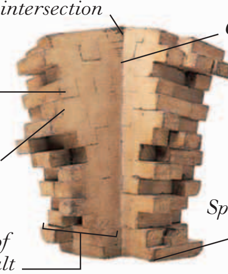


FAN VAULT

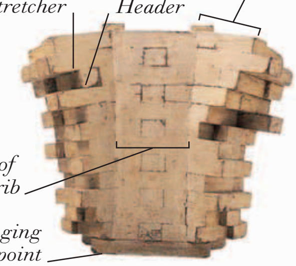
COMPOSITE MODEL OF ANTIQUE FRENCH TEMPLE



ENGLISH BOND BRICKWORK OF GROIN VAULT AND RIB VAULT

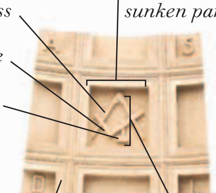


EXTRADOS OF GROIN VAULT



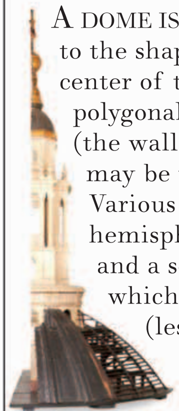
EXTRADOS OF RIB VAULT

INTERIOR DECORATION OF COFFERED VAULT



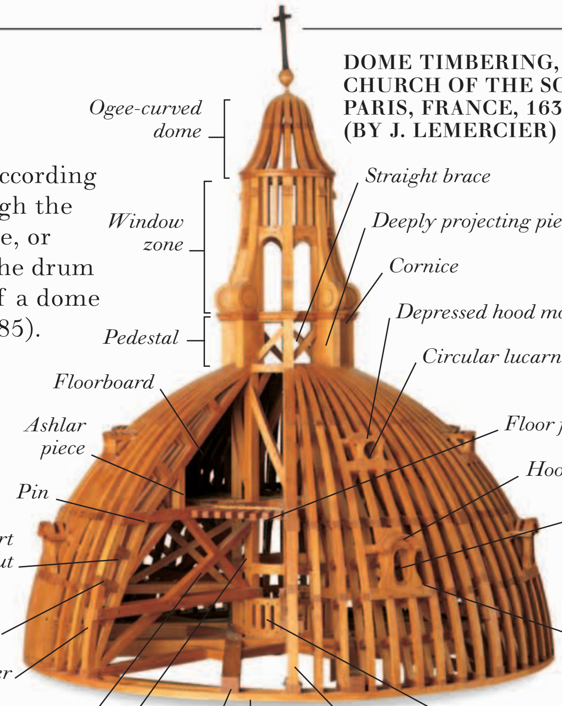
Domes

A DOME IS A CONVEX ROOF. Domes are categorized according to the shapes of both the base and the section through the center of the dome. The base may be circular, square, or polygonal (many-sided), depending on the plan of the drum (the walls on which the dome rests). The section of a dome may be the same shape as any arch (see pp. 484-485). Various types of dome are illustrated here: a hemispherical dome, which has a circular base and a semicircular section; a saucer dome, which has a circular base and a segmental (less than a semicircle) section; a polyhedral dome, which is a dome on a polygonal base whose sides meet at the top of the dome; and an onion dome, which has a circular or polygonal base and an ogee-shaped section. Many domes have a lantern (a turret with windows) to provide light inside.

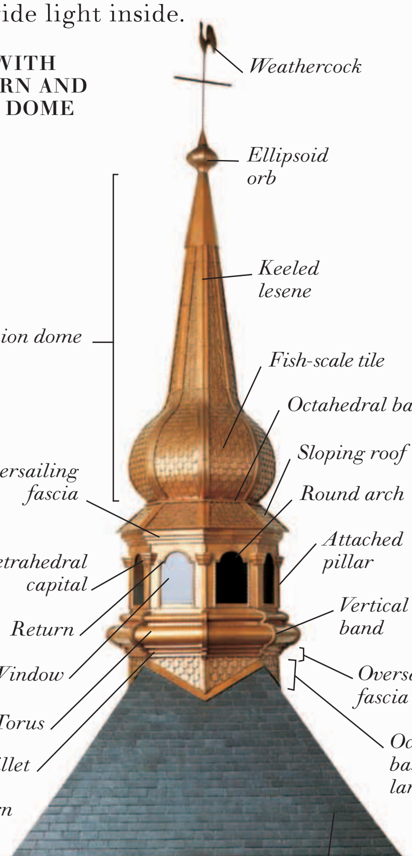


LANTERN AND UPPER DOME TIMBERING, ST. PAUL'S CATHEDRAL

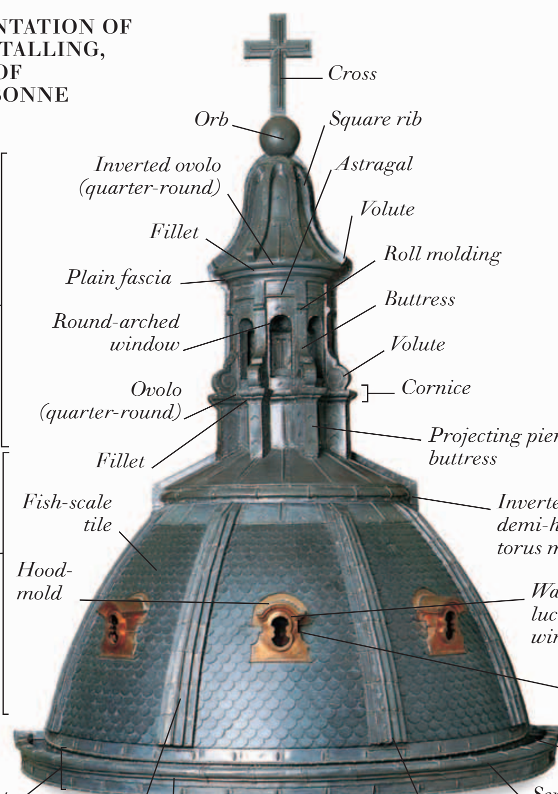
DOME TIMBERING, CHURCH OF THE SORBONNE, PARIS, FRANCE, 1635-1642 (BY J. LEMERCIER)



ROOF WITH LANTERN AND ONION DOME



REPRESENTATION OF DOME METALLING, CHURCH OF THE SORBONNE



TYPES OF DOME

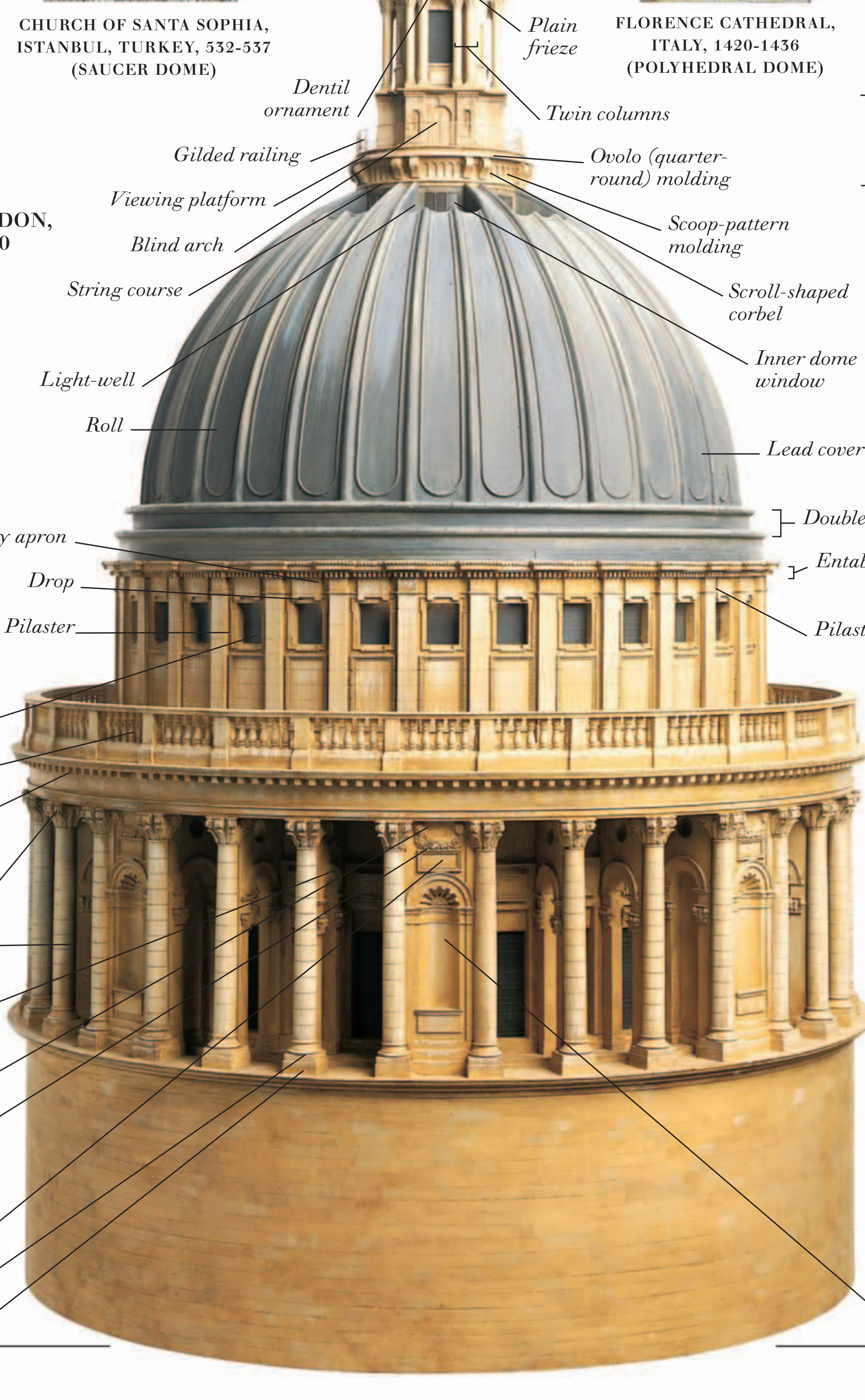
DOME OF THE ROCK, JERUSALEM, ISRAEL, FROM c.684 (HEMISPHERICAL DOME)

CHURCH OF SANTA SOPHIA, ISTANBUL, TURKEY, 532-537 (SAUCER DOME)

FLORENCE CATHEDRAL, ITALY, 1420-1436 (POLYHEDRAL DOME)

ST. BASIL'S CATHEDRAL, MOSCOW, RUSSIA, 1555-1561 (ONION DOME)

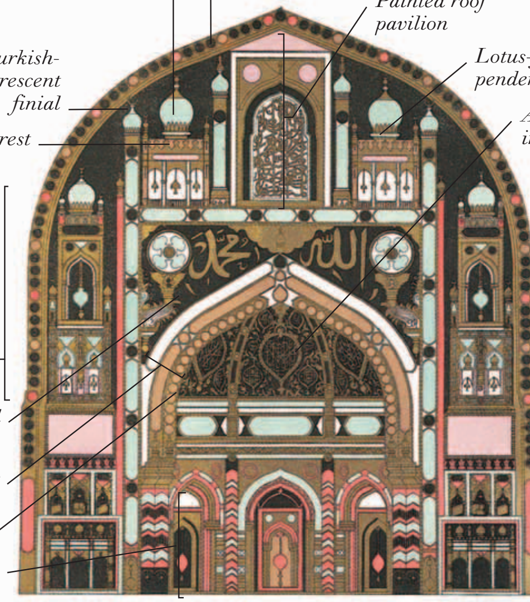
DOME, ST. PAUL'S CATHEDRAL, LONDON, BRITAIN, 1675-1710 (BY C. WREN)



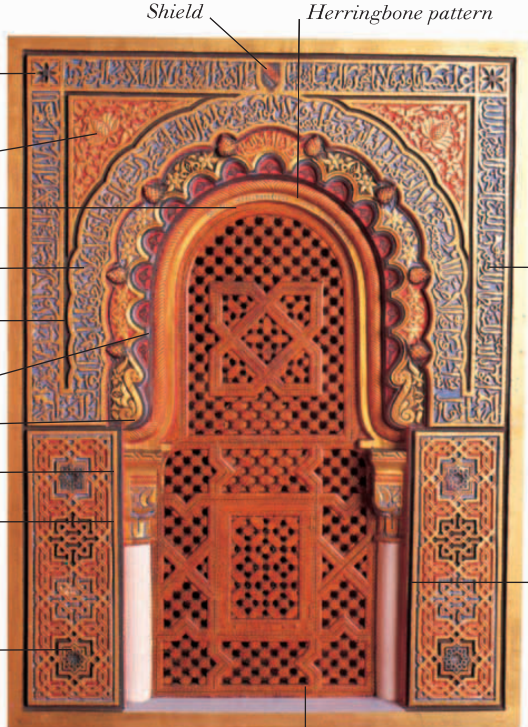
Islamic buildings

OPUS SECTILE MOSAIC DESIGN

THE ISLAMIC RELIGION was founded by the prophet Mohammed, who was born in Mecca (in present-day Saudi Arabia) about 570 AD. In the following three centuries, Islam spread from Arabia to North Africa and Spain, as well as to India and much of the rest of Asia. The worldwide influence of Islam remains strong today. Common characteristics of Islamic buildings include ogee arches and roofs, onion domes, and walls decorated with carved stone, paintings, inlays, or mosaics. The most important type of Islamic building is the mosque—the place of worship—which generally has a minaret (tower) from which the muezzin (official crier) calls Muslims to prayer. Most mosques have a mihrab (decorative niche) that indicates the direction of Mecca. As figurative art is not allowed in Islam, buildings are ornamented with geometric and arabesque motifs, and inscriptions (frequently Koranic verses).



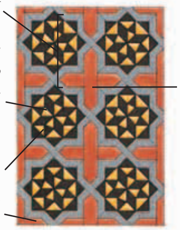
MIHRAB, JAMI MASJID (PRINCIPAL OR CONGREGATIONAL MOSQUE), BIJAPUR, INDIA, c.1636



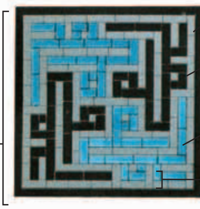
ARCH, THE ALHAMBRA, GRANADA, SPAIN, 1333-1354

MIHRAB WITH COLUMN, EL-AINYI MOSQUE, CAIRO, EGYPT, 15TH CENTURY

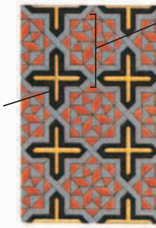
EXAMPLES OF ISLAMIC MOSAICS, EGYPT AND SYRIA



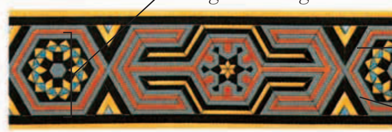
STAR AND GREEK-CROSS MOSAIC



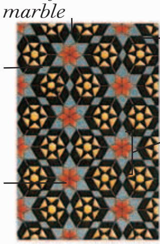
FRET-PATTERN MOSAIC



STAR AND GREEK-CROSS MOSAIC

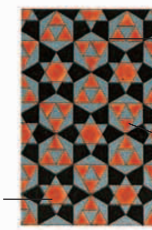


HEXAGON AND BAND MOSAIC



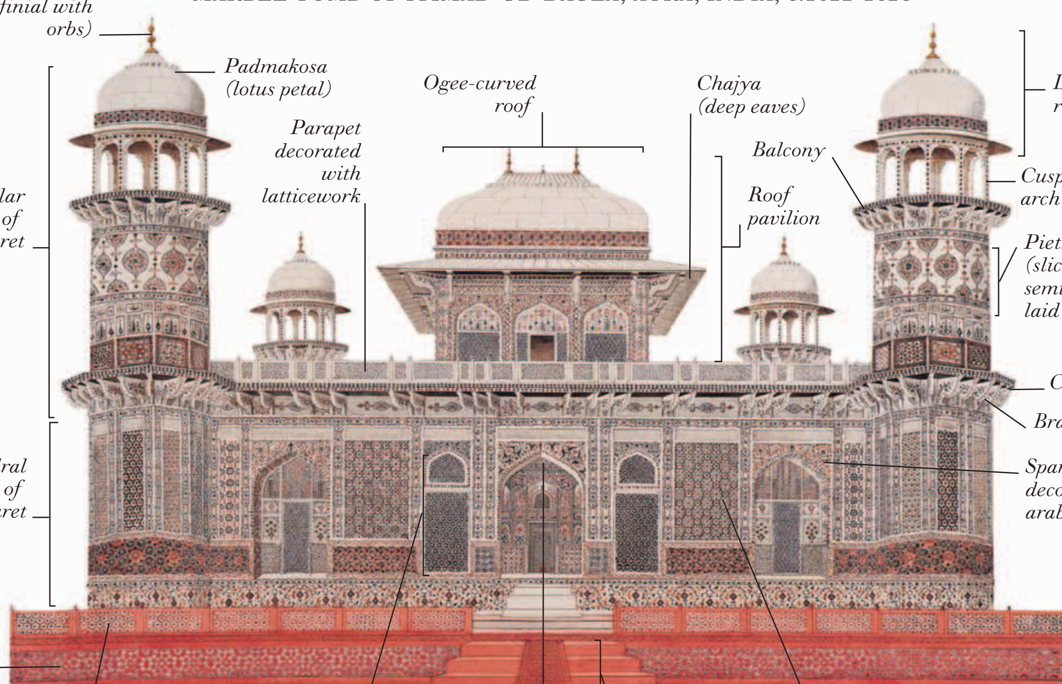
MOSAIC OF HEXAGONS, TRIANGLES, AND SYMMETRICAL QUADRILATERALS

DANCETTE-PATTERN MOSAIC



MOSAIC OF HEXAGONS, TRIANGLES, AND SYMMETRICAL QUADRILATERALS

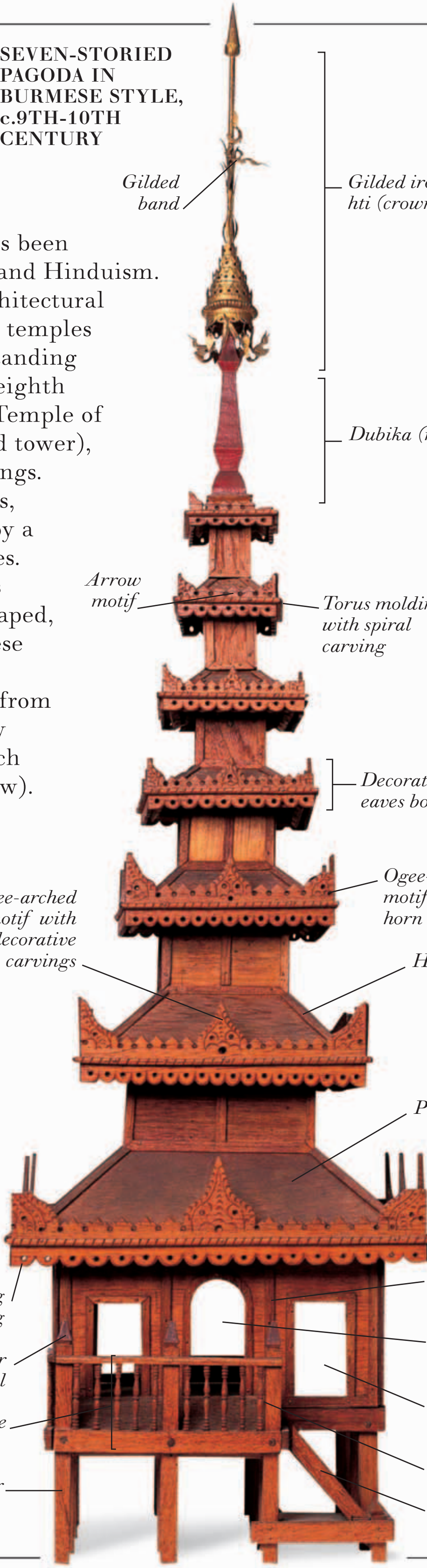
MARBLE TOMB OF ITIMAD-UD-DAULA, AGRA, INDIA, c.1622-1628



South and east Asia

THE TRADITIONAL ARCHITECTURE of south and east Asia has been profoundly influenced by the spread from India of Buddhism and Hinduism. This influence is shown both by the abundance and by the architectural styles of temples and shrines in the region. Many early Hindu temples consist of rooms carved from solid rock-faces. However, free-standing structures began to be built in southern India from about the eighth century AD. Many were built in the Dravidian style, like the Temple of Virupaksha (opposite) with its characteristic antarala (terraced tower), perforated windows, and numerous arches, pilasters, and carvings. The earliest Buddhist religious monuments were Indian stupas, which consisted of a single hemispherical dome surmounted by a chattravali (shaft) and surrounded by railings with ornate gates. Later Indian stupas and those built elsewhere were sometimes modified; for example, in Sri Lanka, the dome became bell-shaped, and was called a dagoba. Buddhist pagodas, such as the Burmese example (right), are multistoried temples, each story having a projecting roof. The form of these buildings probably derived from the yasti (pointed spire) of the stupa. Another feature of many traditional Asian buildings is their imaginative roof-forms, such as gambrel (mansard) roofs, and roofs with angle-rafters (below).

SEVEN-STORIED PAGODA IN BURMESE STYLE, c.9TH-10TH CENTURY



DETAILS FROM EAST ASIAN BUILDINGS

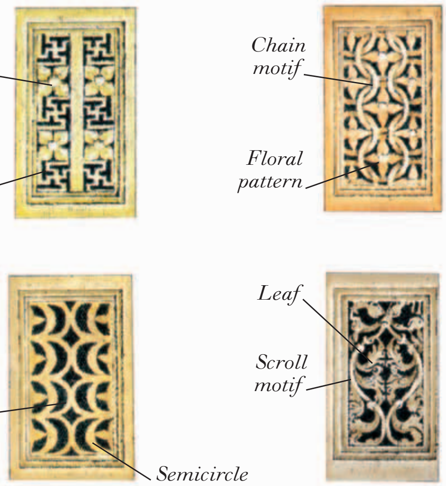
KASUGA-STYLE ROOF WITH SUMIGI (ANGLE-RAFTERS), KASUGADO SHRINE OF ENJOJI, NARA, JAPAN, 12TH-14TH CENTURY

TERRACES, TEMPLE OF HEAVEN, BEIJING, CHINA, 15TH CENTURY

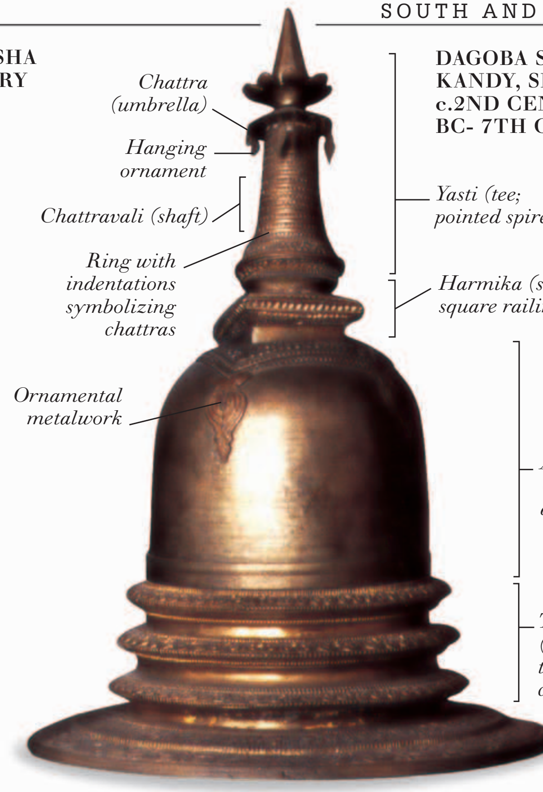
GAMBREL (MANSARD) ROOF WITH UPSWEPT EAVES AND UNDULATING GABLES, HIMEJI CASTLE, HIMEJI, JAPAN, 1608-1609

CORNER CAPITAL WITH ROOF BEAMS, POPCHU-SA TEMPLE, POPCHU-SA, SOUTH KOREA, 17TH CENTURY

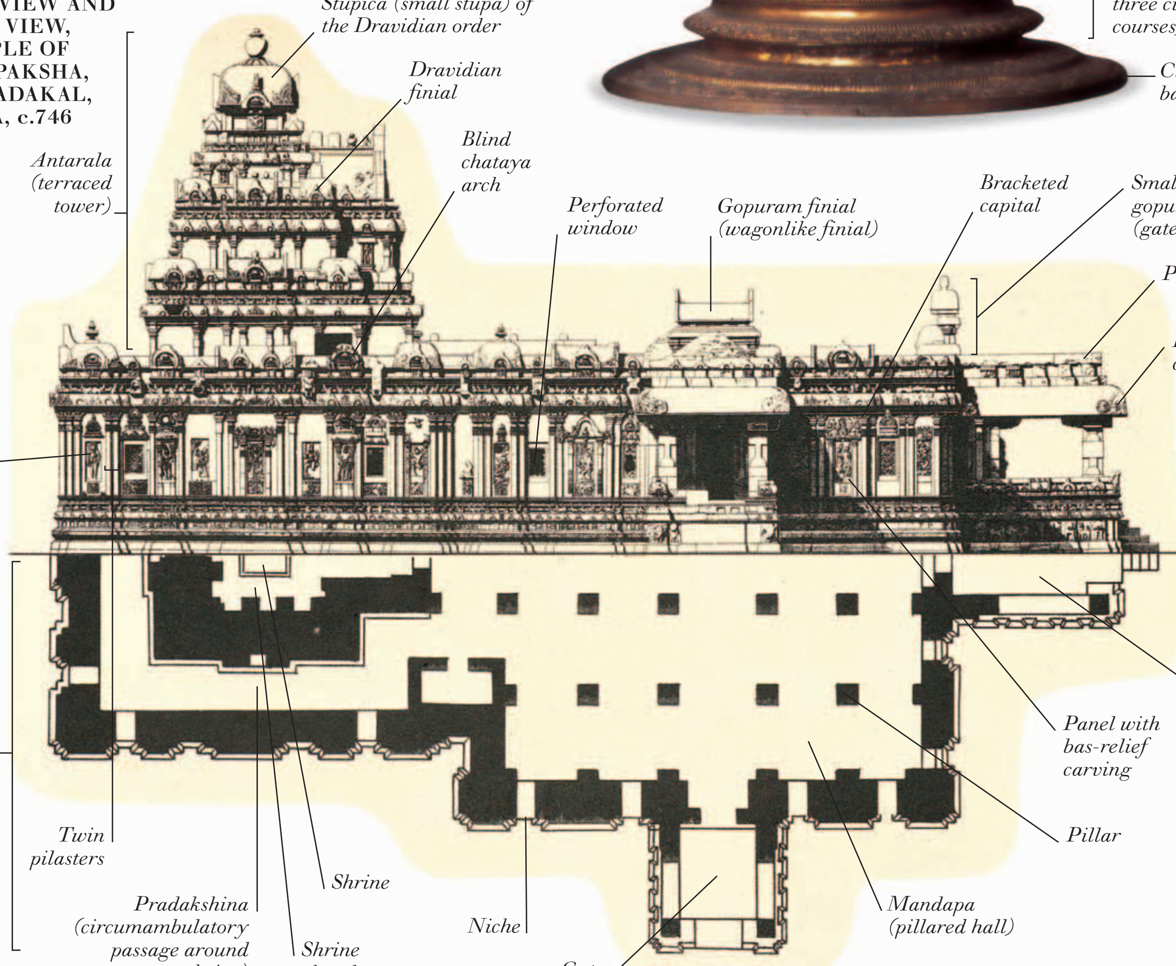
PERFORATED STONE WINDOWS, TEMPLES OF VIRUPAKSHA AND MALLIKARJUNA, PATTADAKAL, INDIA, 8TH CENTURY



DAGOBA STUPA, KANDY, SRI LANKA, c.2ND CENTURY BC- 7TH CENTURY AD



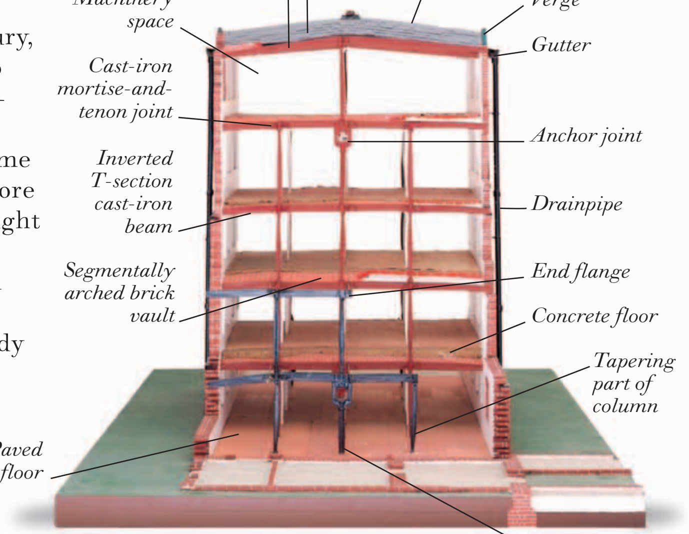
SIDE VIEW AND PLAN VIEW, TEMPLE OF VIRUPAKSHA, PATTADAKAL, INDIA, c.746



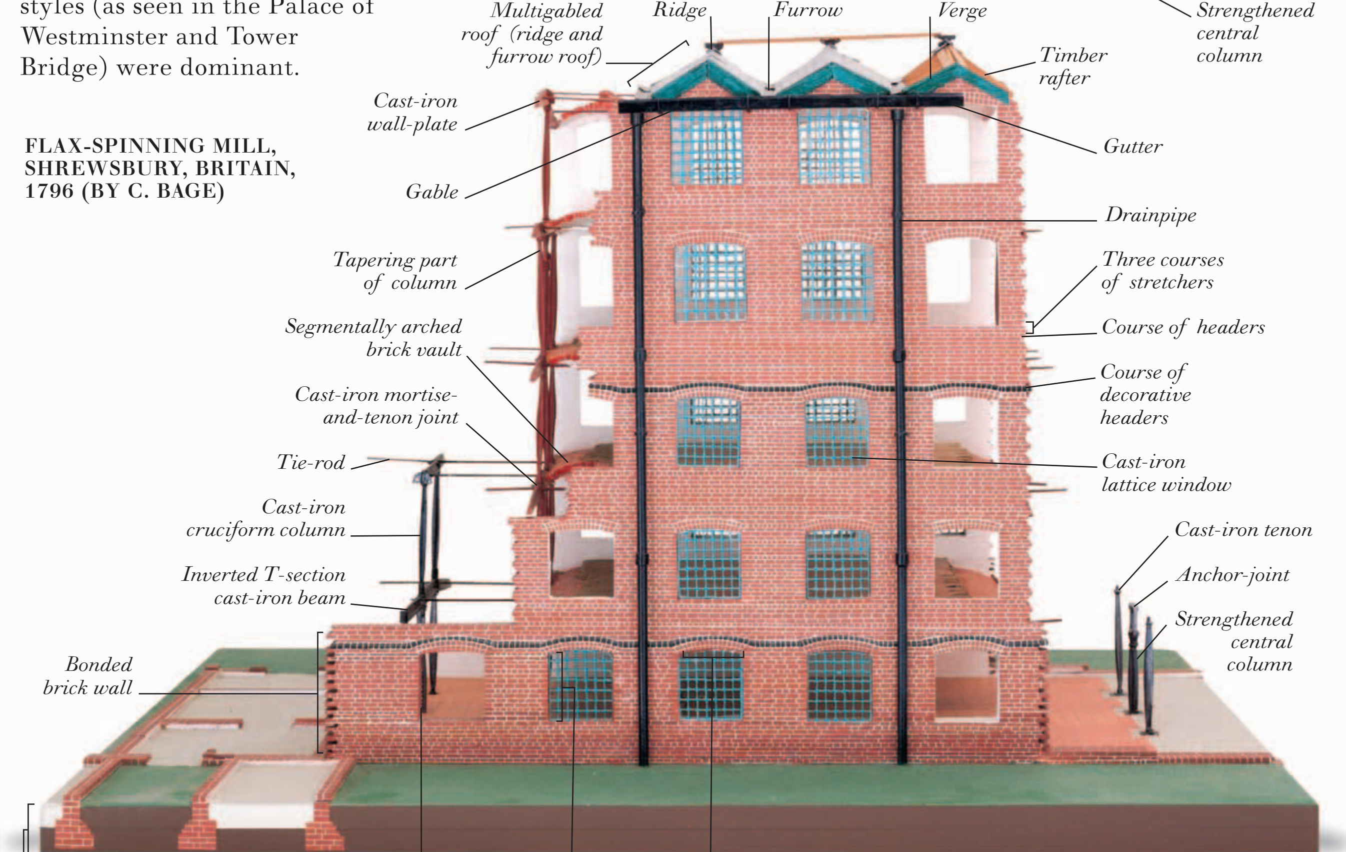
The 19th century

BUILDINGS OF THE 19TH CENTURY are characterized by the use of new materials and by a great diversity of architectural styles. From the end of the 18th century, iron and steel became widely used as alternatives to wood for the framework of buildings, as in the flax-spinning mill shown here. Built in Britain in 1796, this mill exemplifies an architectural style that became common throughout the industrialized world for more than a century. The Industrial Revolution also brought mass-production of building parts—a development that enabled the British architect Sir Joseph Paxton to erect London's Crystal Palace (a building made entirely of iron and glass) in only nine months, ready for the Great Exhibition of 1851. The 19th century saw a widespread revival of older architectural styles. For example, in the US and Germany, Neo-Greek architecture was fashionable; in Britain and France, Neo-Baroque, Neo-Byzantine, and Neo-Gothic styles (as seen in the Palace of Westminster and Tower Bridge) were dominant.

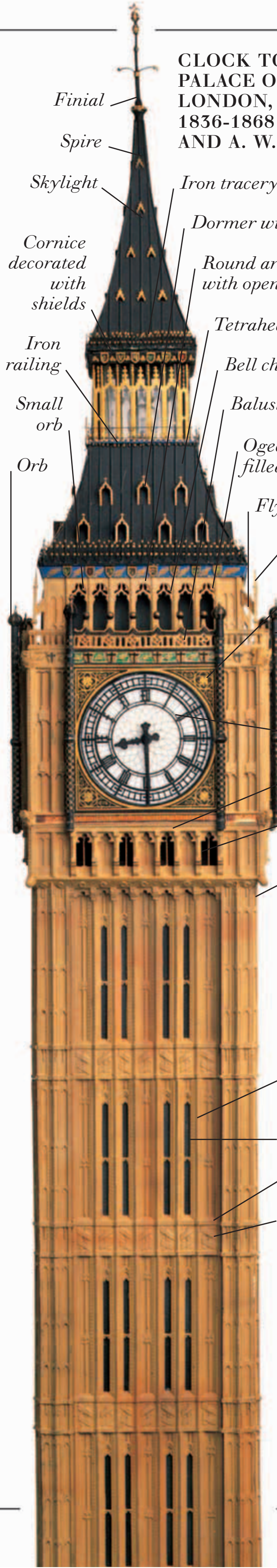
SECTION THROUGH A FLAX-SPINNING MILL



FLAX-SPINNING MILL, SHREWSBURY, BRITAIN, 1796 (BY C. BAGE)



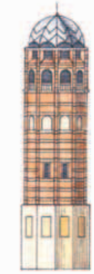
CLOCK TOWER ("BIG BEN"), PALACE OF WESTMINSTER, LONDON, BRITAIN, 1836-1868 (BY C.BARRY AND A. W. N. PUGIN)



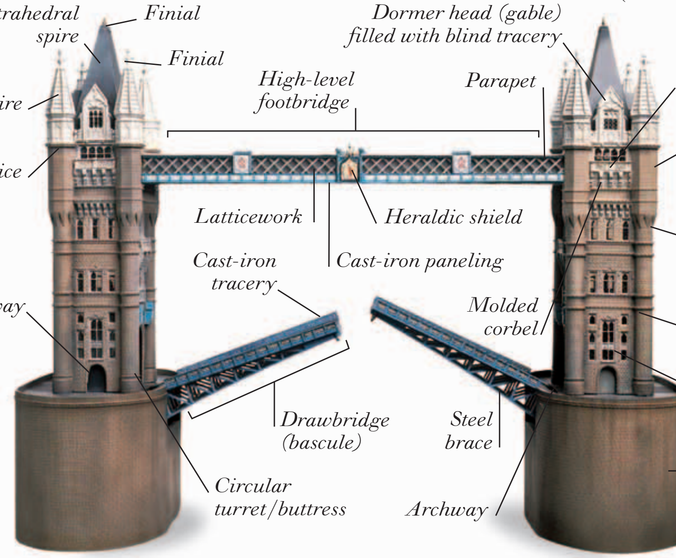
DETAILS FROM BUILDINGS IN REVIVALIST STYLES

CUPOLA, MERCHANTS' EXCHANGE, PHILADELPHIA 1832-1834 (NEO-GREEK)

SCULPTURE AND PEDIMENT, OPERA HOUSE, PARIS, FRANCE, 1861-1874 (NEO-BAROQUE)

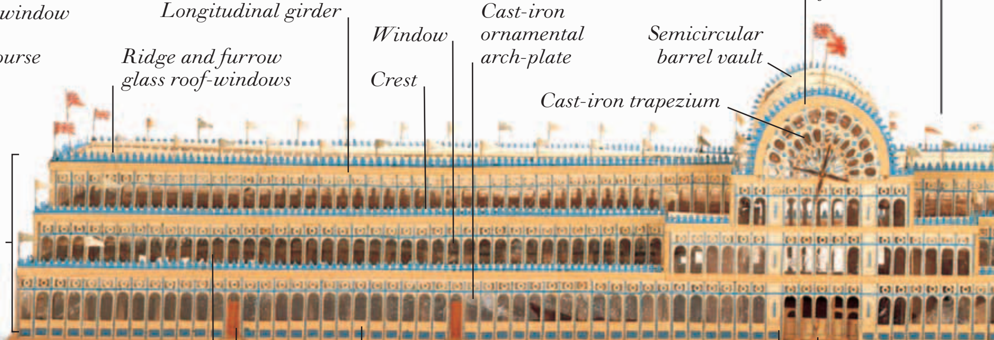


DOMED TURRET, WESTMINSTER CATHEDRAL, LONDON, BRITAIN, 1894-1903 (NEO-BYZANTINE)



TOWER BRIDGE, LONDON, BRITAIN, 1886-1894 (BY H. JONES)

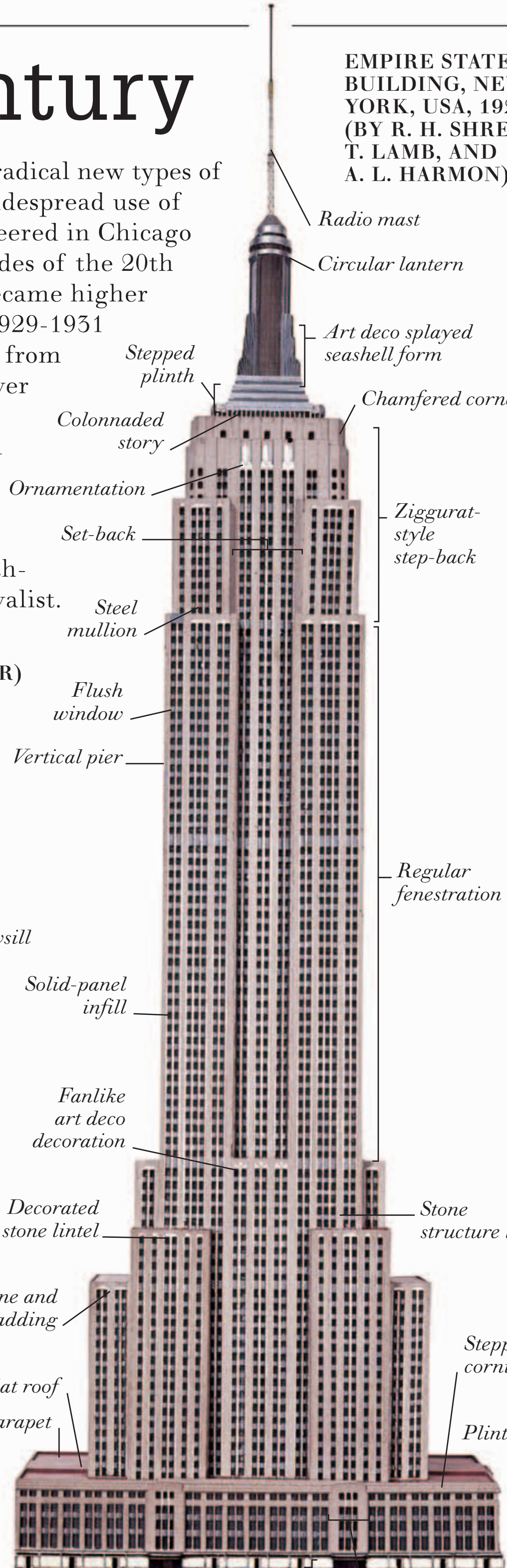
CRYSTAL PALACE EXHIBITION HALL, LONDON, BRITAIN, 1851 (BY J. PAXTON)



The early 20th century

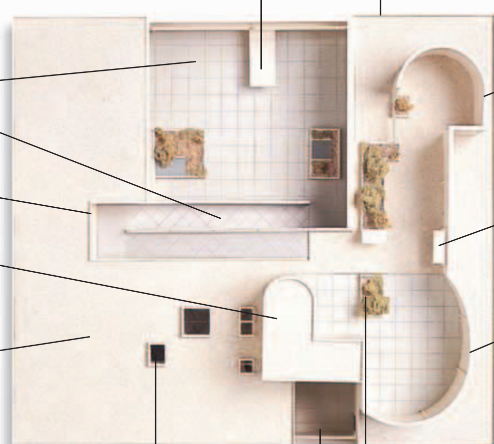
ARCHITECTURE OF THE EARLY 20TH CENTURY is notable for radical new types of steel-and-glass buildings—particularly skyscrapers—and the widespread use of steel-reinforced concrete. The steel-framed skyscraper was pioneered in Chicago in the 1880s, but did not become widespread until the first decades of the 20th century. As construction techniques were refined, skyscrapers became higher and higher; for example, the Empire State Building (right) of 1929-1931 has 102 storeys. Many buildings of this period were constructed from lightweight concrete slabs, which could be supported by cantilever beams or by pilotis (stilts), as in the Villa Savoye (below). The early 20th century also produced a great variety of architectural styles, some of which are illustrated opposite. Despite their diversity, the styles of this period generally had one thing in common: they were completely new, with few links to past architectural styles. This originality is in marked contrast to 19th-century architecture (see pp. 492-493), much of which was revivalist.

EMPIRE STATE BUILDING, NEW YORK, USA, 1929-1931 (BY R. H. SHREVE, T. LAMB, AND A. L. HARMON)



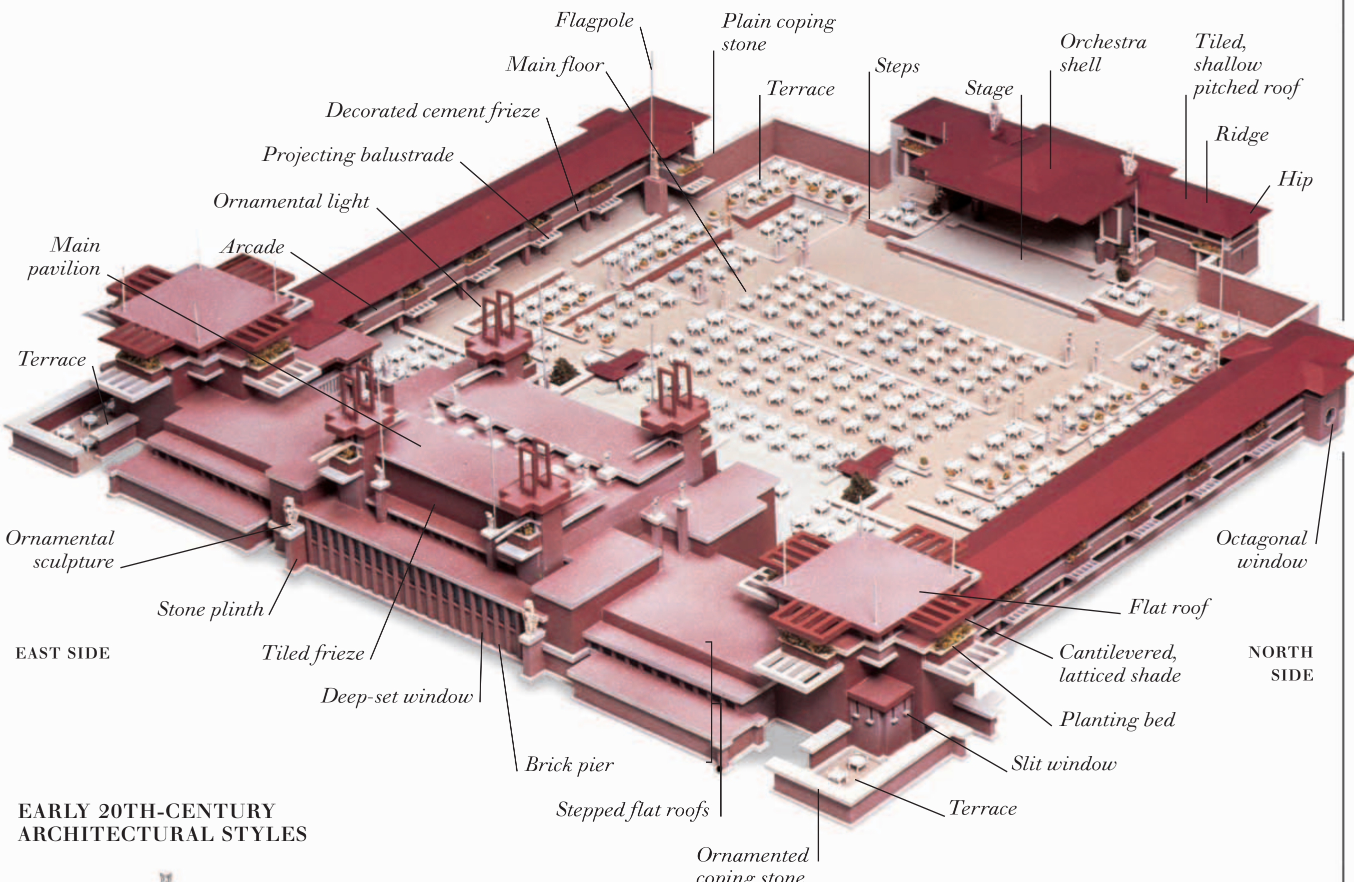
VILLA SAVOYE, POISSY, FRANCE, 1929-1931 (BY LE CORBUSIER)

TOP VIEW



SIDE VIEW

MIDWAY GARDENS, CHICAGO, 1914 (BY F. L. WRIGHT)



EARLY 20TH-CENTURY ARCHITECTURAL STYLES

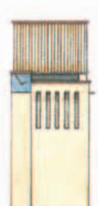

DORMER WINDOW, STUDIO ELVIRA, MUNICH, GERMANY, 1902 (ART NOUVEAU)

AEG TURBINE HALL, BERLIN, GERMANY, 1909 (DEUTSCHER WERKBUND)

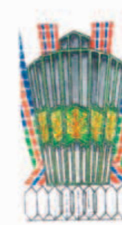

ROBIE HOUSE, CHICAGO, 1909-1910 (PRAIRIE STYLE)


GRUNDTVIG CHURCH, COPENHAGEN, DENMARK, 1920 (EXPRESSIONIST)


VERTEX, CHRYSLER BUILDING, NEW YORK CITY, 1928-1930 (ART DECO)


TOWER, TOWN HALL, HILVERSUM, NETHERLANDS, 1930 (DUTCH CUBIST)

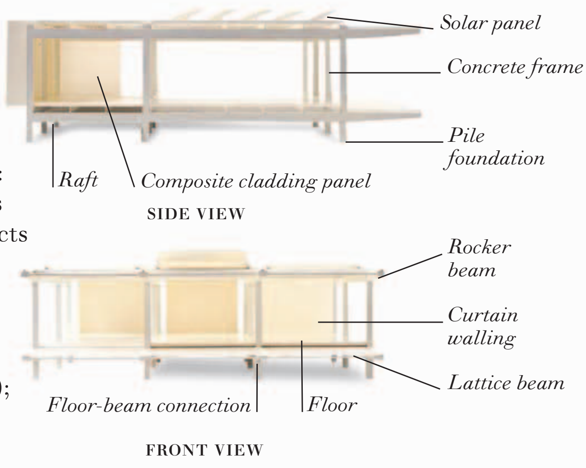

CASA DEL FASCIO, COMO, ITALY, 1932-1936 (GRUPPO SEVEN CUBIST)


MOTIF ABOVE DOORWAY, HOOVER FACTORY, LONDON, BRITAIN, 1933 (ART DECO)

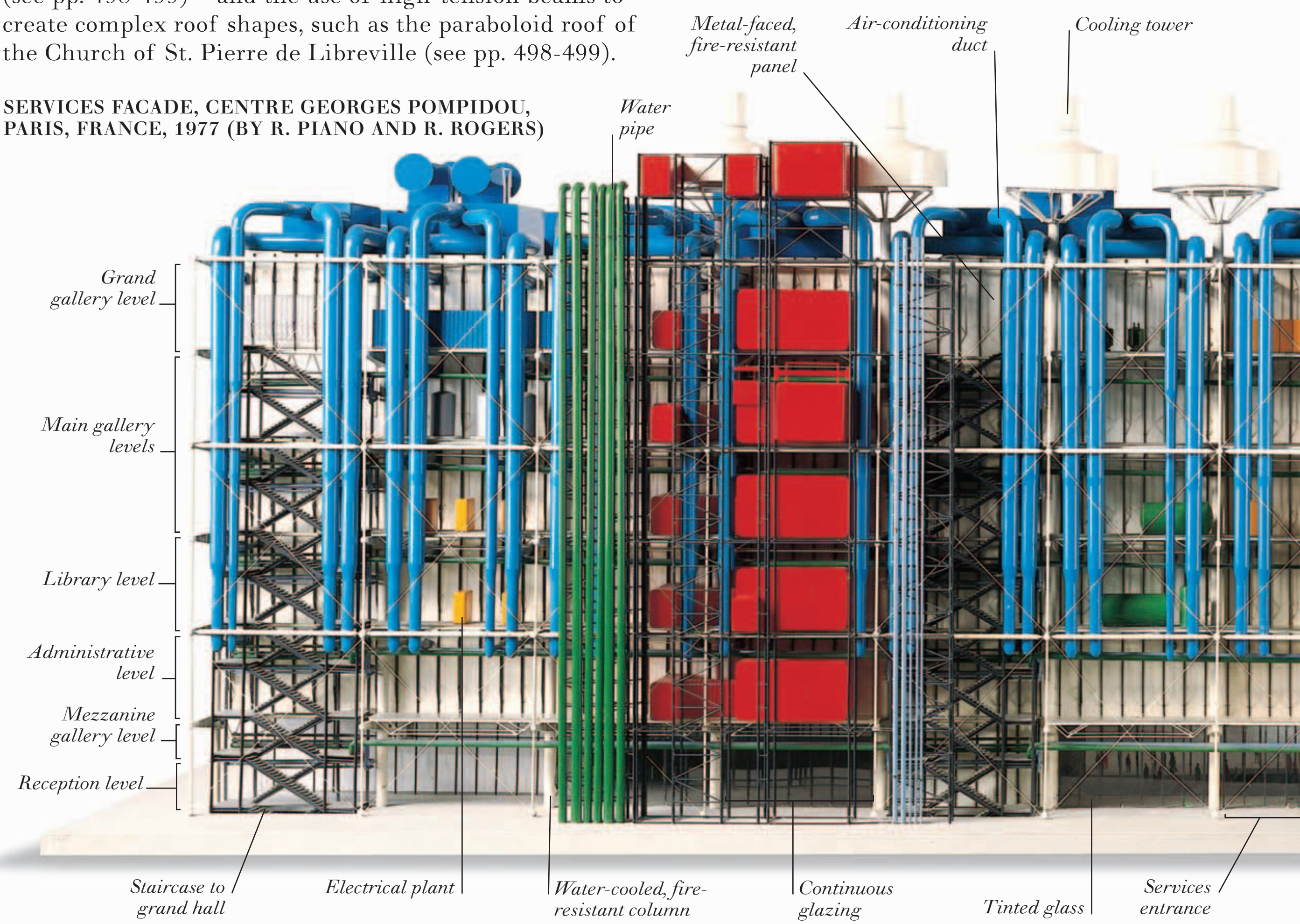
Modern buildings 1

ARCHITECTURE SINCE ABOUT THE 1950s is generally known as modern architecture. One of its main influences has been functionalism—a belief that a building's function should be apparent in its design. Both the Centre Georges Pompidou (below and opposite) and the Hong Kong and Shanghai Bank (see pp. 498-499) are functionalist buildings: on each, elements of engineering and the building's services are clearly visible on the outside. In the 1980s, some architects rejected functionalism in favor of post-modernism, in which historical styles—particularly neoclassicism—were revived, using modern building materials and techniques. In many modern buildings, walls are made of glass or concrete hung from a frame, as in the Kawana House (right); this type of wall construction is known as curtain walling. Other modern construction techniques include the intricate interlocking of concrete vaults—as in the Sydney Opera House (see pp. 498-499)—and the use of high-tension beams to create complex roof shapes, such as the paraboloid roof of the Church of St. Pierre de Libreville (see pp. 498-499).

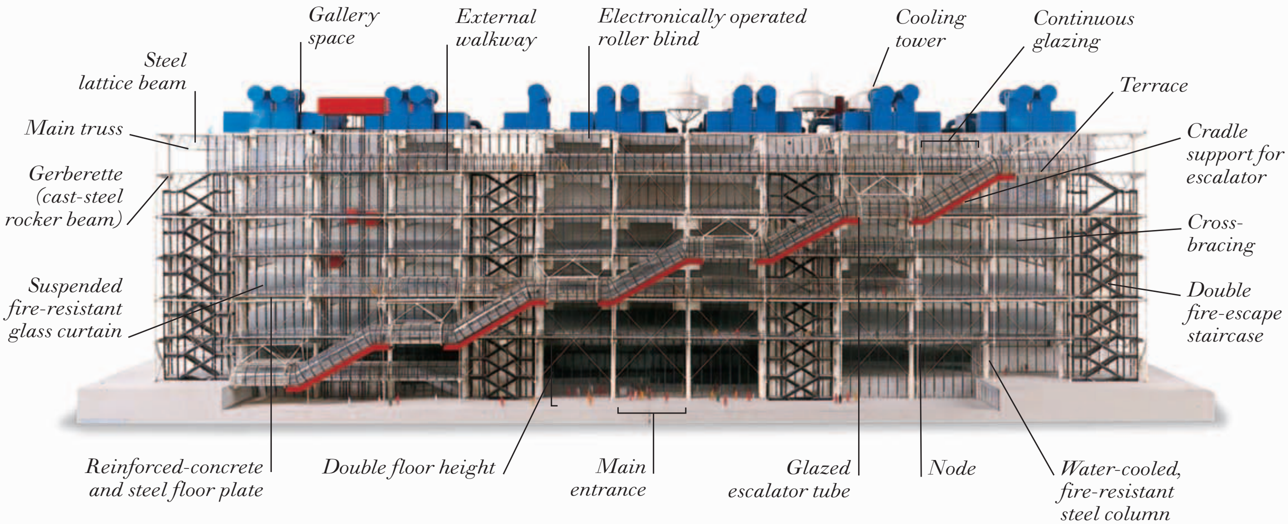
KAWANA HOUSE, JAPAN, FROM 1987 (BY N. FOSTER)

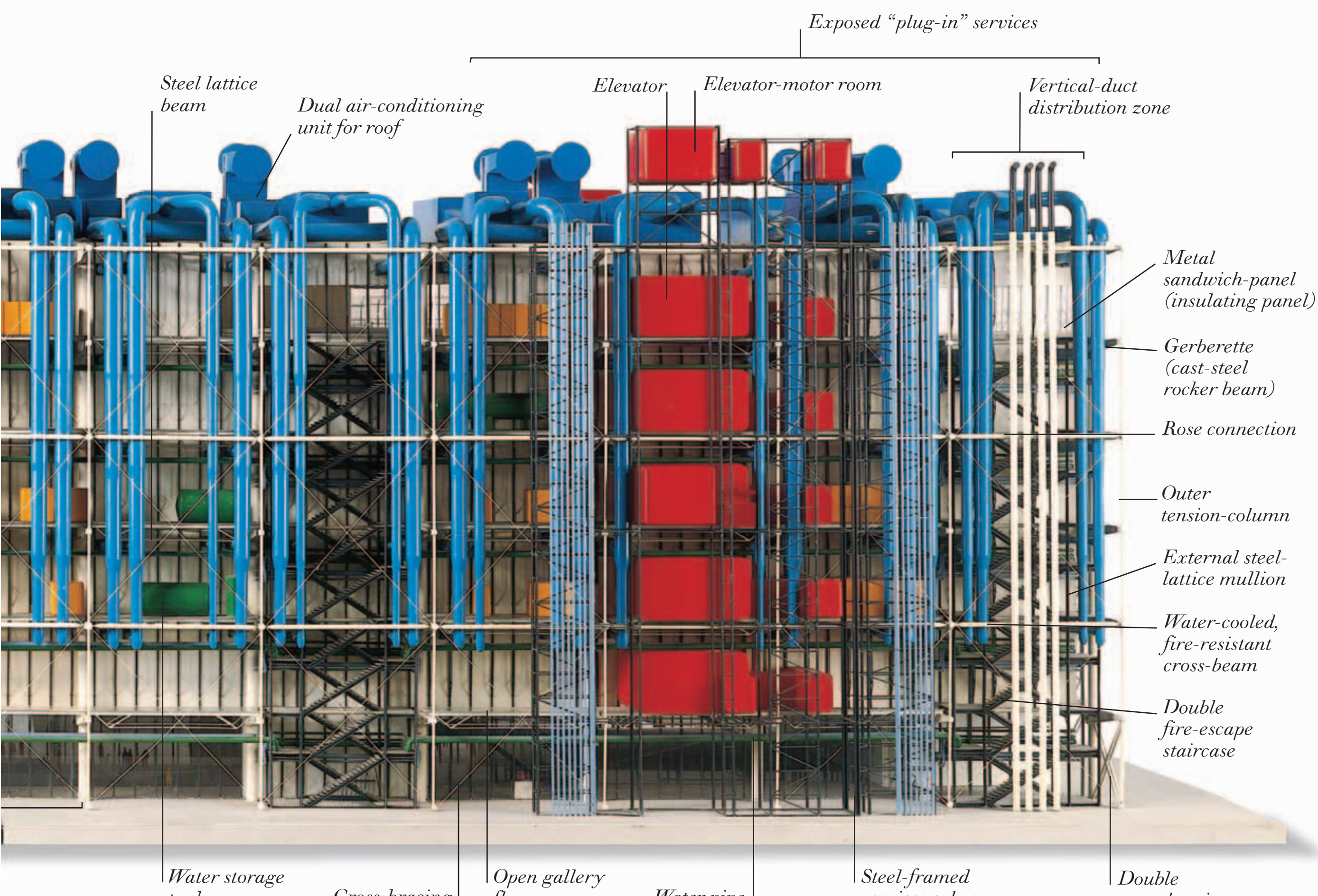


SERVICES FACADE, CENTRE GEORGES POMPIDOU, PARIS, FRANCE, 1977 (BY R. PIANO AND R. ROGERS)



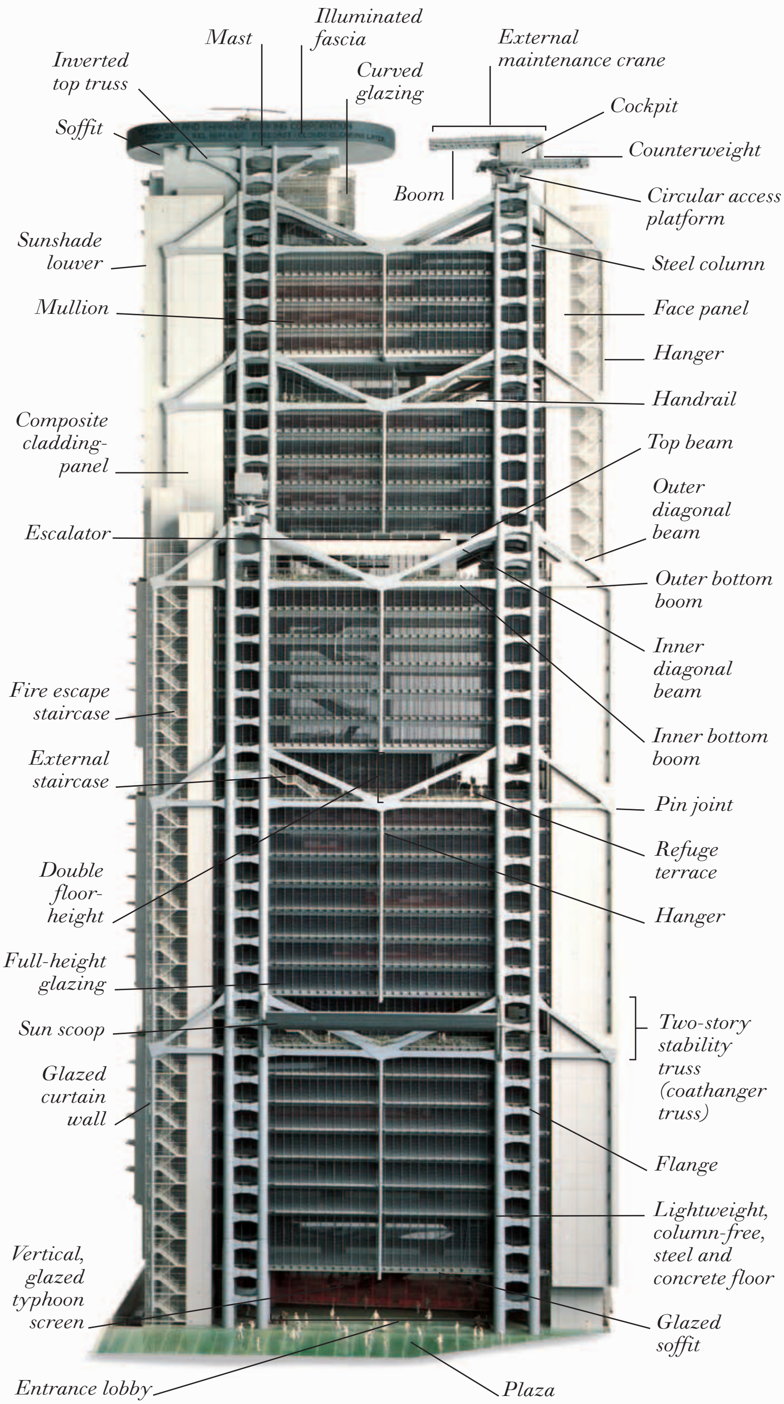
PRINCIPAL FACADE, CENTRE GEORGES POMPIDOU



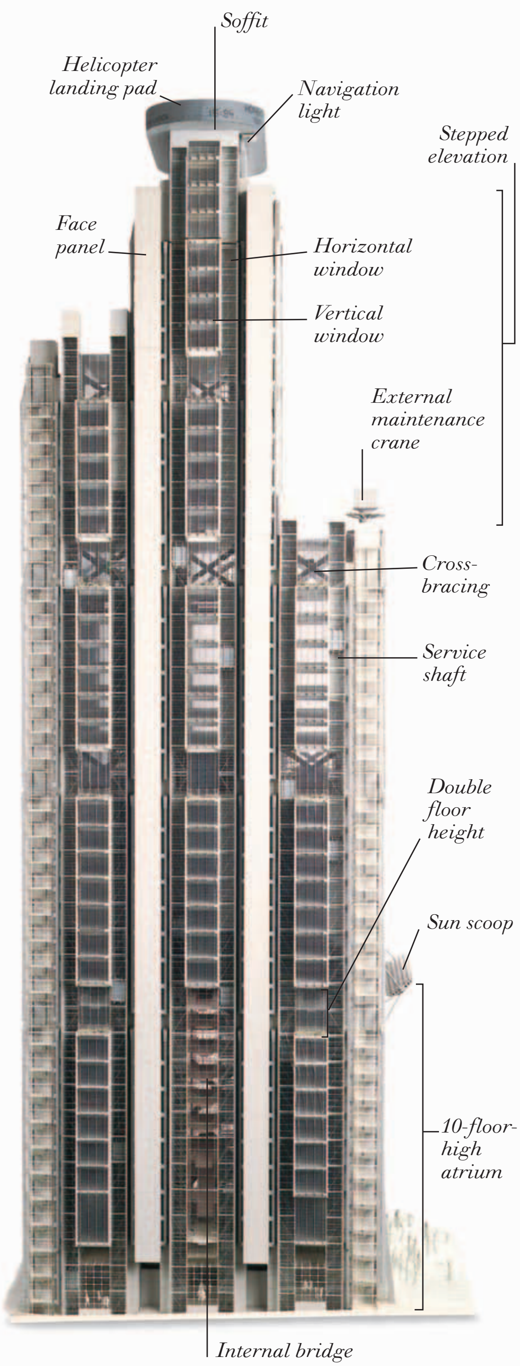


Modern buildings 2

HONG KONG AND SHANGHAI BANK, HONG KONG, 1981-1985 (BY N. FOSTER)

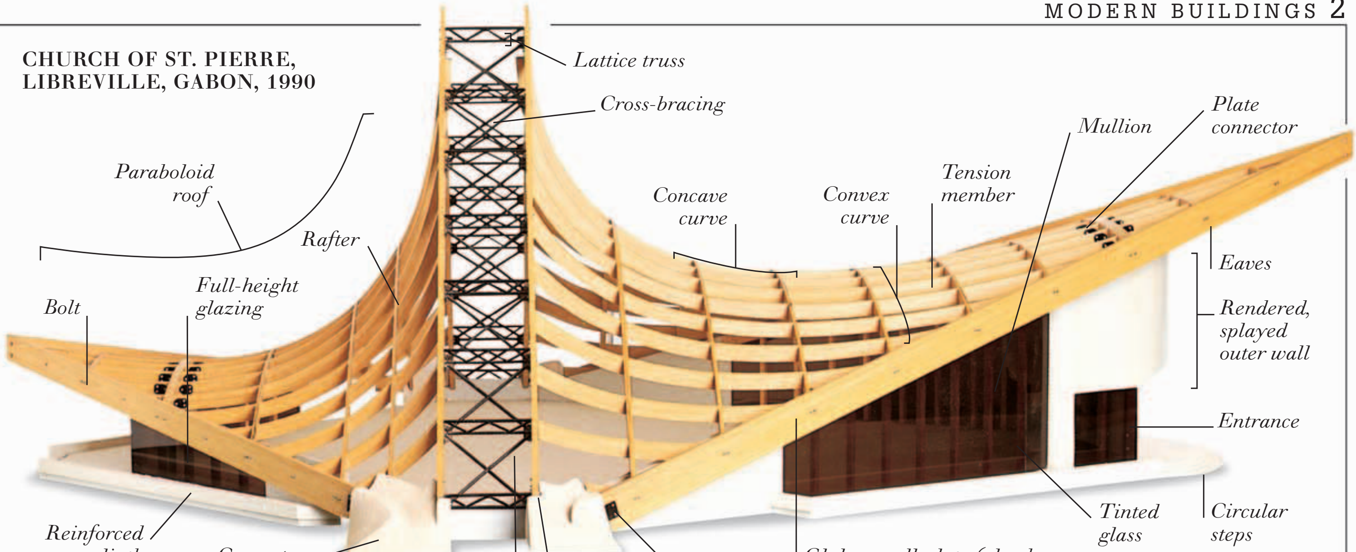


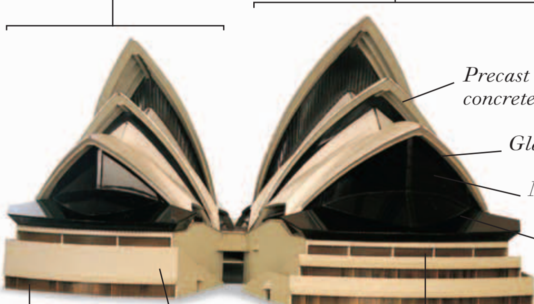
SOUTH FACADE



EAST SIDE

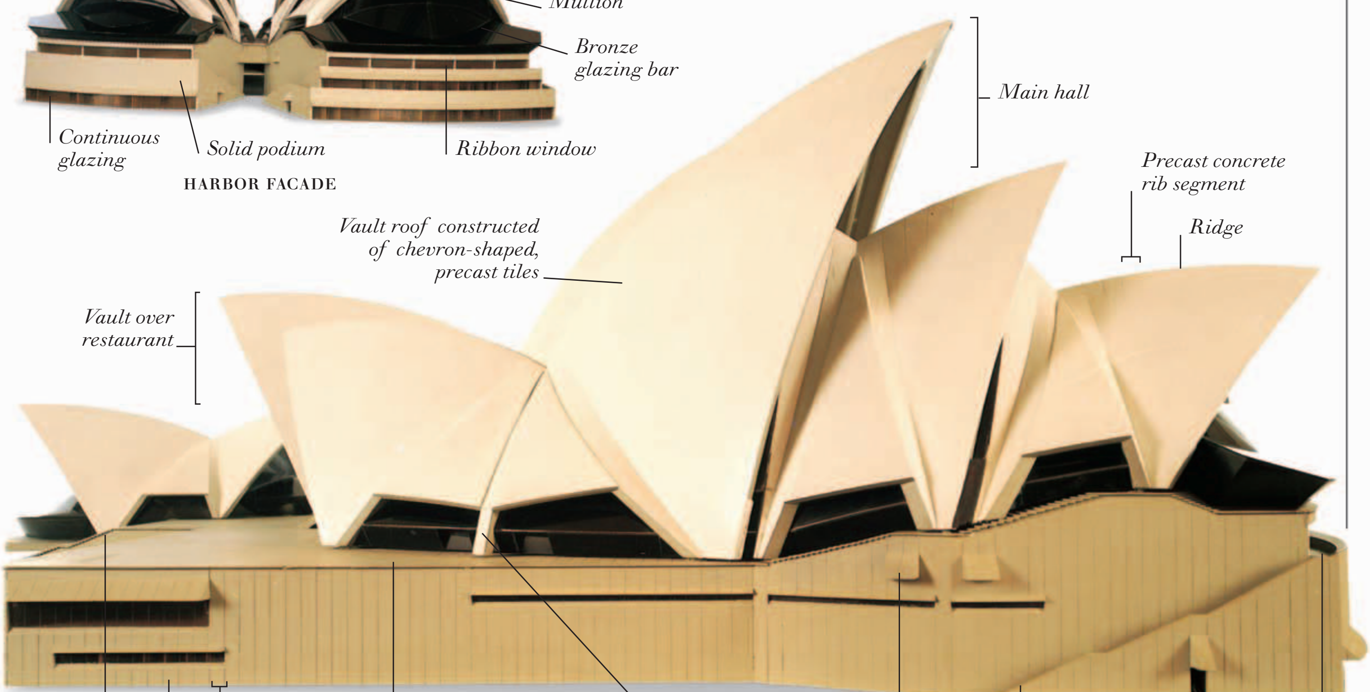
CHURCH OF ST. PIERRE, LIBREVILLE, GABON, 1990





HARBOR FACADE

OPERA HOUSE, SYDNEY, AUSTRALIA, 1959-1973 (BY J. UTZON)



WEST SIDE

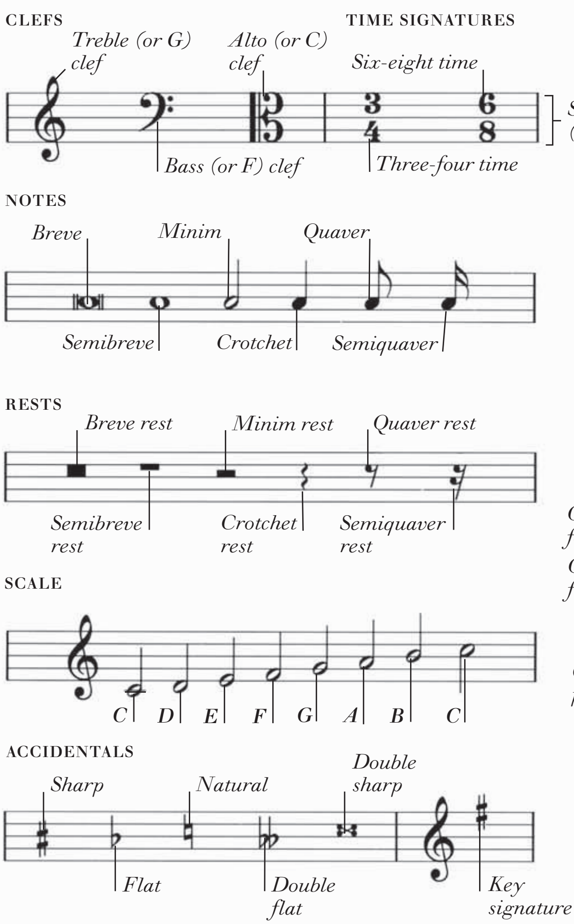

B
518422

Music

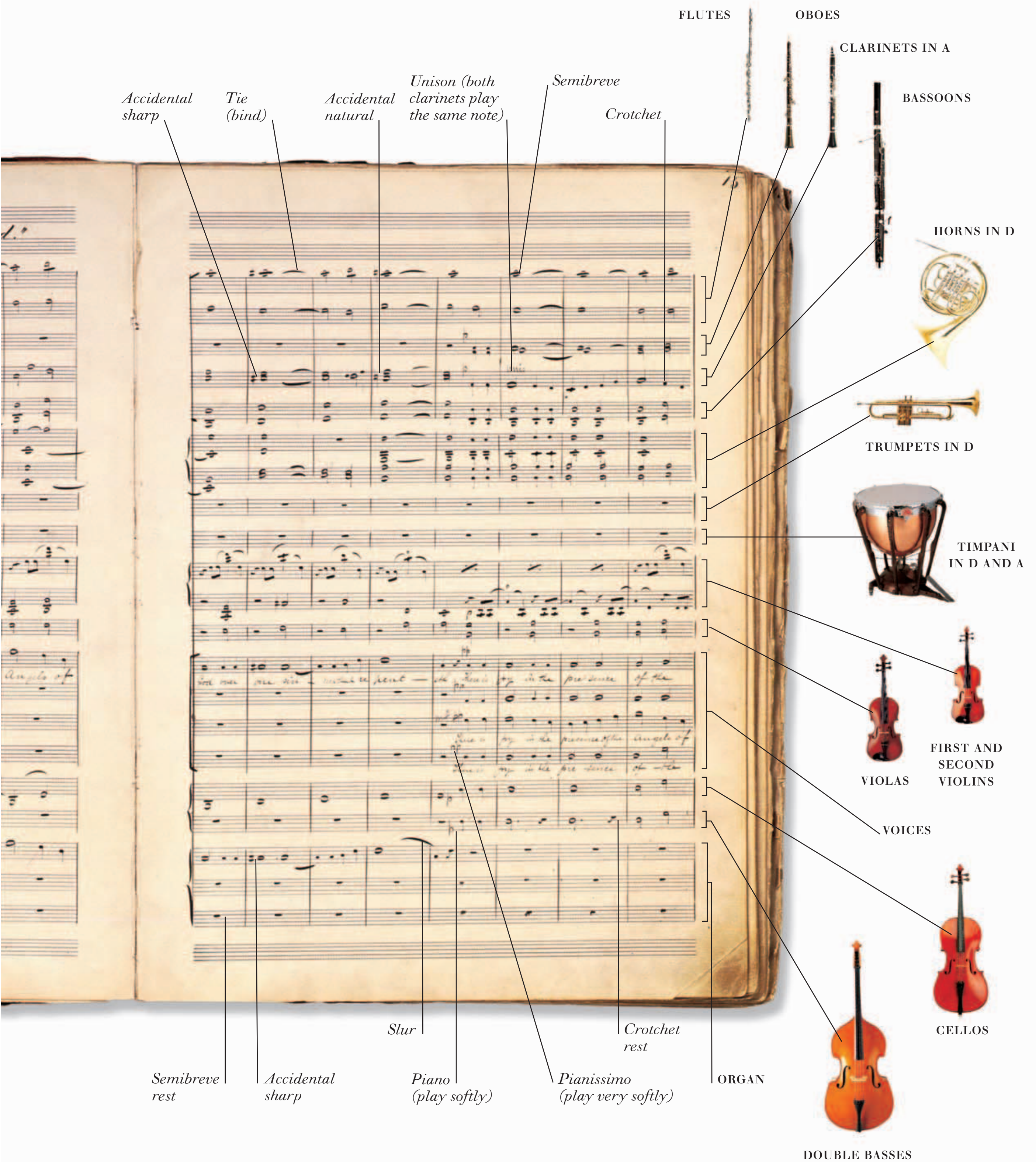
Musical notation

MUSICAL NOTATION IS ANY METHOD by which sounds are written down so that they can be read and performed by others. The present-day conventional system of notation uses a five-line stave (staff)—divided by vertical lines into sections known as bars—on which notes, rests, clefs, key signatures, time signatures, accidentals, and other symbols are written. A note indicates the duration of a sound and, according to its position on the stave, its pitch. Notes can be arranged on the stave in order of pitch to form a scale. A silence in the music is indicated by a rest. The clef, which is placed at the beginninng of a stave, fixes the pitch. The key signature, which is placed after the clef, indicates the key. The time signature, placed after the key signature, shows the number of beats in a bar. Accidentals are used to indicate the raising or lowering of the pitch of a note.

ELEMENTS OF MUSICAL NOTATION



EXAMPLE OF AN ORIGINAL MANUSCRIPT: THE PRODIGAL SON, ARTHUR SULLIVAN, 1869


FLUTES
OBOES
CLARINETS IN A
BASSOONS
HORNS IN D
TRUMPETS IN D
TIMPANI IN D AND A
FIRST AND SECOND VIOLINS
VIOLAS
VOICES
CELLOS
DOUBLE BASSES
ORGAN
Accidental sharp
Tie (bind)
Accidental natural
Unison (both clarinets play the same note)
Semibreve
Crotchet
Slur
Crotchet rest
Semibreve rest
Accidental sharp
Piano (play softly)
Pianissimo (play very softly)

Orchestras

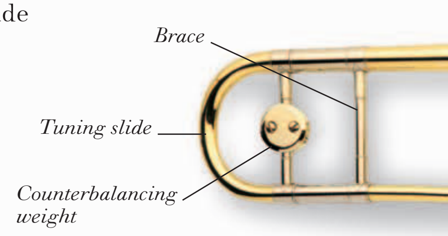
AN ORCHESTRA IS A GROUP of musicians that plays music written for a specific combination of instruments. The number and type of instruments included in the orchestra depends on the style of music being played. The modern orchestra (also known as a symphony orchestra) is made up of four sections of instruments—stringed, woodwind, brass, and percussion. The stringed section consists of violins, violas, cellos (violoncellos), double basses, and sometimes a harp (see pp. 510-511). The main instruments of the woodwind section are flutes, oboes, clarinets, and bassoons—the piccolo, cor anglais, bass clarinet, saxophone, and double bassoon (contrabassoon) can also be included if the music requires them (see pp. 508-509). The brass section usually consists of horns, trumpets, trombones, and the tuba (see pp. 506-507). The main instruments of the percussion section are the timpani (see pp. 518-519). The side drum, bass drum, cymbals, tambourine, triangle, tubular bells, xylophone, vibraphone, tam-tam (gong), castanets, and maracas can also be included in the percussion section (see pp. 516-517). The musicians are usually arranged in a semi-circle—strings spread along the front, woodwind and brass in the center, and percussion at the back. A conductor stands in front of the musicians and controls the tempo (speed) of the music and the overall balance of the sound, ensuring that no instruments are too loud or too soft in relation to the others.

EXAMPLE OF A LAYOUT OF THE INSTRUMENTS FOR A MODERN (SYMPHONY) ORCHESTRA

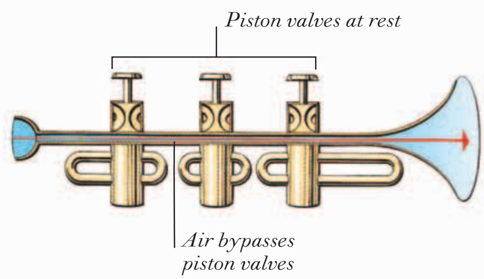
Brass instruments

BUGLE

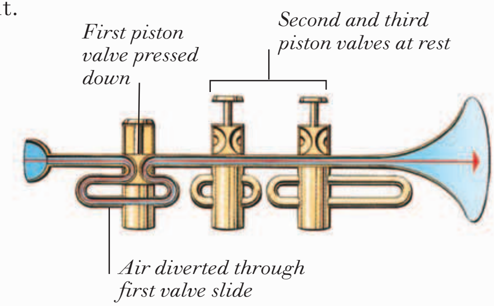
BRASS INSTRUMENTS ARE WIND INSTRUMENTS that are made of metal, usually brass. Although they appear in many different shapes and sizes, all brass instruments have a mouthpiece, a length of hollow tube, and a flared bell. The mouthpiece of a brass instrument may be cup-shaped, as in the cornet, or cone-shaped, as in the horn. The tube may be wide or narrow, mainly conical, as in the horn and tuba, or mainly cylindrical, as in the trumpet and trombone. The sound of a brass instrument is made by the player's lips vibrating against the mouthpiece, so that the air vibrates in the tube. By changing lip tension, the player can vary the vibrations and produce notes of different pitches. The range of notes produced by a brass instrument can be extended by means of a valve system. Most brass instruments, such as the trumpet, have piston valves that divert the air in the instrument along an extra piece of tubing (known as a valve slide) when pressed down. The total length of the tube is increased and the pitch of the note produced is lowered. Instead of valves, the trombone has a movable slide that can be pushed away from or drawn toward the player. The sound of a brass instrument can also be changed by inserting a mute into the bell of the instrument.



SIMPLIFIED DIAGRAM SHOWING HOW A PISTON VALVE SYSTEM WORKS

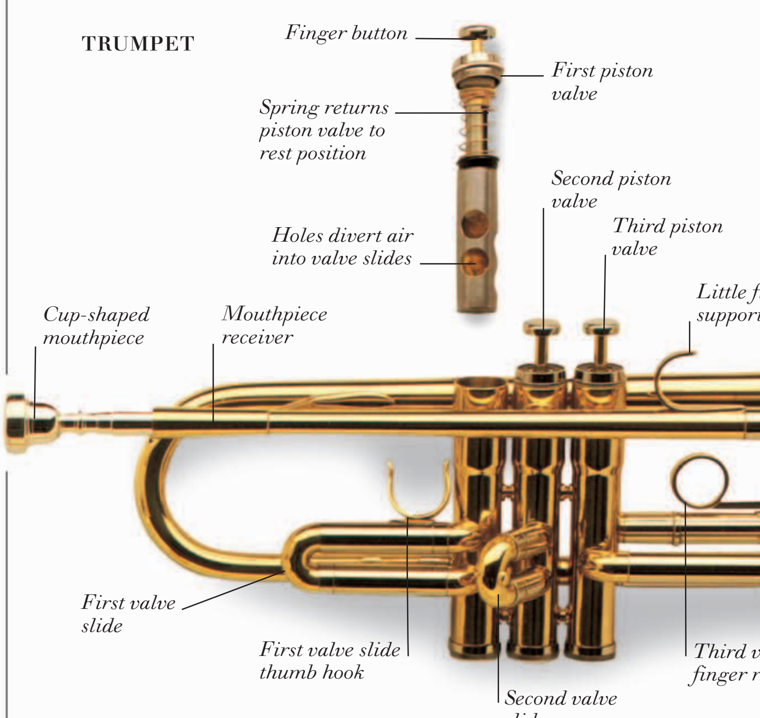


PISTON VALVES AT REST

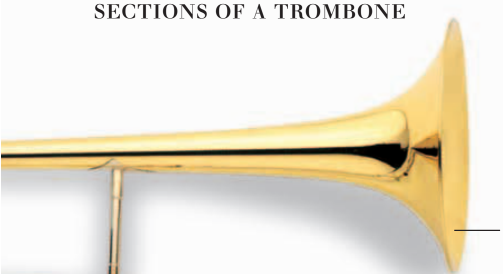


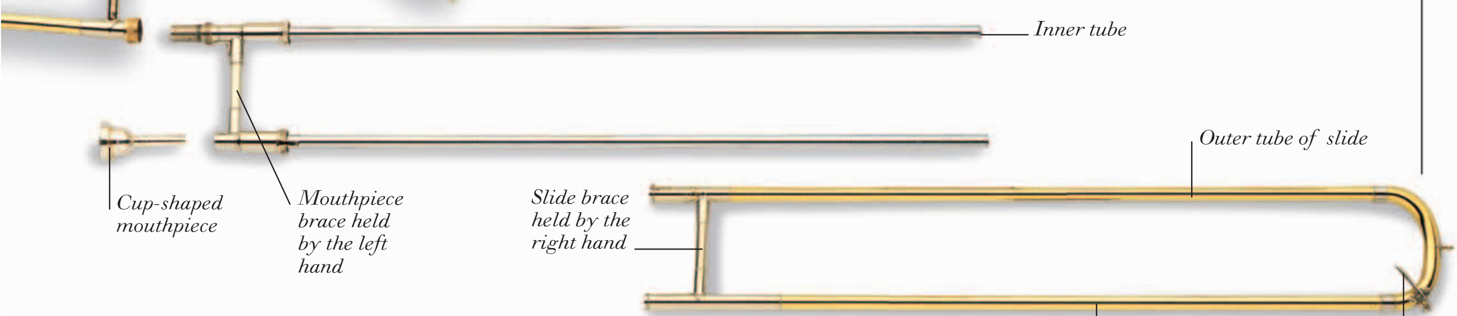
PISTON VALVE PRESSED DOWN

TRUMPET



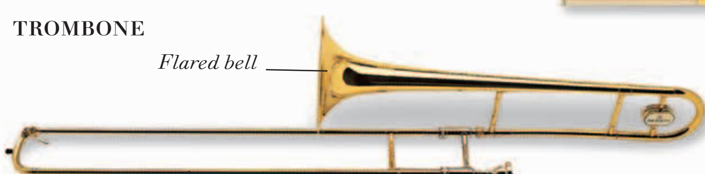
SECTIONS OF A TROMBONE



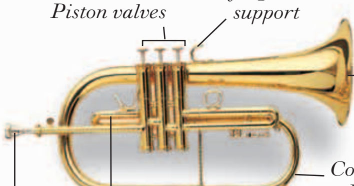


EXAMPLES OF MUTES

TROMBONE



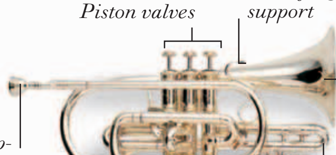
FLUGELHORN



TUBA

HORN

CORNET



Woodwind instruments

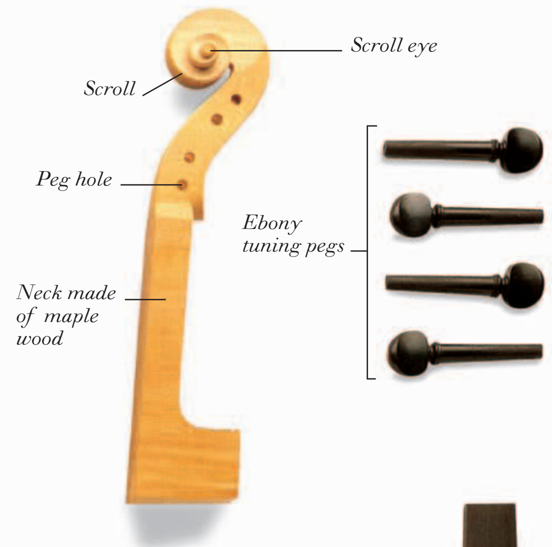
WOODWIND INSTRUMENTS ARE wind instruments that are generally made of wood, although some are made of metal or plastic. The sound of a woodwind instrument is produced by the vibration of air in a hollow tube. The air is made to vibrate by blowing across a blow hole—as in the flute and piccolo—or by blowing through a single reed—as in the clarinet and saxophone—or a double reed—as in the bassoon, cor anglais, and oboe. The pitch of a woodwind instrument can be changed by opening or closing holes cut into the tube of the instrument.

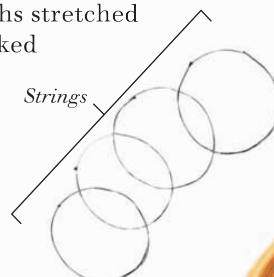
TENOR SAXOPHONE

SECTIONS OF A TENOR SAXOPHONE

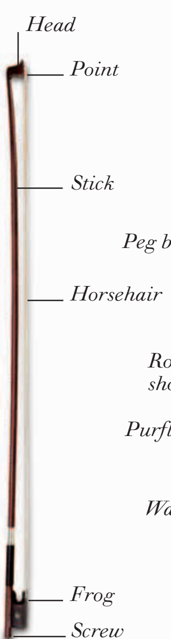
Stringed instruments

STRINGED INSTRUMENTS PRODUCE SOUND by the vibration of stretched strings. This may be done by drawing a bow across the strings, as in the violin; or by plucking the strings, as in the harp and guitar (see pp. 512-513). The four modern members of the bowed string family are the violin, viola, cello (violoncello), and double bass. Each consists of a hollow, wooden body, a long neck, and four strings. The bow is a wooden stick with horsehair stretched across its length. The vibrations made by drawing the bow across the strings are transmitted to the hollow body, and this itself vibrates, amplifying and enriching the sound produced. The harp consists of a set of strings of different lengths stretched across a wooden frame. The strings are plucked by the player's thumbs and fingers—except the little finger of each hand—which produces vibrations that are amplified by the harp's sound board. The pitch of the note produced by any stringed instrument depends on the length, weight, and tension of the string. A shorter, lighter, or tighter string gives a higher note.

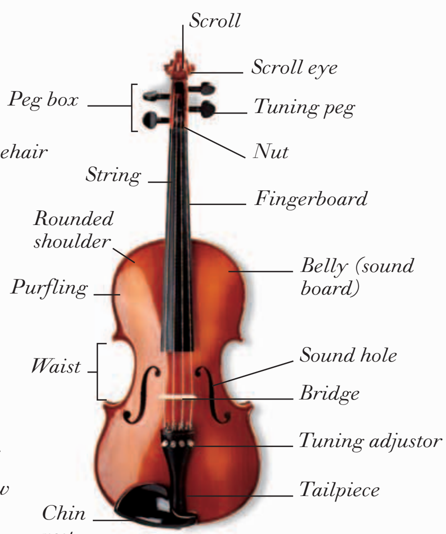




SECTIONS OF A VIOLIN



VIOLIN BOW



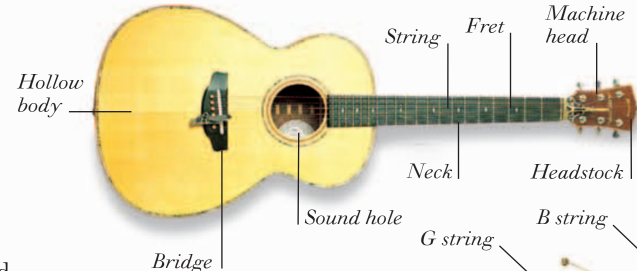
VIOLIN

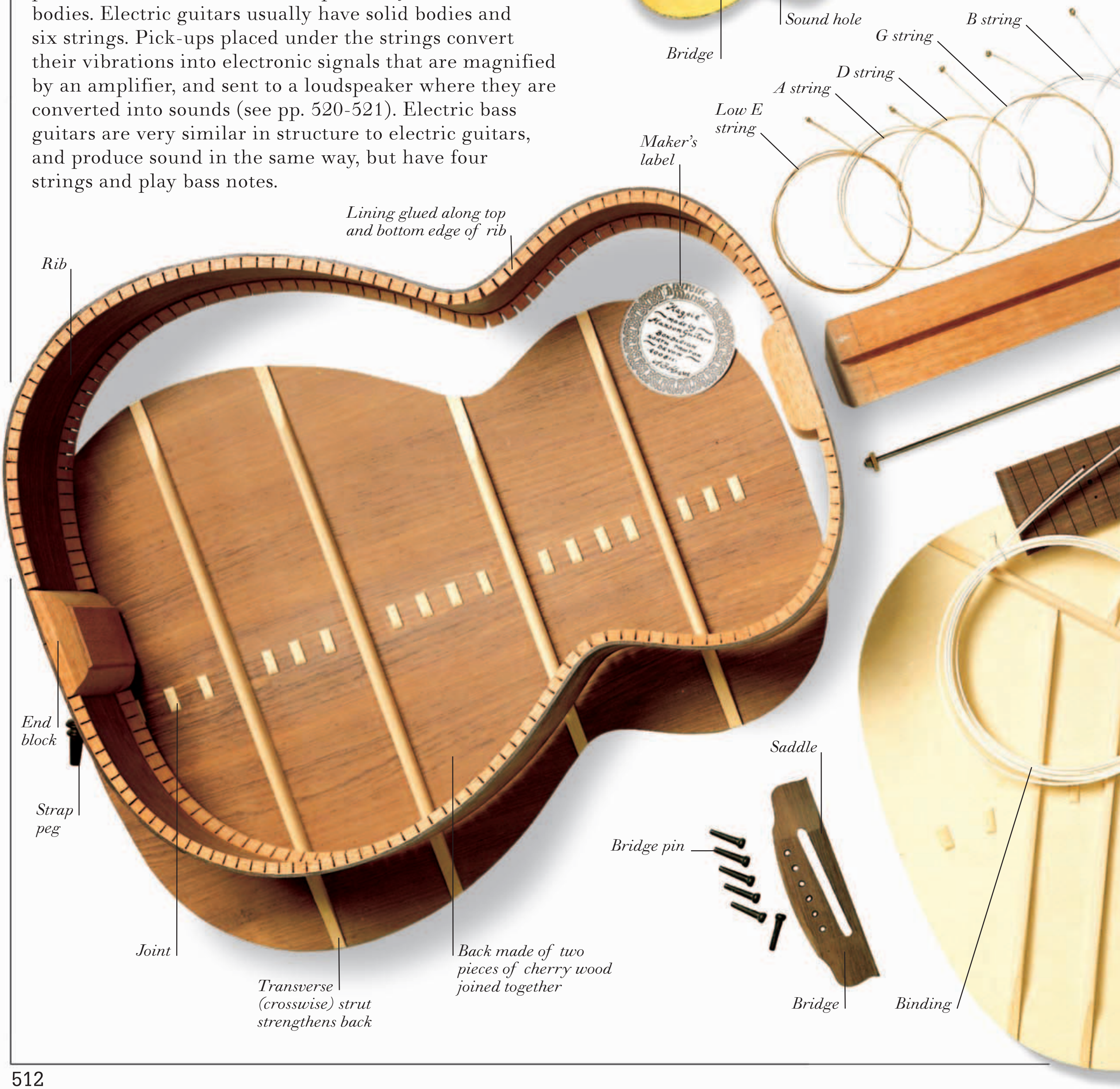

Crown
Tuning peg
Neck (string arm)
Shoulder
String
Sound board
Pillar
Pedestal
Foot
Pedal
HARP
Head
Point
Inward-curving stick
Horsehair
Frog
Screw
DOUBLE BASS BOW
Scroll
Scroll eye
Tuning pegs at back of peg box
Nut
Fingerboard
String
Sloping shoulder
Belly (sound board)
Purfling
Waist
Bridge
Rib
Sound hole
Tailpiece
Spike
DOUBLE BASS
Scroll
Scroll eye
Peg box
Tuning-peg
Nut
Fingerboard
String
Rounded shoulder
Belly (sound board)
Waist
Sound hole
Bridge
Tuning adjustor
Tailpiece
Spike
CELLO (VIOLONCELLO)
Scroll
Scroll eye
Tuning-peg
Peg box
Nut
Fingerboard
String
Belly (sound board)
Rounded shoulder
Purfling
Waist
Bridge
Sound-hole
Tuning adjustor
Chin rest
Tailpiece
VIOLA

Guitars

THE GUITAR IS A PLUCKED stringed instrument (see pp. 510-511). There are two types of guitar—acoustic and electric. Acoustic guitars have hollow bodies and six or 12 strings. Plucking the strings produces vibrations that are amplified by their hollow bodies. Electric guitars usually have solid bodies and six strings. Pick-ups placed under the strings convert their vibrations into electronic signals that are magnified by an amplifier, and sent to a loudspeaker where they are converted into sounds (see pp. 520-521). Electric bass guitars are very similar in structure to electric guitars, and produce sound in the same way, but have four strings and play bass notes.

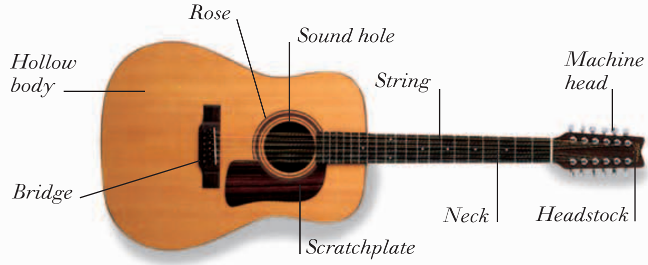
ACOUSTIC GUITAR



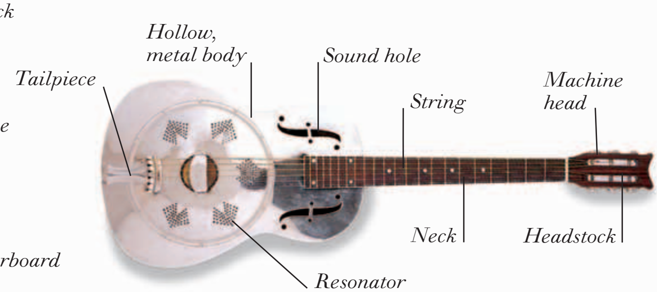


COMPONENTS OF AN ACOUSTIC GUITAR

EXAMPLES OF ACOUSTIC GUITARS

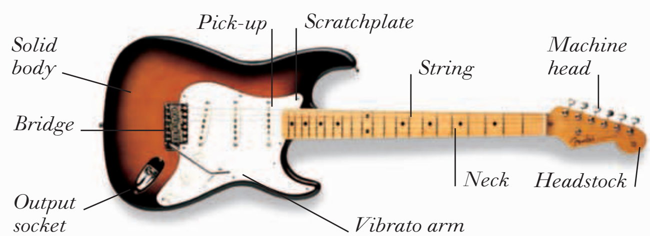


WASHBURN TWELVE-STRING

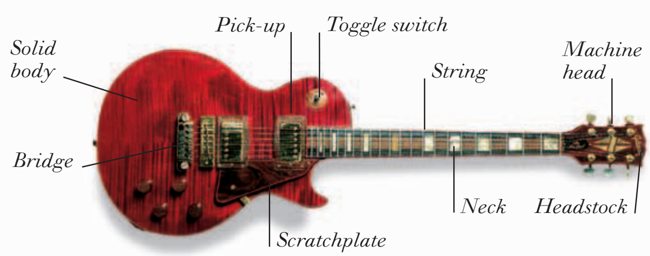


DOBRO RESONATOR

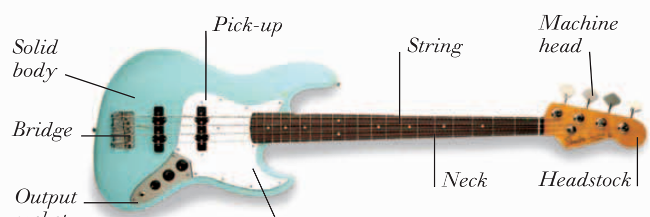
EXAMPLES OF ELECTRIC GUITARS



FENDER STRATOCASTER



GIBSON LES PAUL



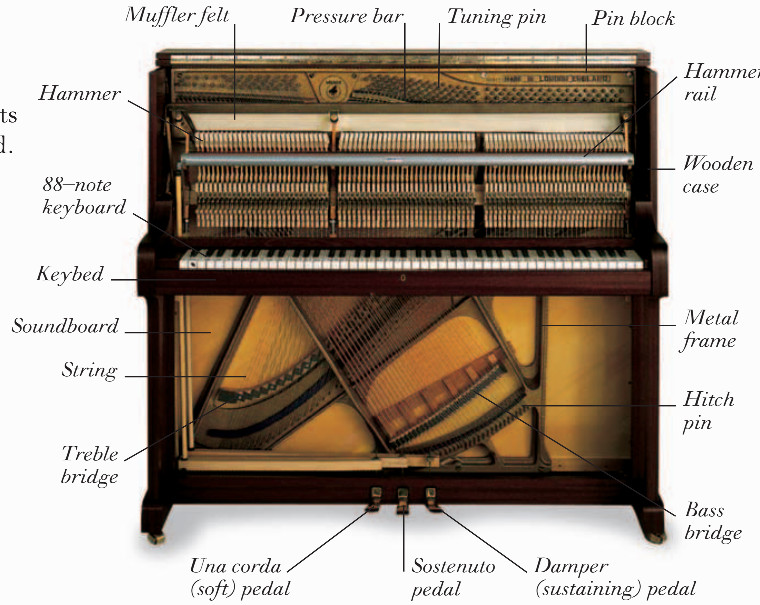
FENDER JAZZ BASS

Keyboard instruments

ORGAN PIPE

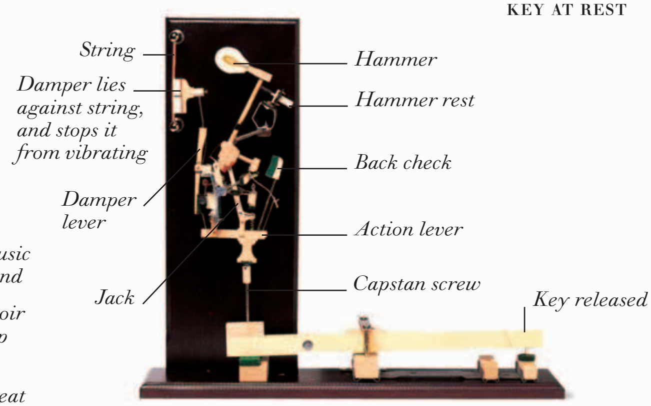
KEYBOARD INSTRUMENTS are instruments that are sounded by means of a keyboard. The organ and piano are two of the principal members of the keyboard family. The organ consists of pipes that are operated by one or more manuals (keyboards) and a pedal board. The pipes are lined up in rows (known as ranks or registers) on top of a wind chest. The sound of the organ is made when air is admitted into a pipe by pressing a key or pedal. The piano consists of wire strings stretched over a metal frame, and a keyboard and pedals that operate hammers and dampers. The piano frame is either vertical—as in the upright piano—or horizontal—as in the grand piano. When a key is at rest, a damper lies against the string to stop it from vibrating. When a key is pressed down, the damper moves away from the string as the hammer strikes it, causing the string to vibrate and sound a note.

UPRIGHT PIANO

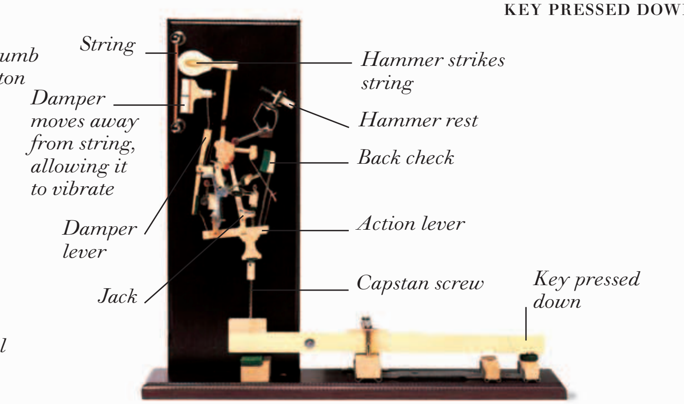


UPRIGHT PIANO ACTION

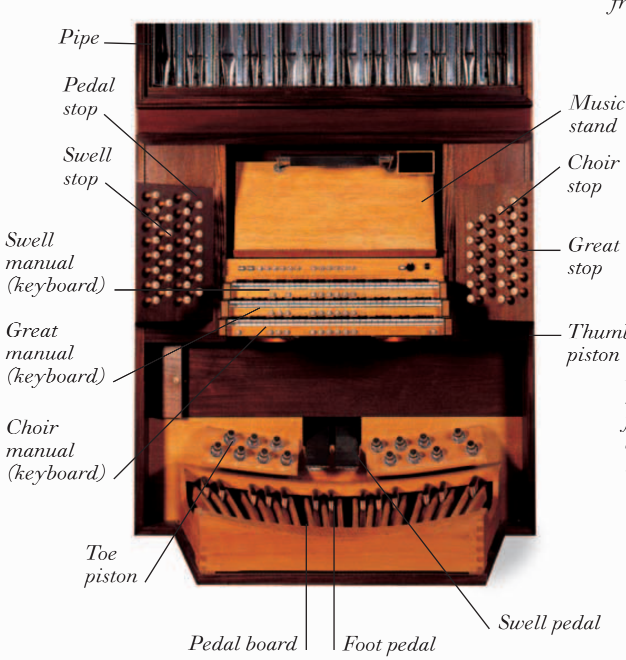
KEY AT REST



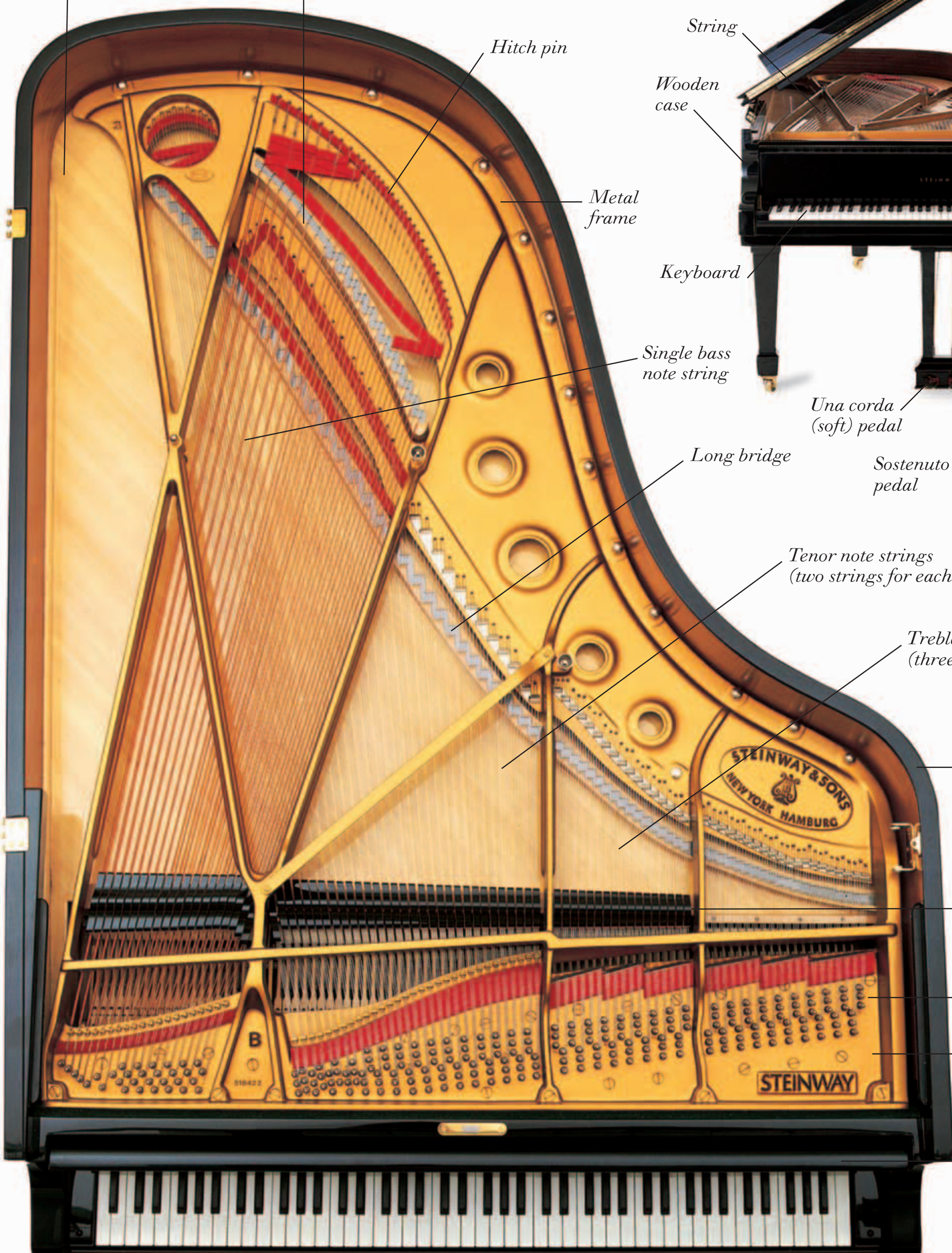
KEY PRESSED DOWN



ORGAN CONSOLE



CONCERT GRAND PIANO (VIEWED FROM ABOVE)



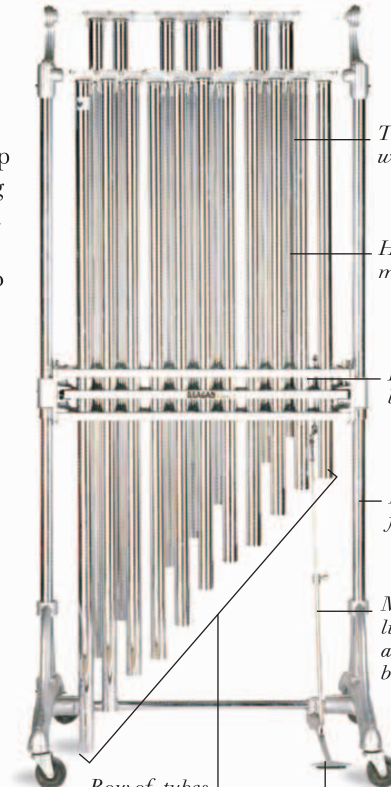
CONCERT GRAND PIANO (FRONT VIEW)

Percussion instruments

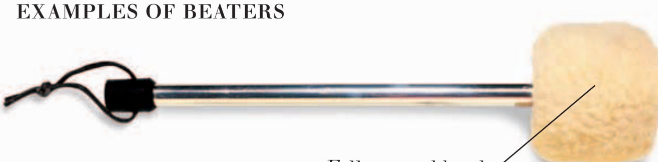
TEMPLE BLOCKS

PERCUSSION INSTRUMENTS are a large group of instruments that produce sound by being struck, shaken, scraped, or clashed together. Most percussion instruments—such as the tam-tam (gong), cymbals, and maracas—do not have a definite pitch and are used for rhythm and impact, and the distinctive timber (color) of their sound. Other percussion instruments—such as the xylophone, vibraphone, and tubular bells—are tuned to a definite pitch and can play melody, harmony, and rhythms. The xylophone and vibraphone each have two rows of bars that are arranged in a similar way to the black and white keys of a piano. Metal tubes are suspended below the bars to amplify the sound. The vibraphone has electrically operated fans that rotate in the tubes and produce a vibrato (wavering pitch) effect.

TUBULAR BELLS



EXAMPLES OF BEATERS

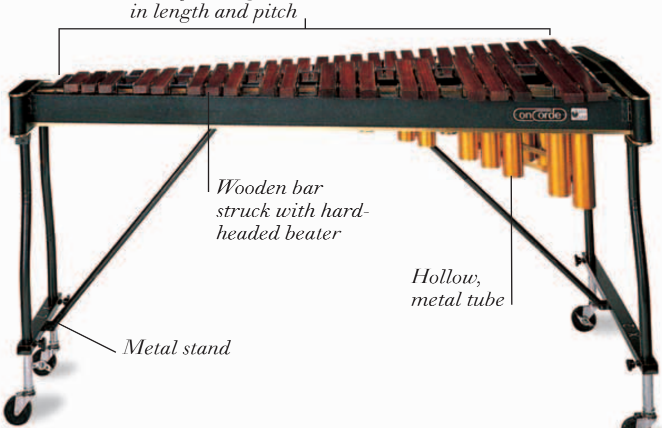


SOFT-HEADED BEATER

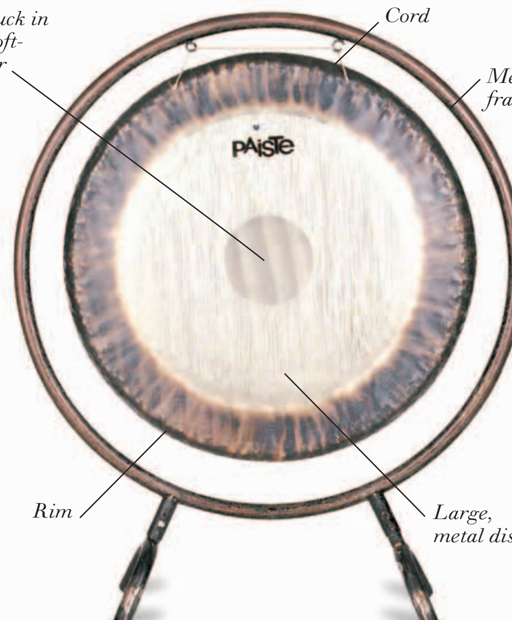
HARD-HEADED BEATER

MALLET

XYLOPHONE

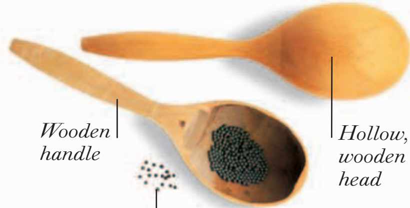


TAM-TAM (GONG)

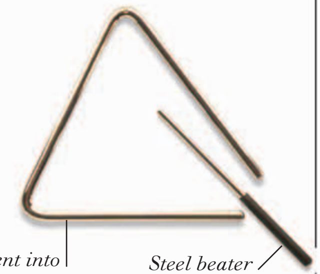


CYMBALS

SECTIONS OF A MARACA



TRIANGLE



CLAVES

CASTANETS

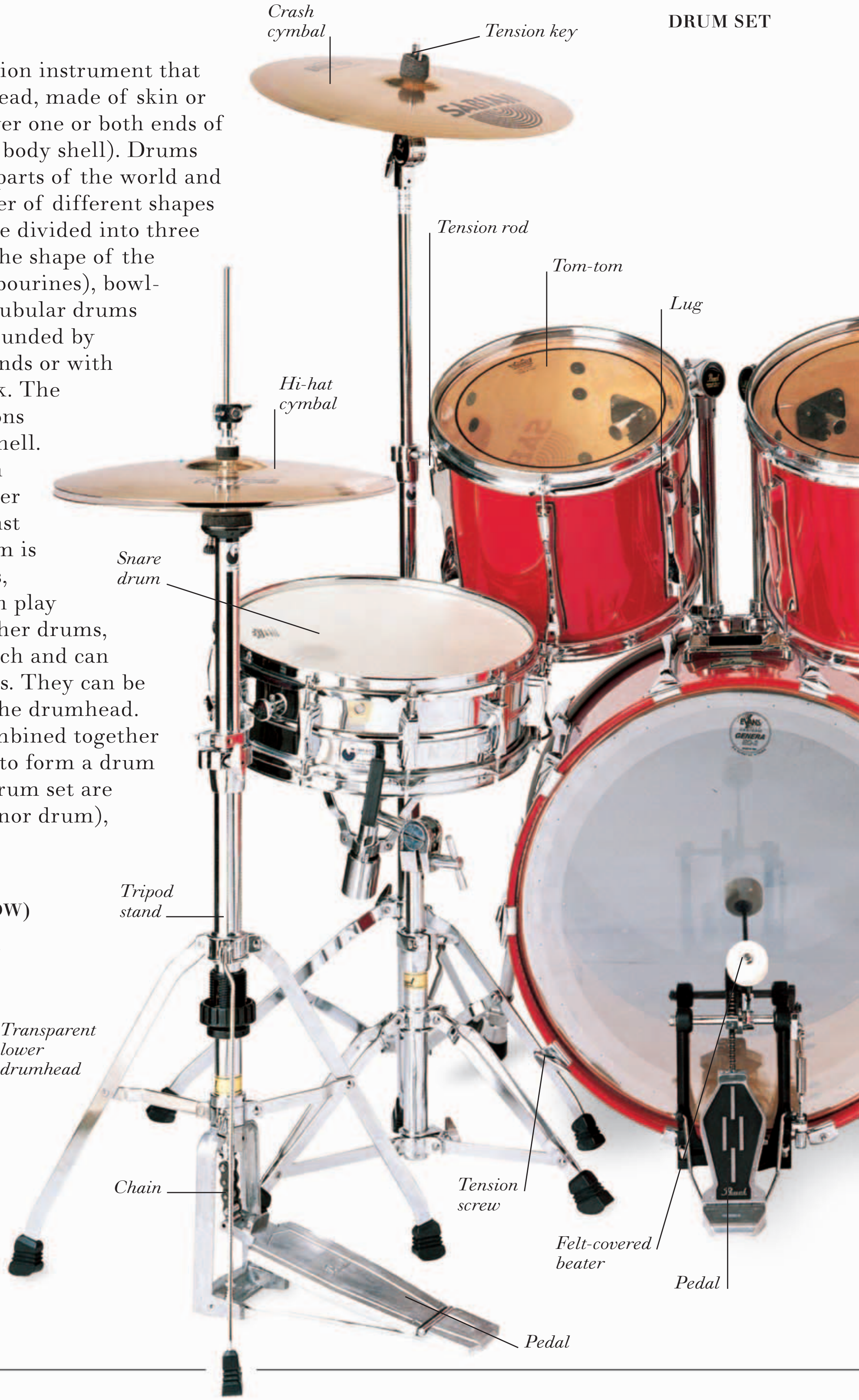
VIBRAPHONE

Drums

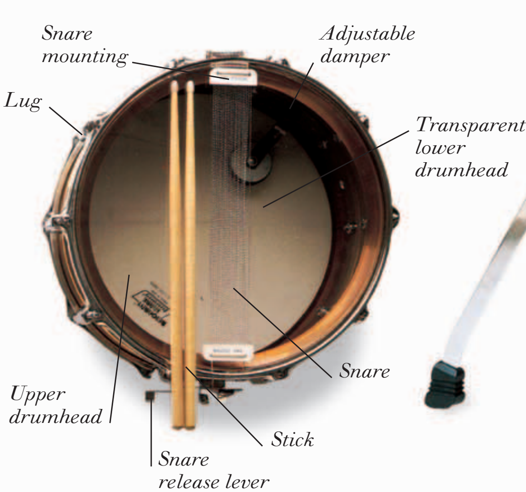
TAMBOURINE

A DRUM IS A percussion instrument that consists of a drumhead, made of skin or plastic, stretched over one or both ends of a hollow vessel (the body shell). Drums are played in most parts of the world and are made in a number of different shapes and sizes. They can be divided into three groups according to the shape of the body-shell: frame drums (e.g., tambourines), bowl-shaped drums (e.g., timpani), and tubular drums (e.g., congas). Drums are usually sounded by striking the drumhead with the hands or with beaters, such as a hard-headed stick. The drumhead vibrates, and its vibrations are amplified by the hollow body shell. The snare drum has wires—known as snares—stretched across the lower drumhead; the snares vibrate against the lower drumhead when the drum is played. Most drums, such as congas, do not have a definite pitch and can play only rhythms (see pp. 516-517). Other drums, such as timpani, have a definite pitch and can play melody, harmony, and rhythms. They can be tuned by adjusting the tension of the drumhead. Different types of drum can be combined together with other percussion instruments to form a drum set. The basic components of the drum set are bass drum, tom-toms, floor tom (tenor drum), snare drum, and cymbals.

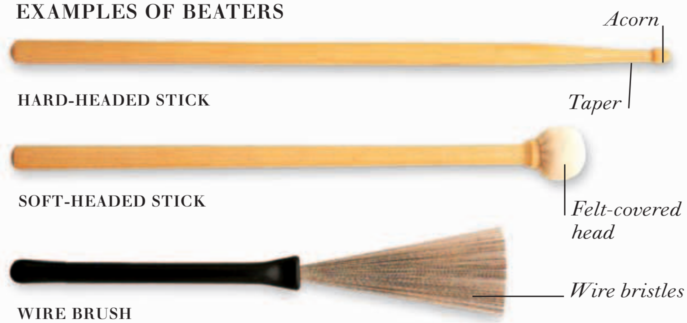
DRUM SET



SNARE DRUM (VIEWED FROM BELOW)



EXAMPLES OF BEATERS



CONGAS

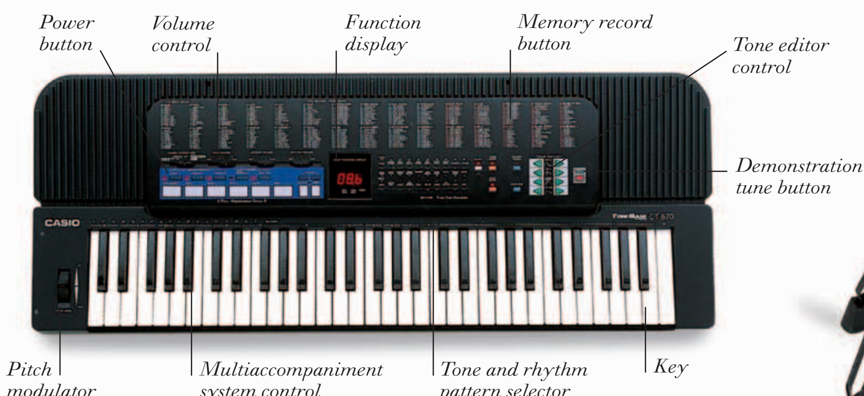
TIMPANUM (KETTLE DRUM)

Electronic instruments

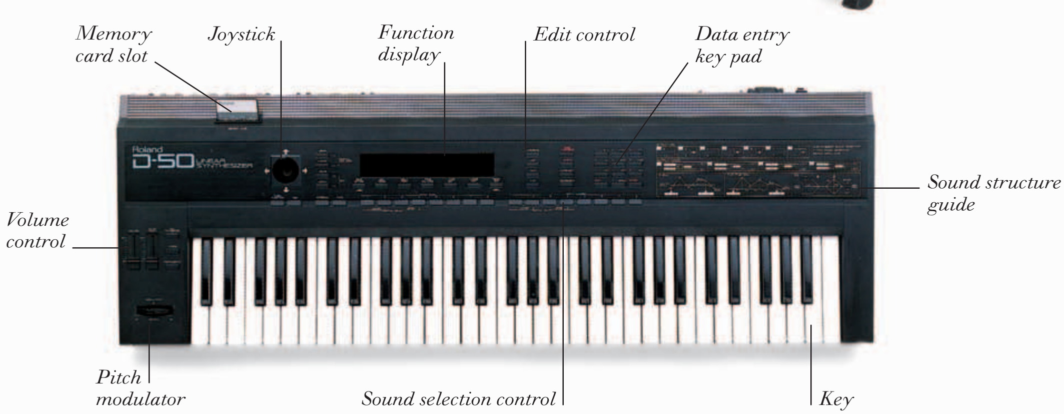
ELECTRONIC INSTRUMENTS generate electronic signals that are magnified by an amplifier and sent to a loudspeaker, where they are converted into sounds. Synthesizers, and other electronic instruments, simulate the characteristic sounds of conventional instruments, and also create entirely new sounds. Most electronic instruments are keyboard instruments, but electronic wind and percussion instruments are also popular. A digital sampler records and stores sounds from musical instruments or other sources. When the sound is played back, the pitch of the original sound can be altered. A keyboard can be connected to the sampler so that a tune can be played using the sampled sounds. With a MIDI (Musical Instrument Digital Interface) system, a computer can be linked with other electronic instruments, such as keyboards and electronic drums, to make sounds together or in sequence. It is also possible, using music software, to compose and play music on a home computer.

ELECTRONIC DRUMS

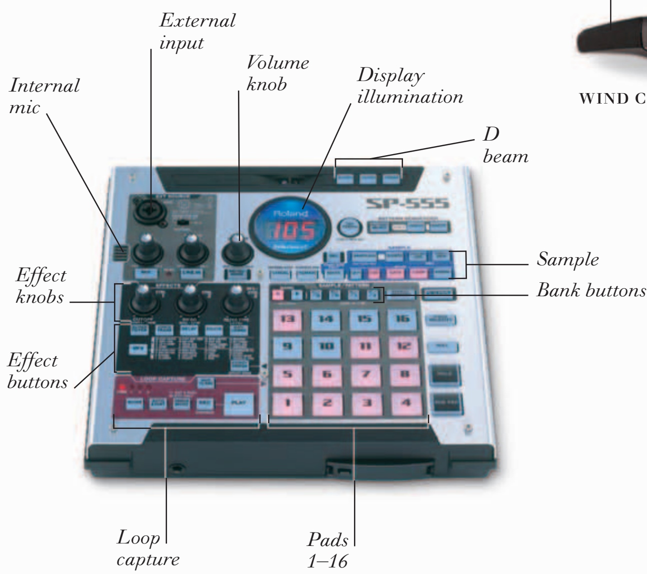
HOME KEYBOARD



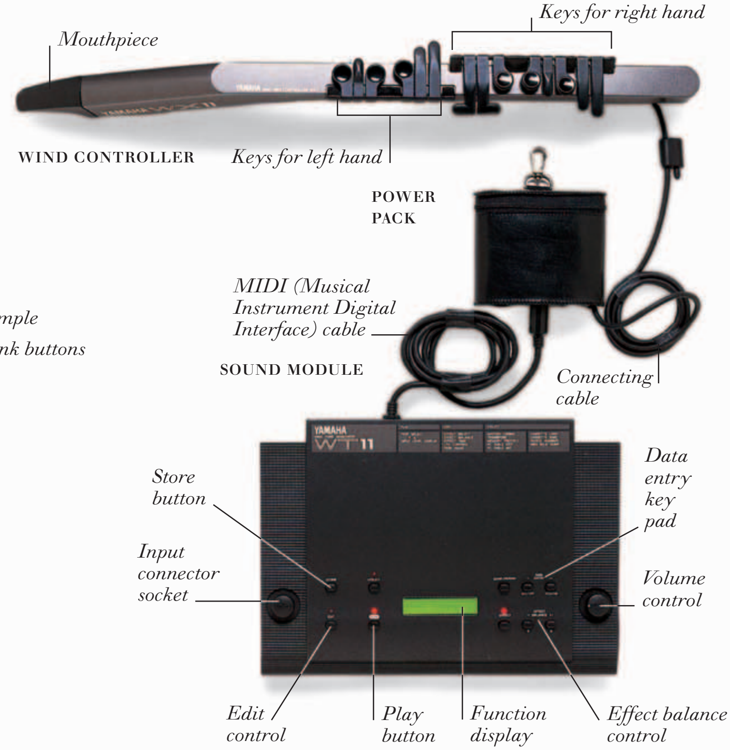
SYNTHESIZER



DIGITAL SAMPLER



WIND SYNTHESIZER



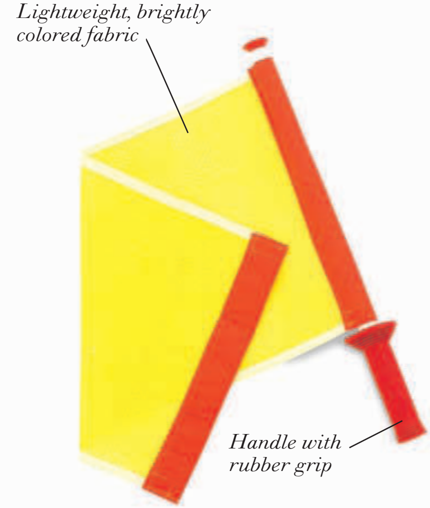
COMPUTER WITH MIDI AND AUDIO SOFTWARE SEQUENCER

SPORTS

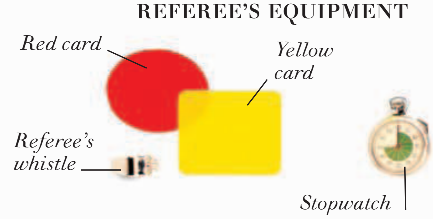
Soccer

GAMES INVOLVING KICKING A BALL have a long history and were recorded in China as early as 300 BC; in medieval Europe, street football was banned as a menace to the public; only in 1863 were the rules established, specifically banning carrying the ball for all players except the goalkeeper, and separating rugby from soccer. Soccer, officially termed association football, is a team sport in which players attempt to score goals by passing and dribbling the ball down the field past opposing defenders, and kicking or heading the ball into the goal net, outwitting the defending goalkeeper. Each team consists of 10 outfield players (defenders, midfielders, and strikers) and a goalkeeper. Players from the opposing team may challenge the player in possession of the ball, but an illegal or foul tackle results in a penalty if a foul occurs inside the penalty area or a free kick if outside the penalty area. The round ball used in soccer is more easily controlled than the oval balls used in American, Canadian, and Australian rules football and in rugby. The result is a more "open" or flowing game that is played and watched by millions of people worldwide.

ASSISTANT REFEREE'S FLAG

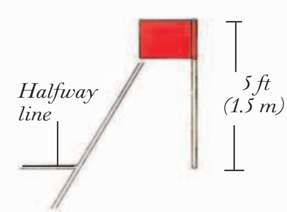


REFEREE'S EQUIPMENT

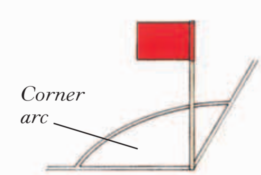


SOCCER FIELD

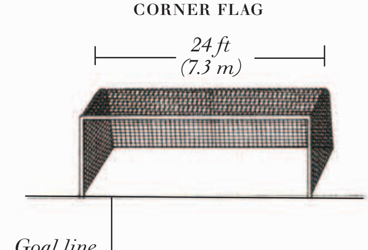
FIELD MARKINGS



HALFWAY-LINE FLAG



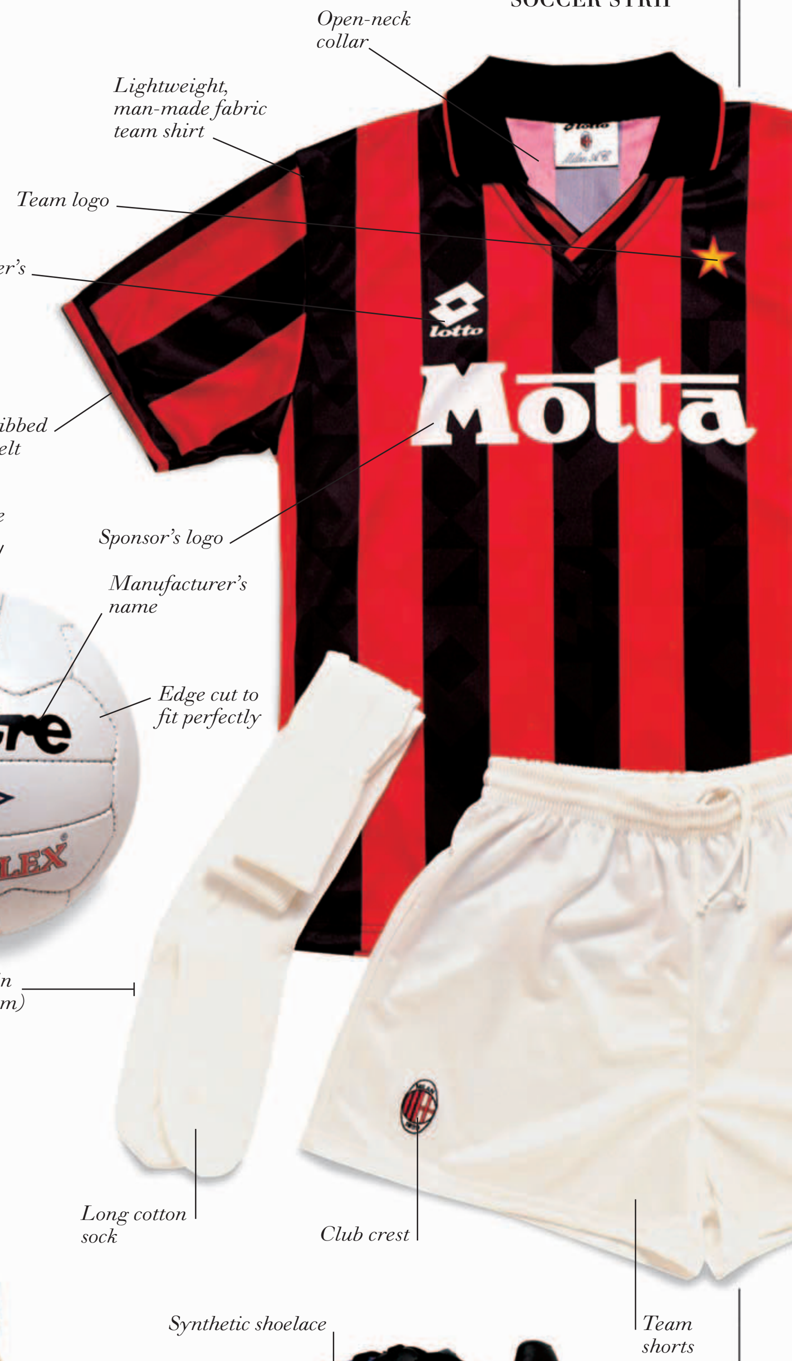
CORNER FLAG



GOAL

GOALKEEPER

SOCCER STRIP



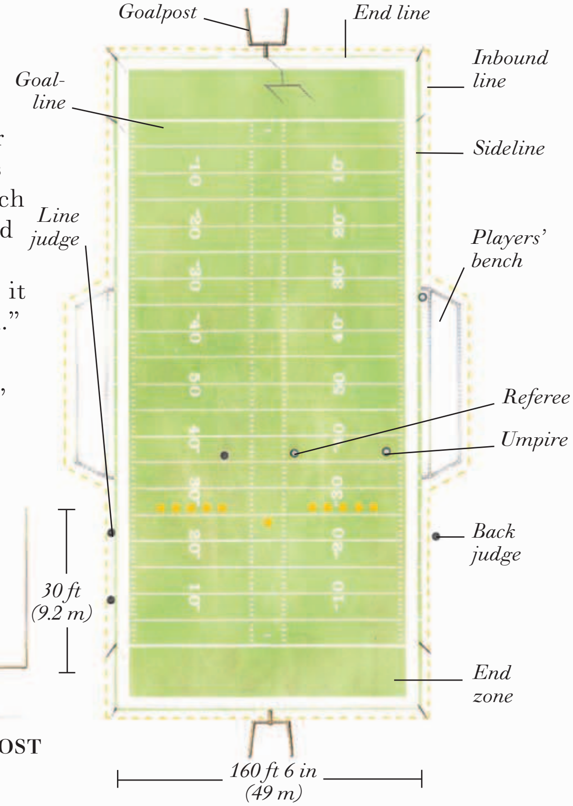
MAKING A SOCCER BALL

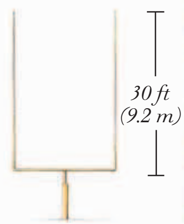
SOCCER SHOE

Football

IN AMERICAN AND CANADIAN FOOTBALL, the object of the game is to get the ball across the opponent's goal line, either by passing or carrying it across (a touchdown), or by kicking it between their goalposts (a field goal). An American football team has 11 players on the field at a time, although up to 40 players can appear for each side in a single game. The agile "offense" tries to score points, and the heavy hitting "defense" holds back the opposition. When in possession of the ball, a team has four chances ("downs"), to move it at least ten yards (nine meters) up the field to make a "first down." The opposition gains possession if they fail, or by tackling and intercepting the ball. Canadian football is played on a larger field, with 12 men on each side. A team has only three chances to achieve a first down. Otherwise, the game is very similar to American football. Helmets, face masks, and layers of body padding are worn by the players for protection.

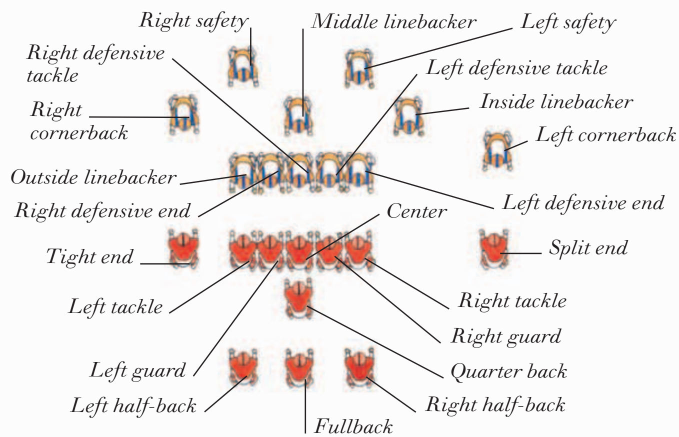
FOOTBALL FIELD



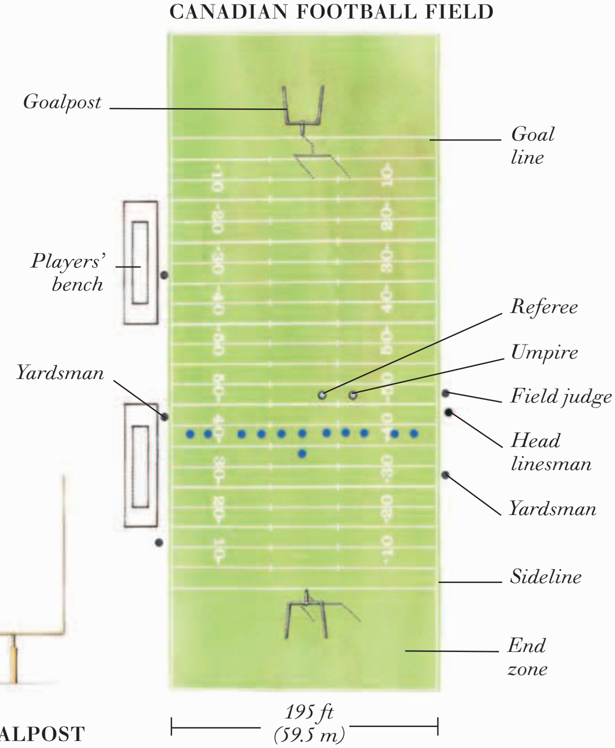


GOALPOST

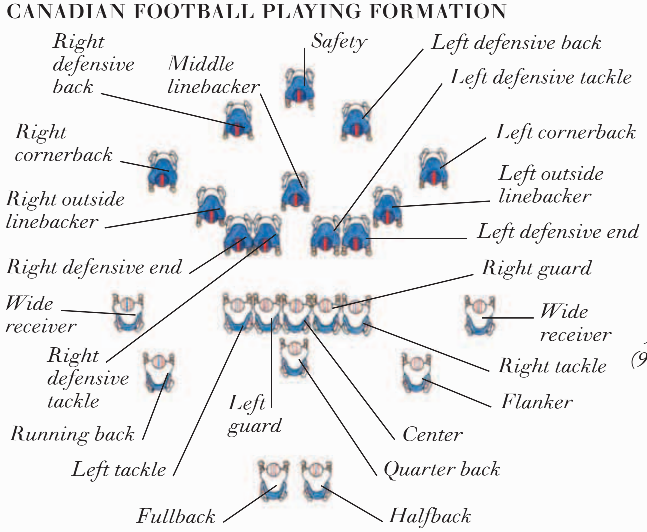
AMERICAN FOOTBALL PLAYING FORMATION

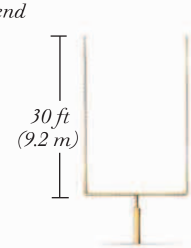


CANADIAN FOOTBALL FIELD

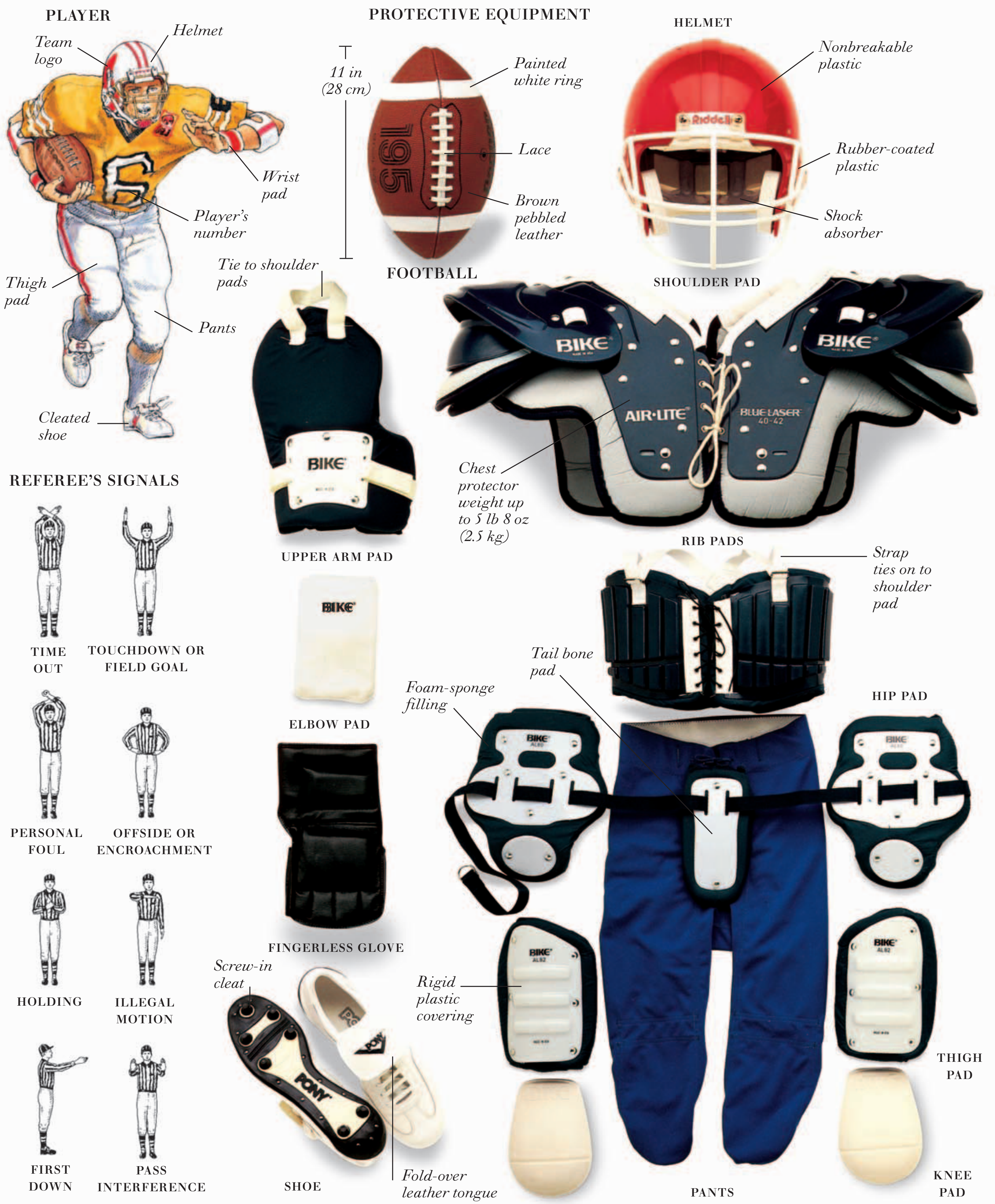


CANADIAN FOOTBALL PLAYING FORMATION





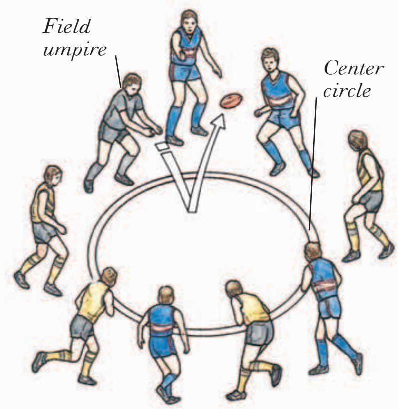
GOALPOST


PLAYER
Team logo
Helmet
Wrist pad
Player's number
Thigh pad
Pants
Cleated shoe
REFEREE'S SIGNALS
TIME OUT
TOUCHDOWN OR FIELD GOAL
PERSONAL FOUL
OFFSIDE OR ENCROACHMENT
HOLDING
ILLEGAL MOTION
FIRST DOWN
PASS INTERFERENCE
PROTECTIVE EQUIPMENT
11 in (28 cm)
Painted white ring
Lace
Brown pebbled leather
FOOTBALL
HELMET
Nonbreakable plastic
Rubber-coated plastic
Shock absorber
Tie to shoulder pads
UPPER ARM PAD
SHOULDER PAD
Chest protector weight up to 5 lb 8 oz (2.5 kg)
ELBOW PAD
RIB PADS
Strap ties on to shoulder pad
FINGERLESS GLOVE
Tail bone pad
Foam-sponge filling
HIP PAD
Screw-in cleat
Rigid plastic covering
SHOE
Fold-over leather tongue
PANTS
THIGH PAD
KNEE PAD

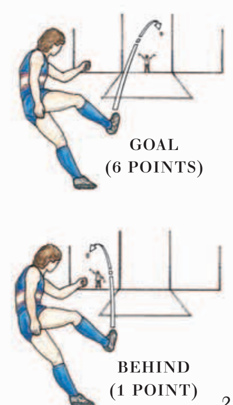
Australian rules and Gaelic football

VARIETIES OF FOOTBALL have developed all over the world and Australian rules football is considered to be one of the roughest versions, allowing full body tackles even though participants wear no protective padding. The game is played on a large, oval field by two sides, each of 18 players. Players can kick or punch the ball, which is shaped like a rugby ball, but cannot throw it. Running with the ball is permitted, as long as the ball touches the ground at least once every 10 meters. The fullbacks defend two sets of posts. Teams try to score "goals" (six points) between the inner posts or "behinds" (one point) inside the outer posts. Each game has four quarters of 25 minutes, and the team with the most points at the end of the allotted time is the winner. In Gaelic football, an Irish version of soccer (see pp. 524–525), a size 5 soccer ball is used. Each team can have 15 players on the field at a time. Players are allowed to catch, fist, and kick the ball, or dribble it using their hands or feet, but cannot throw it. Teams are awarded three points for getting the ball into the net, and one point for getting it through the posts above the crossbar. Gaelic football is rarely played outside of Ireland.

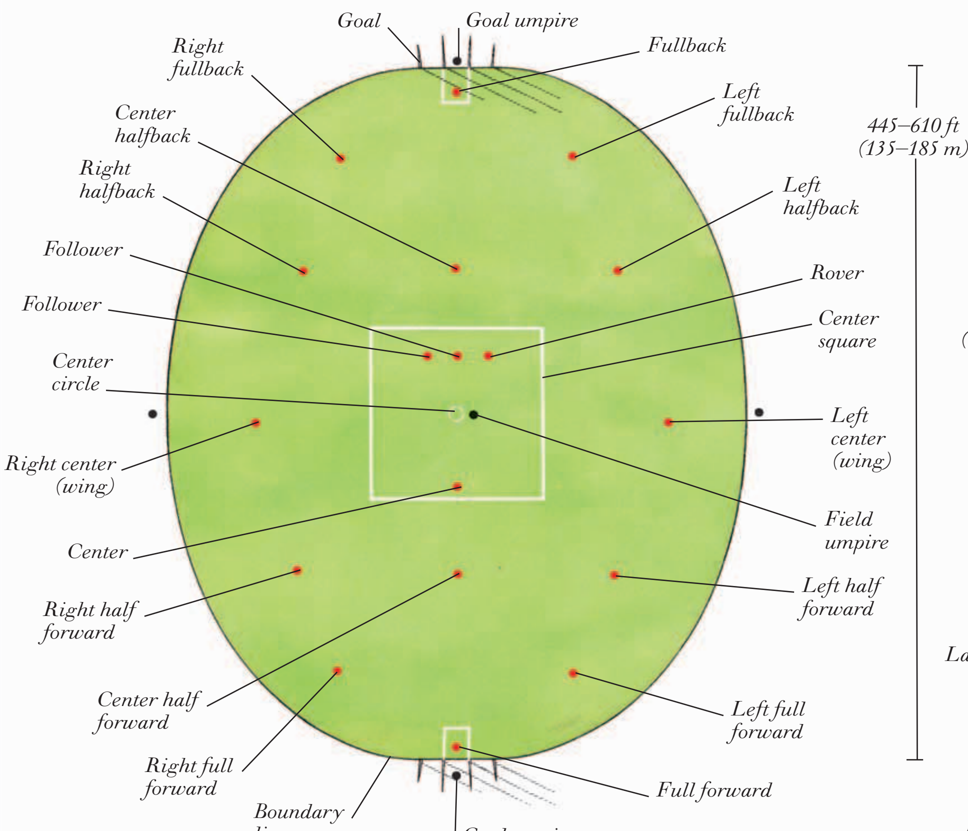
START OF PLAY

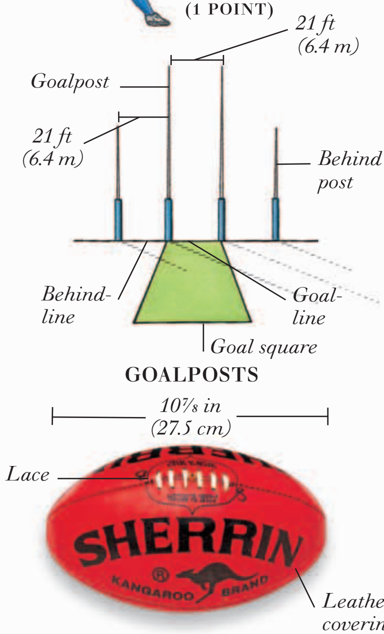


SCORING



AUSTRALIAN RULES FOOTBALL FIELD





GOALPOSTS

AUSTRALIAN RULES FOOTBALL

AUSTRALIAN RULES FOOTBALL SKILLS

RUNNING WITH THE BALL

KICKING

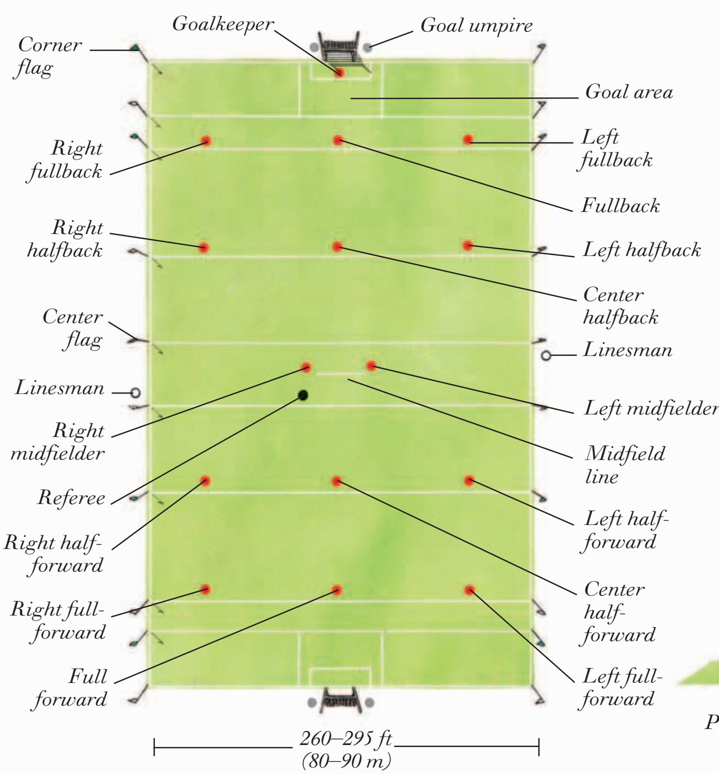
TACKLING

TAKING A MARK

PASSING THE BALL

AUSTRALIAN RULES FOOTBALL UNIFORM

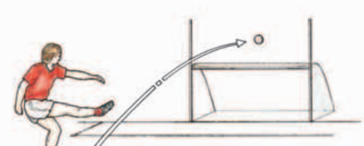
GAELIC FOOTBALL FIELD



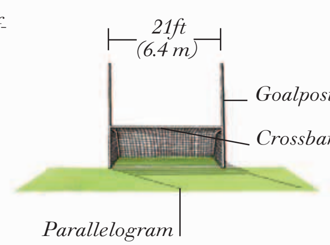
CONTROLLING THE BALL

SCORING IN GAELIC FOOTBALL

GOAL (3 POINTS)



POINT (1 POINT)



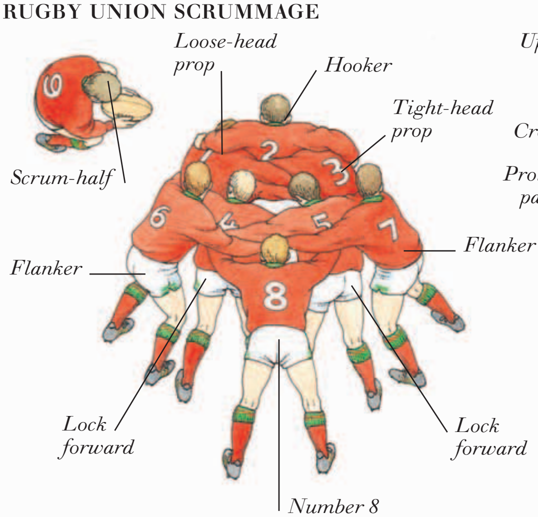
GOAL

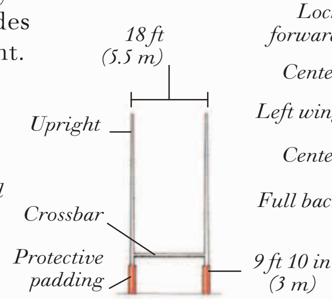
GAELIC FOOTBALL

Rugby

RUGBY IS PLAYED WITH AN OVAL BALL, which may be carried, thrown, or kicked. There are two codes of rugby, both played at amateur and professional levels. Rugby Union is played by two teams of 15 players. They can score points in two ways: by placing the ball by hand over the opponents' goal line (a try, scoring four points) or by kicking it over the crossbar of the opponent's goal (a conversion of a try, scoring two points; a penalty kick, scoring three points; or a dropkick, scoring three points). Rugby League developed from the Union game but is played by 13 players. In League games, a try scores four points; a conversion scores two points; a drop goal scores one point, and a penalty kick scores two points. Scrummages occur in both codes when play stops following an infringement.

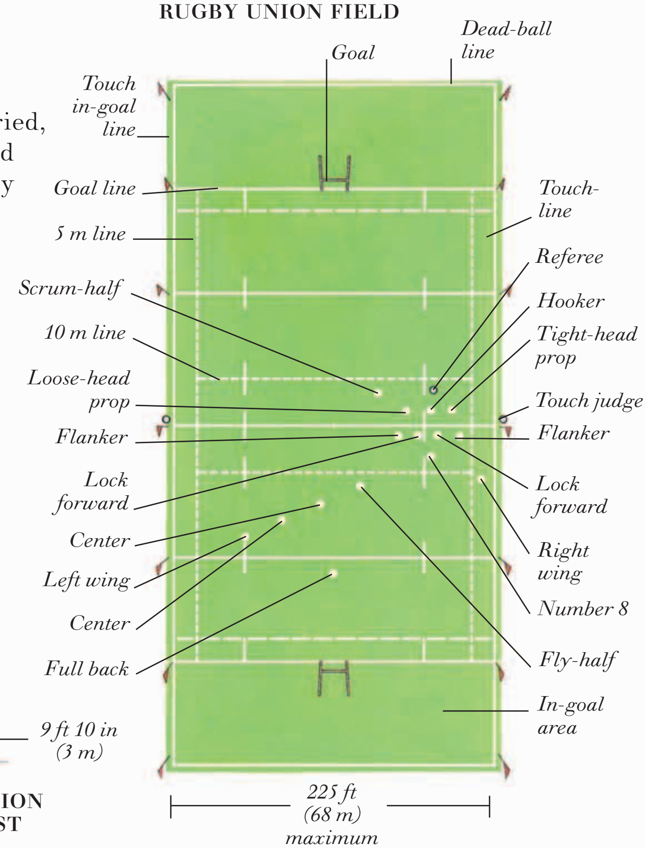
RUGBY UNION SCRUMMAGE



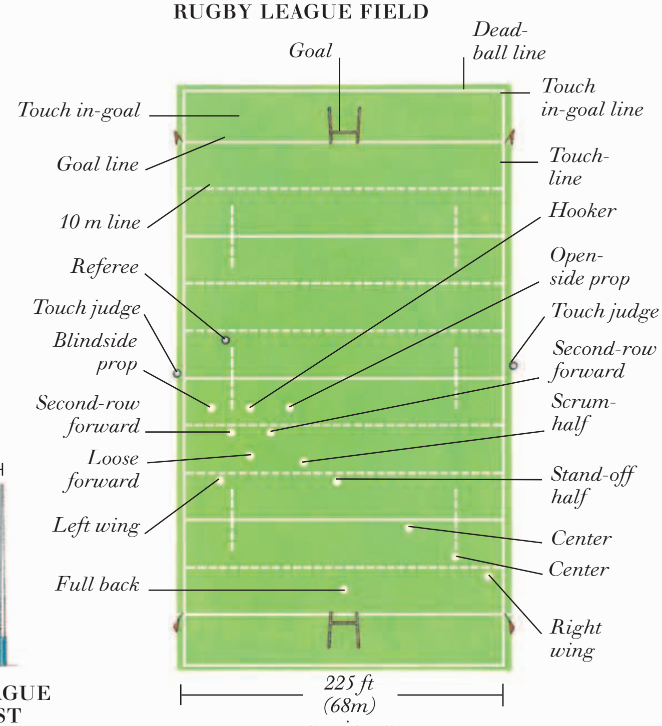


RUGBY UNION GOALPOST

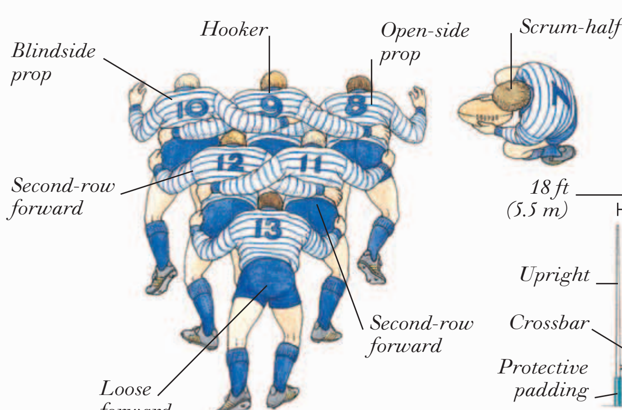
RUGBY UNION FIELD

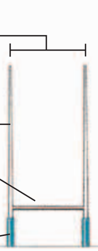


RUGBY LEAGUE FIELD



RUGBY LEAGUE SCRUMMAGE

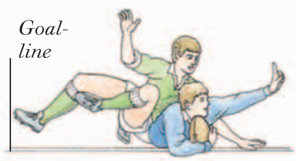




RUGBY LEAGUE GOALPOST

RUGBY SCORING AND SKILLS

GOAL



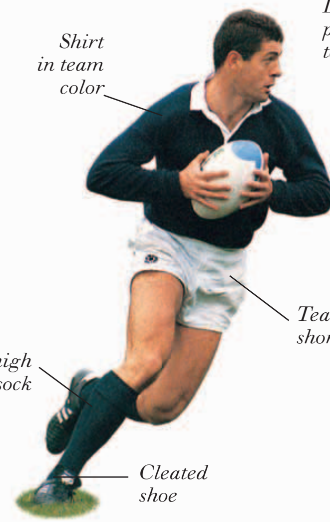
TRY

PASS

PLACE KICK

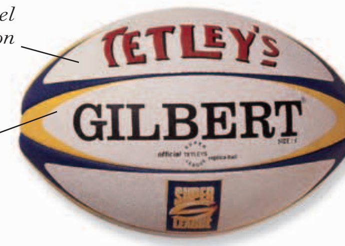
FLYING TACKLE

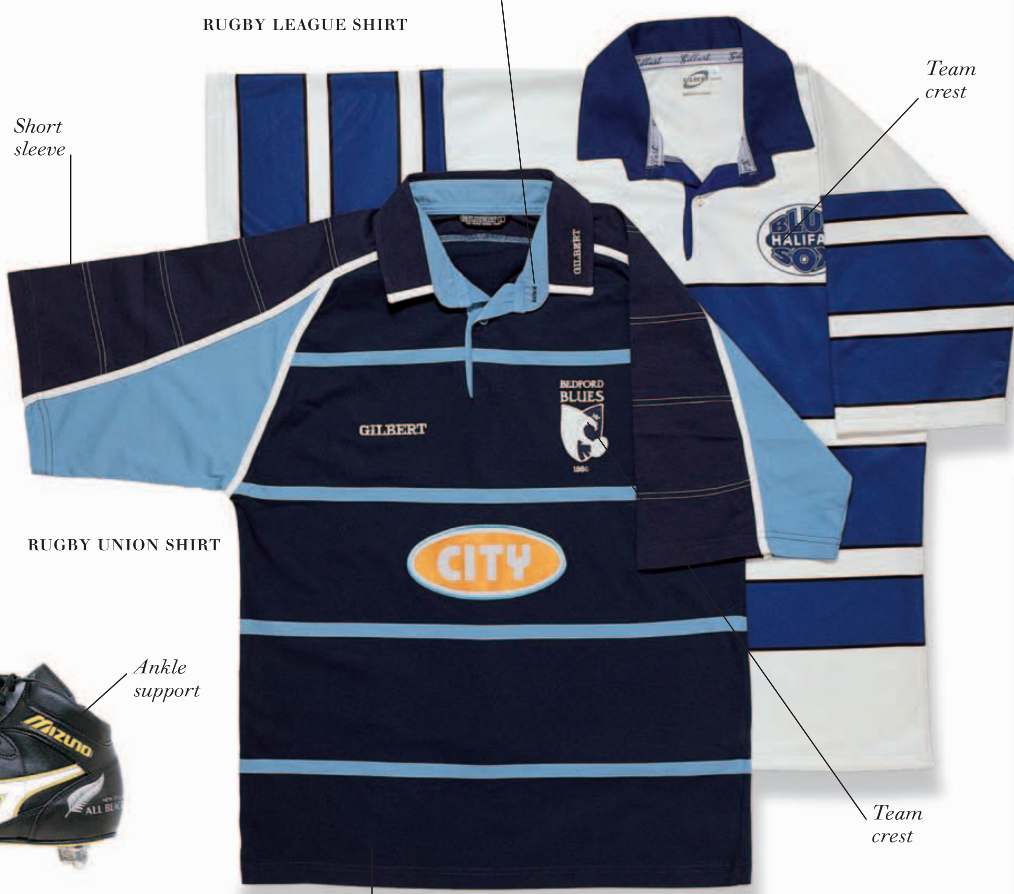
RUGBY UNION PLAYER



RUGBY UNION BALL

RUGBY LEAGUE BALL





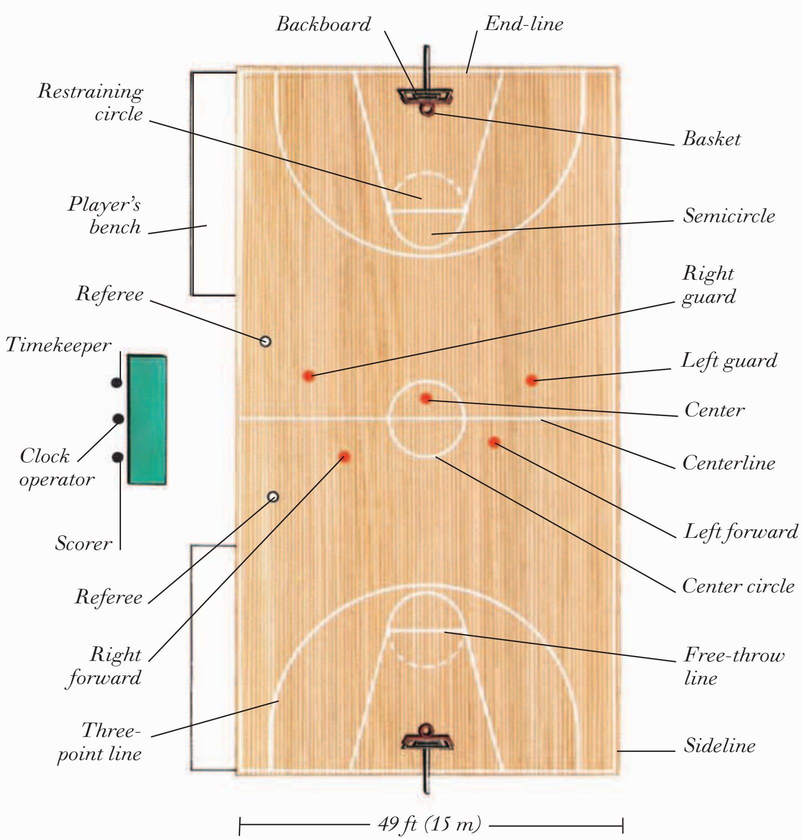
RUGBY SHIRTS

RUGBY SHOE

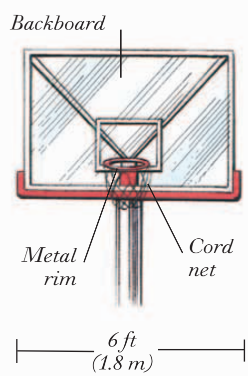
Basketball

BASKETBALL IS A BALL GAME for two teams of five players, originally devised in 1890 by James Naismath for the Y.M.C.A. in Springfield, Massachusetts. The object of the game is to take possession of the ball and score points by throwing the ball into the opposing team's basket. A player moves the ball up and down the court by bouncing it along the ground or "dribbling"; the ball may be passed between players by throwing, bouncing, or rolling. Players may not run with or kick the ball, although pivoting on one foot is allowed. The game begins with the referee throwing the ball into the air and a player from each team jumping up to try and "tip" the ball to a teammate. The length of the game and the number of periods played varies at different levels. There are amateur, professional, and international rules. No game ends in a draw. An extra period of five minutes is played, plus as many extra periods as are necessary to break the tie. In addition to the five players on court, each team has up to seven substitutes, but players may only leave the court with the permission of the referee. Basketball is a noncontact sport and fouls on other players are penalized by a throw-in awarded against the offending team; a free throw at the basket is awarded when a player is fouled in the act of shooting. Basketball is a fast-moving game, requiring both physical and mental coordination. Skillful tactical play matters more than simple physical strength and the agility of the players makes the game an excellent spectator sport.

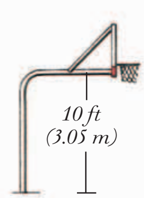
INTERNATIONAL BASKETBALL COURT



BASKET AND BACKBOARD



BASKET AND BACKBOARD STRUCTURE



BASKETBALL SKILLS


CHEST PASS


DRIBBLE

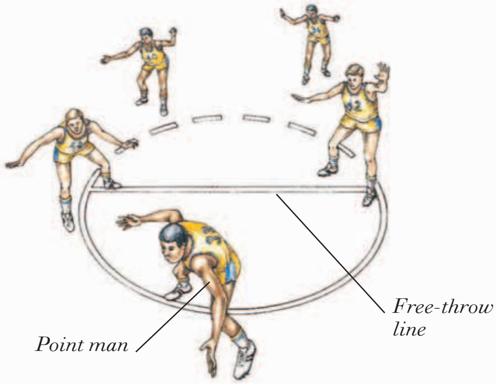

OVERHEAD PASS


LAY-UP SHOT

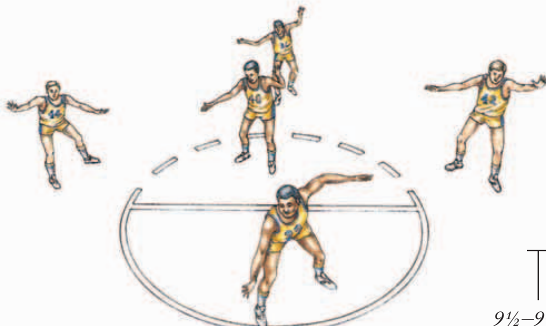

JUMP SHOT


LONG PASS

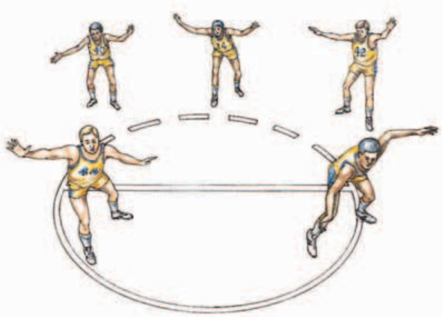
ZONE DEFENSES



1 – 2 – 2 ZONE

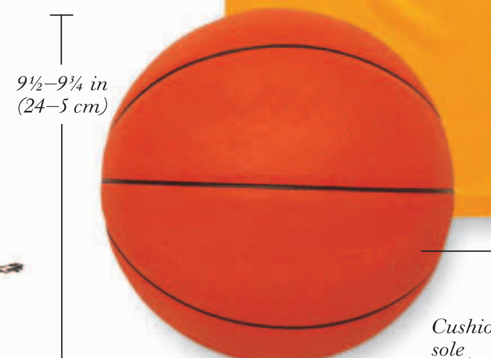


1–3–1 ZONE



2–3 ZONE

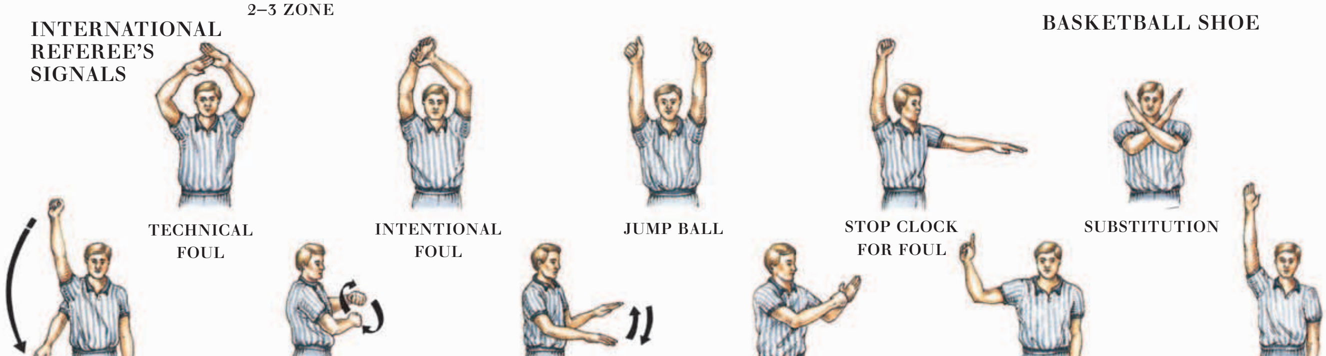
BASKETBALL JERSEY



BASKETBALL

BASKETBALL SHOE

INTERNATIONAL REFEREE'S SIGNALS



TECHNICAL FOUL

INTENTIONAL FOUL

JUMP BALL

STOP CLOCK FOR FOUL

SUBSTITUTION

PERSONAL FOUL: NO FREE THROWS

TRAVELLING

ILLEGAL DRIBBLE

CHARGING WITH THE BALL

ONE FREE THROW

STOP CLOCK

Volleyball, netball, and handball

VOLLEYBALL, NETBALL, AND HANDBALL are fast-moving team sports played with balls on courts with a hard surface. In volleyball, the object of the game is to hit the ball over a net strung across the center of the court so that it touches the ground on the opponent's side. The team of six players can take three hits to direct the ball over the net, although the same player cannot hit the ball twice in a row. Players can hit the ball with their arms, hands, or any other part of their upper body. Teams score points only while serving. The first team to score 15 points, with a two-point margin over their opponent, wins the game. Netball is one of the few sports played exclusively by women. Similar to basketball (see pp. 532–533), it is played on a slightly larger court with seven players instead of five. A team moves the ball toward the goal by throwing, passing, and catching it with the aim of throwing the ball through the opponents' goal net. Players are confined by their playing position to specific areas of the court. Team handball is one of the world's fastest games. Each side has seven players. A team moves the ball by dribbling, passing, or bouncing it as they run. Players may stop, catch, throw, bounce, or strike the ball with any part of the body above the knees. Each team tries to score goals by directing the ball past the opposition's goalkeeper into the net, which is similar to a soccer net.

VOLLEYBALL SHOTS


OVERHAND SERVE


SPIKE (SMASH)

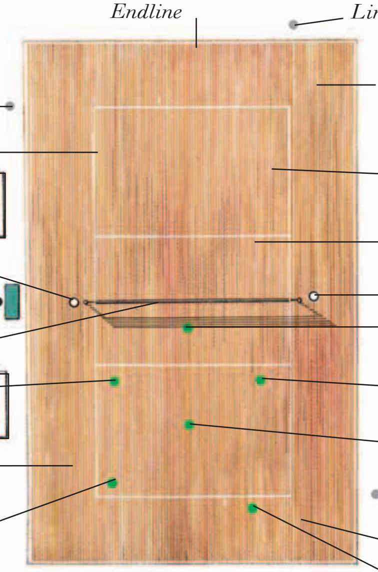

UNDERHAND SERVE

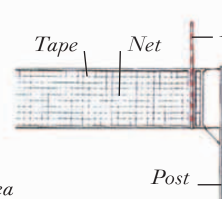

FOREARM PASS (DIG)

UNIFORM

VOLLEYBALL

VOLLEYBALL COURT

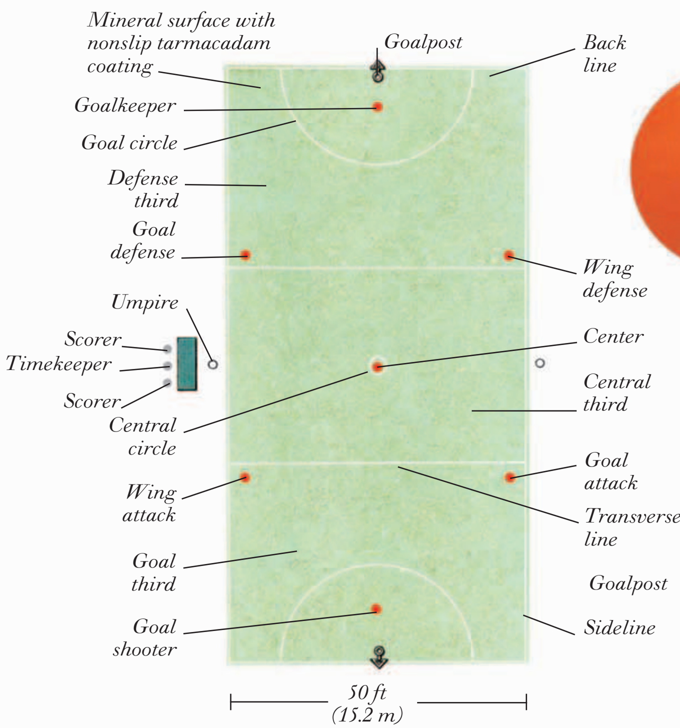


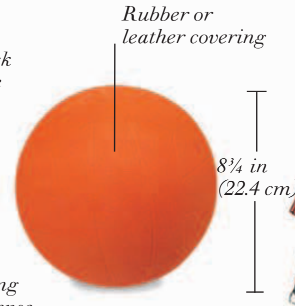


VOLLEYBALL NET

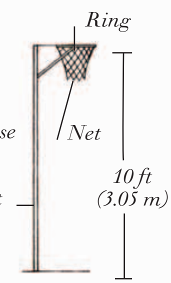
KNEE PADS

NETBALL COURT





NETBALL



NETBALL GOALPOST AND NET

NETBALL PASSES

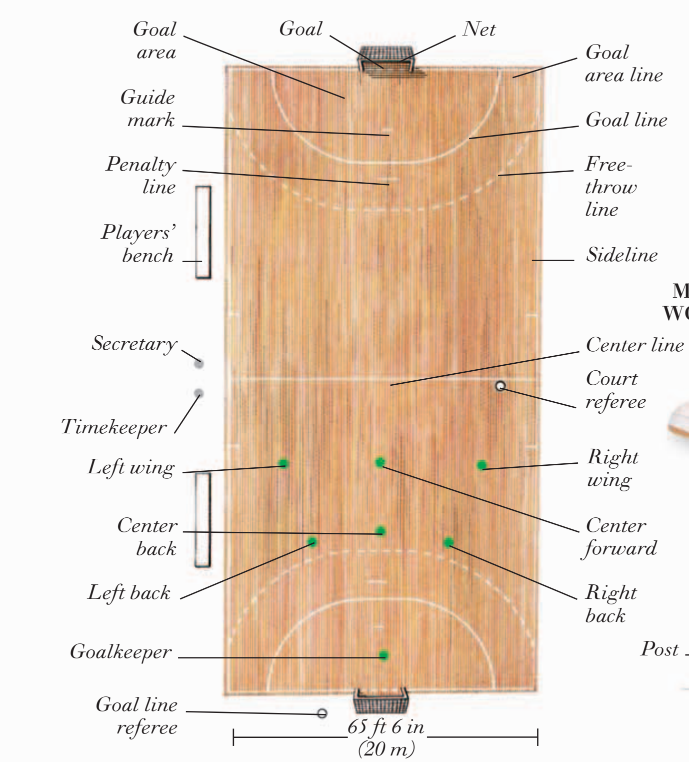
CHEST PASS

UNDERARM PASS

SHOULDER PASS

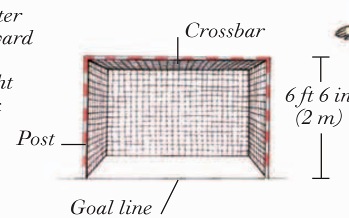
BOUNCE PASS

HANDBALL COURT



HANDBALL
MEN'S: 7½ IN (18.8 CM)
WOMEN'S: 7 IN (17.5 CM)

HANDBALL SHOE

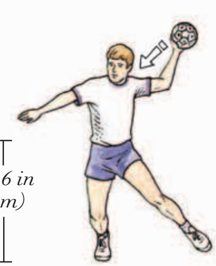


HANDBALL NET

HANDBALL SKILLS

OVERARM PASS

DRIBBLE



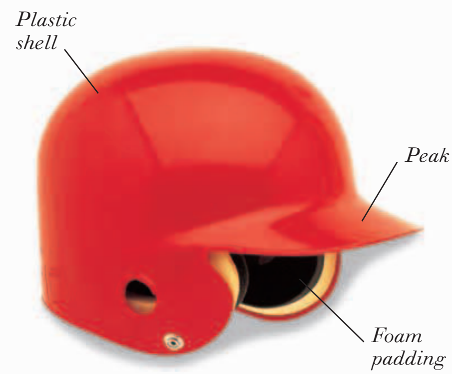
BOUNCE PASS

JUMP SHOT

Baseball

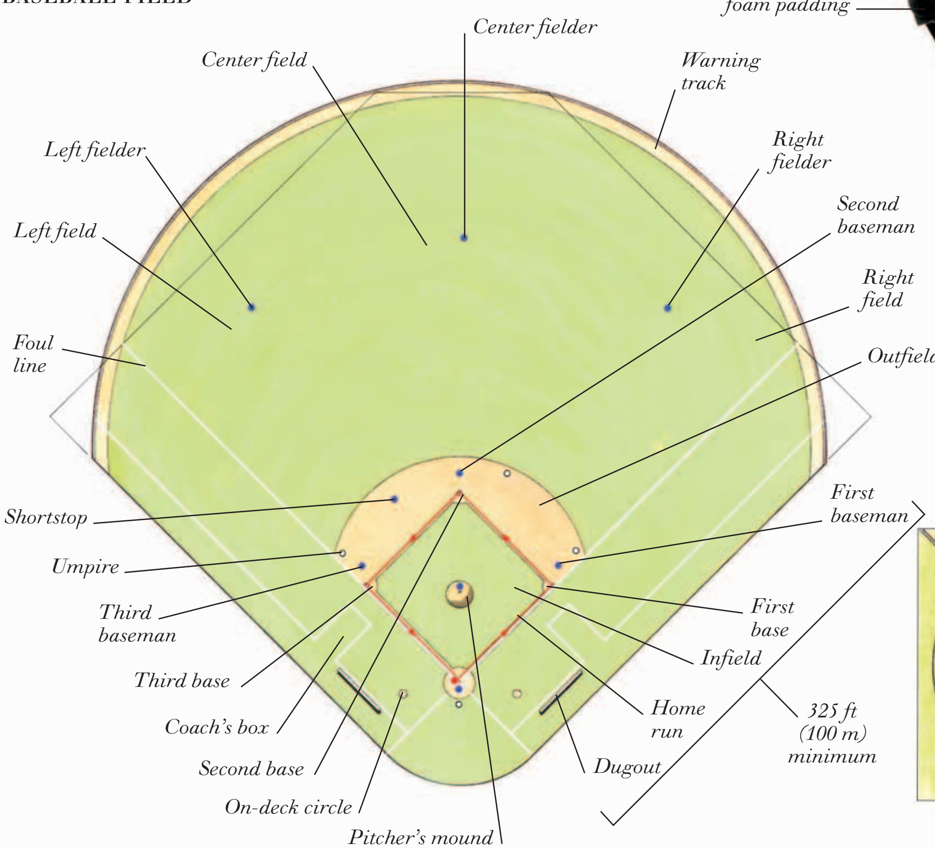
BASEBALL IS A BALL GAME for two teams of nine players. The batter hits the ball thrown by the opposing team's pitcher, into the area between the foul lines. He then runs around all four fixed bases in order to score a run, touching or "tagging" each base in turn. The pitcher must throw the ball at a height between the batter's armpits and knees, a height which is called the "strike zone." A ball pitched in this area that crosses over the "home plate" is called a "strike" and the batter has three strikes in which to try and hit the ball (otherwise he is "struck out"). The fielding team tries to get the batting team out by catching the ball before it bounces, tagging a player of the batting team with the ball who is running between bases, or by tagging a base before the player has reached it. Members of the batting team may stop safely at a base as long as it is not occupied by another member of their team. When the batter runs to first base, his teammate at first base must run on to second—this is called "force play." A game consists of nine innings and each team will bat once during an inning. When three members of the batting team are out, the teams swap roles. The team with the greatest number of runs wins the game.

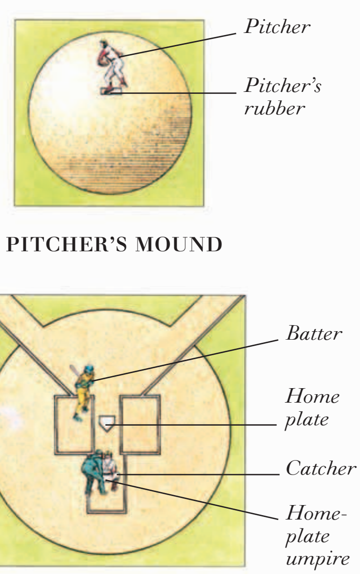
BATTER'S HELMET



CATCHER'S MASK

BASEBALL FIELD



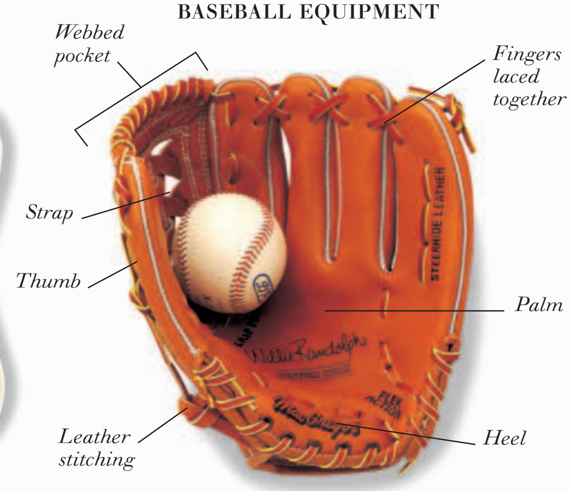


PITCHER'S MOUND

HOME PLATE

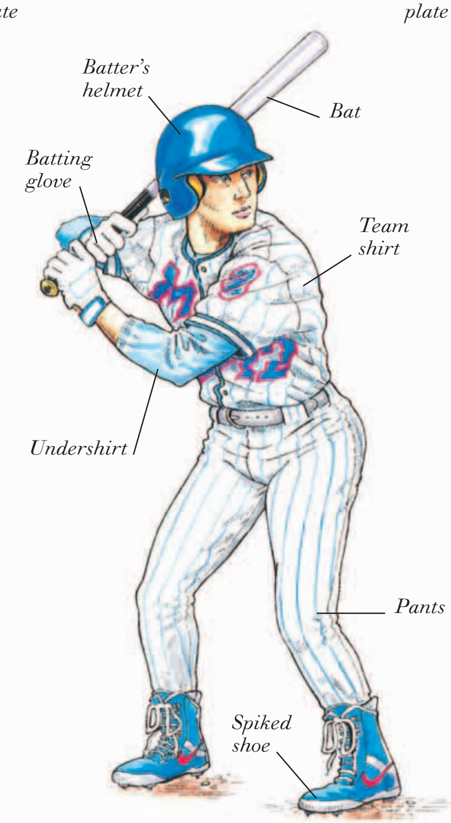
MAKING A BASEBALL

BASEBALL EQUIPMENT

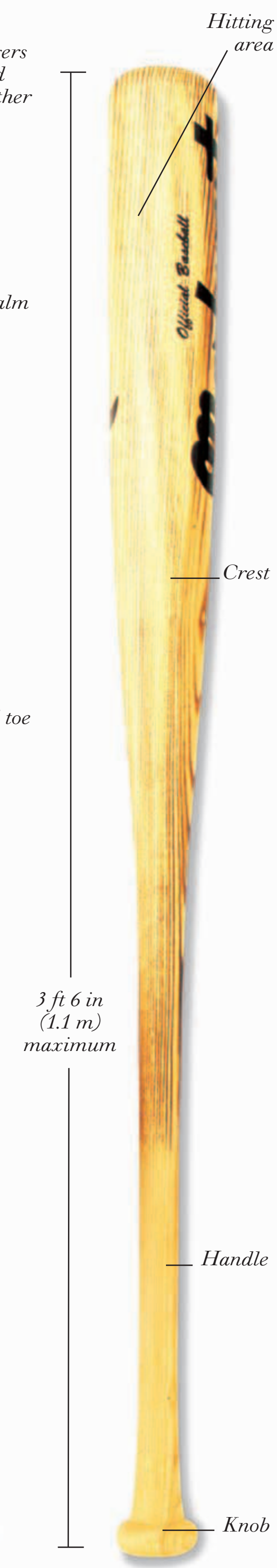


FIELDER'S GLOVE AND BALL

BASEBALL SHOE



BATTER



BAT

THE PITCHING SEQUENCE

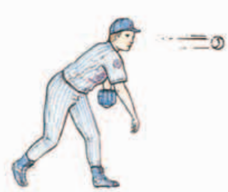
THE WIND-UP 1

THE WIND-UP 2

THE WIND-UP 3

THE WIND-UP 4

THE RELEASE

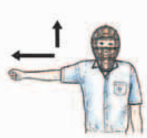


THE FOLLOW-THROUGH

UMPIRING SIGNALS

BALL

INFIELD



STRIKE

FAIR BALL

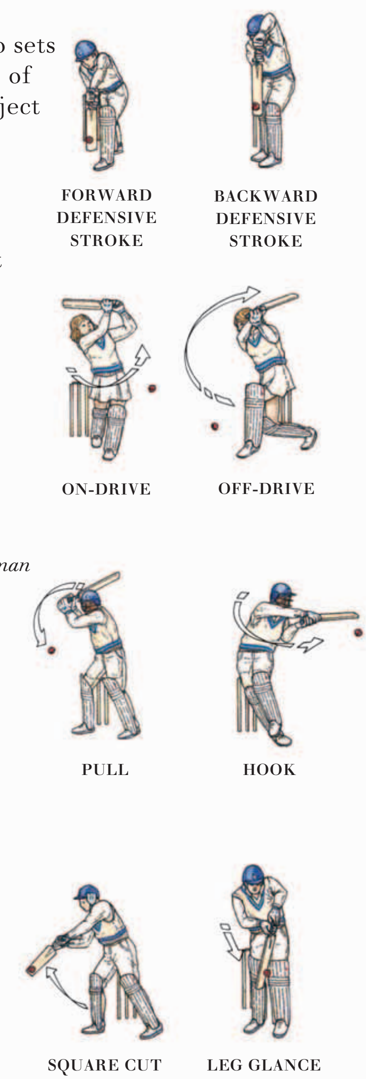
RUNNER IS SAFE

FOUL TIP

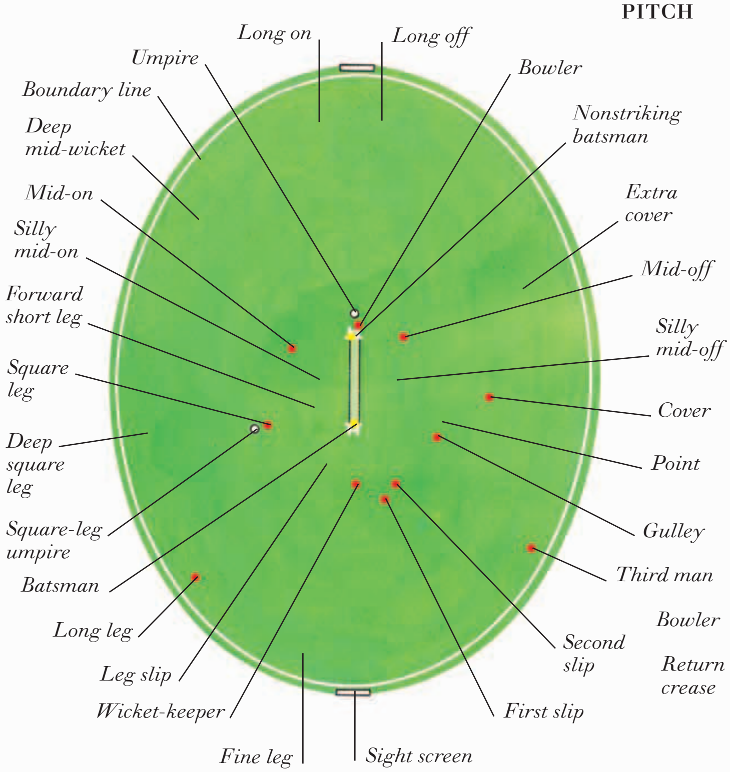
Cricket

CRICKET IS A BALL GAME PLAYED by two teams of eleven players on a pitch with two sets of three stumps (wickets). The bowler bowls the ball down the pitch to the batsman of the opposing team, who must defend the wicket in front of which he stands. The object of the game is to score as many runs as possible. Runs can be scored individually by running the length of the playing strip, or by hitting a ball that lands outside the boundary ("six"), or that lands inside the boundary but bounces or rolls outside ("four"); the opposing team will bowl and field, attempting to dismiss the batsmen. A batsman can be dismissed in one of several ways: by the bowler hitting the wicket with the ball ("bowled"); by a fielder catching the ball hit by the batsman before it touches the ground ("caught"); by the wicket-keeper or another fielder breaking the wicket while the batsman is attempting a run and is therefore out of his ground ("stumped" or "run out"); by the batsman breaking the wicket with his own bat or body ("hit wicket"); by a part of the batsman's body being hit by a ball that would otherwise have hit the wicket ("leg before wicket" ["lbw"]). A match consists of one or two innings and each inning ends when the tenth batsman of the batting team is out, when a certain number of overs (a series of six balls bowled) have been played, or when the captain of the batting team "declares" ending the innings voluntarily.

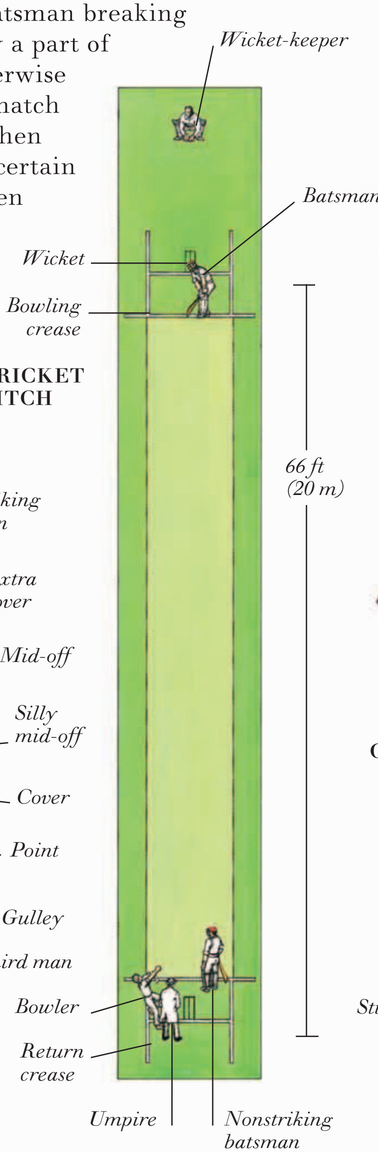
CRICKET STROKES



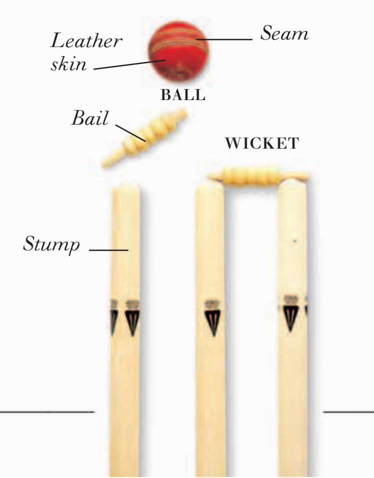
POSSIBLE FIELD POSITIONS FOR AN AWAY SWING BOWLER TO A RIGHT-HANDED BATSMAN (IN RED) AND OTHER FIELD POSITIONS



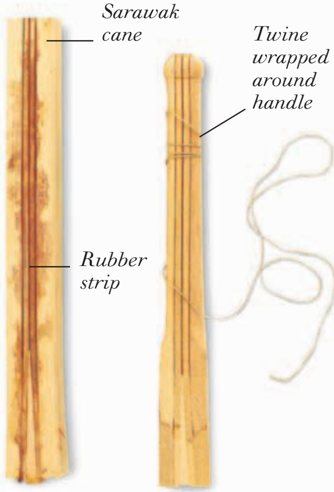
CRICKET PITCH



CRICKET BALL AND WICKET



MAKING A BAT HANDLE



LAMINATING THE WOOD

BINDING THE HANDLE

PROTECTIVE CLOTHING

BATTING GLOVE

WICKET-KEEPER'S GLOVES

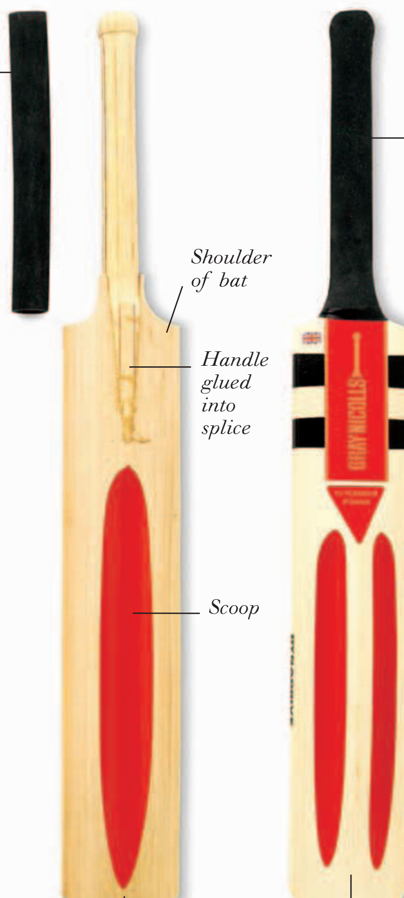
HELMET

MAKING A BAT BLADE

SEASONING THE TIMBER

CUTTING THE SPLICE

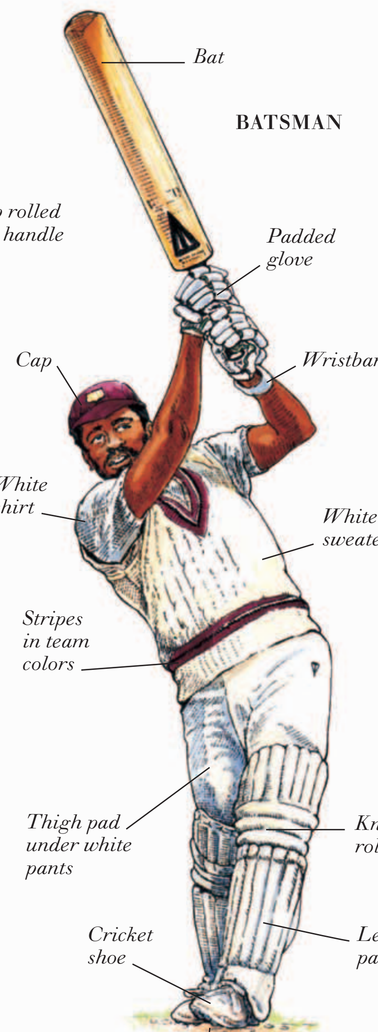
ADDING THE HANDLE TO THE BAT



FITTING THE HANDLE

FINISHING TOUCHES

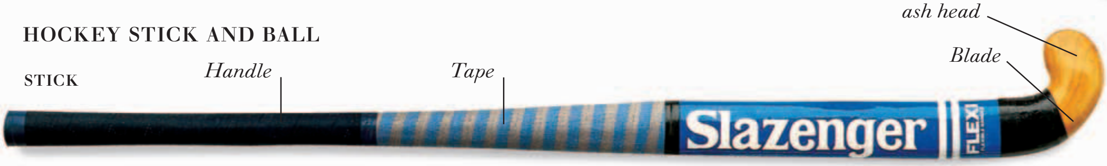
BATSMAN



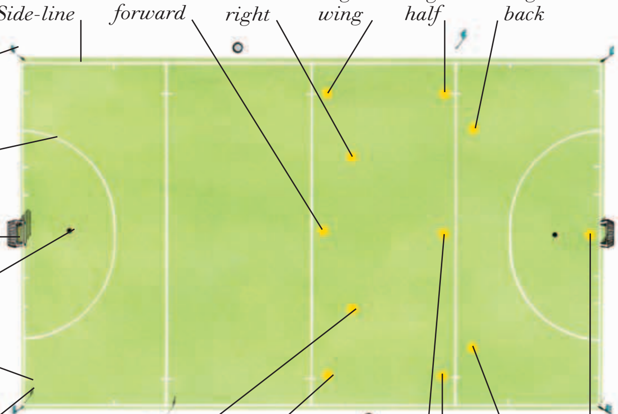
Field hockey, lacrosse, and hurling

ALL OVER THE WORLD, TEAM GAMES have evolved that require that a ball be struck or carried, and tossed at the end of a stick. Early forms of these games include hurling, shinty, bandy, and pelota. Field hockey is played by men and women: two teams of 11 players try to gain and keep possession of the ball and score goals by using the hockey stick to propel the ball into their opponents' goal net. Skills such as passing, pushing, or hitting the ball by slapping or lifting it in a flicking movement, and shooting at goal are crucial. Hockey is played indoors and outdoors on grass or synthetic fields. Lacrosse is played internationally as a 12-a-side game for women and as 10-a-side game for men. The women's field has no absolute boundaries but the men's field has clearly defined side-lines and end-lines. The ball is kept in play by being carried, thrown, or batted with the crosse, and rolled or kicked in any direction. In men's and women's lacrosse, play can continue behind the marked goal areas. Similar skills are required in hurling—a Gaelic field game played on the same field as Gaelic football (see pp. 528–529), using the same goalposts and net. In hurling, the ball may be struck with or carried on the hurley and, when off the ground, may be struck with the hand or kicked. Goals (three points) are scored when the ball passes between the posts and under the crossbar; one point is scored when it passes between the posts and over the crossbar.

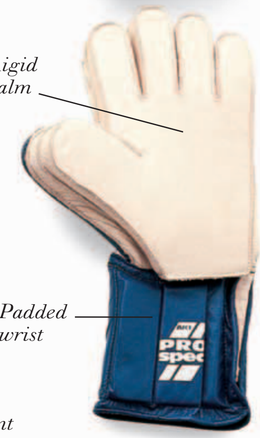
HOCKEY STICK AND BALL



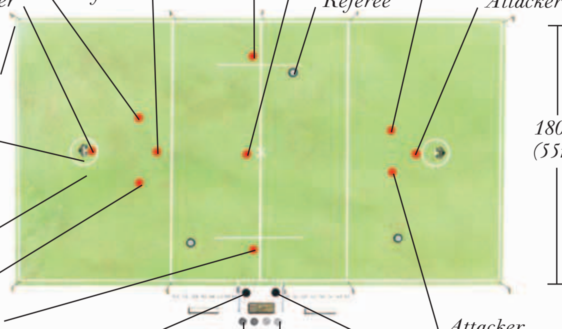
HOCKEY FIELD



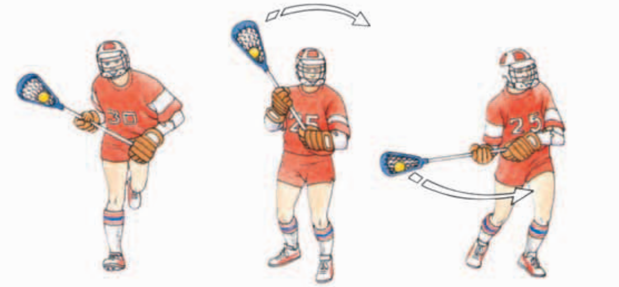
GOALKEEPER'S EQUIPMENT



MEN'S LACROSSE FIELD

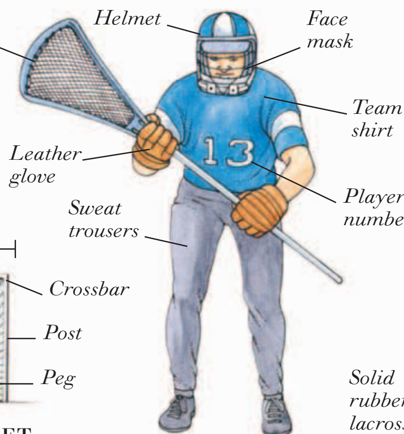


LACROSSE SKILLS

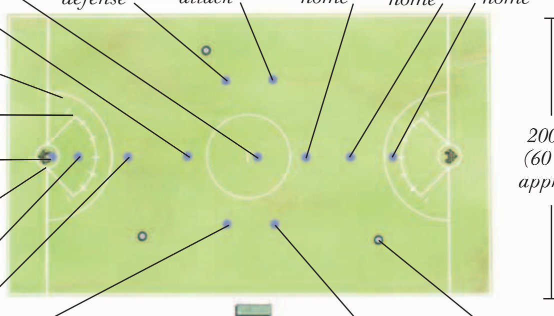


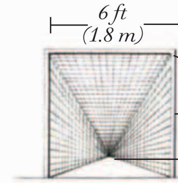
CRADLING THROWING SIDE-SHOOTING

LACROSSE GOALKEEPER



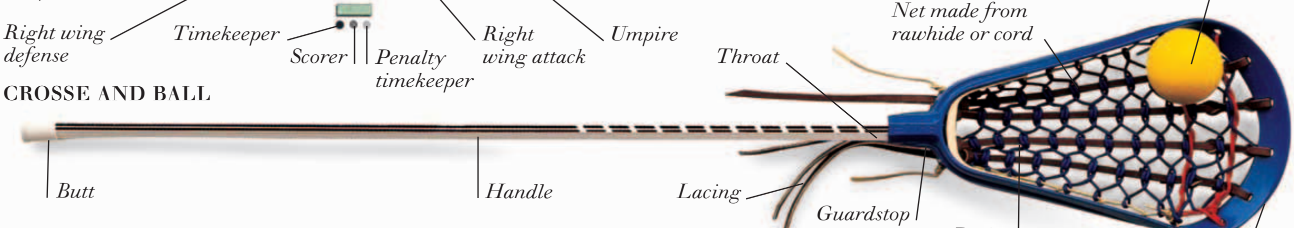
WOMEN'S LACROSSE FIELD



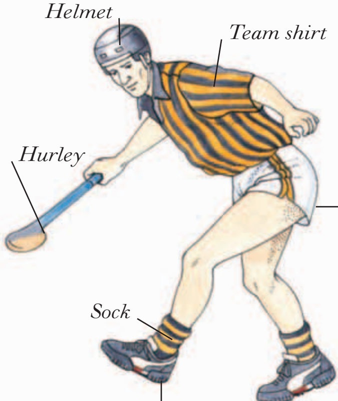


LACROSSE NET

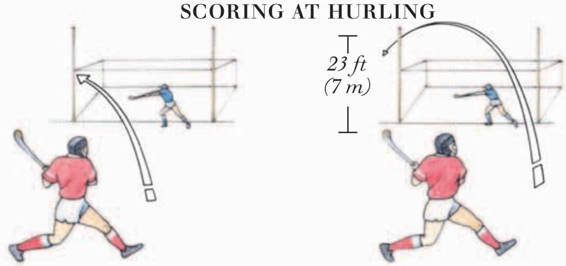
CROSSE AND BALL



HURLER



SCORING AT HURLING



GOAL (3 POINTS) POINT (1 POINT)

HURLING BALL

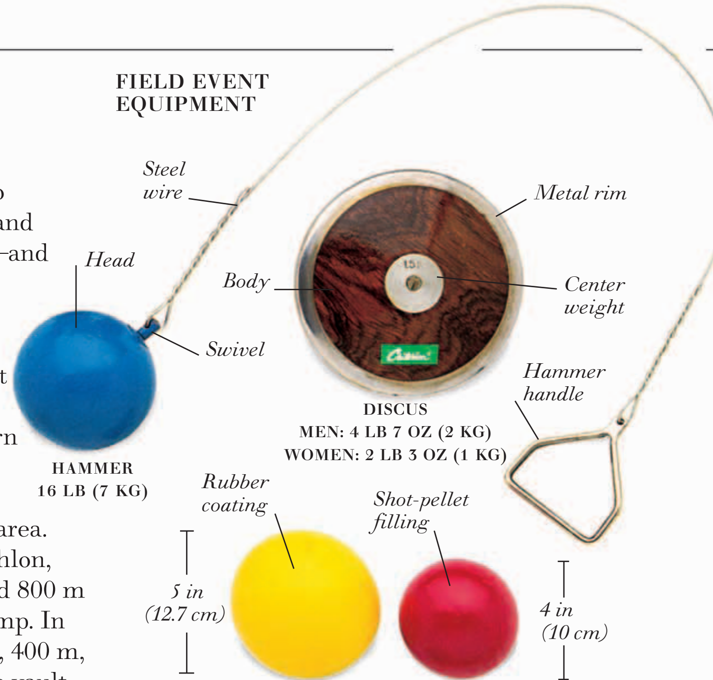
HURLEY AND HURLING BALL

HURLEY

Track and field

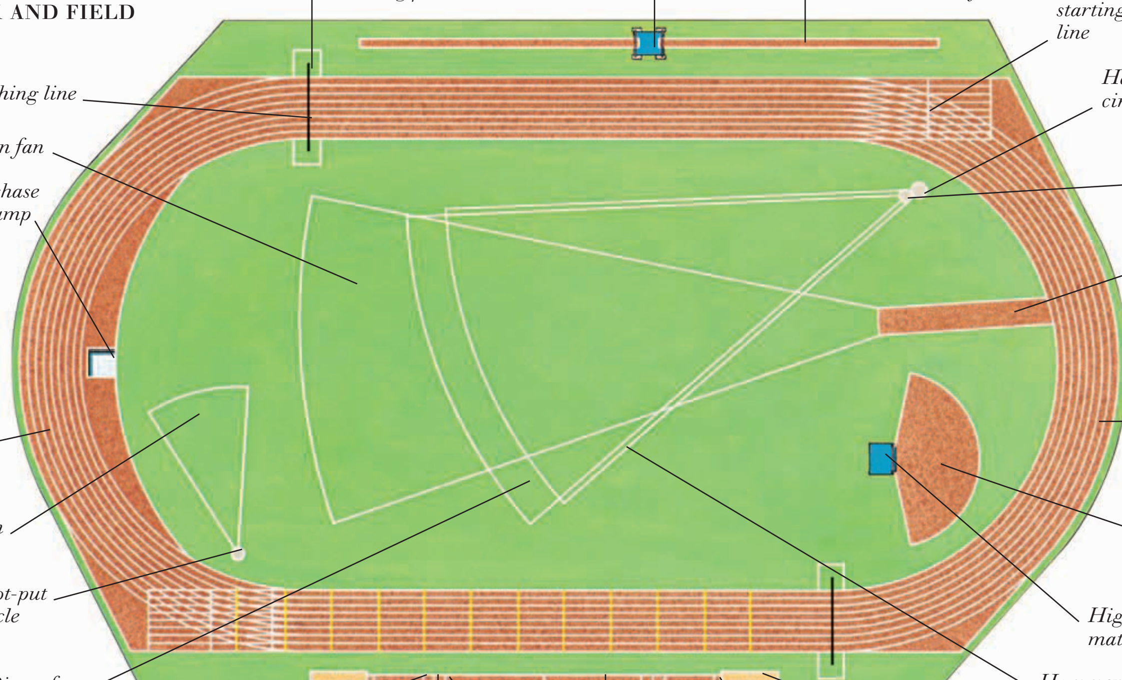
THE SPORTS that make up track and field are divided into two main groups: track events—which include sprinting, middle- and long-distance running, relay running, hurdling, and walking—and field events that require jumping and throwing skills. Contests designed to test the speed, strength, agility, and stamina of athletes were held by the ancient Greeks over 4,000 years ago. However, the abolition of the Olympic Games in 393 AD meant that track and field events were neglected until the revival of large-scale competitions in the mid-nineteenth century. Modern stadia offer areas reserved for the long jump, triple jump, and pole vault usually situated outside the running track. The javelin, shot, hammer, and discus are thrown within the track area. Most athletes specialize in one or two events but, in the heptathlon, women compete in seven events, held over two days: 200 m and 800 m races, 100 m hurdles, javelin, shot put, high jump, and long jump. In the decathlon, men compete in 10 events over two days: 100 m, 400 m, and 1,500 m races, 110 m hurdles, javelin, discus, shot put, pole vault, high jump, and long jump.

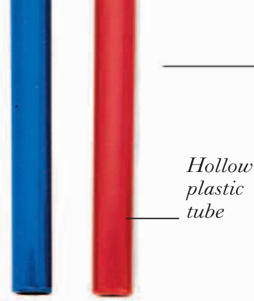
FIELD EVENT EQUIPMENT



JAVELIN

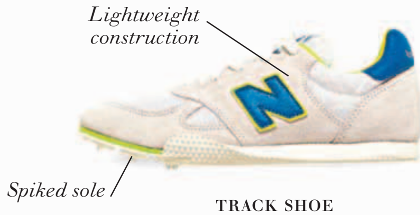
TRACK AND FIELD





RELAY BATONS

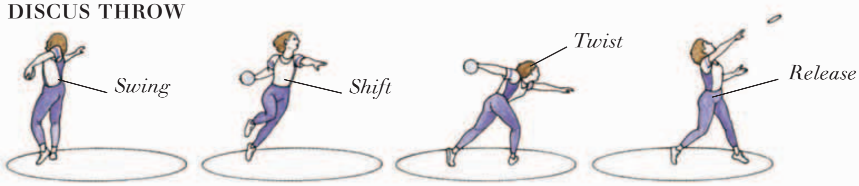
TYPES OF SHOE



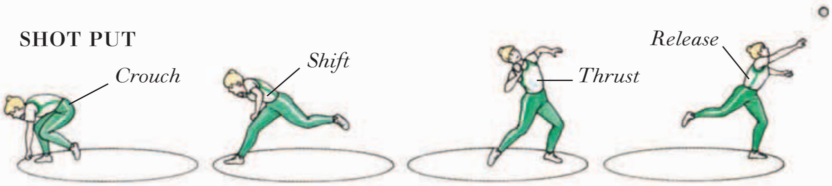
TRACK SHOE

RUNNING SHOE

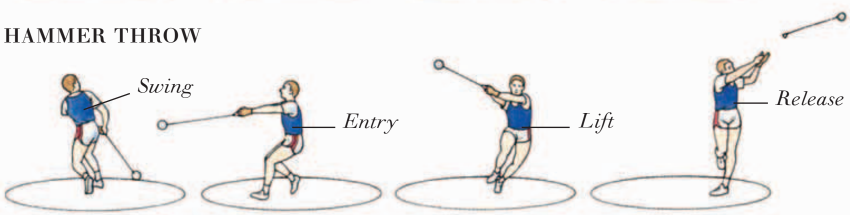
DISCUS THROW

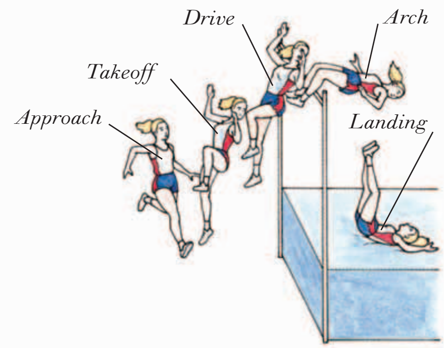


SHOT PUT



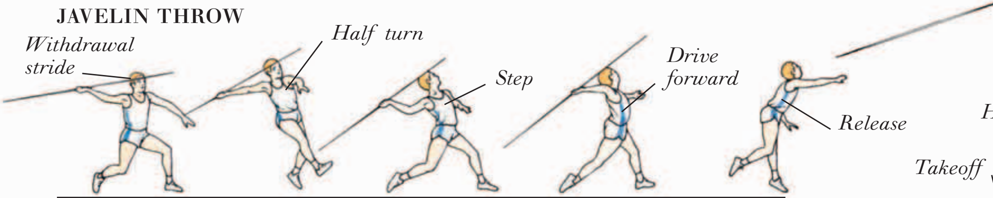
HAMMER THROW

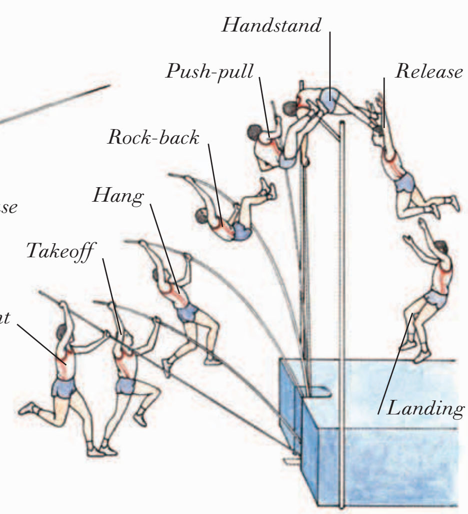




HIGH JUMP

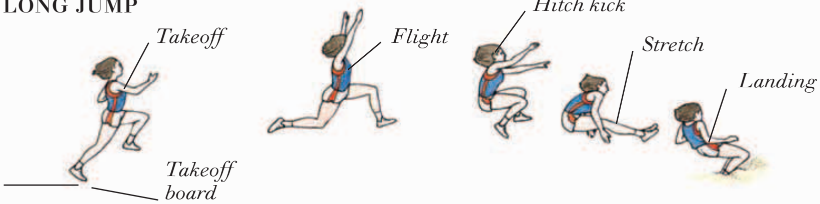
JAVELIN THROW



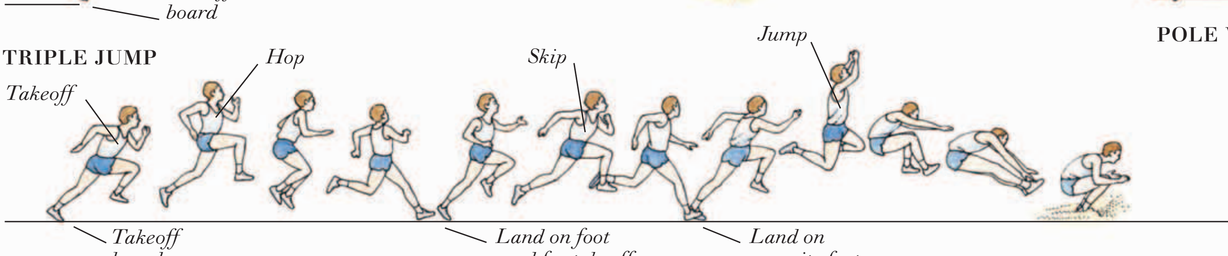


POLE VAULT

LONG JUMP



TRIPLE JUMP

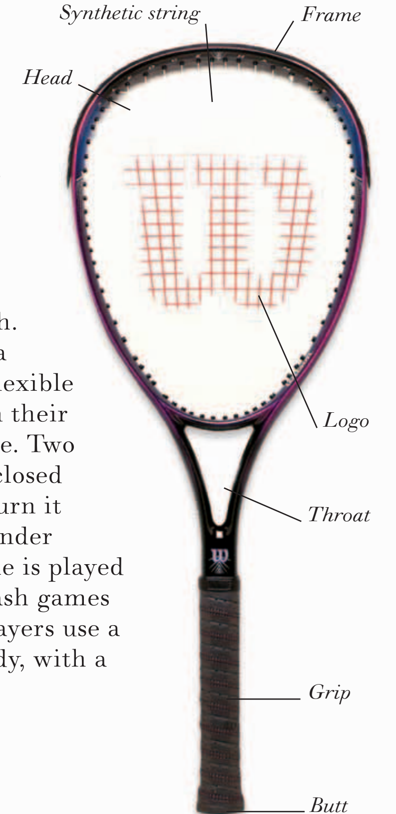


Racket sports

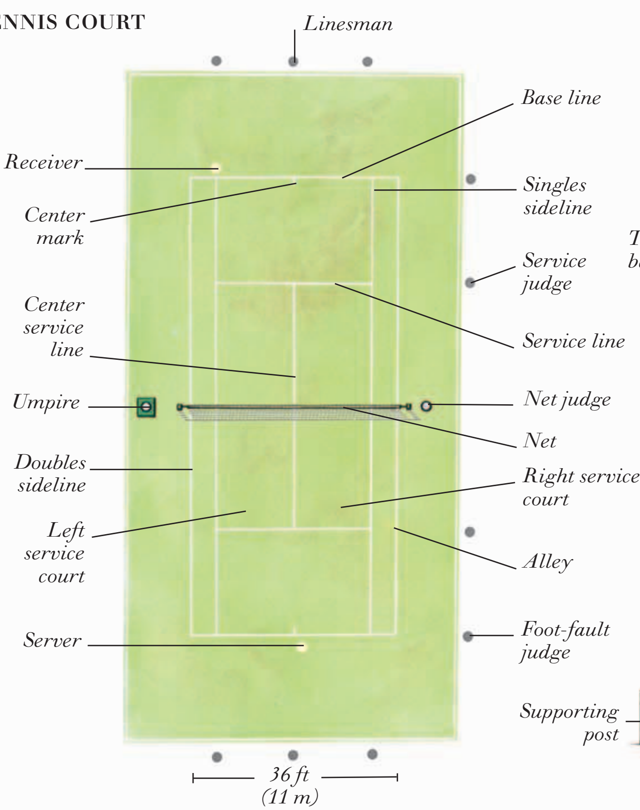
PROTECTIVE EYEWEAR

THE OBJECT OF ALL RACKET SPORTS is to make shots the opponent cannot return. Games are played by two players (singles) or four players (doubles). Racket shape and size is tailored to each sport, but all rackets are constructed of wood, plastic, aluminum, or high-performance materials such as fiberglass and carbon graphite. Racket strings are usually synthetic, although natural gut is still used. Tennis is played on a court divided by a low net. Opposing players serve alternate games. At least six games must be won to gain a set, and two or sometimes three sets are needed to win a match. Tennis courts may be concrete, grass, clay, or synthetic, each surface requiring a different style of play. Badminton is an indoor sport that is played with light, flexible rackets and a birdie on a court with a high net. Players can score points only on their serve. The first to reach 15 points (11 points for women's singles) wins the game. Two games are needed to win a match. Squash and racketball are both played in enclosed courts. One player hits the ball against the front wall, and the other tries to return it before it bounces on the floor more than once. Squash rackets have smaller, rounder heads and stiffer frames than badminton rackets. In the United States, the game is played on a narrower court than an international court using a much harder ball. Squash games are played to 15 points (American) or 9 points (international). In racketball, players use a ball that is larger and bouncier than a squash ball. The racket is thick and sturdy, with a large head, short handle, and a thong that loops around the wrist. Points can be won only when serving, and the first player to reach 21 points wins.

TENNIS RACKET

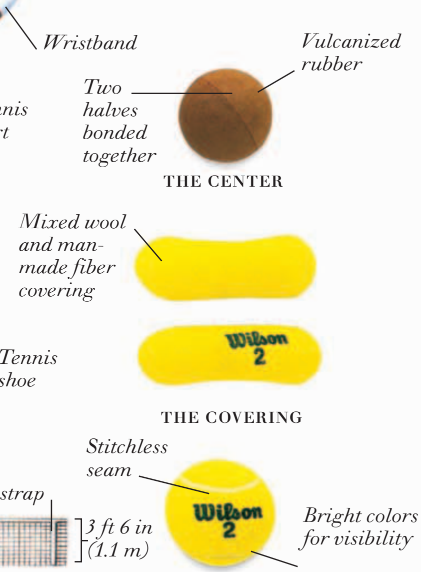


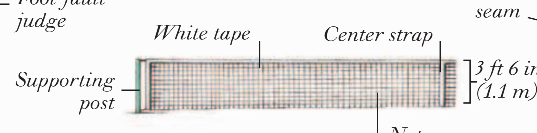
TENNIS COURT



TENNIS PLAYER

MAKING A TENNIS BALL

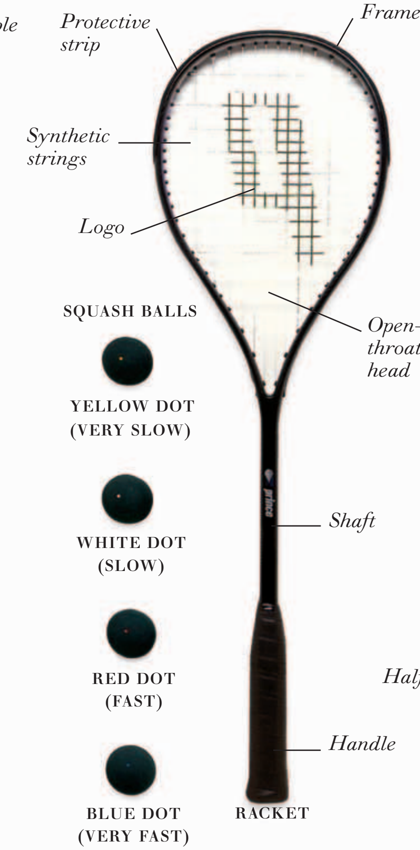




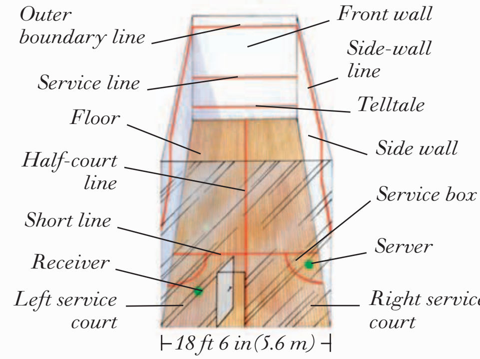
TENNIS NET

BADMINTON RACKET AND BIRDIE

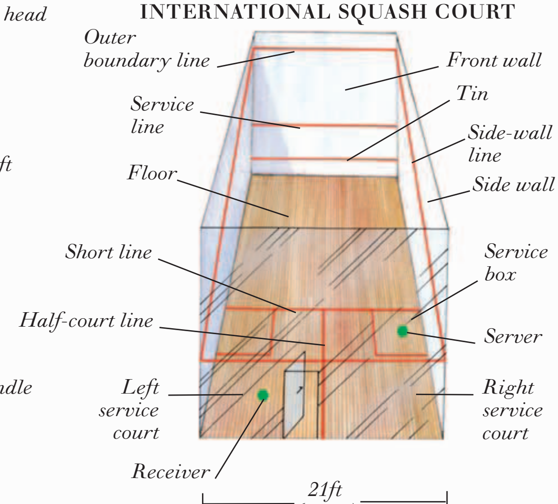
SQUASH RACKET AND SQUASH BALLS



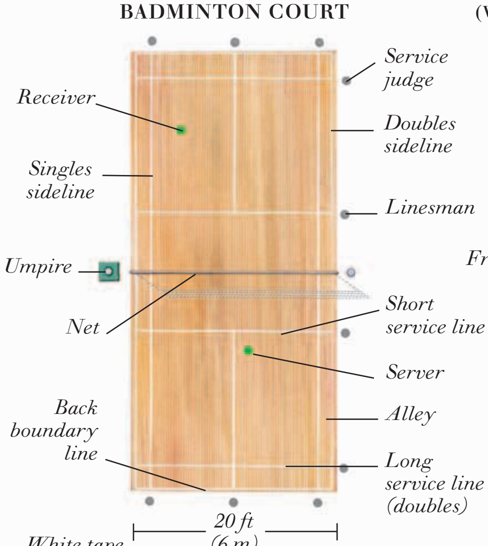
AMERICAN SQUASH COURT

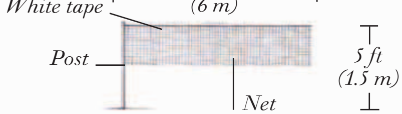


INTERNATIONAL SQUASH COURT



BADMINTON COURT

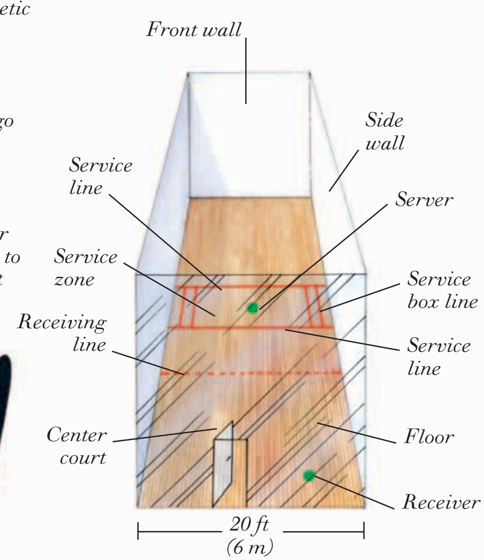




BADMINTON NET

RACKETBALL RACKET, BALL, AND GLOVE

RACKETBALL COURT

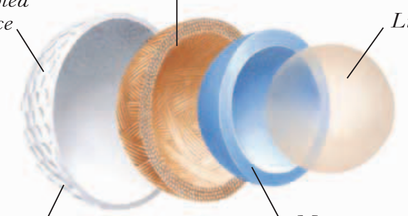


Golf

GOLF BALL AND TEE

THE GAME OF GOLF was first played in Scotland some 400 years ago. Players are required to hit a ball, using a wooden or iron club, from a smooth level point or "teeing ground," down the "fairway," and on to a putting green where the target hole is located. The fairway is a strip of clear land along which there are natural hazards—such as ponds and streams, man-made hazards—such as bunkers (sand pits), and rough (areas of uncut grass). Championship golf courses have 18 holes. The object of the game is to hit the ball into each hole in turn, and to complete the "round" using as few strokes as possible. Players compete individually or in teams, playing the course together in groups of two, three, or four. The two basic forms of competition are match play and stroke play. In match play, the side winning the majority of holes over a certain number of rounds wins the match. In stroke play, the winner is the player who finishes a certain number of rounds having made the fewest strokes.

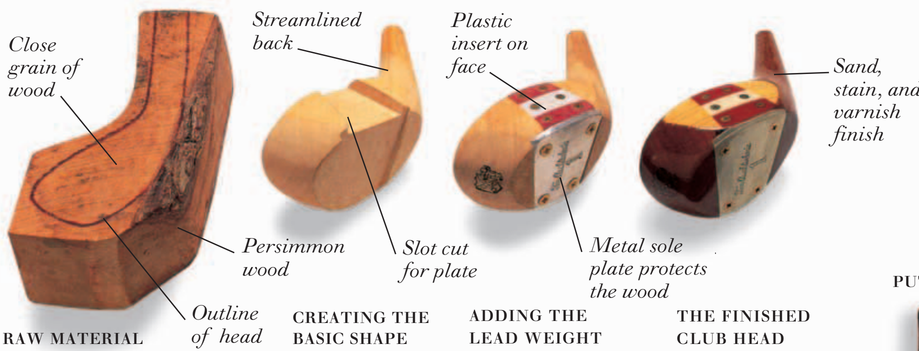
GOLF BALL WITH BALATA SURFACE



AUGUSTA NATIONAL GOLF COURSE, AUGUSTA, GEORGIA, US

A TYPICAL HOLE

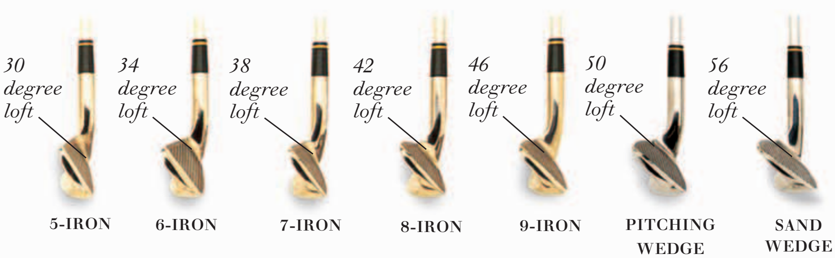
MAKING A WOODEN CLUB



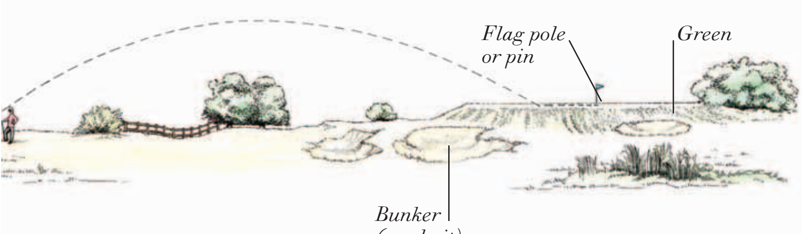
PUTTER, WOOD, AND IRON

RANGE OF WOODEN CLUBS

RANGE OF IRON CLUBS



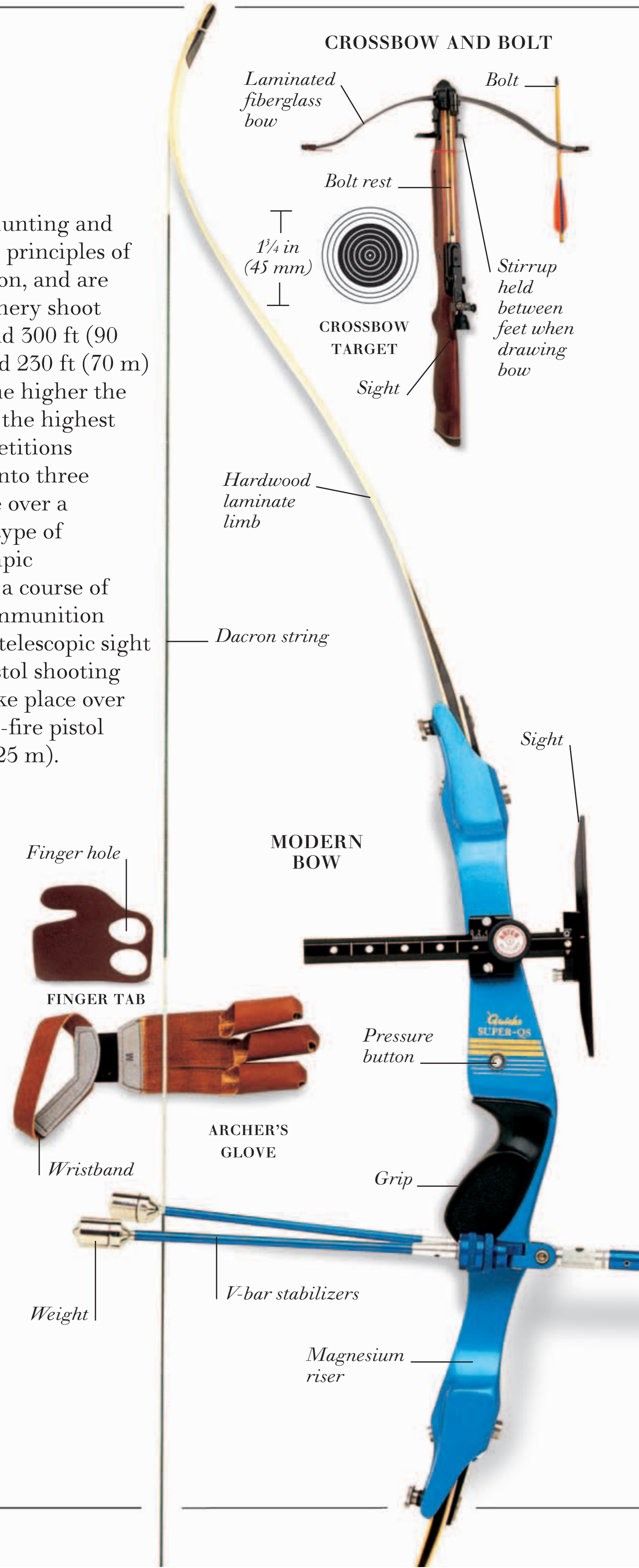
GOLF ACCESSORIES



Archery and shooting

TARGET SHOOTING AND ARCHERY EVOLVED as practice for hunting and battle skills. Modern bows, although designed according to the principles of early hunting bows, use laminates, fiberglass, dacron, and carbon, and are equipped with sights and stabilizers. Competitors in target archery shoot over distances of 100 ft (30 m), 165 ft (50 m), 230 ft (70 m), and 300 ft (90 m) for men, and 100 ft (30 m), 165 ft (50 m), 200 ft (60 m), and 230 ft (70 m) for women. The closer the shot is to the center of the target, the higher the score. The individual scores are added up, and the archer with the highest total wins the competition. Crossbows are used in match competitions over 33 ft (10 m), and 100 ft (30 m). Rifle shooting is divided into three categories: smallbore, bigbore, and air rifle. Contests take place over a variety of distances and further subdivisions are based on the type of shooting position used: prone, kneeling, or standing. The Olympic biathlon combines cross-country skiing and rifle shooting over a course of approximately 12½ miles (20 km). Additional magazines of ammunition are carried in the butt of the rifles. Bigbore rifles fitted with a telescopic sight can be used for hunting and running game target shooting. Pistol shooting events, using rapid-fire pistols, target pistols, and air pistols, take place over 33 ft (10 m), 82 ft (25 m), and 165 ft (50 m) distances. In rapid-fire pistol shooting, a total of 60 shots are fired from a distance of 83 ft (25 m).

CROSSBOW AND BOLT



CROSSBOW TARGET

MODERN BOW

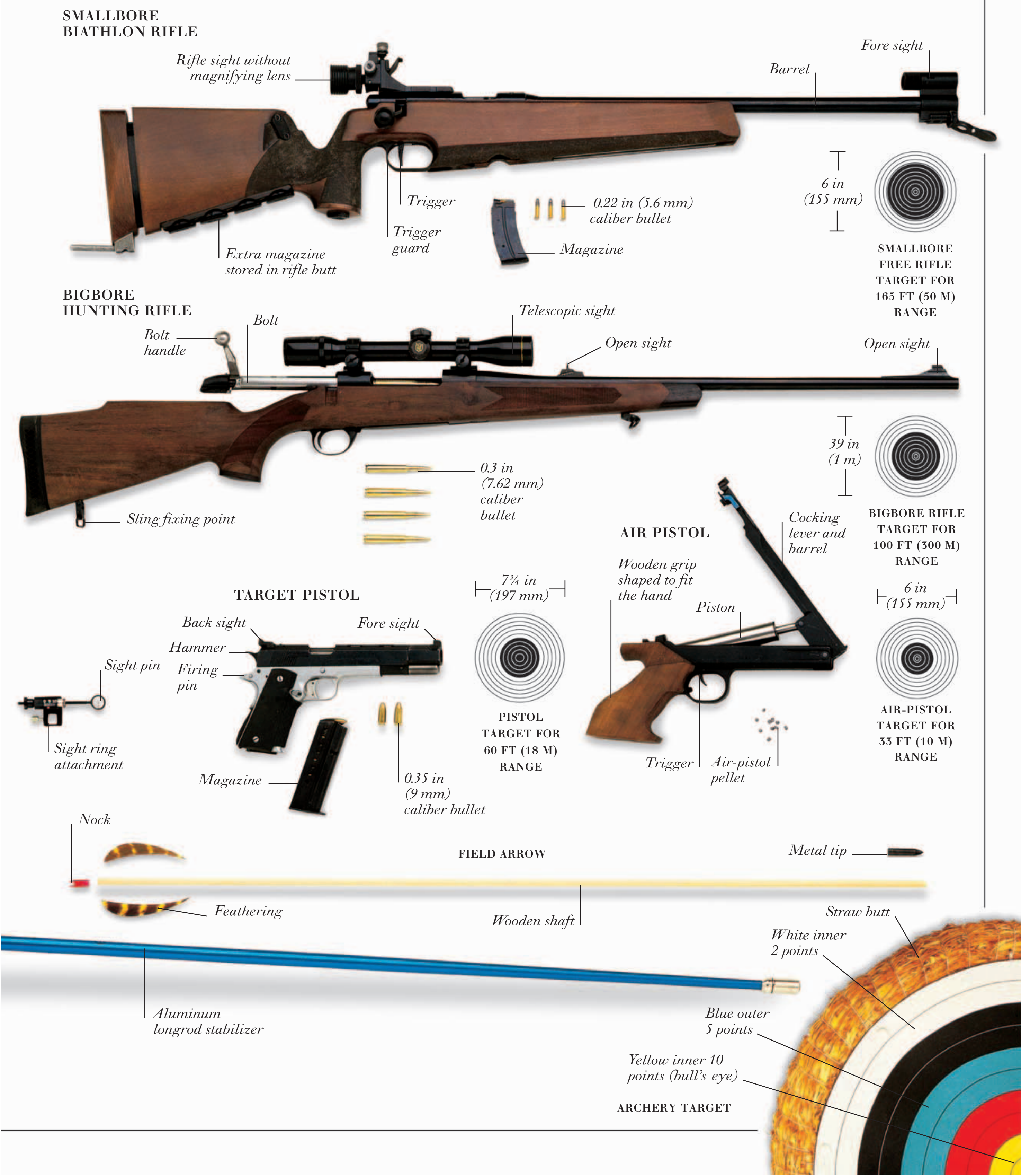
ARCHER'S GLOVE

QUIVER

BRACER

FINGER TAB

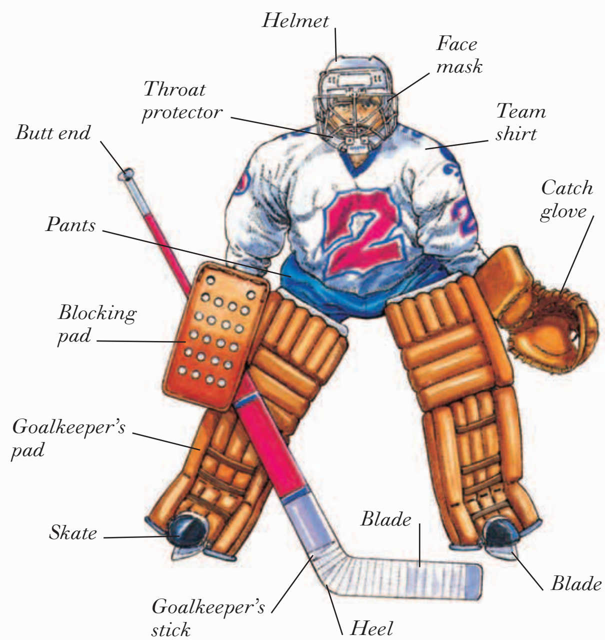
ARCHERY EQUIPMENT


SMALLBORE BIATHLON RIFLE
Rifle sight without magnifying lens
Fore sight
Barrel
Trigger
Trigger guard
Extra magazine stored in rifle butt
0.22 in (5.6 mm) caliber bullet
Magazine
6 in (155 mm)
SMALLBORE FREE RIFLE TARGET FOR 165 FT (50 M) RANGE
BIGBORE HUNTING RIFLE
Bolt handle
Bolt
Telescopic sight
Open sight
Open sight
Sling fixing point
0.3 in (7.62 mm) caliber bullet
39 in (1 m)
BIGBORE RIFLE TARGET FOR 100 FT (300 M) RANGE
AIR PISTOL
Cocking lever and barrel
Wooden grip shaped to fit the hand
Piston
Trigger
Air-pistol pellet
6 in (155 mm)
AIR-PISTOL TARGET FOR 33 FT (10 M) RANGE
TARGET PISTOL
Back sight
Fore sight
Hammer
Firing pin
Sight pin
Sight ring attachment
Magazine
0.35 in (9 mm) caliber bullet
7¾ in (197 mm)
PISTOL TARGET FOR 60 FT (18 M) RANGE
Nock
FIELD ARROW
Metal tip
Feathering
Wooden shaft
Aluminum longrod stabilizer
Straw butt
White inner 2 points
Blue outer 5 points
Yellow inner 10 points (bull's-eye)
ARCHERY TARGET

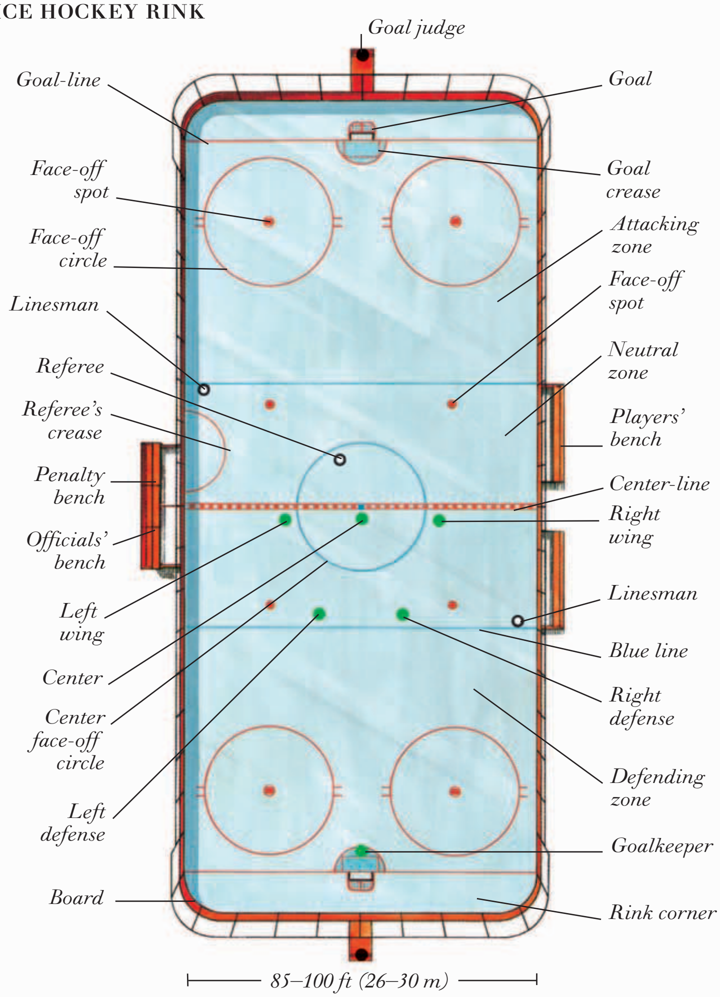
Ice hockey

ICE HOCKEY IS PLAYED by two teams of six players on an ice rink, with a goal net at each end. The object of this fast, and often dangerous, game is to hit a frozen rubber puck into the opposing team's net with a ice hockey stick. The game begins when the referee drops the puck between the sticks of two players from opposing teams, who "face off." The rink is divided into three areas: defending, neutral, and attacking zones. Players may move with the puck and pass the puck to one another along the ice, but may not pass it more than two zones across the rink markings. A goal is scored when the puck entirely crosses the goal-line between the posts and under the crossbar of the goal. A team may field up to 20 players although only six players are allowed on the ice at one time; substitutions occur frequently. Each game consists of three periods of 20 minutes, divided by breaks of 15 minutes.

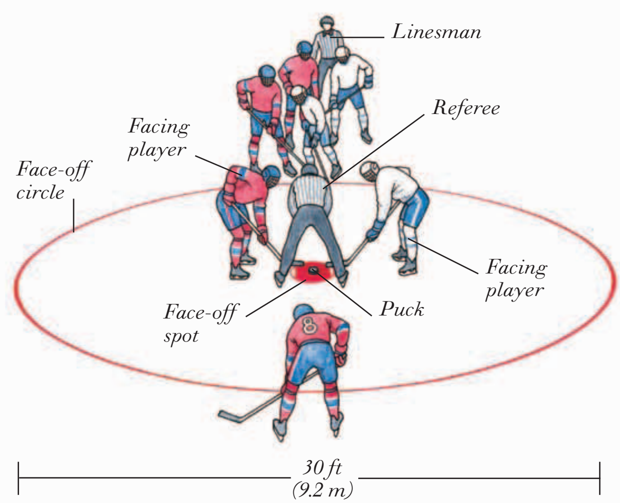
GOALKEEPER

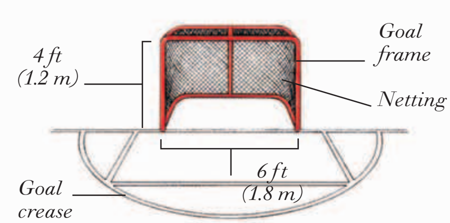


ICE HOCKEY RINK



THE FACE OFF





ICE HOCKEY GOAL


GOALKEEPER'S HELMET
Customized paintwork
Face guard
Chin protection
JOFA
PLAYER'S BODY ARMOR
Air vents
Rigid plastic shell
Manufacturer's logo
Foam padding
Chin strap
PLAYER'S HELMET
ICE HOCKEY STICKS
GOALKEEPER'S STICK
OUTFIELD PLAYER'S STICK
SHOULDER AND CHEST PADDING
Shoulder padding
ELBOW PADS
Strap
Chest padding
4 ft 9 in (147 cm)
Wrist protection
Heavy padding
Flexible gusset
Rigid finger cap
GLOVE
LEG PROTECTOR
Knee protection
Rigid plastic casing
Thick foam backing
Leg pad
Puck stopper
Wide lower shaft
Thin shaft
Vulcanized rubber
3 in (7.6 cm)
FROZEN PUCK
Ankle support
Safety heel tip
Blade
SKATE
15 in (39 cm)
Thick blade
12½ in (32 cm)
Heel
TORSPO
Pro 5000
Pro 500
CENTURION

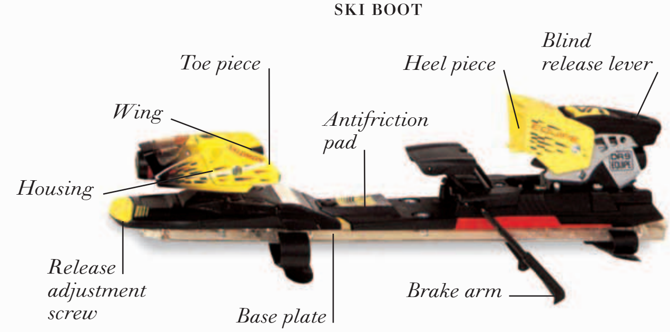
Alpine skiing

COMPETITIVE ALPINE SKIING is divided into four disciplines: downhill, slalom, giant slalom, and super-giant slalom (Super-G). Each one tests different skills. In downhill skiing, competitors race down a slope marked out by control flags, known as "gates," and are timed on a single run only. Competitors wear crash helmets, one-piece Lycra suits, and long skis with flattened tips to minimize air resistance. Slalom and giant slalom skiiers negotiate a twisting course requiring balance, agility, and quick reactions. Courses are defined by pairs of gates. Racers must pass through each pair of gates to complete the course successfully. Competitors are timed on two runs over different courses, and the skier who completes the courses in the shortest time wins. The equipment and protective guards used by slalom skiiers are shown opposite. In Super-G races, competitors ski a single run that combines the technical challenge of slalom with the speed of downhill. The course requires skiers to complete medium-to-long radius turns at high speed, and contain up to two jumps. Clothing is the same as for downhill, but slightly shorter skis are used.

DOWNHILL SKIER

ALPINE SKI SLOPE COURSES

SKI BOOT

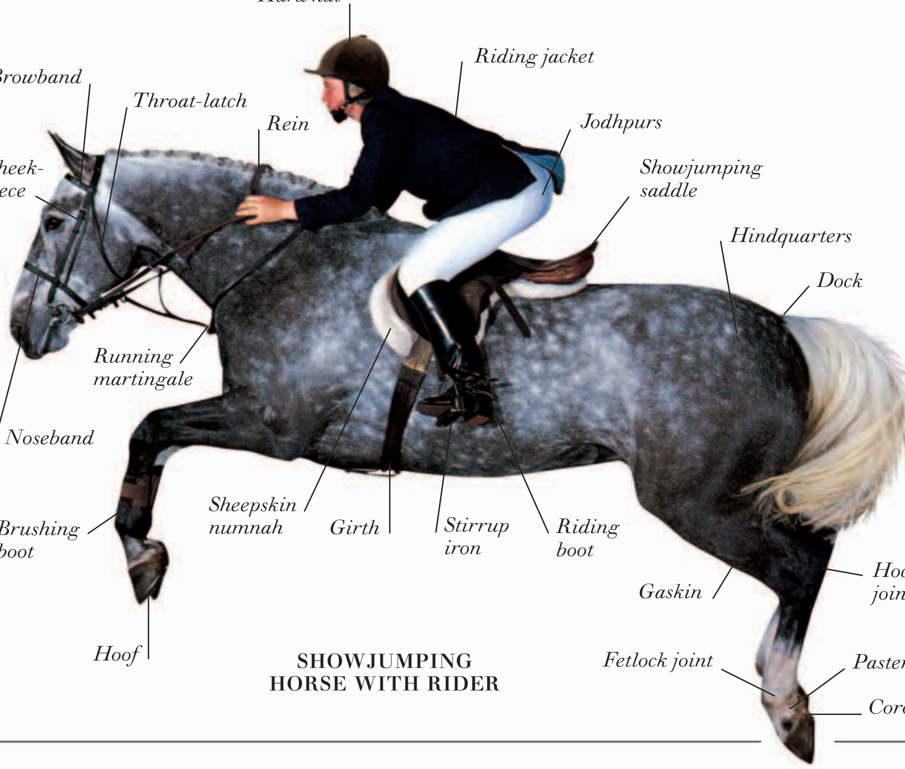


SAFETY BINDING

SLALOM CLOTHING AND EQUIPMENT

Equestrian sports

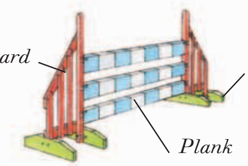
Equestrian sports have taken place throughout the world for centuries: events involving mounted horses were recorded in the Olympic Games of 642 BC. Showjumping, however, is a much more recent innovation, and the first competitions were held at the beginning of the 1900s. In this sport, horse and rider must negotiate a course of variable, unfixed obstacles, making as few mistakes as possible. Showjumping fences consist of wooden stands, known as standards or wings, that support planks or poles. Parts of the fence are designed to collapse on impact, preventing injury to the horse and rider. Judges penalize competitors for errors, such as knocking down obstacles, refusing jumps, or deviating from the course. Depending on the type of competition, the rider with the fewest faults, most points, or fastest time wins. There are two basic forms of horse racing—flat races and races with jumps, such as steeplechase or hurdle races. Thoroughbred horses are used in this sport, since they have great strength and stamina and can achieve speeds of up to 40 mph (65 kph). Jockeys wear "silks"—caps and jackets designed in distinctive colors and patterns that help identify the horses. In harness racing, the horse is driven from a light, two-wheeled carriage called a sulky. Horses are trained to trot and to pace, and different races are held for each of these types of gait. In pacing races, the horses wear hobbles to prevent them from breaking into a trot or gallop. Breeds such as the Standardbred and the French Trotter have been developed especially for this sport.



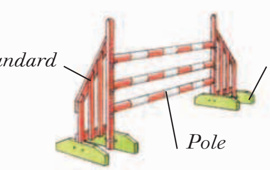
SHOWJUMPING HORSE WITH RIDER

SHOWJUMPING SADDLE

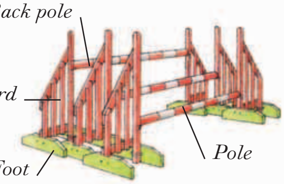
SHOWJUMPING FENCES



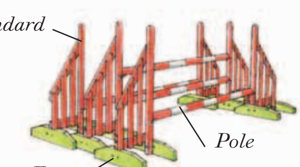
UPRIGHT PLANKS



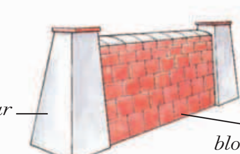
UPRIGHT POLES



TRIPLE BAR (STAIRCASE)



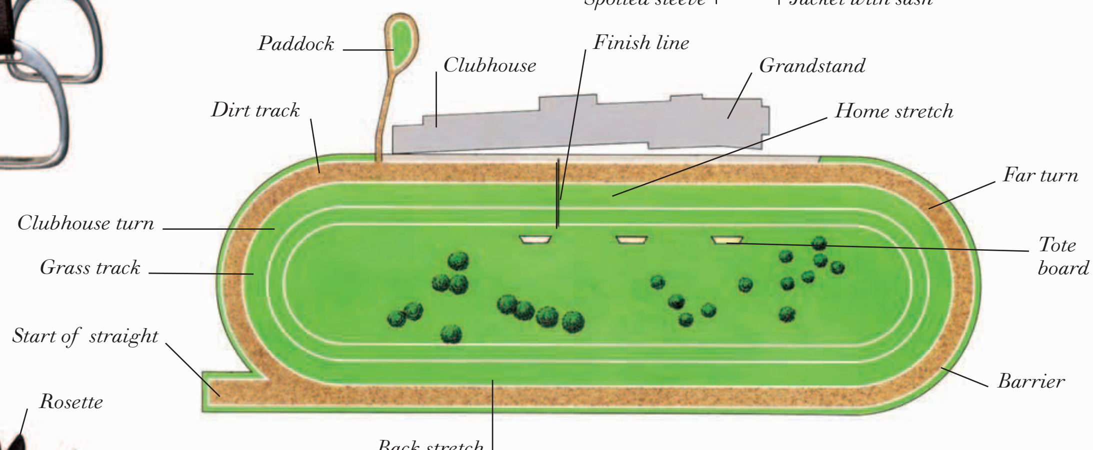
HOG'S-BACK



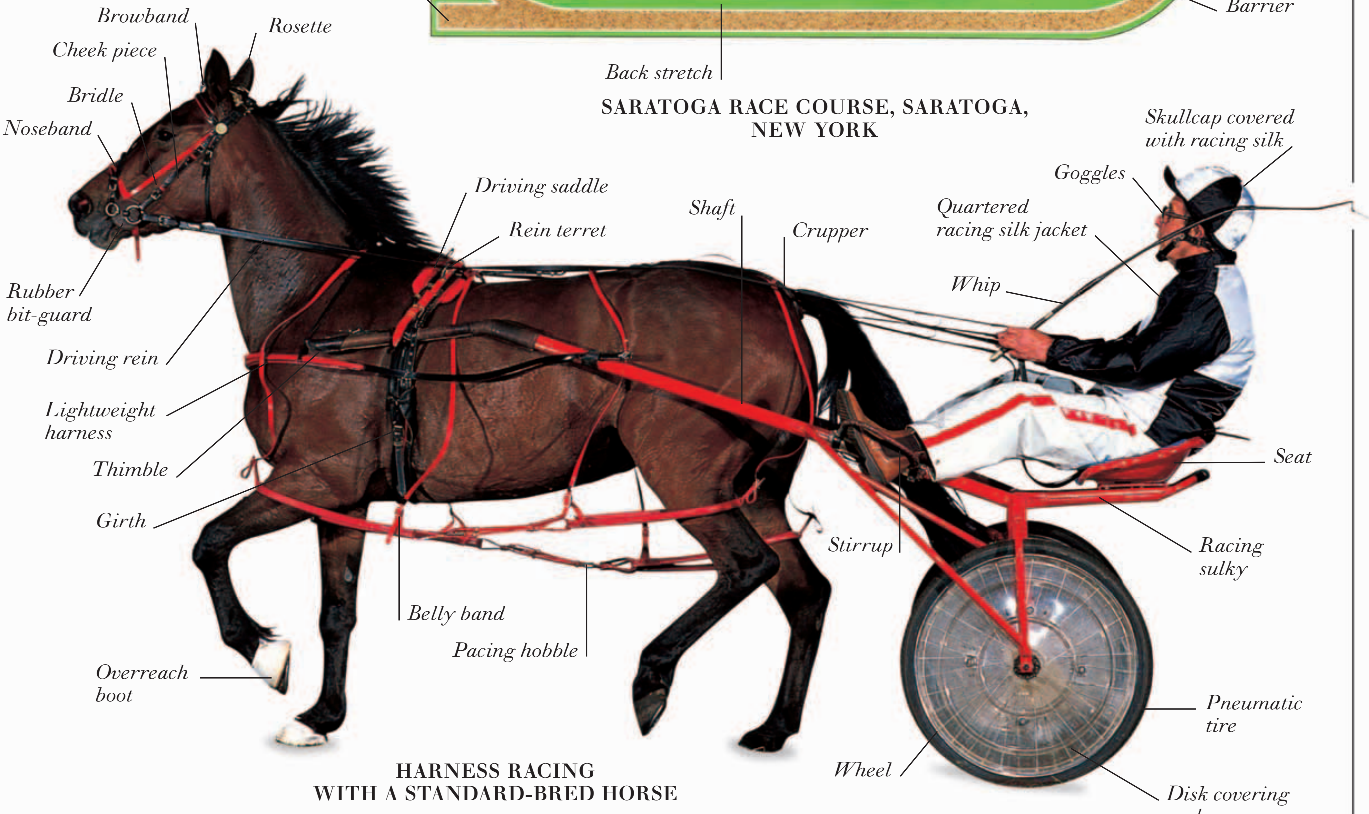
WALL

RACING SADDLE

RACING SILKS



SARATOGA RACE COURSE, SARATOGA, NEW YORK

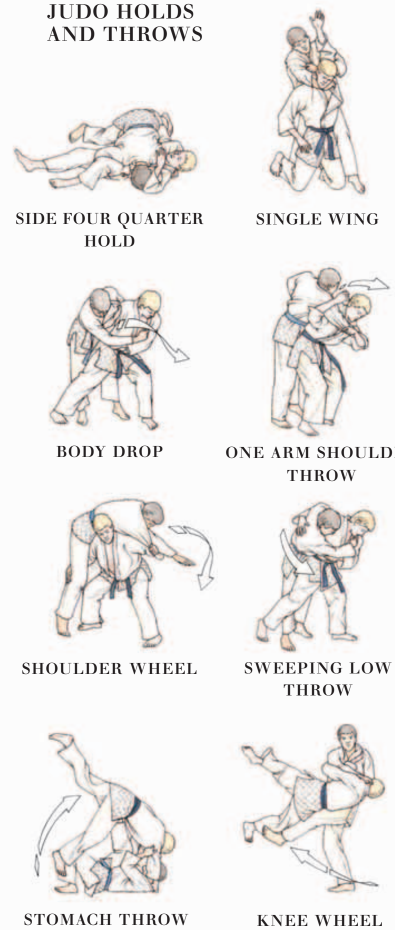


HARNESS RACING WITH A STANDARD-BRED HORSE

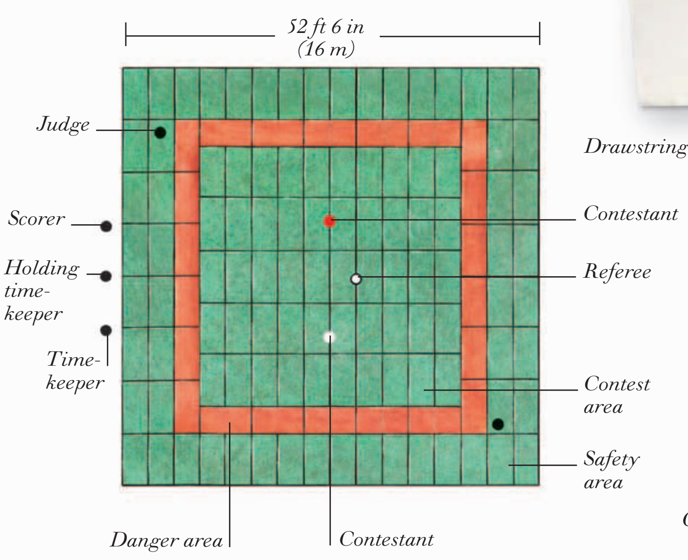
Judo and fencing

COMBAT SPORTS ARE BASED ON THE SKILLS used in fighting. In these sports, the competitors may be unarmed—as in judo and boxing—or armed—as in fencing and kendo. Judo is a system of unarmed combat developed in the East. Translated from the Japanese, the name means "the gentle way." Students learn how to turn an opponent's force to their own advantage. The usual costume is loose white pants and a jacket, fastened with a cloth belt. The color of belt indicates the student's level of expertise, from white-belted novices to the expert "black belts." Competitions take place on a mat or "shiaijo," 30 or 33 ft (9 or 10 m) square in size, bounded by "danger" and "safety" areas to prevent injury. Competitors try to throw, pin, or master their opponent by applying pressure to the arm joints or neck. Judo bouts are strictly monitored, and competitors receive points for superior technique, not for injuring their opponent. Fencing is a combat sport using swords, which takes place on a narrow "piste" 46 ft (14 m) long. Competitors try to touch specific target areas on their opponent with their sword or "foil" while avoiding being touched themselves. The winner is the one who scores the greatest number of hits. Fencers wear clothing made from strong white material that affords maximum protection while allowing freedom of movement, steel mesh masks with padded bibs to protect the fencer's neck, and a long white glove on their sword hand. Fencing foils do not have sharpened blades, and their tips end in a blunt button to prevent injuries. Three types of swords are used—foils, épées, and sabers. Official foil and épée competitions always use an electric scoring system. The sword tips are connected to lights by a long wire that passes underneath each fencer's jacket. A bulb flashes when a hit is made.

JUDO HOLDS AND THROWS

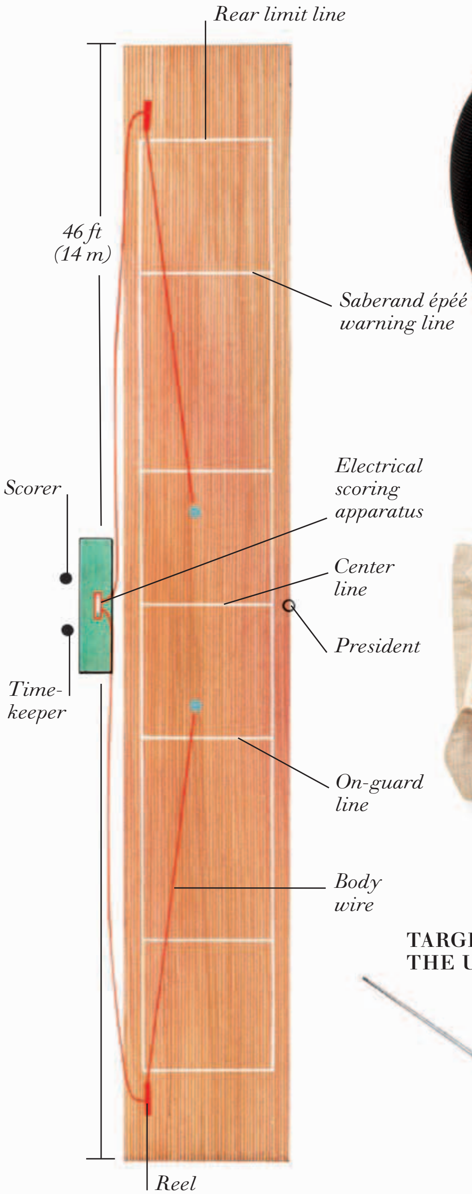


JUDO MAT

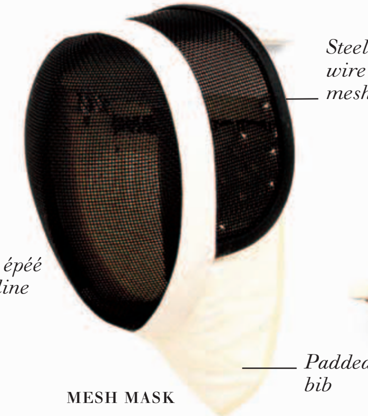


UNIFORM

FENCING PISTE



FENCING EQUIPMENT

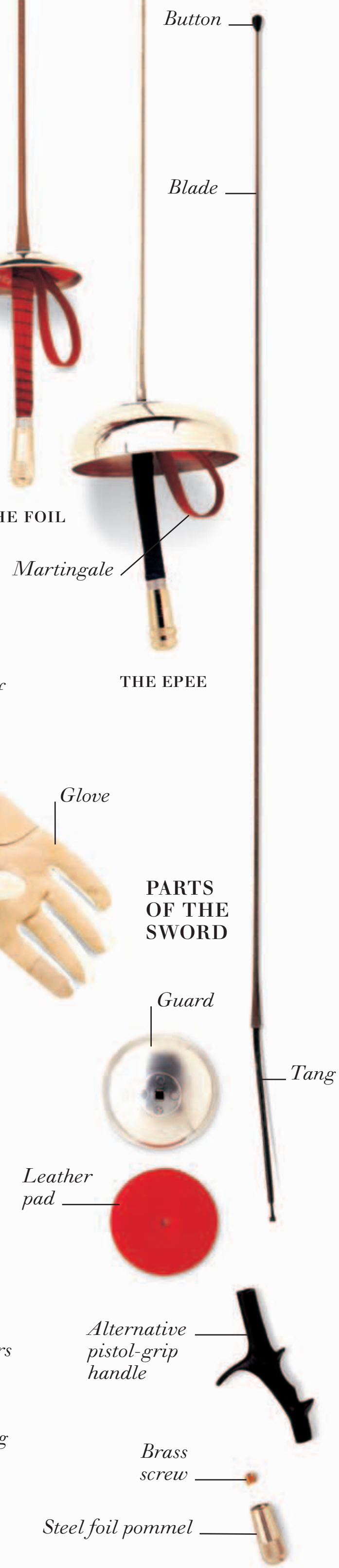


MESH MASK

METAL JACKET

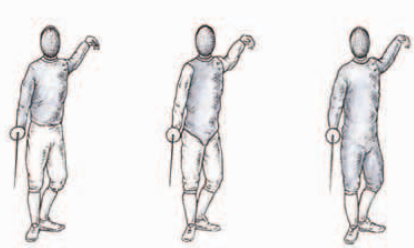
GAUNTLET

PARTS OF THE SWORD



TARGET AREAS ON THE UPPER BODY

FENCING TARGET AREAS

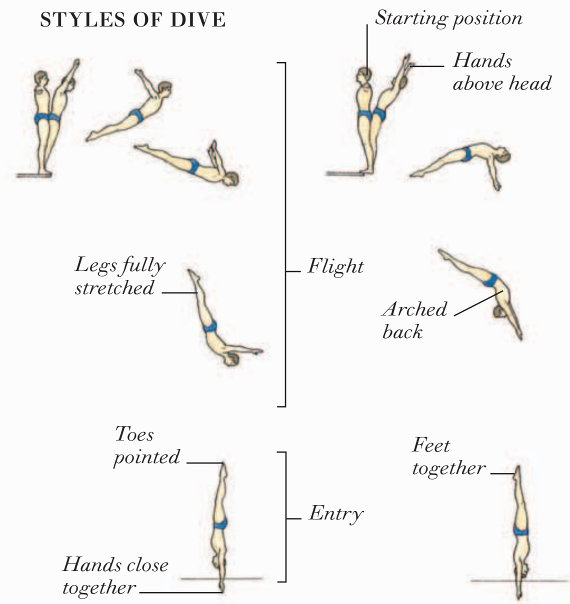


Swimming and diving

SWIMMING GOGGLES

SWIMMING WAS INCLUDED in the first modern Olympic Games in 1896 and diving events were added in 1904. Swimming is both an individual and a team sport and races take place over a predetermined distance in one of the four major categories of stroke—freestyle (usually front crawl), butterfly, breaststroke, and backstroke. Competition pools are clearly marked for racing and antiturbulence lane lines are used to separate the swimmers and help keep the water calm. The first team or individual to finish the race is the winner. Competitive diving is divided into men's and women's springboard and platform (highboard) events. There are six official groups of dives: forward dives, backward dives, armstand dives, twist dives, reverse dives, and inward dives. Competitors perform a set number of dives and after each one a panel of judges award marks according to the quality of execution and the degree of difficulty.

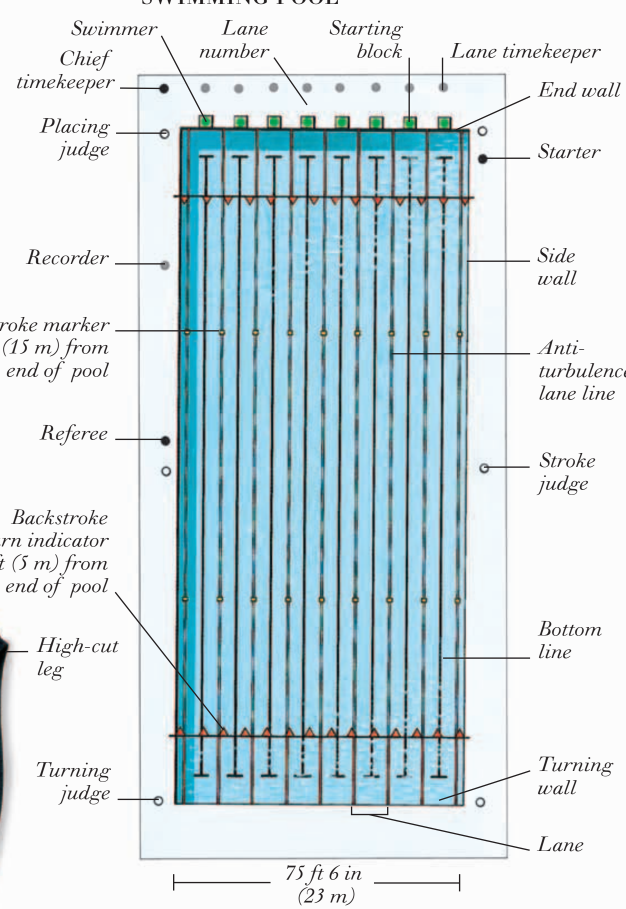
STYLES OF DIVE



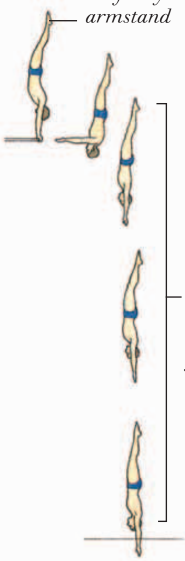
FORWARD DIVE

BACKWARD DIVE

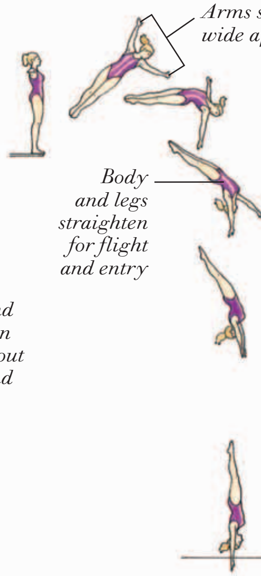
SWIMMING POOL



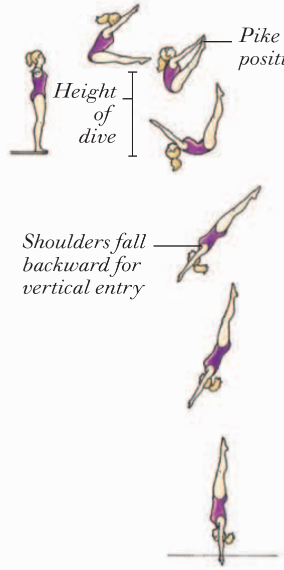
SWIMWEAR



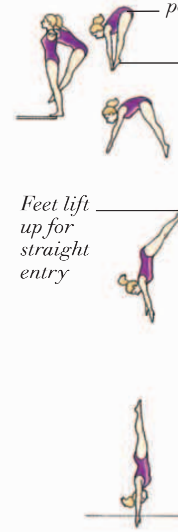
ARMSTAND DIVE



TWIST DIVE

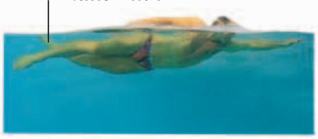


REVERSE DIVE PIKED



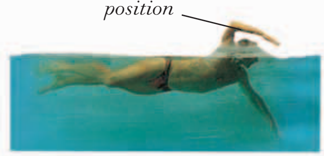
INWARD DIVE PIKED

FRONT CRAWL



FULL BODY STRETCH

LOWER ARM PULL



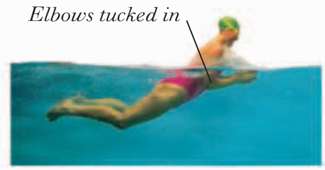
STREAMLINED ARM ENTRY

SIDE-TO-SIDE BODY ROLL

BREASTSTROKE

BODY GLIDE

DOUBLE ARM PULL



SQUEEZING THE WATER

FROG KICK

BACKSTROKE

BODY ROLL

PULLING THROUGH

STRAIGHTENING OUT

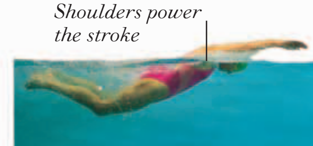
SHOULDER LIFT

BUTTERFLY

CATCHING THE WATER

DOUBLE ARM PULL

KICKING DOWN



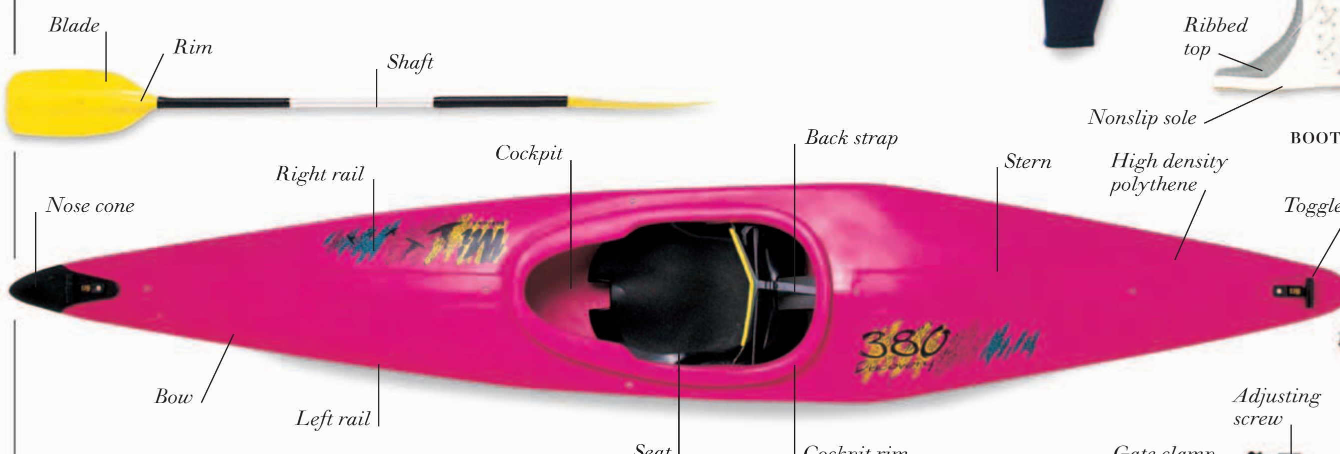
WHOLE BODY UNDULATION

Canoeing, rowing, and sailing

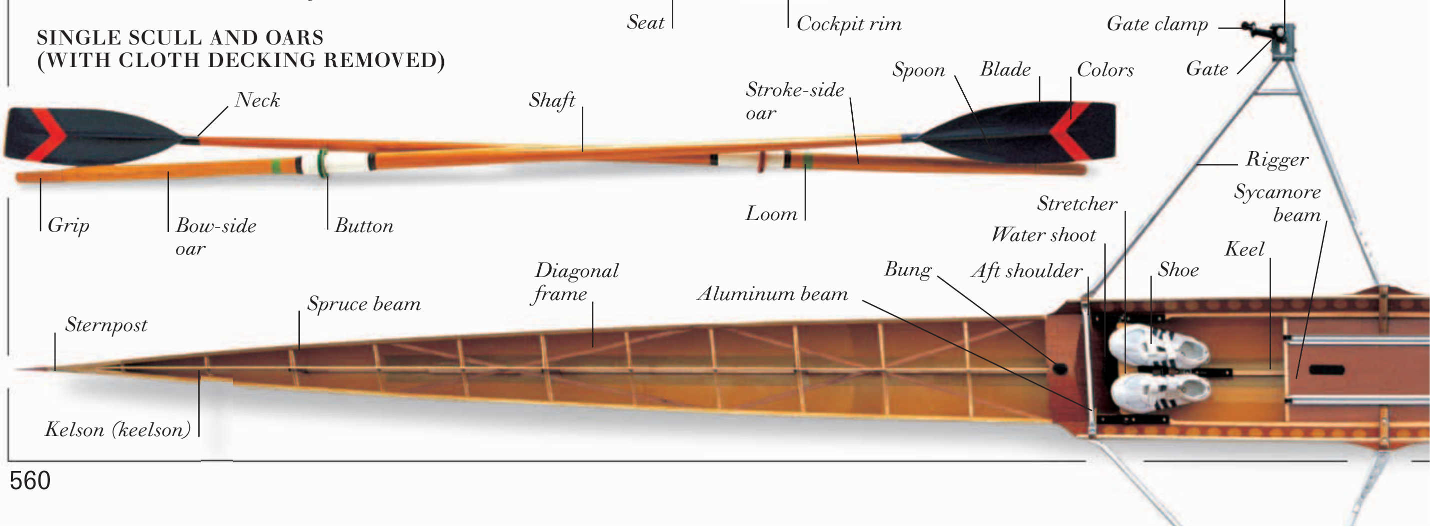
WATERBORNE SPORTS are as varied as the crafts used. There are two disciplines in rowing; sweep rowing, in which each rower has one oar, and sculling, in which rowers use two oars. There are a number of different Olympic and competitive rowing events for both men and women. The number of rowers and weight classes vary. Some rowing events use a coxswain; a steersman who does not row but directs the crew. Kayaks and canoes are used in straight sprint and slalom races. Slalom races take place over a course consisting of 20 to 25 gates, including at least six upstream gates. In yacht racing, competitors must complete prescribed courses, organized by the race committees, in the shortest possible time, using sail power only. Olympic events include classes for keel boats, dinghies, and catamarans.

SAILING GEAR

ONE-PERSON KAYAK AND PADDLE

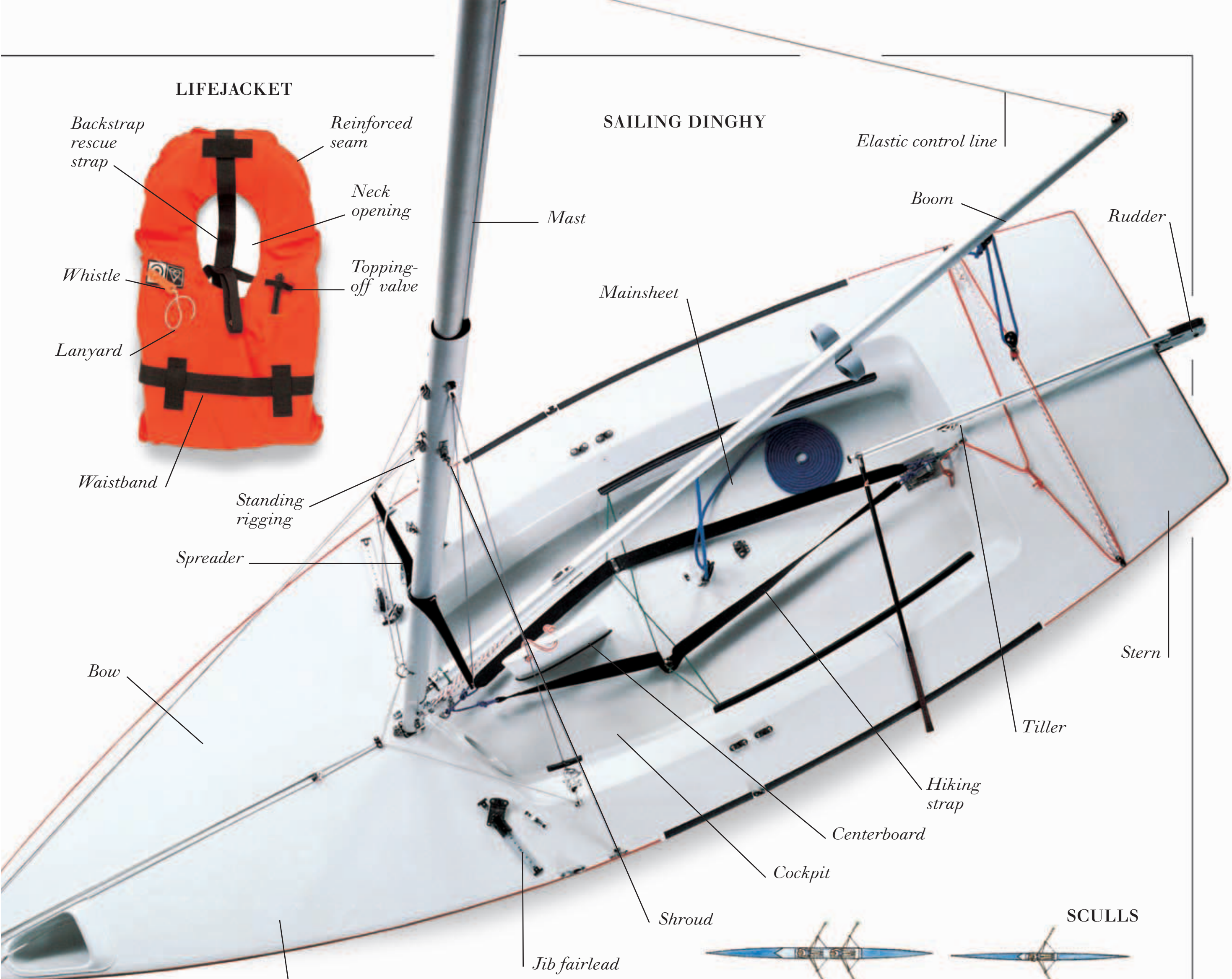


SINGLE SCULL AND OARS (WITH CLOTH DECKING REMOVED)

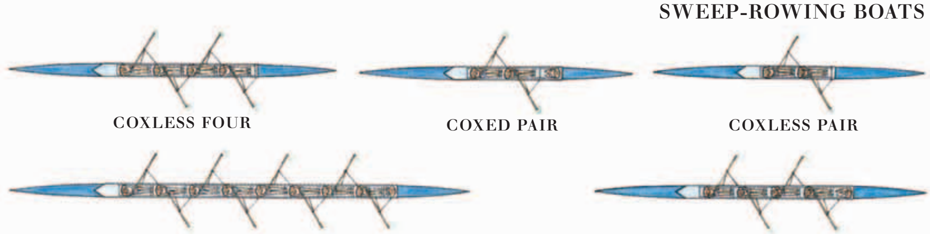


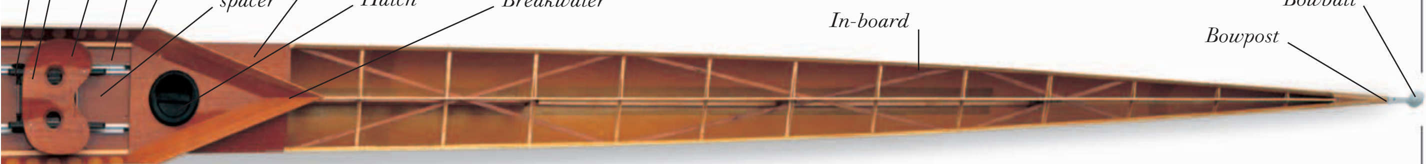
LIFEJACKET

SAILING DINGHY



SWEEP-ROWING BOATS



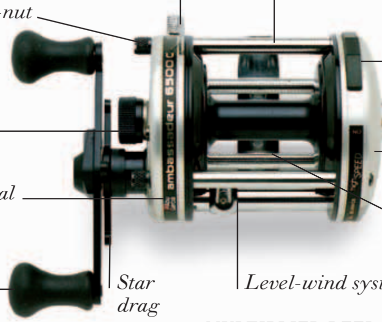


Angling

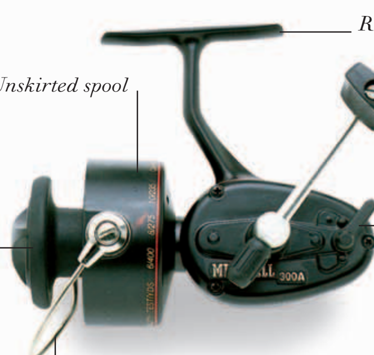
ANGLING MEANS FISHING WITH A ROD, reel, line, and lure. There are several different types of angling: freshwater coarse angling, for members of the carp family and pike; freshwater game angling, for salmon and trout; and sea angling, for sea fish such as flatfish, bass, and mackerel. Anglers use a variety of methods for catching fish. These include bait fishing, in which bait (food to allure the fish) is placed on a hook and cast into the water; fly fishing, in which a natural or artificial fly is used to lure the fish; and spinning, in which a lure that looks like a small fish revolves as it is pulled through the water. The angler uses the rod, reel, and line to cast the lure over the water. The reel controls the line as it spills off the spool and as it is wound back. Weights may be fixed to the line so that it will sink. Swivels are attached to prevent the line from twisting. When a fish bites, the hook must become embedded in its mouth and remain there while the catch is reeled in.

BUTT SECTION

REELS

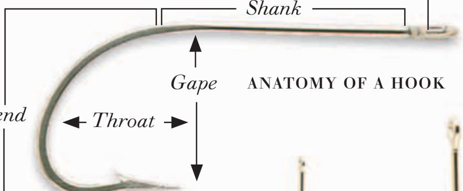


MULTIPLIER REEL

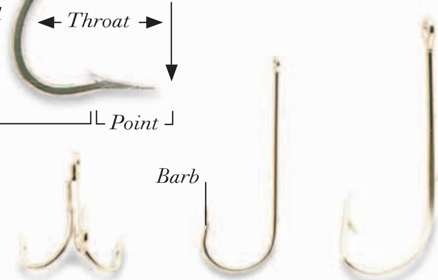


FIXED-SPOOL REEL

HOOKS, SWIVELS, AND WEIGHTS



ANATOMY OF A HOOK



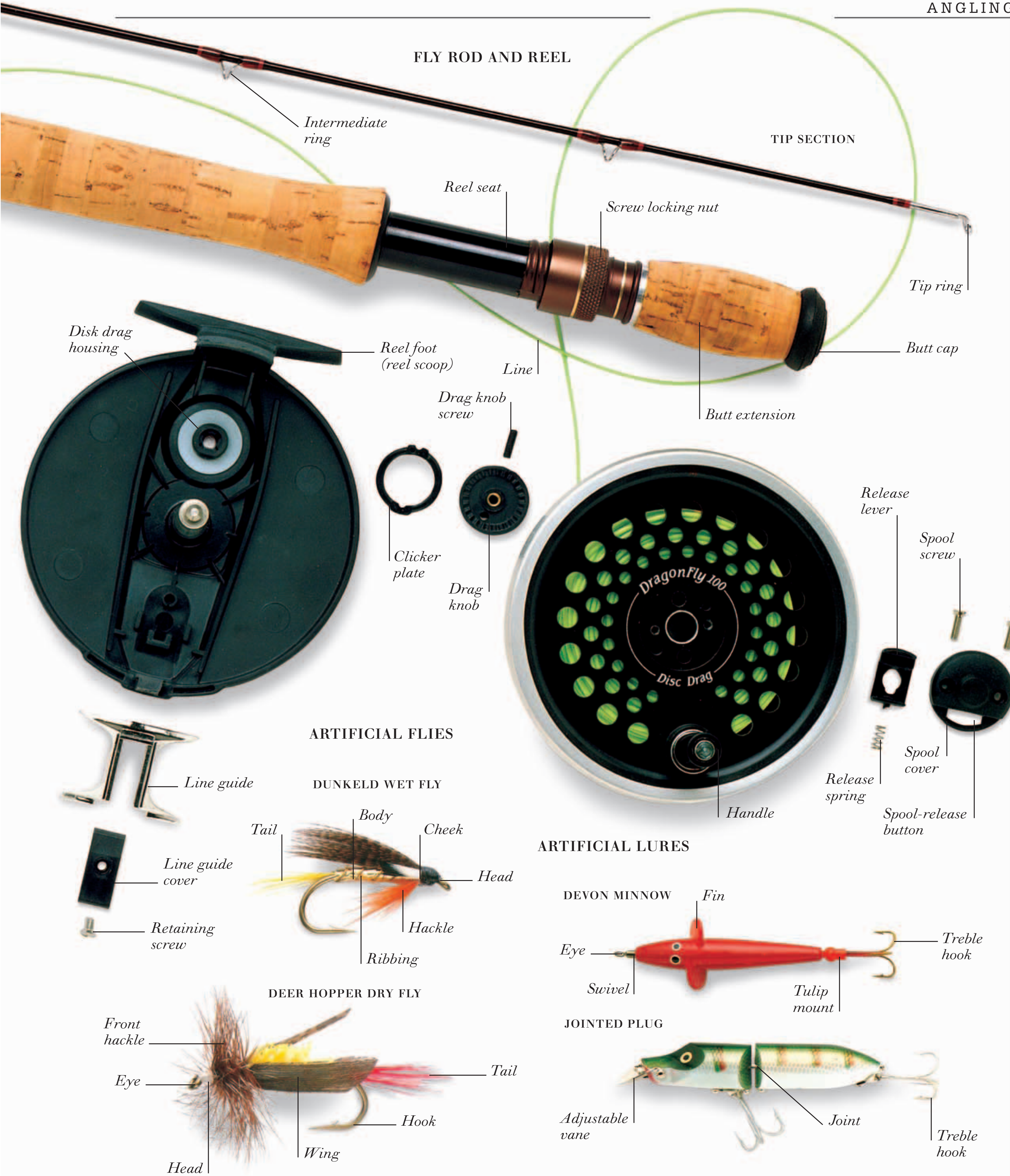
TREBLE HOOK

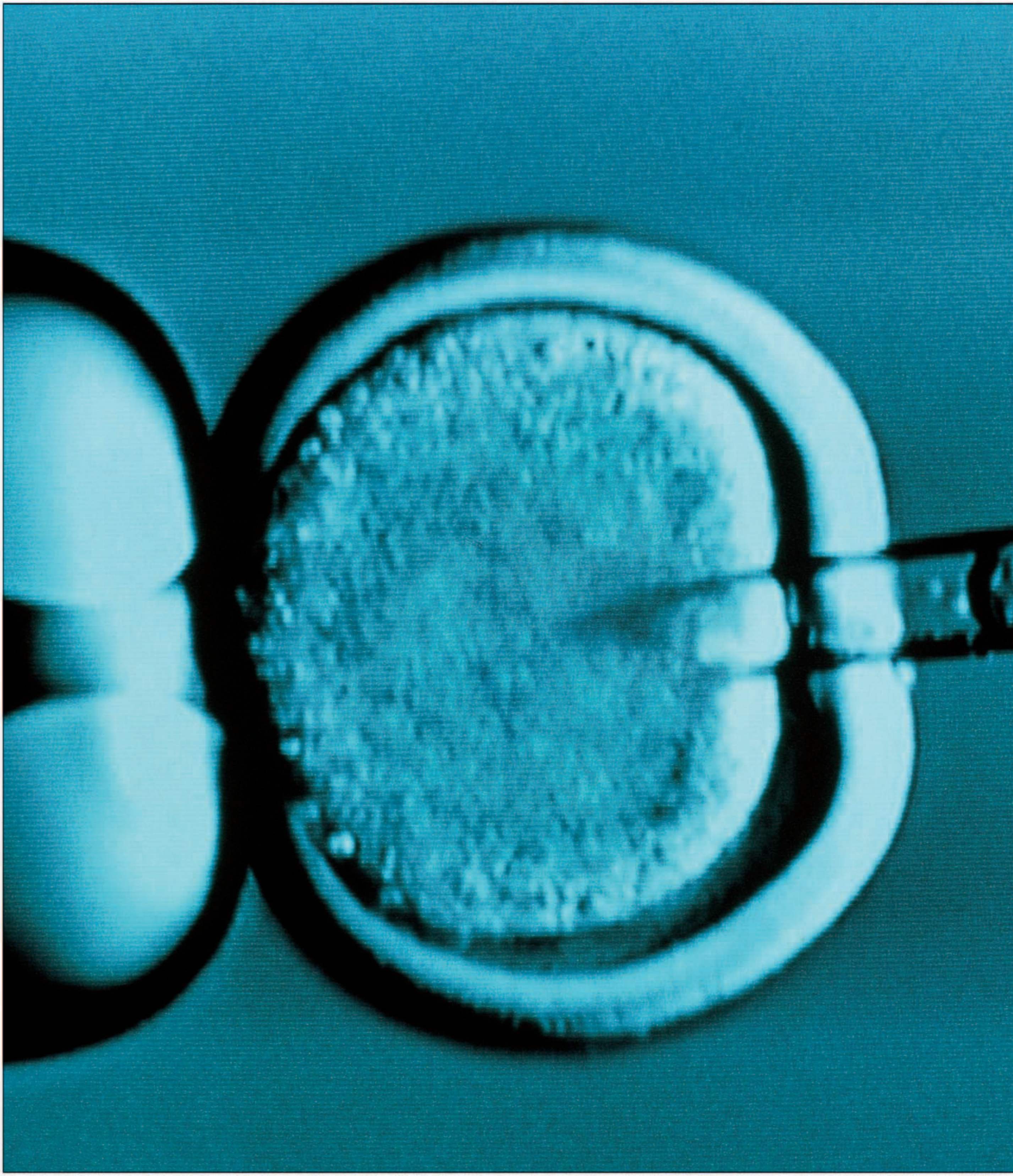
ABERDEEN HOOK

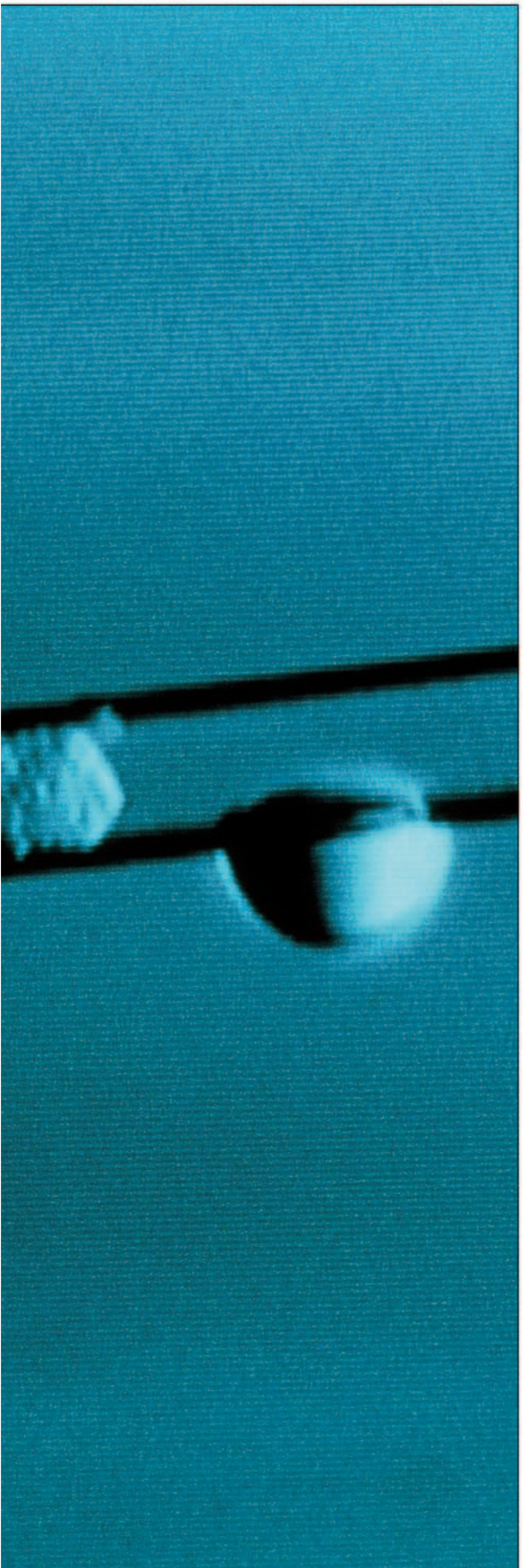
REVERSED BEND HOOK

EXAMPLES OF BARREL SWIVELS

HILLMAN ANTIKINK WEIGHT


FLY ROD AND REEL
Intermediate ring
TIP SECTION
Reel seat
Screw locking nut
Tip ring
Disk drag housing
Reel foot (reel scoop)
Line
Butt cap
Drag knob screw
Butt extension
Clicker plate
Drag knob
Release lever
Spool screw
DragonFly 100
Disc Drag
Spool cover
Release spring
Handle
Spool-release button
ARTIFICIAL FLIES
Line guide
DUNKELD WET FLY
Body
Tail
Cheek
Head
Line guide cover
Hackle
Retaining screw
Ribbing
ARTIFICIAL LURES
DEVON MINNOW
Fin
Eye
Treble hook
Swivel
Tulip mount
DEER HOPPER DRY FLY
Front hackle
Eye
Tail
Hook
Wing
Head
JOINTED PLUG
Adjustable vane
Joint
Treble hook





THE MODERN WORLD

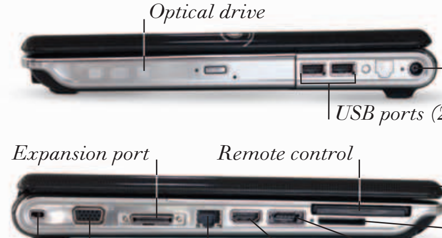
Personal computer

PERSONAL COMPUTERS (PCs) fall into two main types: IBM-compatible PCs, known simply as PCs, and Apple Macintosh PCs, known as "Macs." They differ in the way files and programs, and the user's access to them, are organized, and programs must be tailored for each type. However, in most other respects PCs and Macs have much in common. Both contain microchips, or integrated circuits, that store and process data. The "brain" of any PC is a chip known as the central processing unit (CPU), which performs mathematical operations in order to run program instructions and receive, store, and output data. The most powerful personal computer CPUs today can perform more than a billion calculations a second. Data can be input via CDs, USB memory sticks, and other storage media. Highly portable laptop and network PCs are also in widespread use. Most PCs are able to communicate with many other devices, including digital cameras (see pp. 580-81) and smartphones (see pp. 588-89).

iMAC

REAR OF iMAC

HP PAVILION DV4 LAPTOP

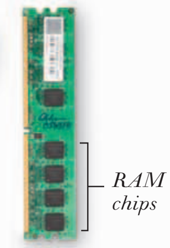


SIDE VIEW OF HP PAVILION DV4 LAPTOP

COMPONENTS OF A SYSTEM UNIT

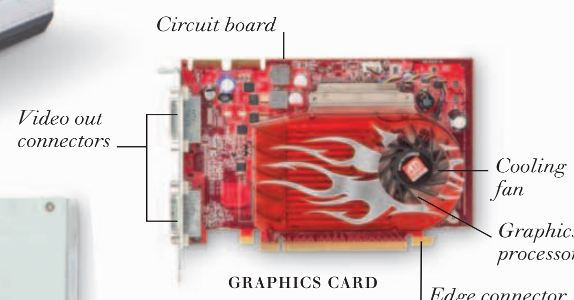
SYSTEM UNIT OF A PC

COOLING FAN



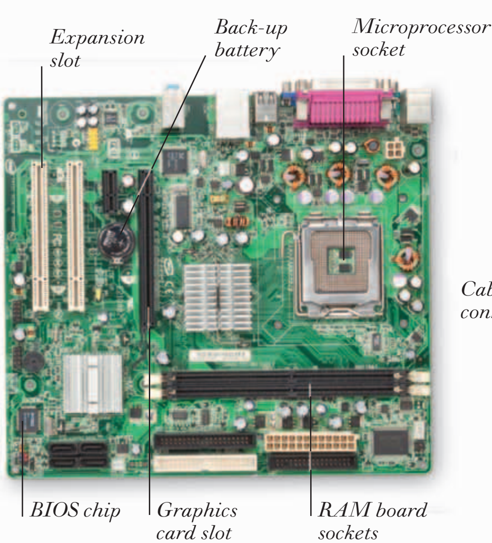
RAM BOARD

CD DRIVE

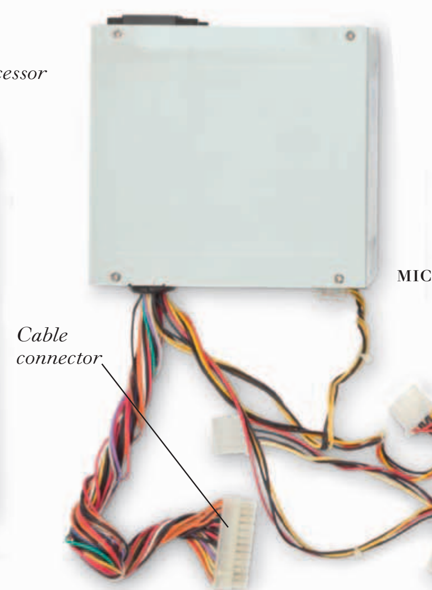


GRAPHICS CARD

SIDE CABLE



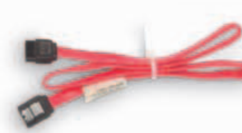
MOTHERBOARD



POWER SUPPLY

MICROPROCESSOR

HARD DISC DRIVE

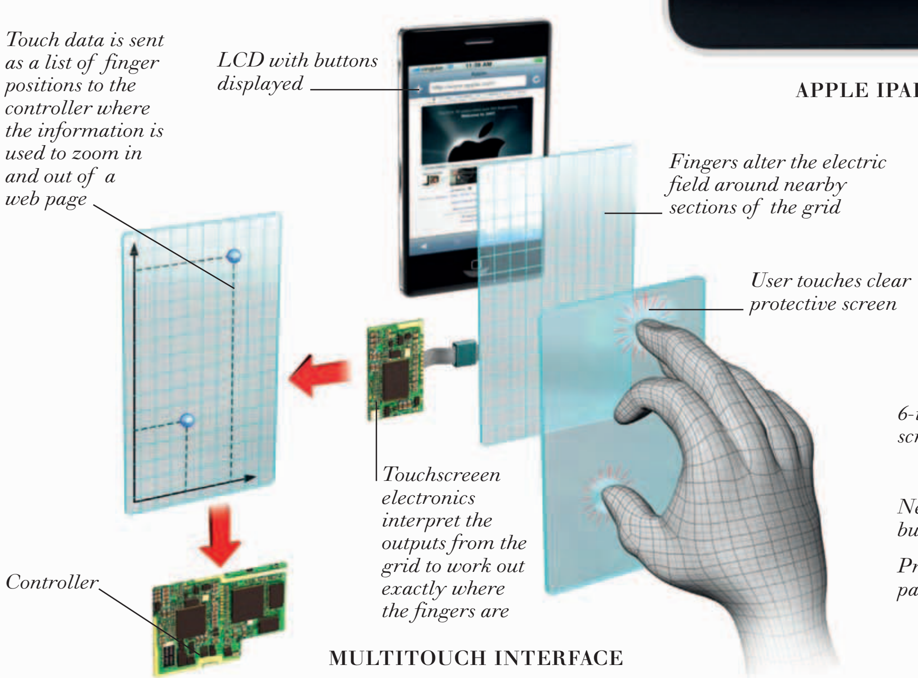


DATA CABLE

Handheld computer

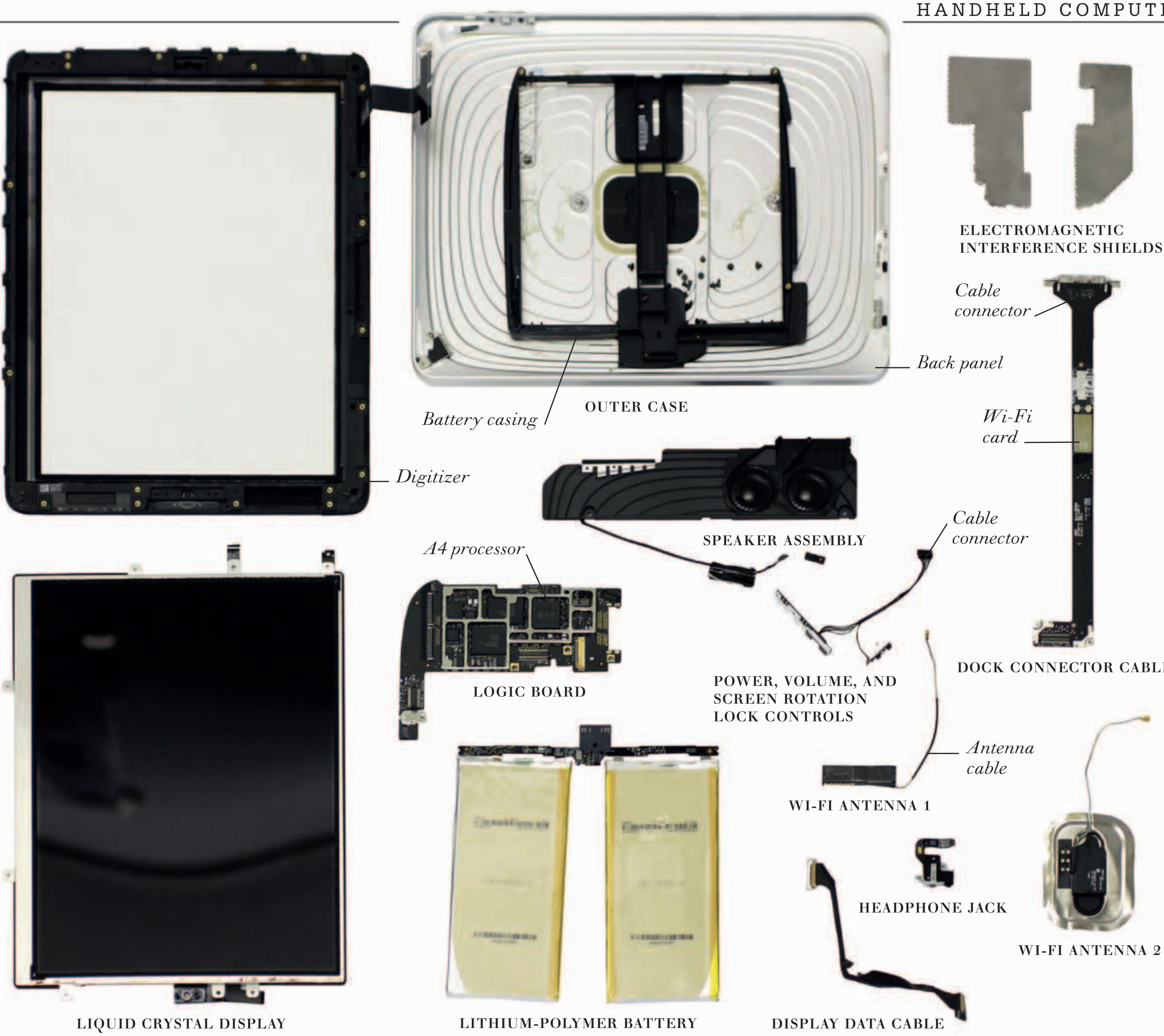
BY THE EARLY 1990s electronic circuitry had been miniaturized to such an extent that it was possible to make small handheld computing devices. The first of these was the Personal Digital Assistant (PDA), which offered features including an address book, calendar, and notepad. In recent years, PDAs have been overtaken by smartphones with internet and email access (see pp. 588–589). A related product is the e-book reader, which stores books in digital form and uses "electronic paper" to mimic the appearance of ink on real paper. An e-book reader no bigger than a thin paperback can store several thousand digital books in its memory. The most recent small computing device is the handheld computer. This looks like a thin flat display, but it is actually a complete computer. Handheld computers are typically controlled by a touch-sensitive screen and have a wireless link to other computers and the internet. They run software applications, or apps, downloaded from the internet. The most popular handheld computer currently is the Apple iPad. It has a multitouch interface that enables its screen to detect the movements of fingertips. In addition to selecting options and apps by touching the screen, images can be enlarged or shrunk by moving fingertips apart or together on the screen.

APPLE IPAD

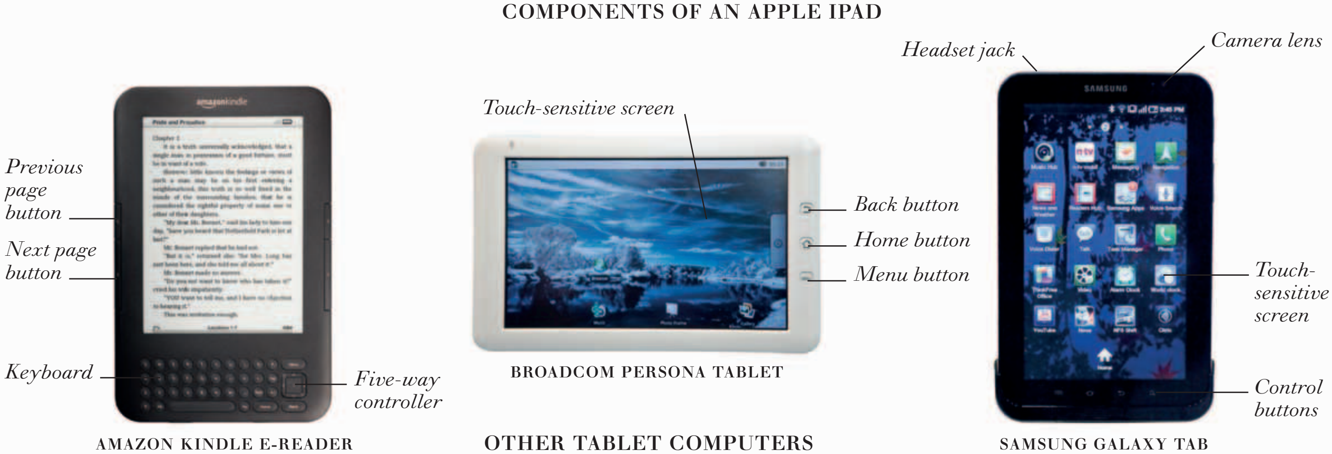


MULTITOUCH INTERFACE

ACER LUMIREAD E-READER



COMPONENTS OF AN APPLE IPAD

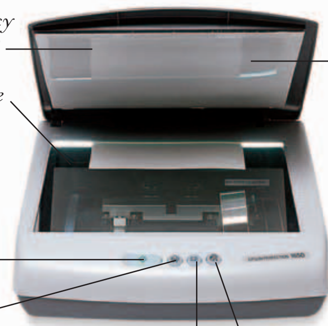


OTHER TABLET COMPUTERS

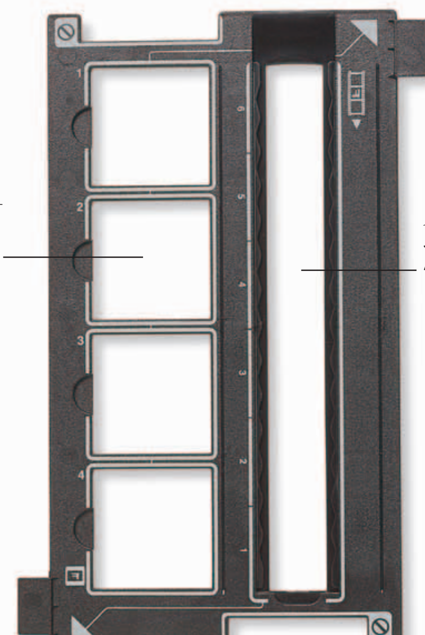
Flatbed scanner

SCANNERS CONVERT physical images into electronic form, allowing them to be sent over the internet, displayed on a website, stored on a computer, and manipulated using specialized software. Scanners work by detecting and analyzing light reflected from an opaque image, such as a photographic print. Some can also scan photographic transparencies by analyzing light that has passed through the image. Flatbed scanners contain a unit, called the scan head, that contains a lamp, mirrors, a lens, and an array of CCDs (Charge-Coupled Devices). The carriage passes beneath the image; the lamp shines light on to or through the original; the mirrors reflect the light on to the lens, which focuses it on to the CCD array. Each CCD detects the brightness of light from a particular pixel (picture element) along a horizontal strip and converts this data into an electric signal. For color images, the light is usually passed through red, green, and blue filters and then directed to the CCD array so that it can be broken down into its component colors. This information is then converted to digital form. The quality of the image depends on its resolution, measured in dpi (Dots Per Inch).

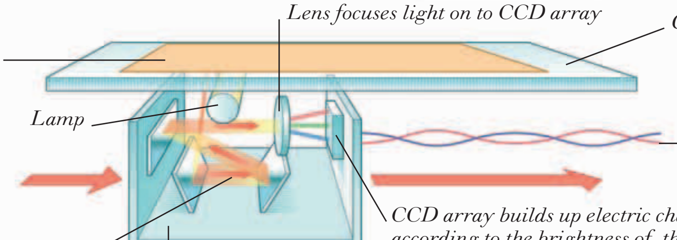
SCANNER



FILM AND SLIDE HOLDER



HOW A FLATBED SCANNER WORKS



COMPONENTS OF A SCANNER

UNDERSIDE OF SCAN HEAD COVER

OVERHEAD VIEW

LID ASSEMBLY

UNDERSIDE OF COVER

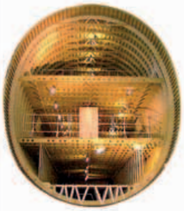
THE EFFECT OF SCANNING AT DIFFERENT RESOLUTIONS

15 DPI
Lowest resolution at which you may scan.

72 DPI
Used for websites and screen images.

300 DPI
Used for printing books and magazines.

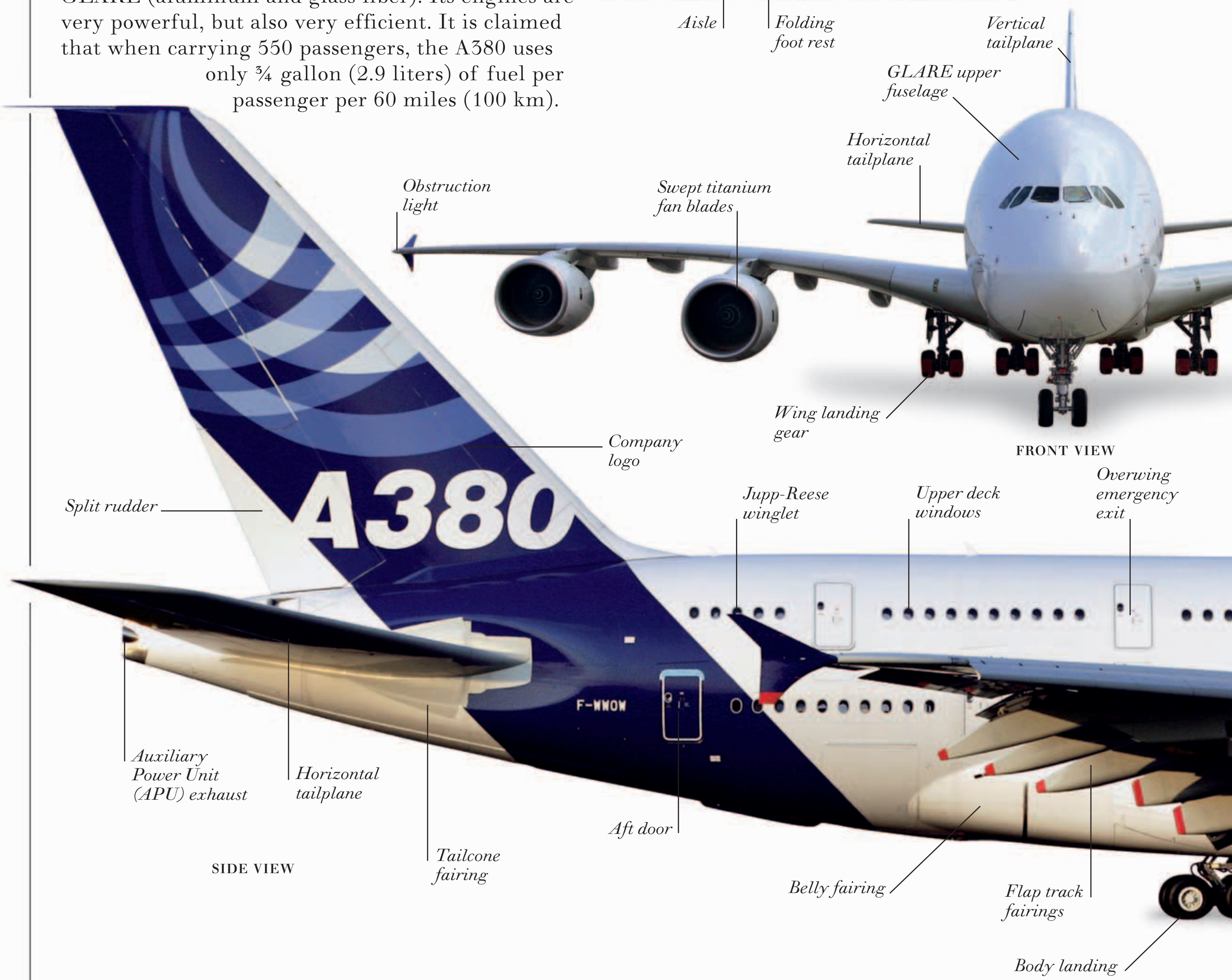
Airbus 380



CROSS-SECTION OF FUSELAGE

THE AIRBUS A380 WAS CONCEIVED in the early 1990s to compete with, and if possible replace, the Boeing 747. Work began in earnest on what was then called the A3XX in 1994. Its maiden flight was in April 2005. The A380's shape is subtly molded to minimize drag from its ovoid fuselage. The structure makes extensive use of composite materials, such as thermoplastics and GLARE (aluminum and glass fiber). Its engines are very powerful, but also very efficient. It is claimed that when carrying 550 passengers, the A380 uses only ¾ gallon (2.9 liters) of fuel per passenger per 60 miles (100 km).

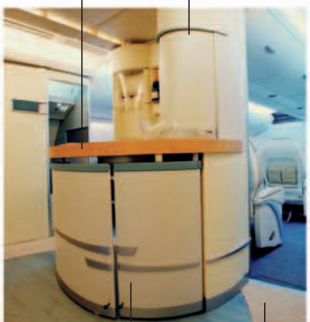
INTERIOR VIEW OF BUSINESS CLASS CABIN



FRONT VIEW

SIDE VIEW

INTERIOR VIEW OF GALLEY

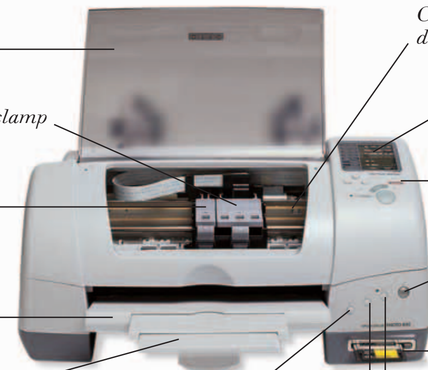


COCKPIT

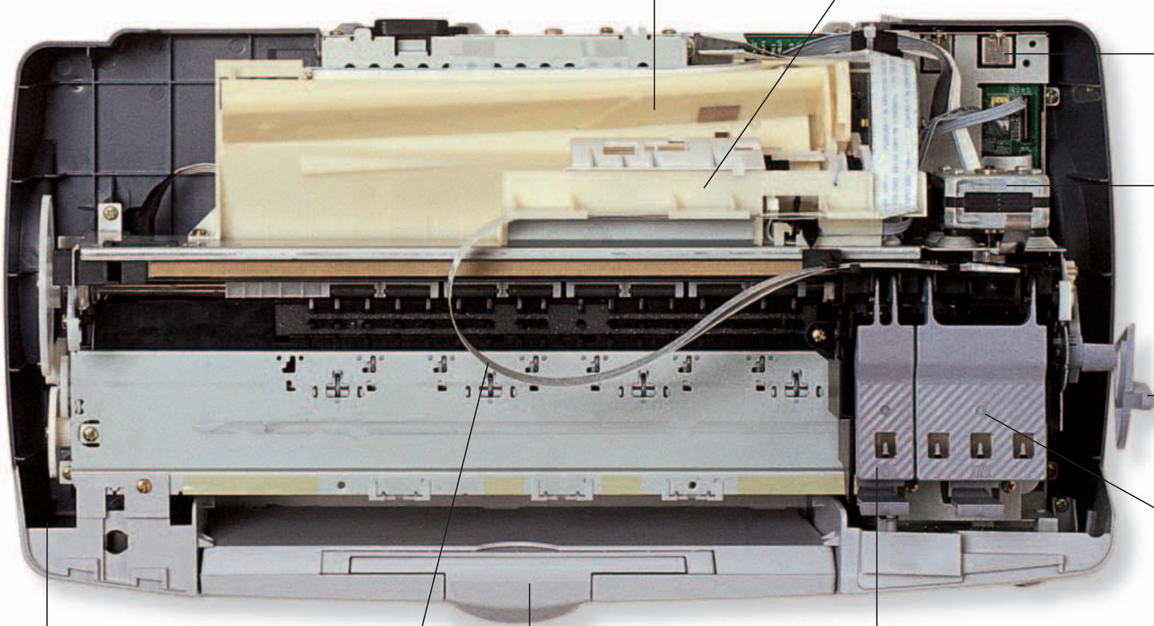
Inkjet printer

INKJET PRINTERS EXPEL ink droplets from hundreds of tiny jets, or nozzles, on to a medium, such as paper, to print an image. Each droplet corresponds to a single pixel (picture element). Black-and-white printers use only black ink, while color printers overprint combinations of the printing colors (cyan, yellow, magenta, and black) to create a full color range. The printhead containing the nozzles moves sideways across the paper, creating a line of pixels, before the paper moves slightly forward so the next line can be printed. Two basic methods are used to eject ink: thermal, in which ink is heated to form an expanding bubble that expels a droplet from the nozzle, and piezoelectric, in which an electric current expands a crystal causing it to push out the ink droplet. The printer shown here can print digital photographs directly from a memory card.

EPSON STYLUS PHOTO 895 COLOR INKJET PRINTER



OVERHEAD VIEW WITH OUTER CASING REMOVED

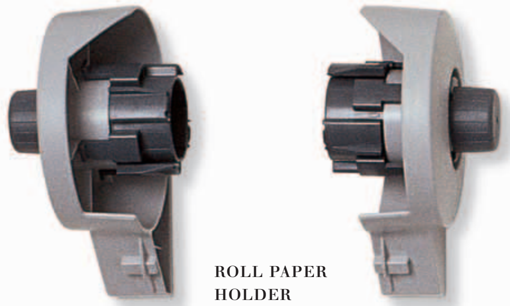


INK CARTRIDGES

PC CARD ADAPTER

PAPER FEED COMPONENTS

ROLL PAPER HOLDER ADAPTER

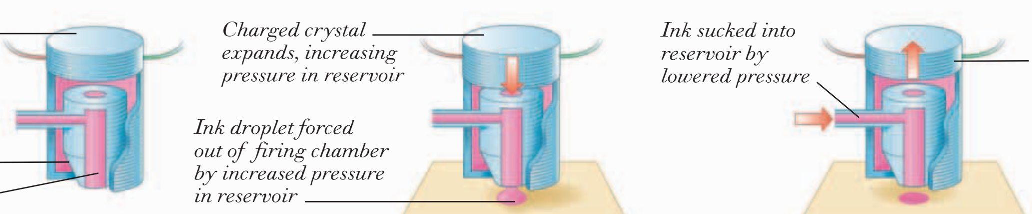


ROLL PAPER HOLDER

PAPER SUPPORT

OVERHEAD VIEW OF CASING

HOW A PIEZOELECTRIC INKJET PRINTHEAD WORKS



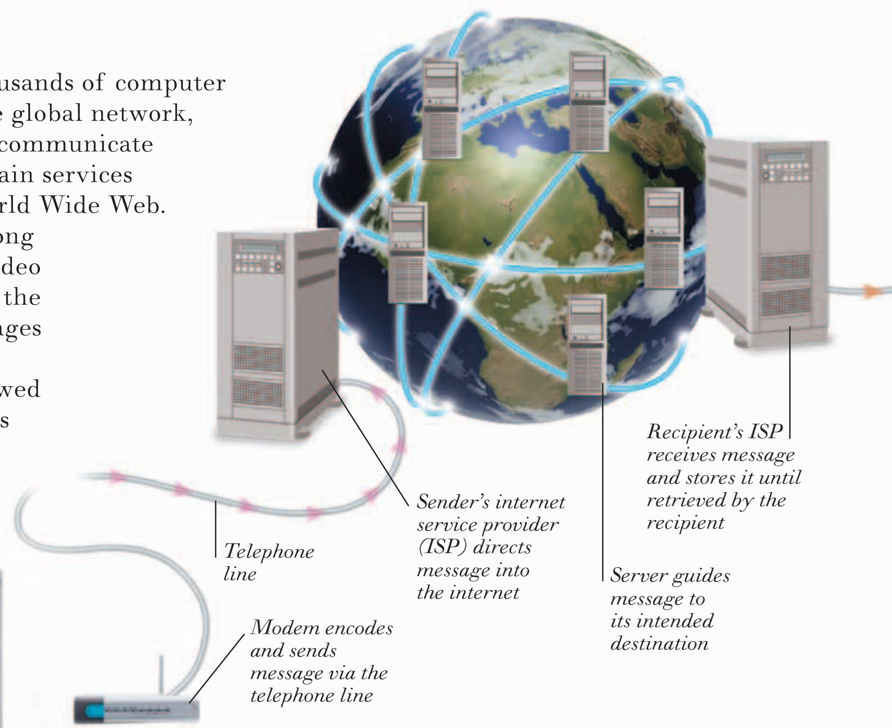
INKJET NOZZLE

DROPLET EJECTED

CHAMBER REFILLED

The internet

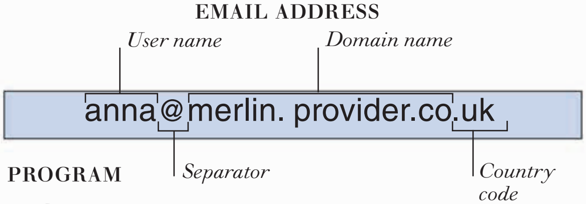
THE INTERNET CONSISTS OF TENS of thousands of computer networks linked together to form one huge global network, allowing any computer on one network to communicate with any computer on another. The two main services used on the internet are email and the World Wide Web. Email allows text messages to be sent—along with attached computer files, images, or video clips, for example—to other computers on the internet. The web consists of billions of pages made up of digital files that are stored on computers across the world and can be viewed using a web browser. The web also provides interactive access to various services, for example, banking and shopping.



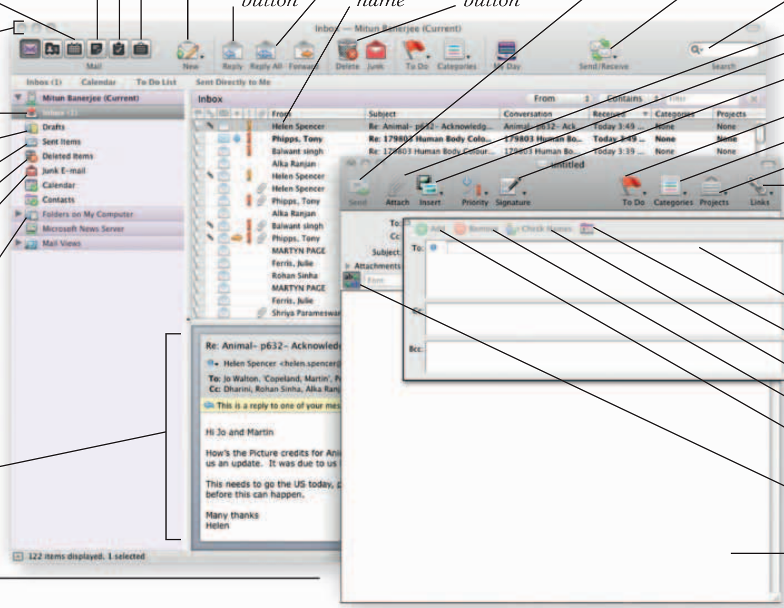
HOW EMAIL WORKS

EMAIL SENDER

EMAIL ADDRESS

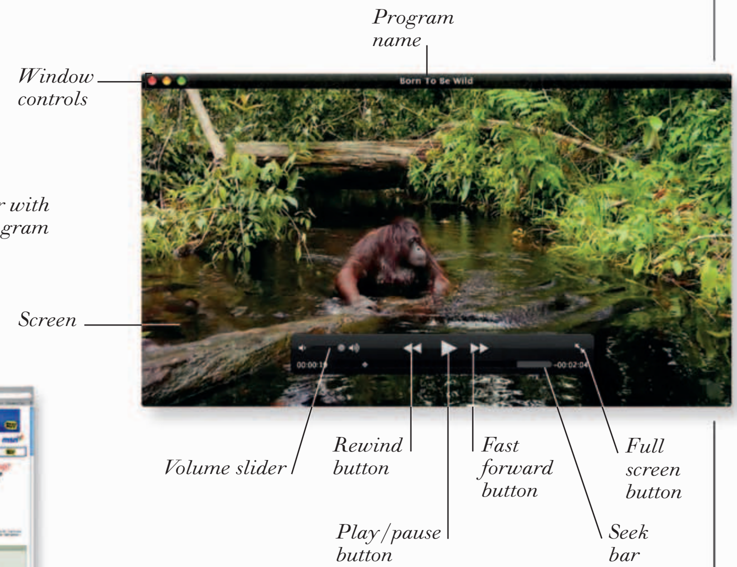


EMAIL PROGRAM

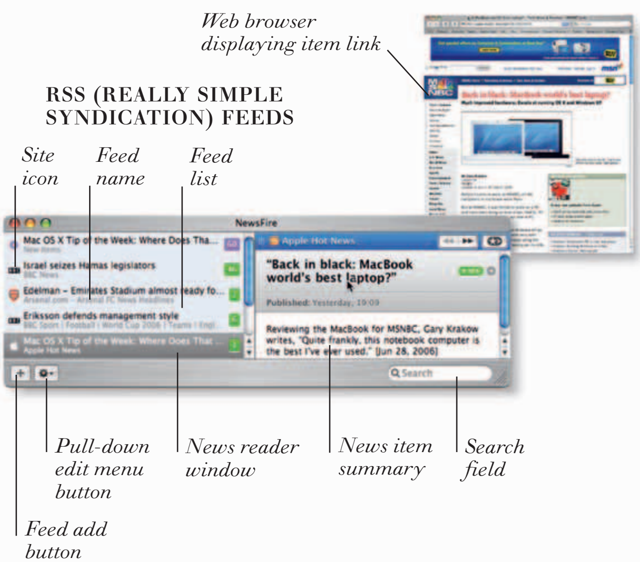


EMAIL RECIPIENT

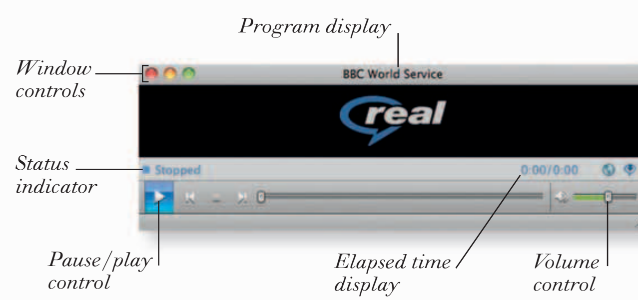
STREAMED INTERNET VIDEO ON-SCREEN DISPLAY



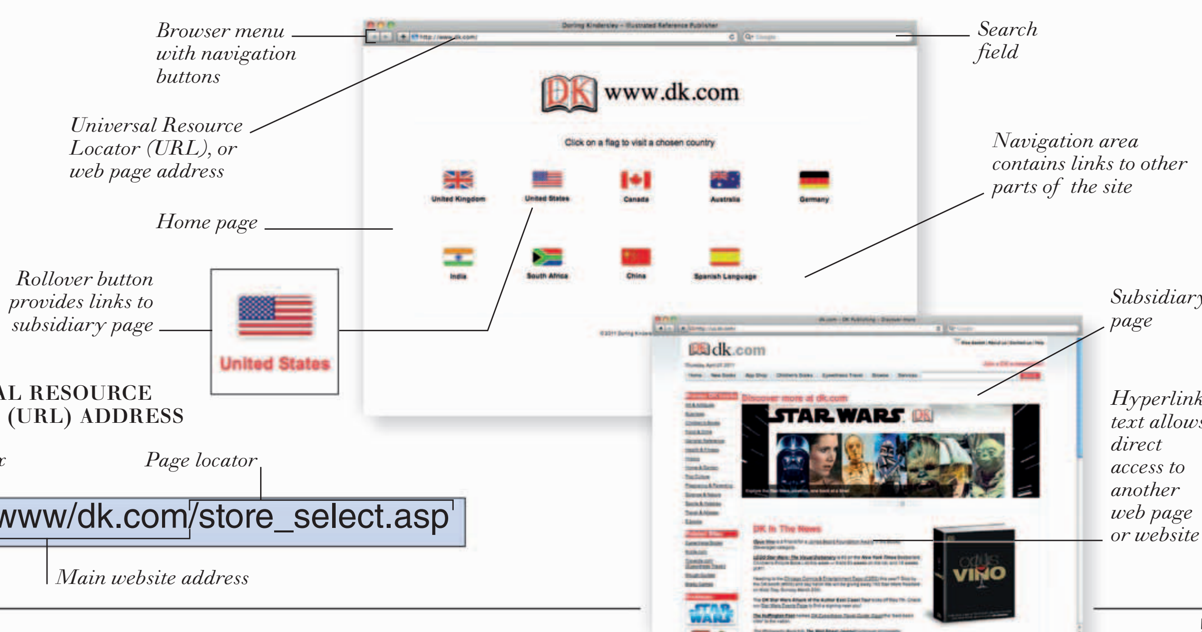
RSS (REALLY SIMPLE SYNDICATION) FEEDS



STREAMED INTERNET RADIO ON-SCREEN DISPLAY



WEB PAGES



UNIVERSAL RESOURCE LOCATOR (URL) ADDRESS

Prefix — *Page locator*

http://www/dk.com/store_select.asp

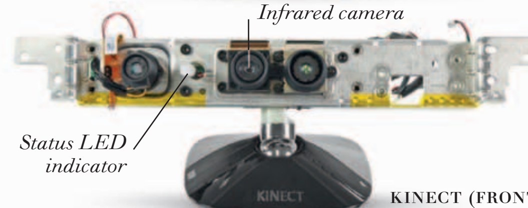
Main website address

Electronic games

MARIO SPORTS MIX WII

VIDEO GAMES HAVE BEEN around since the early 1970s. They are played on PCs, arcade machines, on a TV using a home console, and on portable handheld consoles. Players use devices such as joysticks and control pads with buttons to control movement and action on screen. The latest generation of consoles uses motion sensor technology to allow players to manipulate objects on screen by simply moving the controller. The most advanced game systems respond to gestures and commands spoken by a player, without any need to use a hand controller. The game itself is stored in the form of digital information on CD, DVD, or microchip—which may be integral or stored in a removable cartridge—or on an internal hard disk. A central processing unit (CPU) (see pp. 566–567) is needed to process commands from the players, while specialized graphics chips are used to process the complex mapping and texturing functions that make modern games appear so realistic.

MICROSOFT KINECT AND XBOX

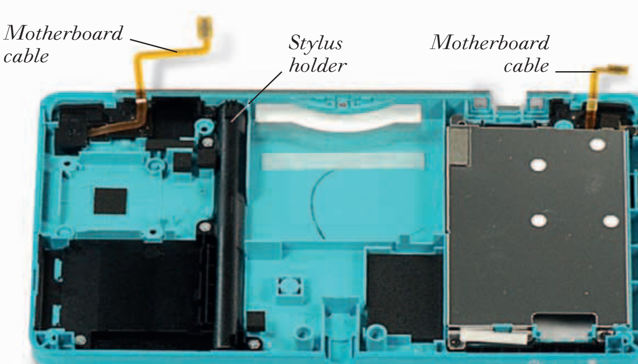


KINECT (FRONT PANEL REMOVED)

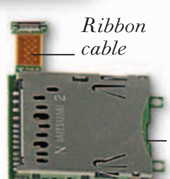
NINTENDO 3DS

NINTENDO 3DS (OPENED UP)

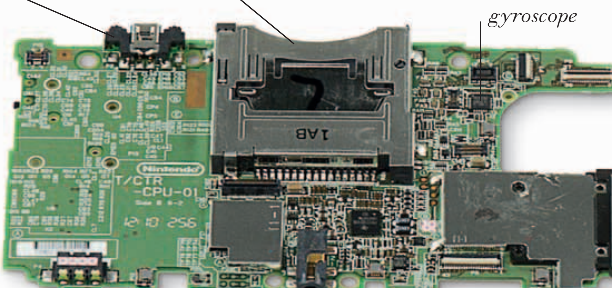
COMPONENTS OF NINTENDO 3DS



LOWER CASE BASE



SD CARD READER



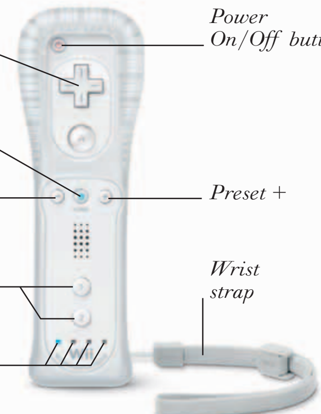
NINTENDO 3DS MOTHERBOARD

NINTENDO Wii FIT PLUS

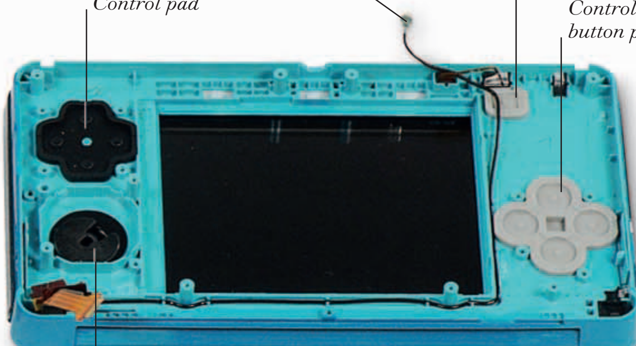
Wii FIT PLUS BALANCE GAME

ACTIVITIES ON A BALANCE BOARD

Wii BALANCE BOARD



Wii HAND CONTROLLER



LOWER CASE TOP

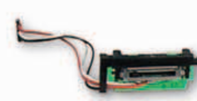
LOWER LCD ASSEMBLY

WI-FI BOARD

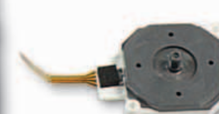
INFRARED BOARD

BATTERY COVER

RECHARGEABLE BATTERY



VOLUME CONTROL

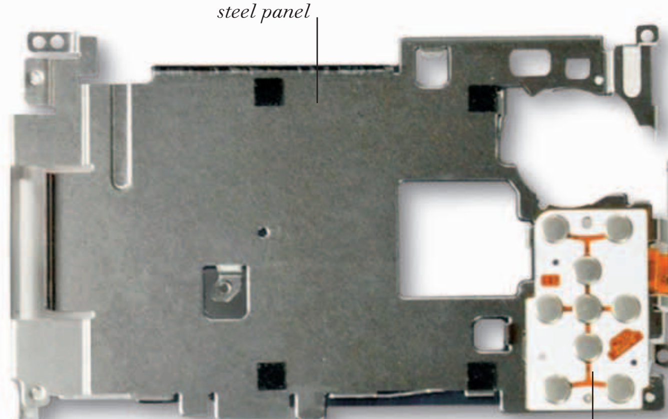


CIRCLE PAD

Digital camera

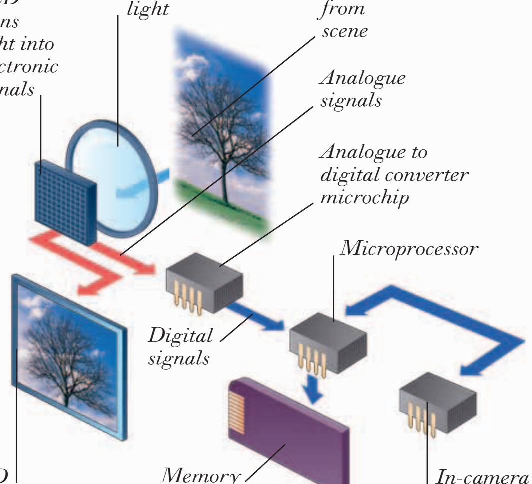
FOR MORE THAN 200 YEARS, CAMERAS recorded pictures as chemical changes in silver-containing substances, on a strip of flexible, celluloid film. The digital camera records pictures in electronic form. At its heart is a specialized integrated circuit known as a charge-coupled device (CCD). This has millions of microunits known as pixels. It works in the opposite way from a miniature computer or TV screen. Instead of electric signals making pixels shine, when light hits a pixel it generates a tiny electrical signal, according to the light's color and brightness. The signals from the CCD's millions of pixels are analogue: they vary continuously in a wavelike fashion. They are converted by a microchip to digital codes of numbers, represented as on-off electronic pulses. The digital signals are processed and fed to the camera's internal memory or a removable memory device such as a data card or memory stick. Photographs can be downloaded from a digital camera to a computer via a cable or in some cases a wireless link. Some digital cameras automatically reduce blurring caused by camera shake or fast movement, some can record video clips as well as still pictures.

MONITOR



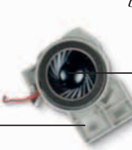
CHASSIS

HOW A DIGITAL CAMERA WORKS



CHROMED PLASTIC SIDE COVER

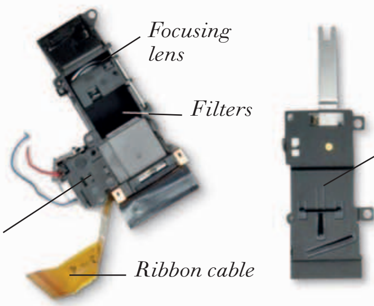
REAR CASE



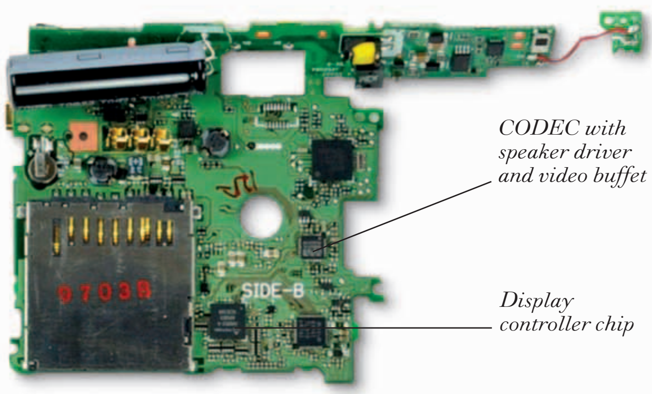
SPEAKER ASSEMBLY

COMPONENTS OF NIKON COOLPIX S1000PJ

TOP PANEL

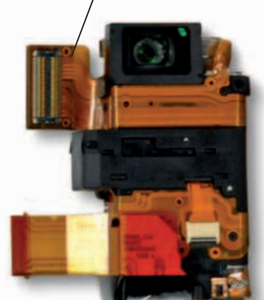


PROJECTOR ASSEMBLY



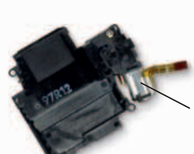
LOGIC BOARD

FRONT CASE



CAMERA MODULE

EN-EL12 RECHARGEABLE BATTERY

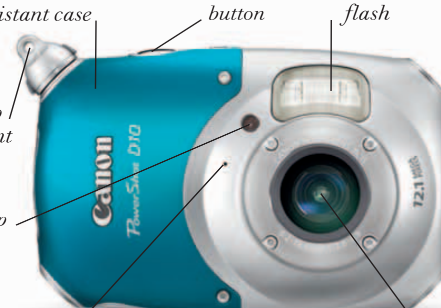


LENS COVER

TYPES OF DIGITAL CAMERA

DIGITAL SLR

DIGITAL CAMERA WITH INTERCHANGEABLE LENS



UNDERWATER DIGITAL CAMERA

3-D DIGITAL CAMERA

Digital video camera

A VIDEO CAMERA, OR CAMCORDER, records a scene as a sequence of 25 or 30 still images per second, along with sound. It comprises a video camera to capture light from the scene, a viewfinder through which the scene may be viewed, a screen on which the recorded scene may be viewed, a charge-coupled device (CCD) to convert the visual data into an electric signal, and a means of storing the signal. Digital video cameras convert the signal into digital form—a series of separate measurements of the initial analogue (continuously varying) signal. They record the digital signal, usually on a chip or hard disk. Video cameras often have a slot where a memory card can be inserted to expand the memory and store longer recordings or more still pictures.

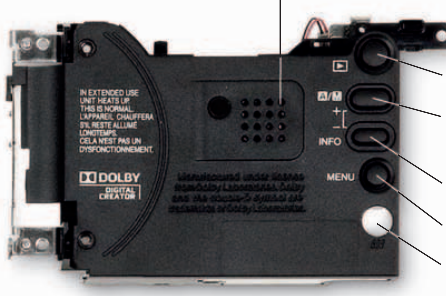
COMPONENTS OF A JVC EVERIO VIDEO CAMERA

MONITOR SHELL

MONITOR MOUNT

MONITOR FRAME

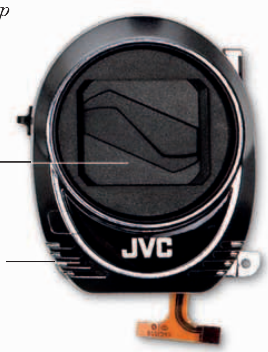
MONITOR SCREEN



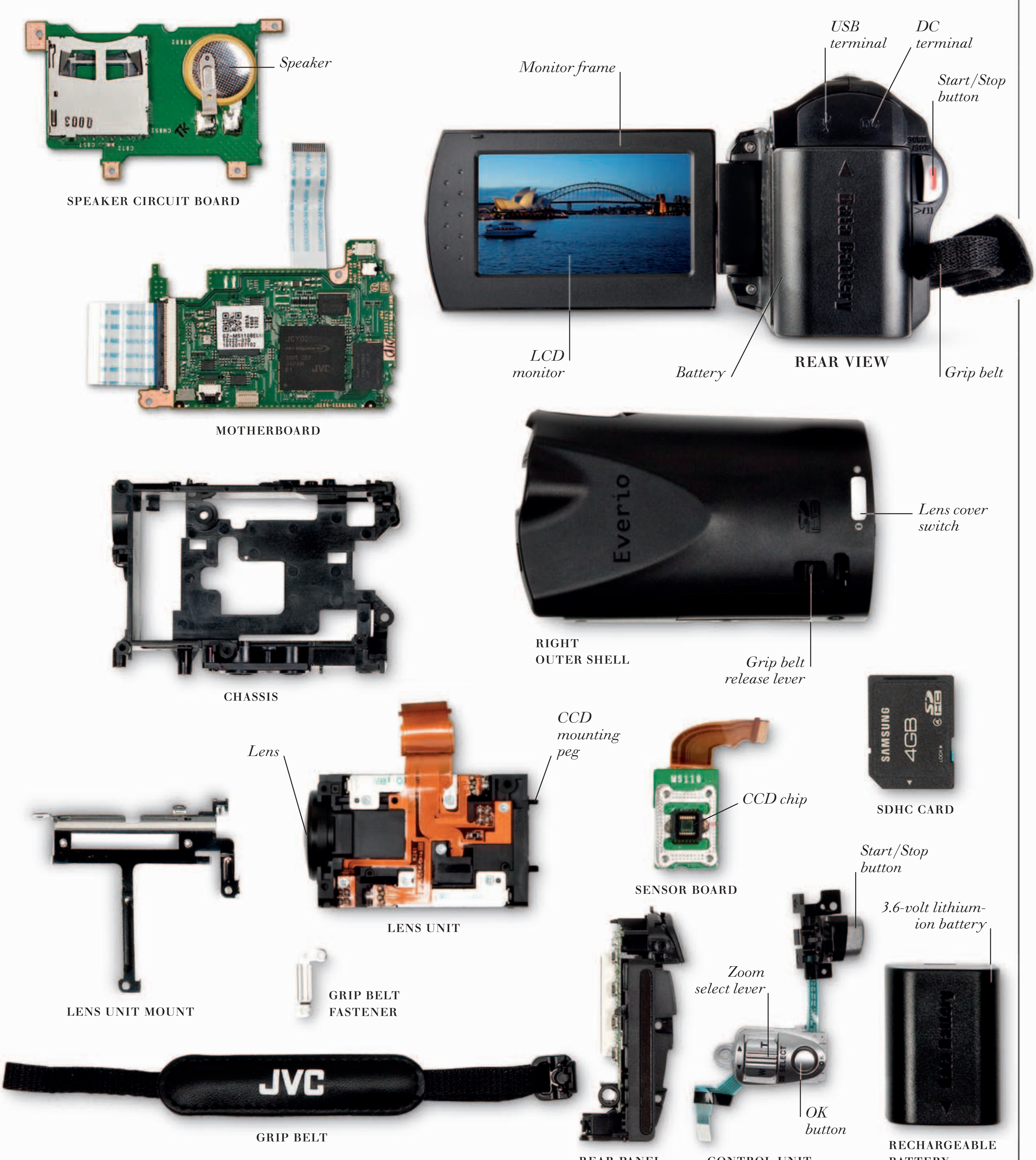
LEFT SIDE

TOP VIEW

LEFT OUTER SHELL



LENS COVER ASSEMBLY

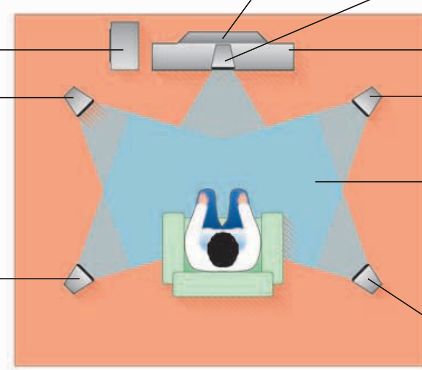

Speaker
SPEAKER CIRCUIT BOARD
MOTHERBOARD
CHASSIS
Monitor frame
USB terminal
DC terminal
Start/Stop button
LCD monitor
Battery
REAR VIEW
Grip belt
Lens cover switch
RIGHT OUTER SHELL
Grip belt release lever
Lens
CCD mounting peg
LENS UNIT
CCD chip
SENSOR BOARD
SDHC CARD
LENS UNIT MOUNT
GRIP BELT FASTENER
GRIP BELT
Start/Stop button
3.6-volt lithium-ion battery
Zoom select lever
OK button
REAR PANEL
CONTROL UNIT
RECHARGEABLE BATTERY

Home cinema

HOME CINEMA REPLICATES a real "movie theater" using pictures displayed on a high-quality widescreen television set, such as a plasma TV, and surround sound from strategically sited loudspeakers. The source for sound and vision is a DVD (Digital Versatile Disc). Its player uses standard CD (Compact Disc) digital technology, but with a higher density of laser-read microscopic pits—more than 20 billion such pits in multilevel spiral tracks that, stretched out, would extend nearly 25 miles (40km). Blu-ray is a high-quality DVD system that fits much more data on its disc than standard DVDs, allowing High Definition video files to be stored. It is hard for the human ear to discern the direction of low-pitched sounds, so these emanate from a central bass speaker, often built into or below the screen unit. High-pitched sounds, the direction of which is easier to detect, emanate from mid- and high-frequency speakers positioned around the viewer. Plasma screens use fluorescent tube ("strip-light") technology. Tiny three-cell pixels, each about one millimeter across, contain red, green, and blue phosphor chemicals and a gas mix. Where electric pulses coincide for a split second in the crisscross matrix of wire electrodes, the gas energizes and emits ultraviolet light, which in turn makes the phosphor glow.

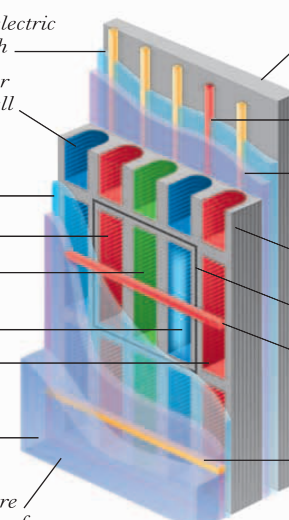
BLU-RAY PLAYER

HOW SURROUND SOUND WORKS

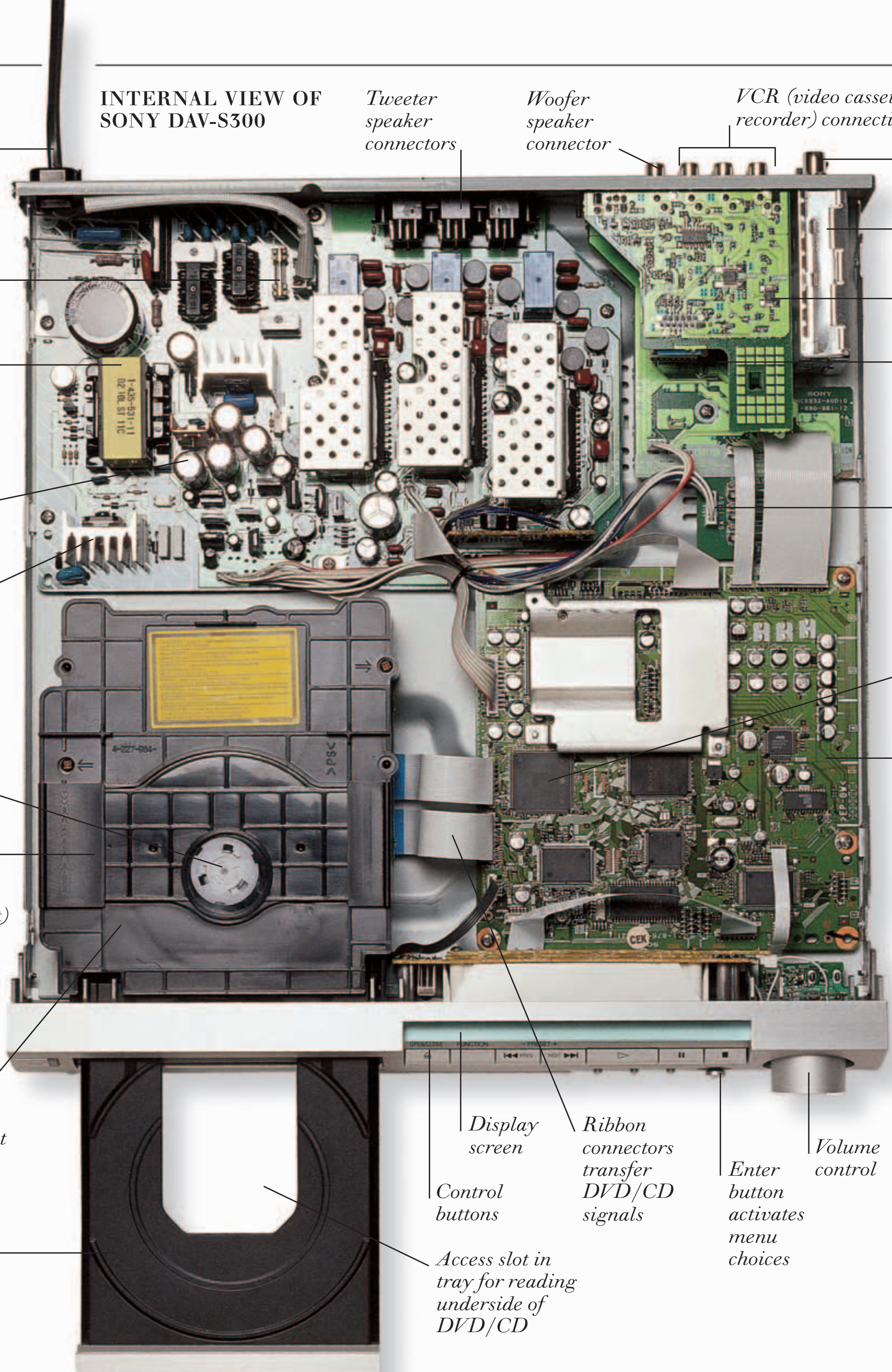


WIDE-SCREEN PLASMA DISPLAY

HOW A PLASMA SCREEN WORKS

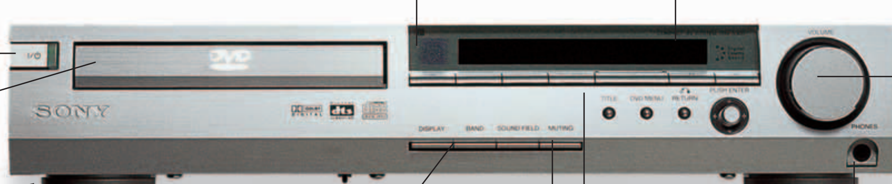


INTERNAL VIEW OF SONY DAV-S300



REMOTE CONTROL

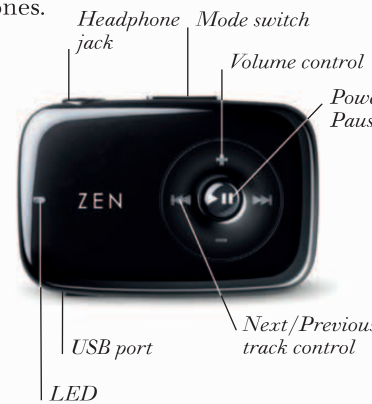
FRONT VIEW



Personal music and video

THE FIRST BATTERY-DRIVEN PORTABLE source of sound and music was the transistor radio of the 1950s. In the 1970s, the magnetic audio cassette tape allowed recordings to be played on portable tape players. Also, new metal alloys permitted the tiny but high-power magnets needed for lightweight earphones. In the 1980s, compact discs brought music into the digital era. Sony's MD, or minidisc, introduced re-recordable CDs that used magnetic and optical technology. From the mid 1990s, music could be stored in all-electronic digital form in a microchip, usually in the MP3 file format. These files can be transferred between devices and via the Internet. Today, a variety of portable media gadgets can record, play, and store video, photographs, and music in electronic form.

MP3 PLAYERS



CREATIVE ZEN STONE

SONY B-SERIES MP3 PLAYER

SONY W-SERIES WALKMAN

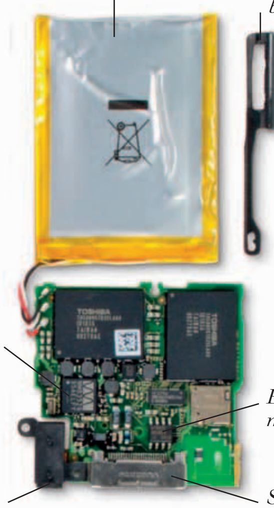
JBL SPYRO SPEAKERS

ZEPPELIN IPOD SPEAKER DOCK

COMPONENTS OF MICROSOFT ZUNE HD

FRONT PANEL

CHASSIS



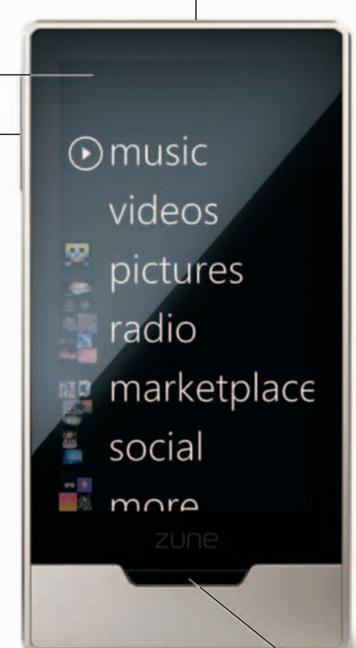
LOGIC BOARD

DISPLAY

REAR VIEW

SIDE VIEW

MICROSOFT ZUNE HD



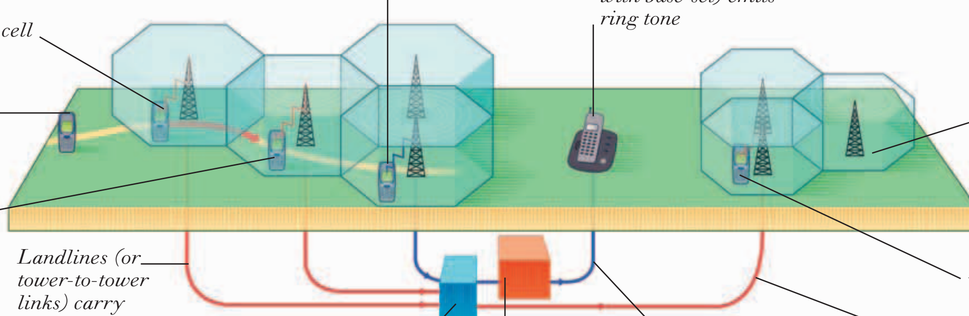
Cellphones

IN THE EARLY 1990s, THE CELLPHONE (or mobile phone) was a rare luxury, but in recent years it has outsold almost every other electrical gadget—as a professional tool, domestic convenience, and even a fashion accessory. Cellphones have also generally shrunk in size, due to improvements in rechargeable batteries, which now store more electricity for longer in a smaller package, and to smaller, more efficient electronics that use less electricity. A "cellphone" is basically a low-power radio receiver-transmitter, plus a tiny microphone to convert sounds into electrical signals, and a small speaker that does the reverse. When the cellphone is activated, it sends out a radio signal that is answered by nearby mast transmitter-receivers. The phone locks onto the clearest signal and uses this while within range (the range of each transmitter is known as a cell). The phone continuously monitors signal strength and switches to an alternative transmitter when necessary. The phone's liquid crystal display (LCD) shows numbers, letters, symbols, and color pictures. Newer models have a larger screen for more complex color images, and commonly incorporate a camera, radio, and MP3 functionality. Smartphones, which are increasingly widespread, contain additional software and more may be downloaded. Smartphones typically offer internet and email access, PDA-like functions (see pp. 568–569), and may even contain GPS navigation software.

I-PHONE 4

LG OPTIMUS 2X

HOW A CELLPHONE WORKS



COMPONENTS OF BLACKBERRY CURVE 8520

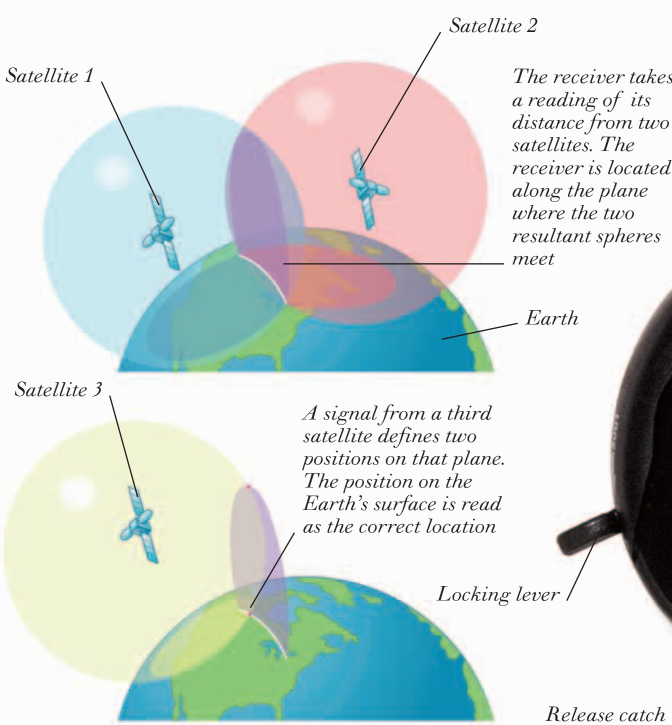
BLACKBERRY CURVE 8520

Global positioning system

THE GLOBAL POSITIONING SYSTEM (GPS) is a network of 24 navigation satellites orbiting the Earth that people can use to pinpoint their position. The satellites orbit at a height of 12,500 miles (20,000 km). A GPS receiver picks up signals from any of these satellites that are above the horizon. It uses information in each signal to work out how far away it is from the satellite. It can calculate its position on the Earth's surface when it has information from at least three satellites. A basic GPS receiver shows the latitude and longitude of its position on its screen. More advanced receivers, especially those designed for use in vehicles, show their position on a digital map. These receivers often show extra information, such as the vehicle's speed and the length of the journey. Some receivers warn drivers if they exceed the speed limit for a road and even tell drivers which traffic lane to use at the next junction. Directions are shown on the screen and also spoken by a synthesized voice.

IN-CAR GPS

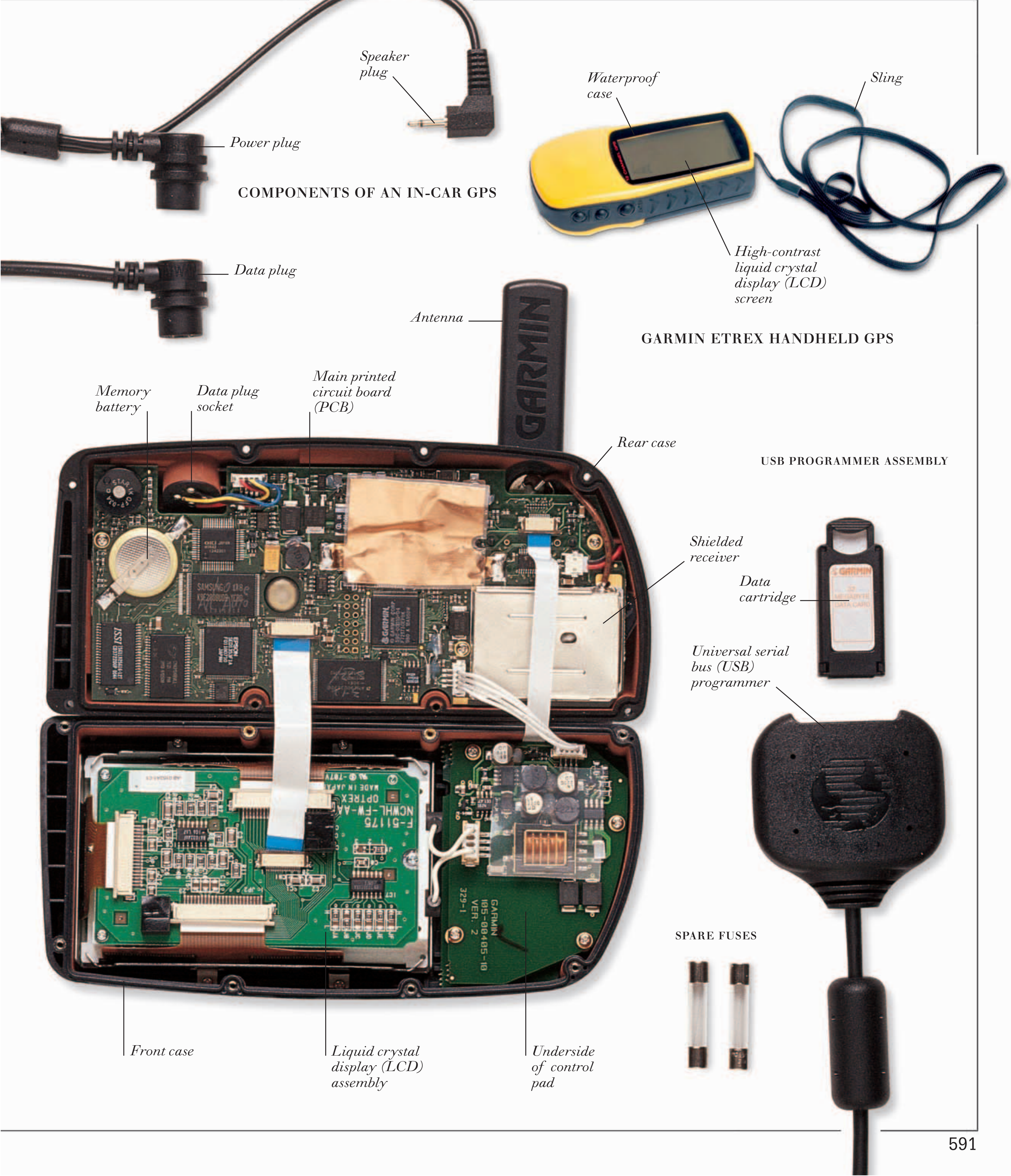
HOW GPS WORKS



IN-CAR MOUNTING BRACKET ASSEMBLY

QUICK-RELEASE BASE

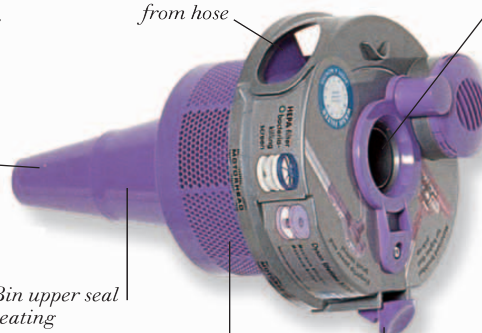
MOUNTING BRACKET


Speaker plug
Power plug
COMPONENTS OF AN IN-CAR GPS
Data plug
Waterproof case
Sling
High-contrast liquid crystal display (LCD) screen
GARMIN ETREX HANDHELD GPS
Antenna
Memory battery
Data plug socket
Main printed circuit board (PCB)
Rear case
USB PROGRAMMER ASSEMBLY
Shielded receiver
Data cartridge
Universal serial bus (USB) programmer
SPARE FUSES
Front case
Liquid crystal display (LCD) assembly
Underside of control pad

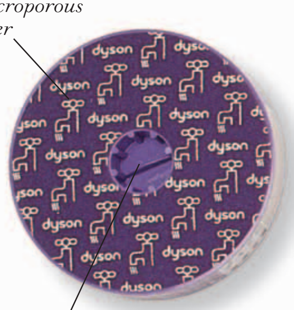
Vacuum cleaner

IN A CONVENTIONAL VACUUM CLEANER, an electric motor spins a fan that sucks in air carrying dust and debris. The air is forced through tiny pores in a dust bag, trapping most particles. In the 1990s, James Dyson's dual cyclone "bagless" design did away with the dust bag—and the reduced airflow caused by clogging of its pores. An electrically driven fan creates a partial vacuum within the machine. This sucks air into the machine past a rotating brush that loosens dirt. The air flows into a cylinder-shaped bin. As the air whirls around the bin like a miniature storm, or cyclone, larger particle are flung outward and fall to the bottom of the bin. The air then passes through perforations into a cone-shaped inner bin and then into a series of smaller cones, spinning faster all the time and flinging smaller and smaller particle out. The nearly clean air exits the machine through microfilters that trap the tiniest particles. Some Dyson vacuum cleaners run on a large ball instead of wheels. The ball makes it easier to steer the cleaner.

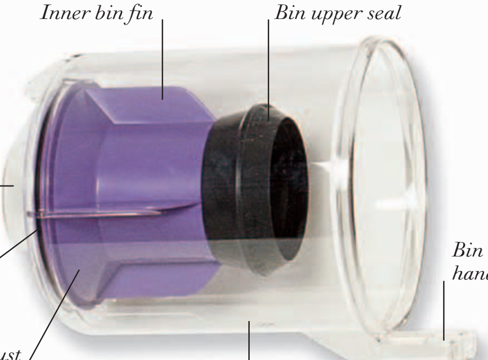
CYCLONE ASSEMBLY



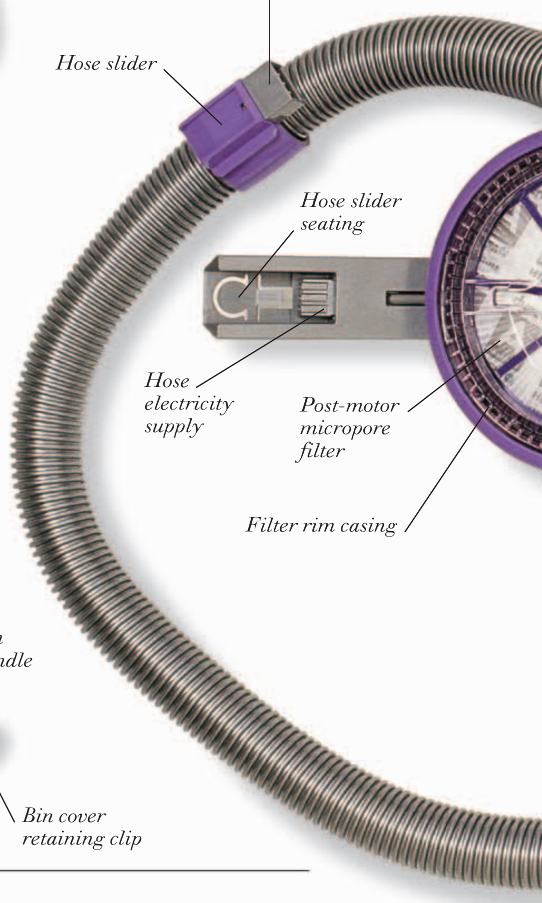
WASHABLE PRE-MOTOR FILTER

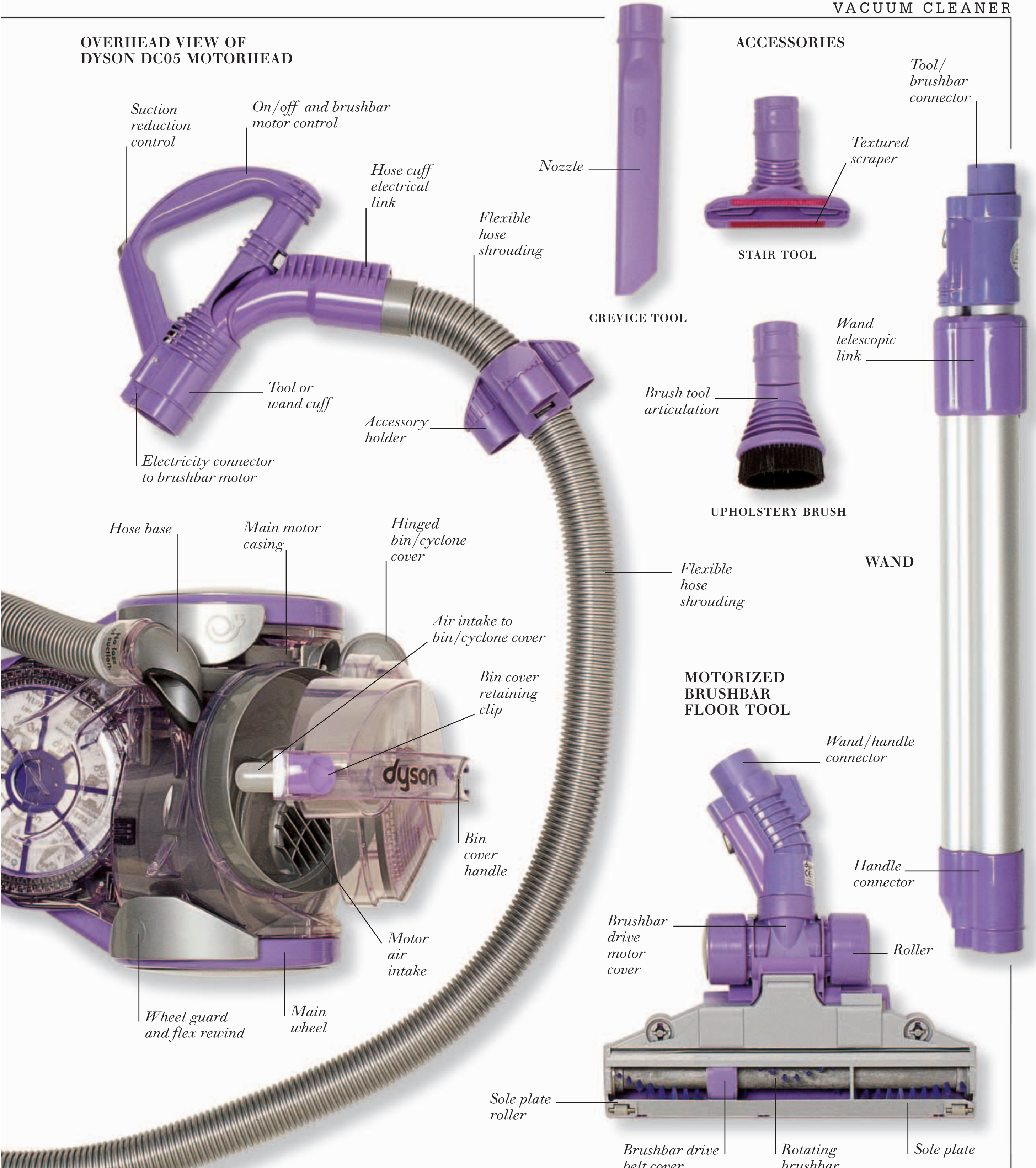


DUST COLLECTION BIN



DYSON DC05 MOTORHEAD



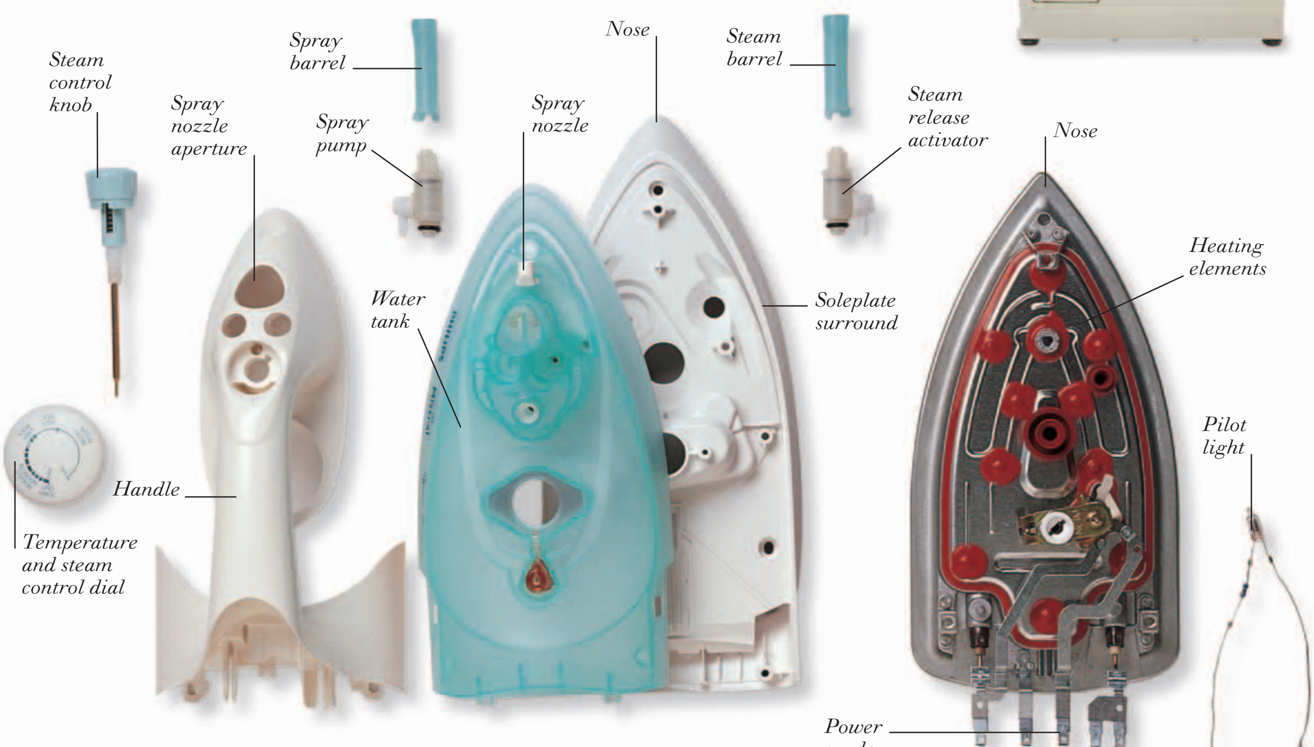

OVERHEAD VIEW OF DYSON DC05 MOTORHEAD
Suction reduction control
On/off and brushbar motor control
Hose cuff electrical link
Flexible hose shrouding
Tool or wand cuff
Accessory holder
Electricity connector to brushbar motor
Hose base
Main motor casing
Hinged bin/cyclone cover
Flexible hose shrouding
Air intake to bin/cyclone cover
Bin cover retaining clip
dyson
Bin cover handle
Motor air intake
Wheel guard and flex rewind
Main wheel
ACCESSORIES
Nozzle
CREVICE TOOL
Textured scraper
STAIR TOOL
Brush tool articulation
UPHOLSTERY BRUSH
Tool/ brushbar connector
Wand telescopic link
WAND
Handle connector
MOTORIZED BRUSHBAR FLOOR TOOL
Wand/handle connector
Brushbar drive motor cover
Roller
Sole plate roller
Brushbar drive belt cover
Rotating brushbar
Sole plate

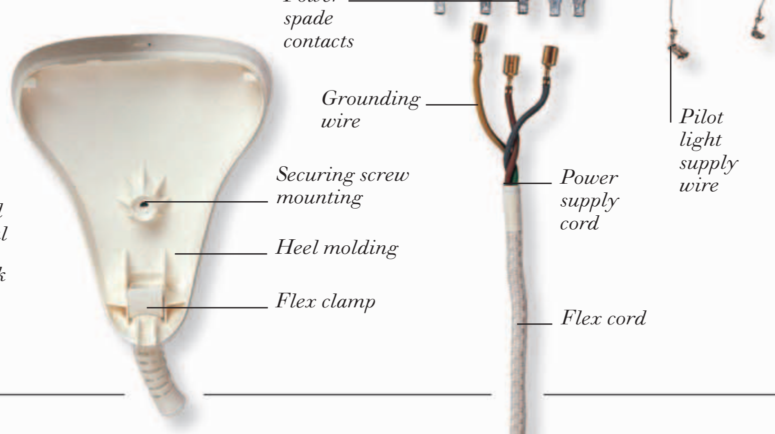
Iron and washer-dryer

IN THE DAYS BEFORE WASHING MACHINES, laundry was done by hand—washed in a barrel, squeezed in a roller-mangle, hung on a line, and smoothed with an iron heated on the stove. In the 1880s, electrically heated irons were one of the first home electrical appliances. Today's iron still applies heat, sometimes moistened with steam, to dampen and flatten garment fibers. Machines with electric heaters and motors took the strain out of washing from the 1910s. Up to the 1960s, three machines were needed to wash, spin, and dry. Now clothes are swirled in a rotating ribbed tub of hot water, then spun fast to throw off most of the water, before slowly tumbling in electrically heated air to dry—all in one appliance.

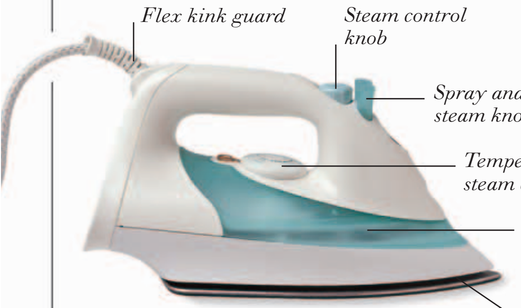
FRONT VIEW OF A MIELE WASHER-DRYER

COMPONENTS OF A STEAM IRON

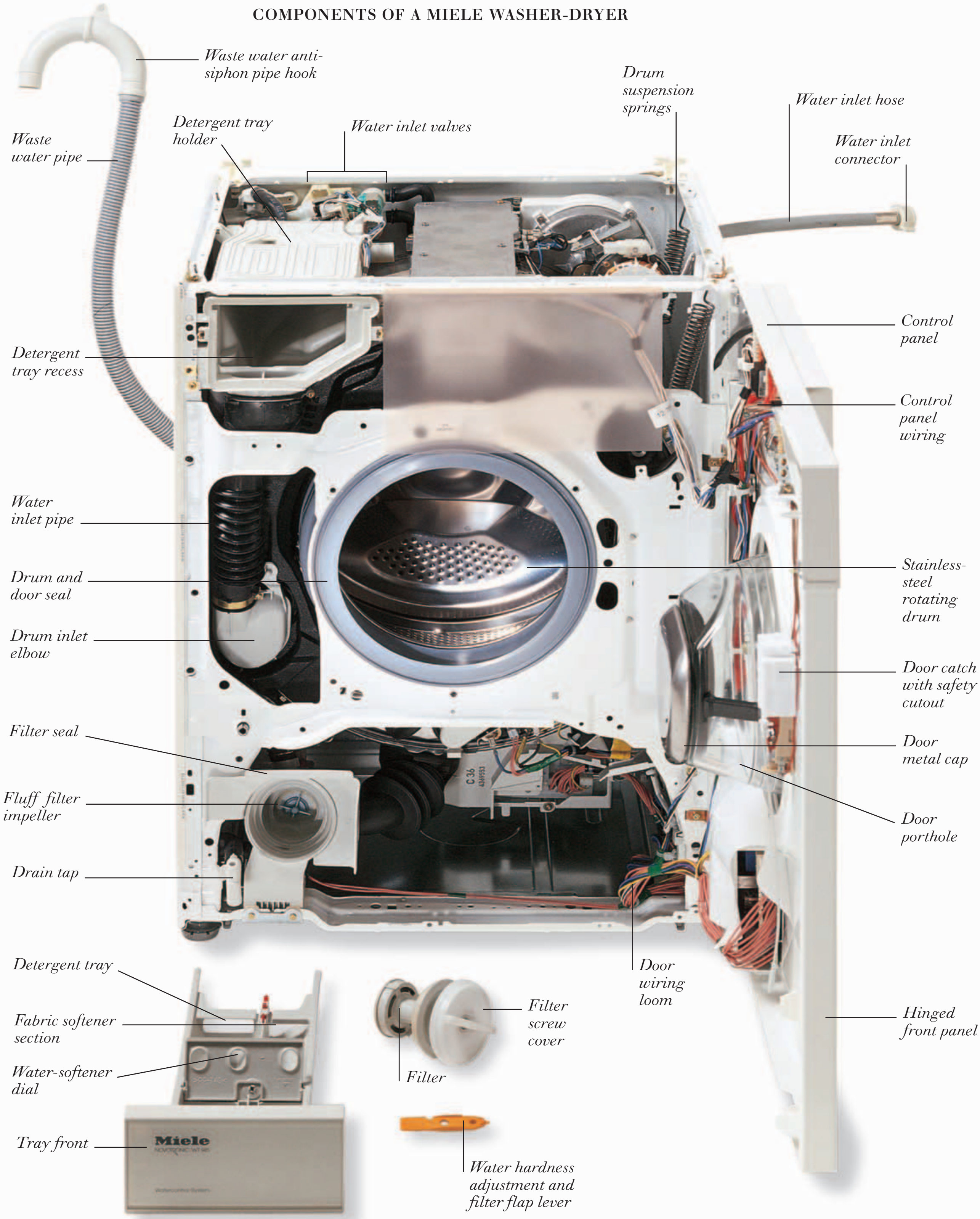




SIDE VIEW OF STEAM IRON



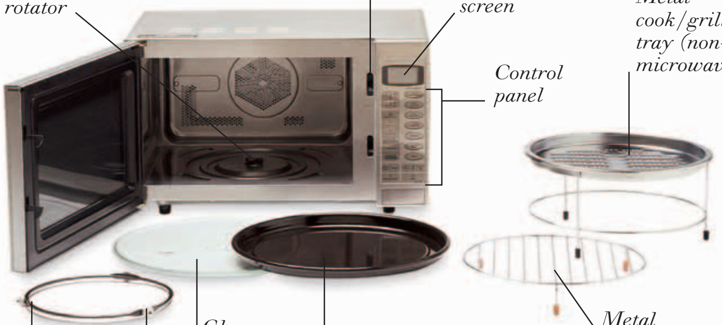
COMPONENTS OF A MIELE WASHER-DRYER



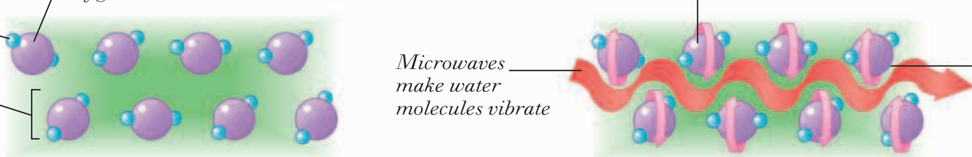
Microwave combination oven

CONVENTIONAL OVENS use electrically warmed elements or a flame to heat food. In a microwave oven heat energy is created by electromagnetic waves produced by a magnetron and led by waveguides into the oven compartment. These microwaves cannot pass through the compartment's metal casing, being reflected within and spread evenly by a fan. But they do pass through most types of plastic, ceramics, and glass. Therefore platters or containers made from these materials are suitable for use in microwave ovens. A combination oven also has conventional heating elements, to grill and "brown" in the traditional fashion, either alone or in conjunction with microwaves.

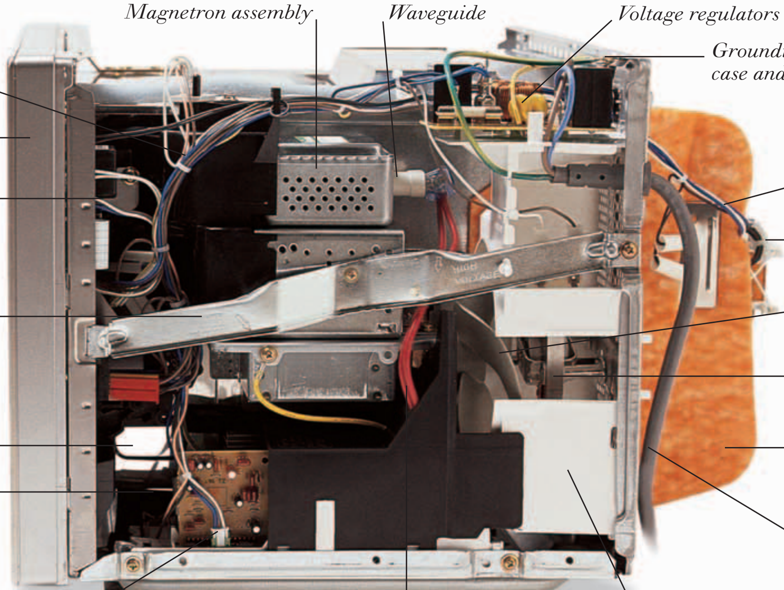
MICROWAVE COMBINATION OVEN



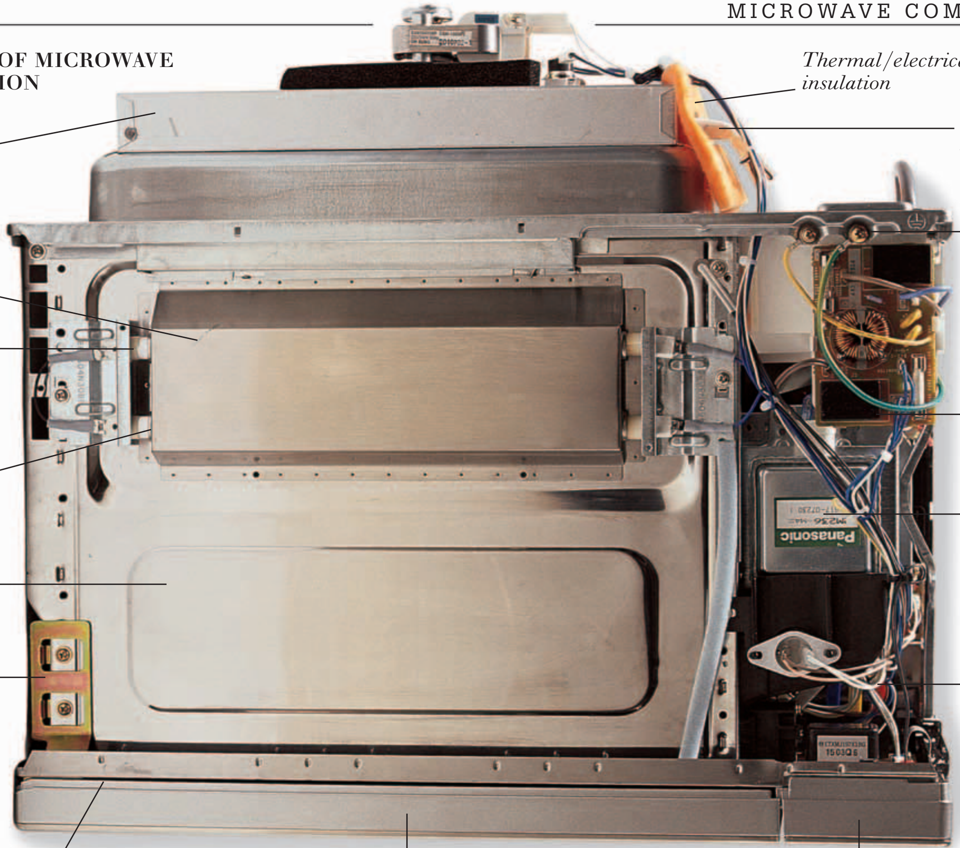
HOW MICROWAVES HEAT FOOD



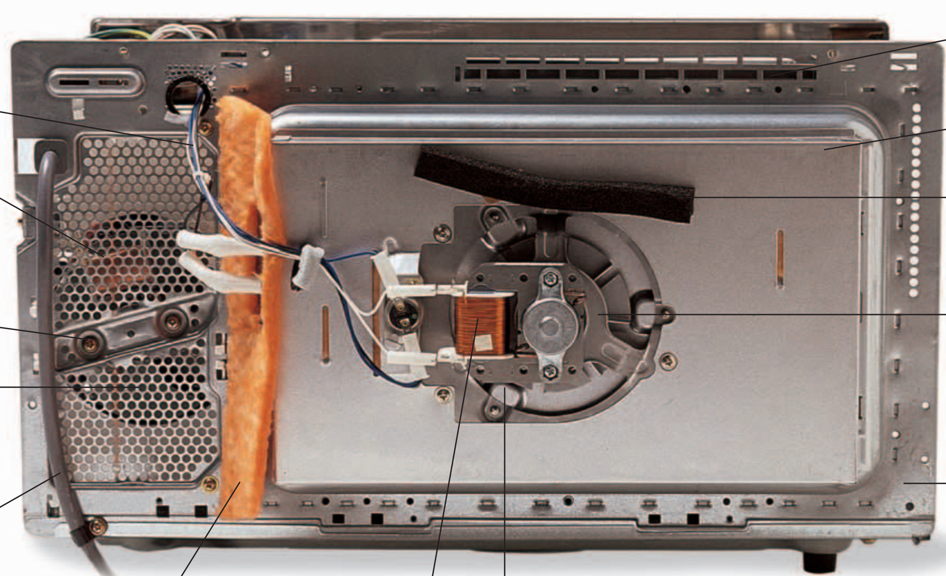
SIDE VIEW OF MICROWAVE COMBINATION OVEN



TOP VIEW OF MICROWAVE COMBINATION OVEN

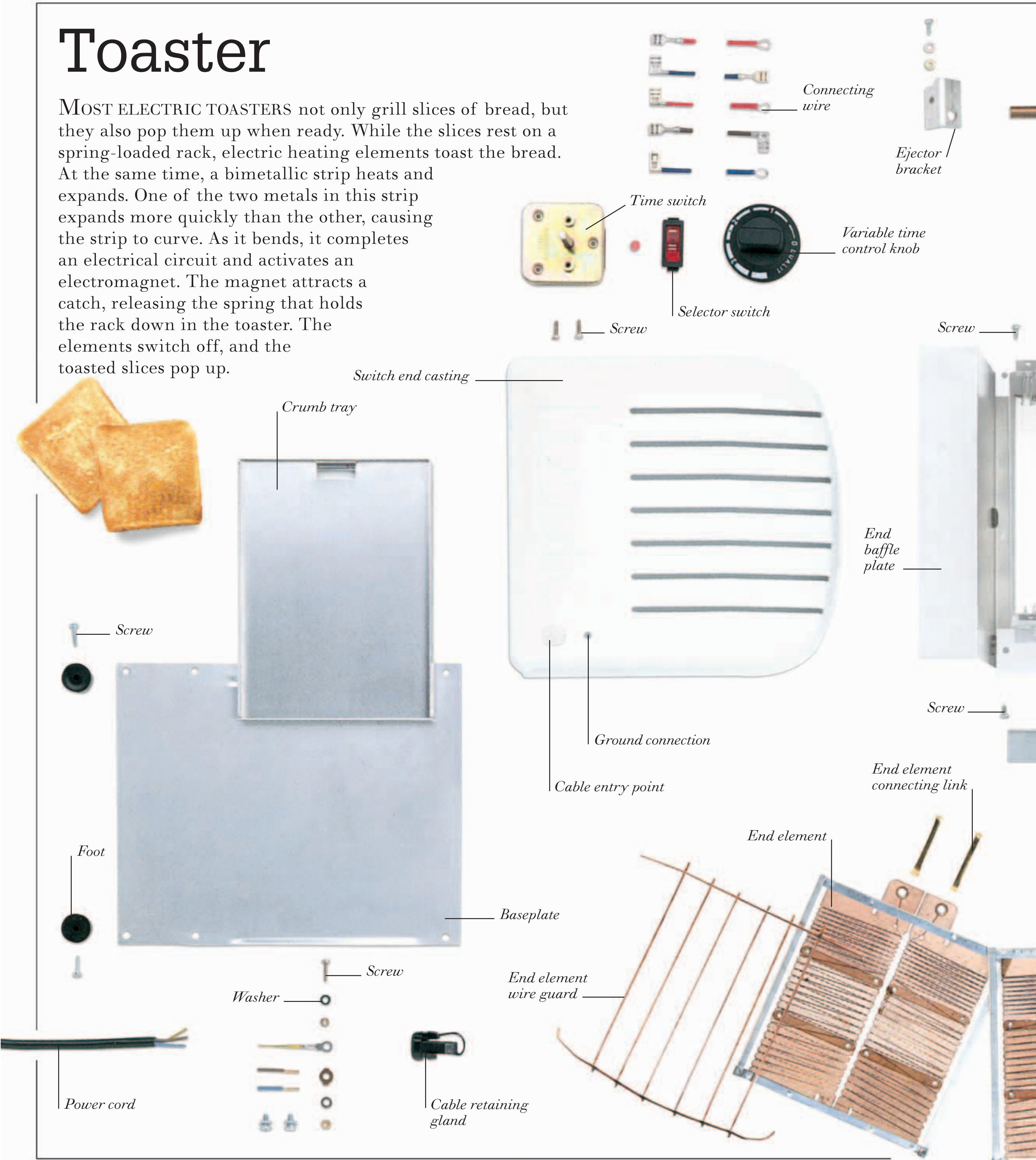


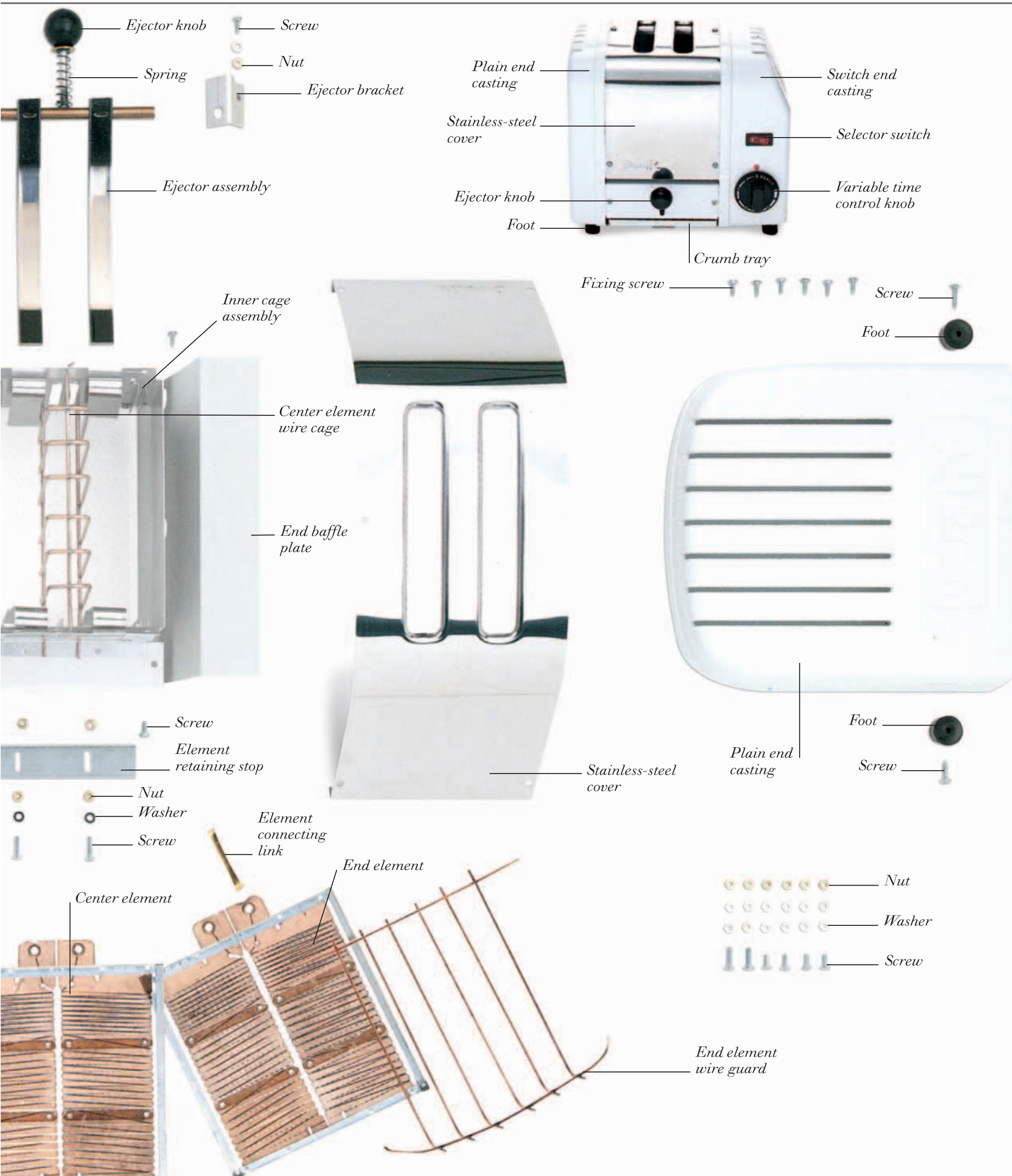
BACK VIEW OF MICROWAVE COMBINATION OVEN



Toaster

MOST ELECTRIC TOASTERS not only grill slices of bread, but they also pop them up when ready. While the slices rest on a spring-loaded rack, electric heating elements toast the bread. At the same time, a bimetallic strip heats and expands. One of the two metals in this strip expands more quickly than the other, causing the strip to curve. As it bends, it completes an electrical circuit and activates an electromagnet. The magnet attracts a catch, releasing the spring that holds the rack down in the toaster. The elements switch off, and the toasted slices pop up.

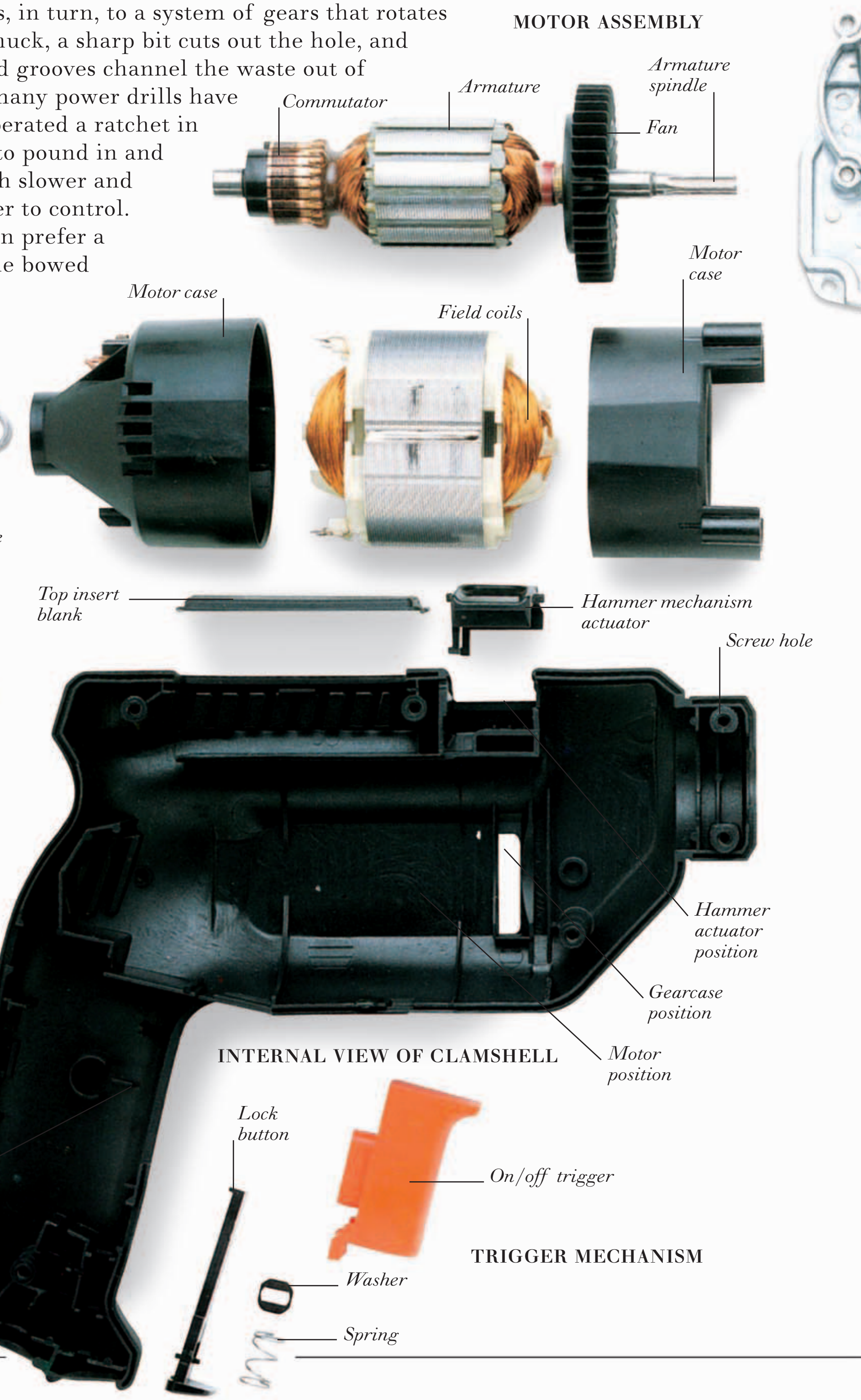


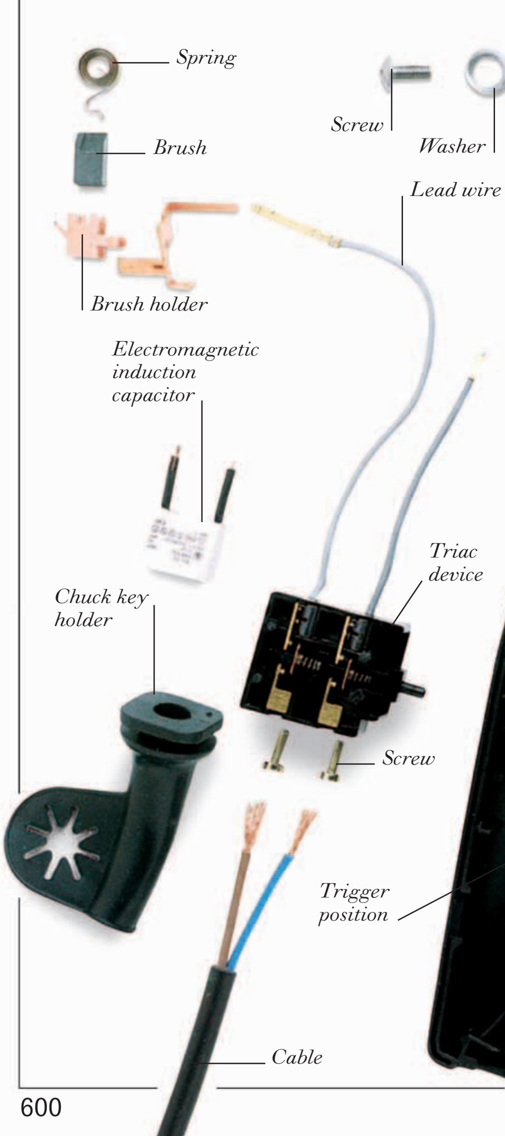


Ejector knob
Spring
Screw
Nut
Ejector bracket
Ejector assembly
Plain end casting
Switch end casting
Stainless-steel cover
Selector switch
Ejector knob
Variable time control knob
Foot
Crumb tray
Fixing screw
Screw
Foot
Inner cage assembly
Center element wire cage
End baffle plate
Screw
Element retaining stop
Nut
Washer
Screw
Element connecting link
Stainless-steel cover
Plain end casting
Foot
Screw
End element
Center element
Nut
Washer
Screw
End element wire guard

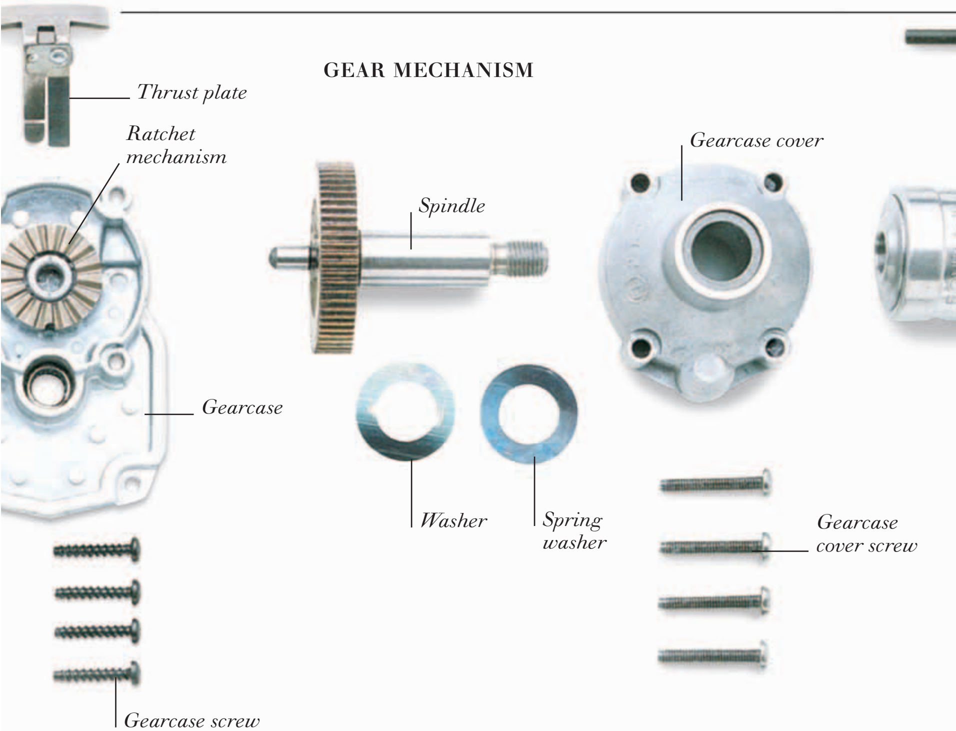
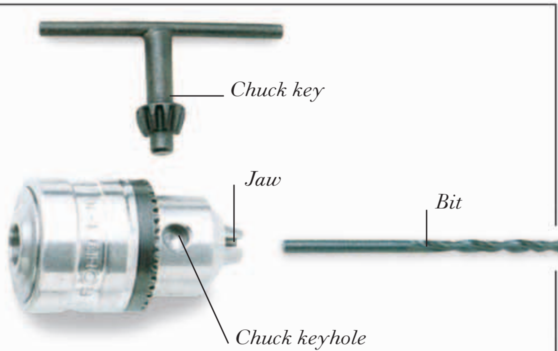
Drills

THE ELECTRICALLY POWERED MOTOR OF A POWER DRILL, cooled by a fan, turns a shaft at high speed. The shaft connects, in turn, to a system of gears that rotates a chuck even faster. Clamped by the chuck, a sharp bit cuts out the hole, and at the same time the bit's screw-shaped grooves channel the waste out of the hole. For drilling hard materials, many power drills have a hammer mechanism; when this is operated a ratchet in the gearcase causes the chuck and bit to pound in and out as they drill. A hand drill, although slower and less forceful than a power drill, is easier to control. For cutting wide holes, carpenters often prefer a brace-and-bit. This acts like a lever: the bowed handle of the brace moves a larger distance than the bit, turning the bit with extra force.



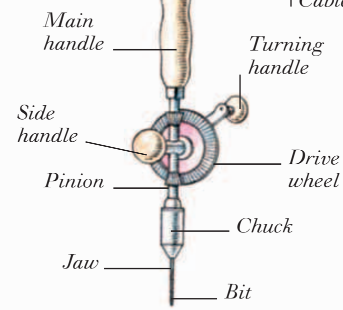


GEAR MECHANISM

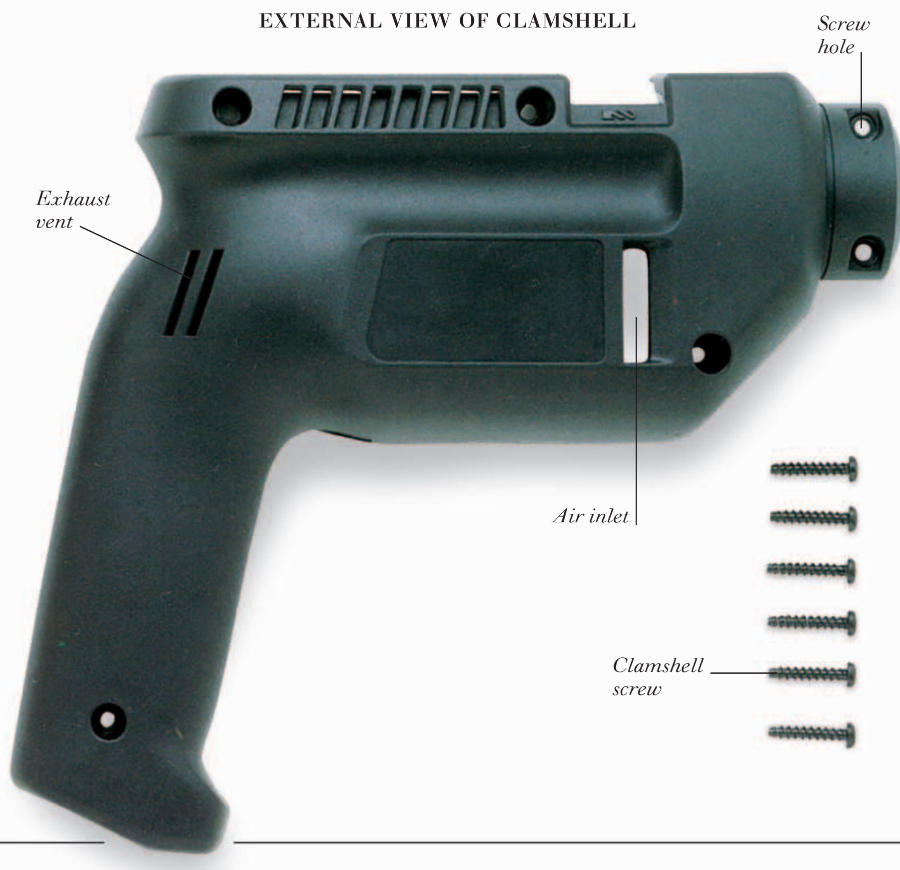



POWER DRILL

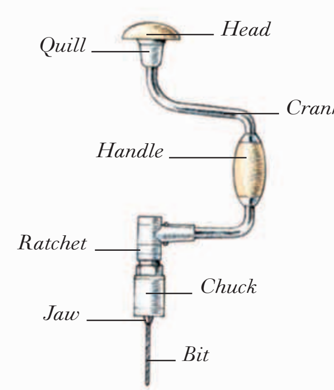
HAND DRILL



EXTERNAL VIEW OF CLAMSHELL



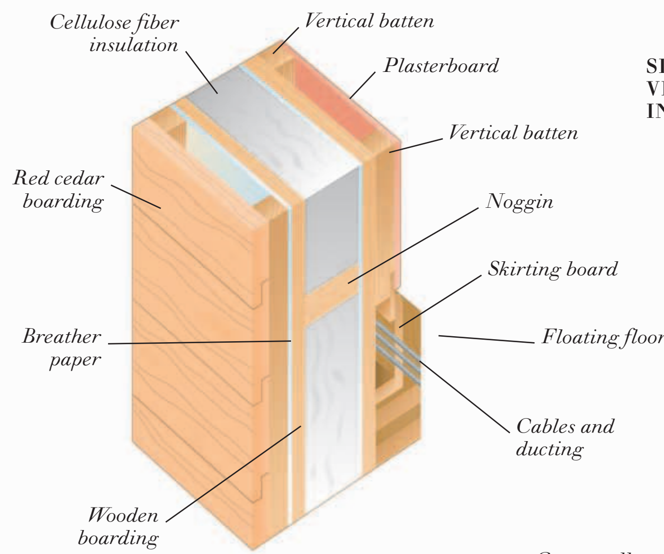
BRACE-AND-BIT



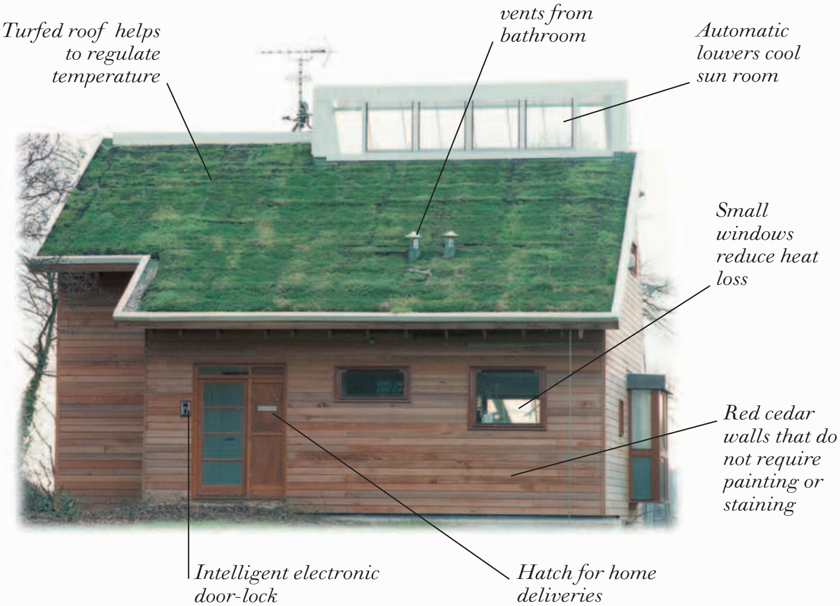
House of the future

HOUSES IN THE FUTURE are likely to be more environmentally friendly and energy-efficient than older dwellings, by making better use of materials and intelligent control systems. The Integer house was designed by Cole Thompson Associates, Bree Day Partnership, and Paul Hodgkins Associates, and built in conjunction with the Building Research Establishment in the UK. One of its key features is a large sun room that warms one side of the house. Extensive use is made of recycled, natural, and renewable materials and energy. The walls are made from timber and insulated with fiber from recycled newspaper; waste water from the bathrooms is saved and used to flush the toilets; and a wind turbine and solar panels contribute some of the electricity requirements. Many elements were prefabricated off-site for ease of construction. The Integer house uses only half the energy and a third less water than a traditionally built house.

WALL CONSTRUCTION

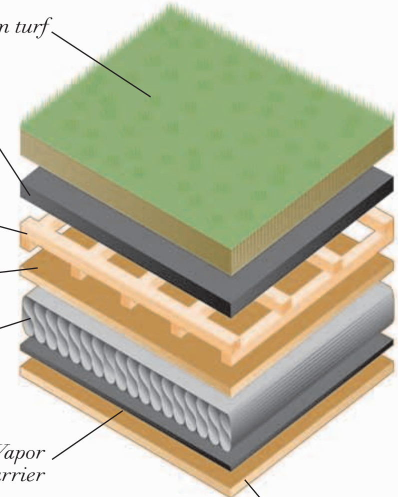


FRONT VIEW OF THE INTEGER HOUSE



SIDE AND REAR VIEW OF THE INTEGER HOUSE

ROOF CONSTRUCTION

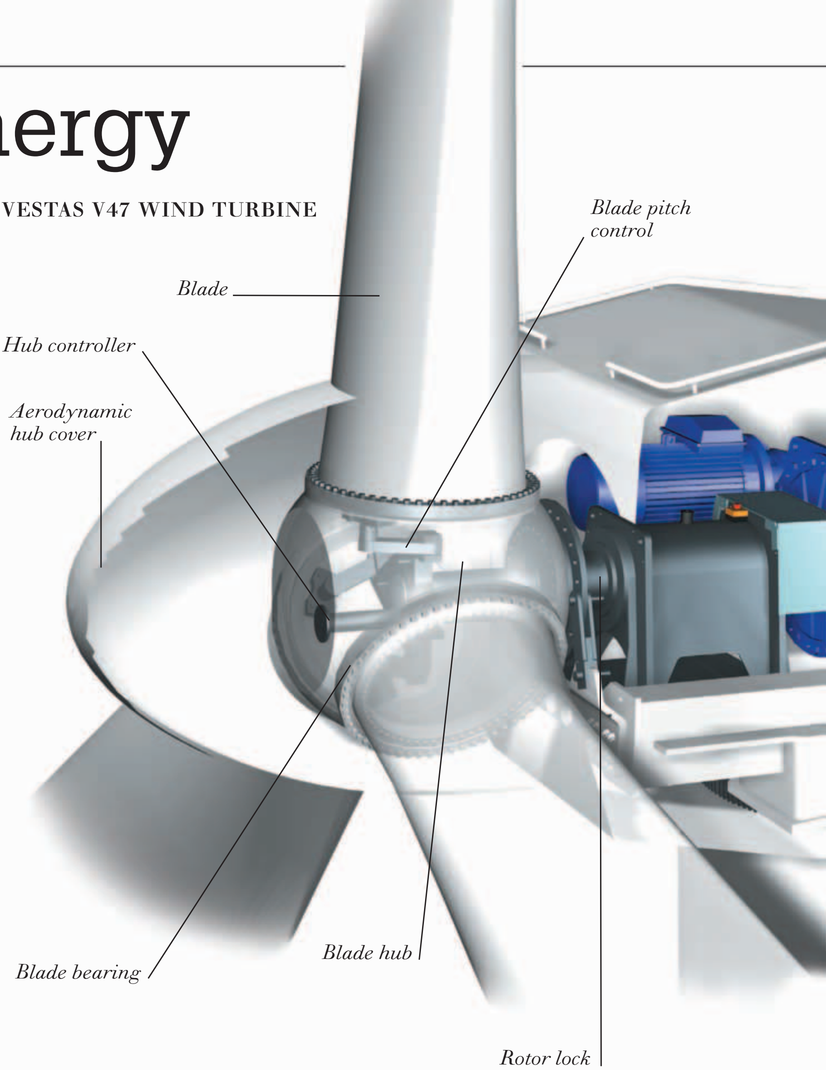


SUN ROOM INTERIOR

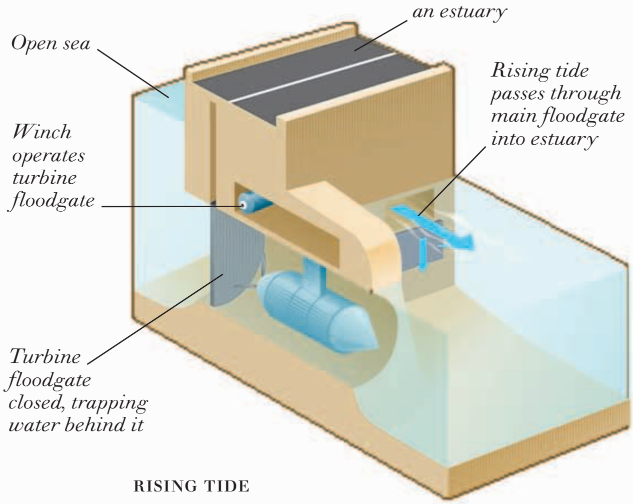
Renewable energy

RENEWABLE ENERGY COMES from sources that do not become depleted as we use the energy. When a fossil fuel such as coal is burned, it is gone forever, but a renewable source remains available no matter how much is used. The tides, waves, flowing water, sunlight, and the wind are all renewable sources of energy. Wind and water energy are captured by a device called a turbine. The turbine spins and drives an electricity generator. Energy from sunlight, or solar energy, is changed into electricity in two main ways. One uses mirrors to concentrate solar energy and magnify its heating effect which is used to change water into steam to drive turbines. Photovoltaic cells change sunlight directly into electricity. A cell is made from two layers of silicon. One gives out electrons (negative particles) and the other receives them. Sunlight knocks electrons out of atoms where the two layers meet, separating them from the positive particles. The electrons are attracted to one layer of the cell, the positive particles to the other layer. Electrons are naturally attracted to the positive particles, but to come together again, the electrons must flow out of the cell, through an external electric circuit, or load, and back to the other side of the cell, creating a charge. The cell supplies electric current for as long as light keeps falling on it.

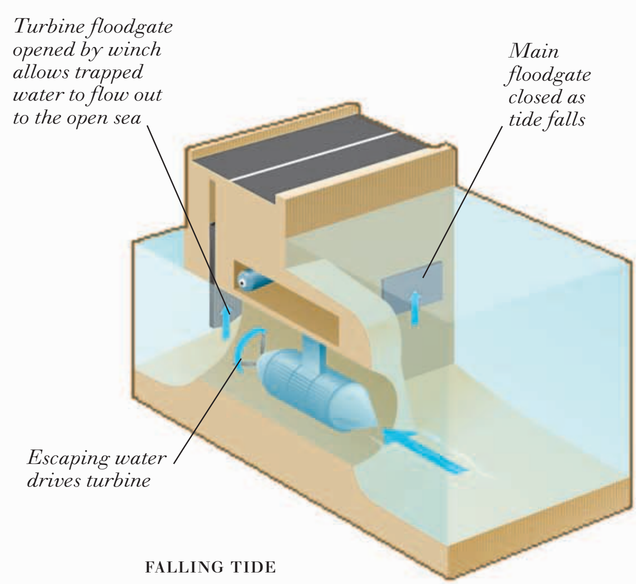
VESTAS V47 WIND TURBINE



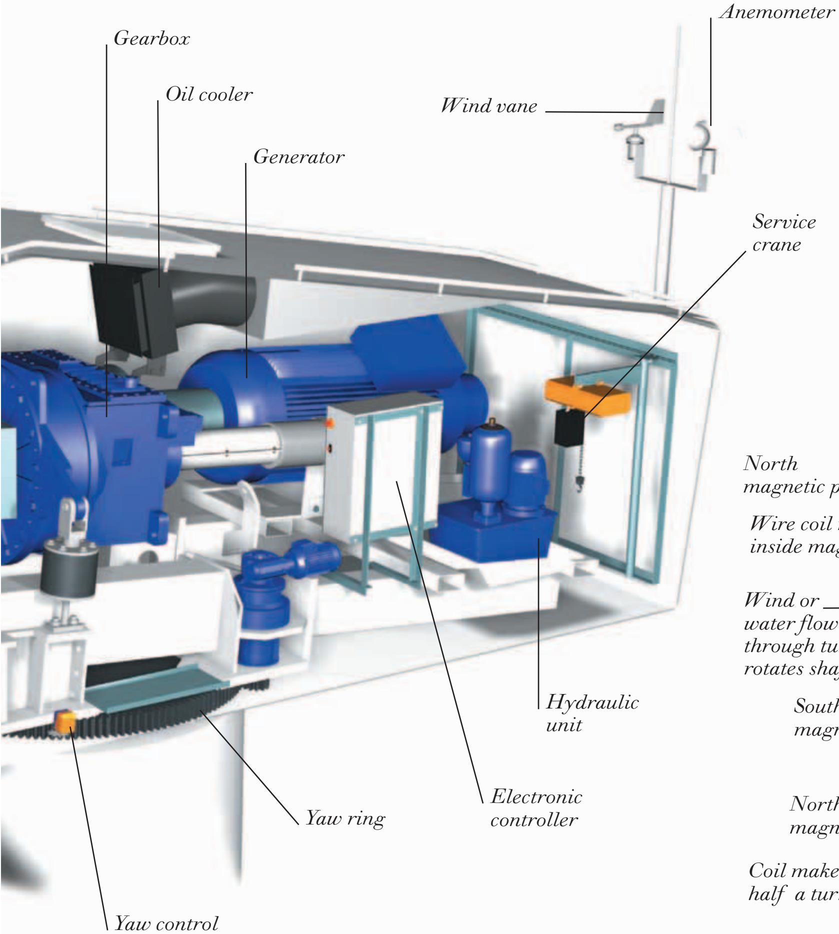
TIDAL POWER



RISING TIDE

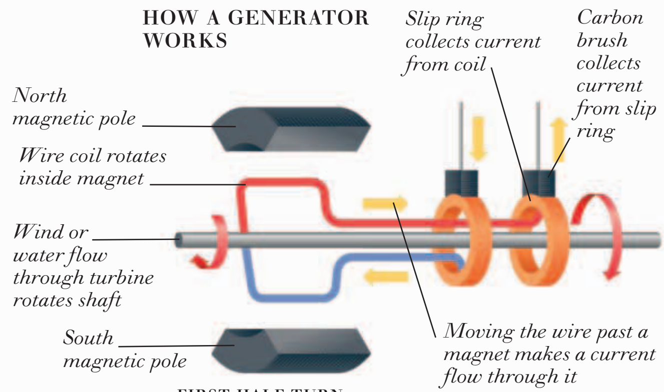


FALLING TIDE

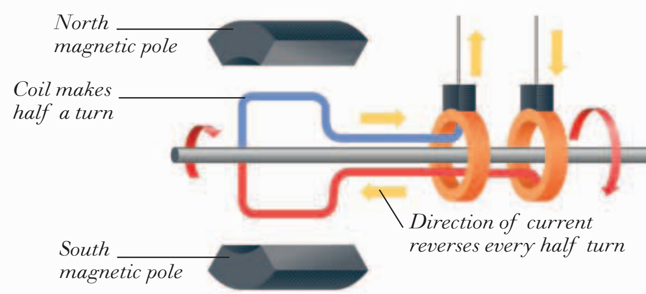



WIND TURBINES IN A WIND FARM

HOW A GENERATOR WORKS

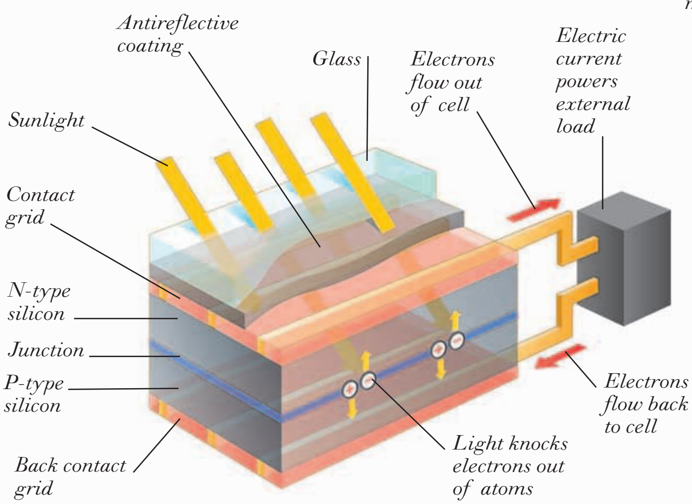


FIRST HALF TURN

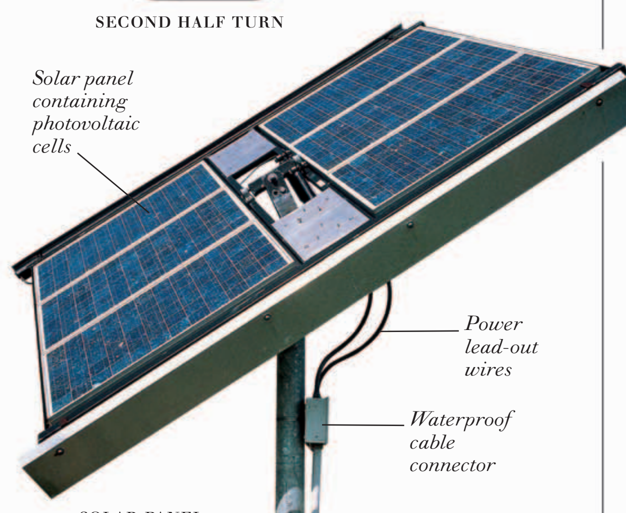


SECOND HALF TURN

SOLAR POWER



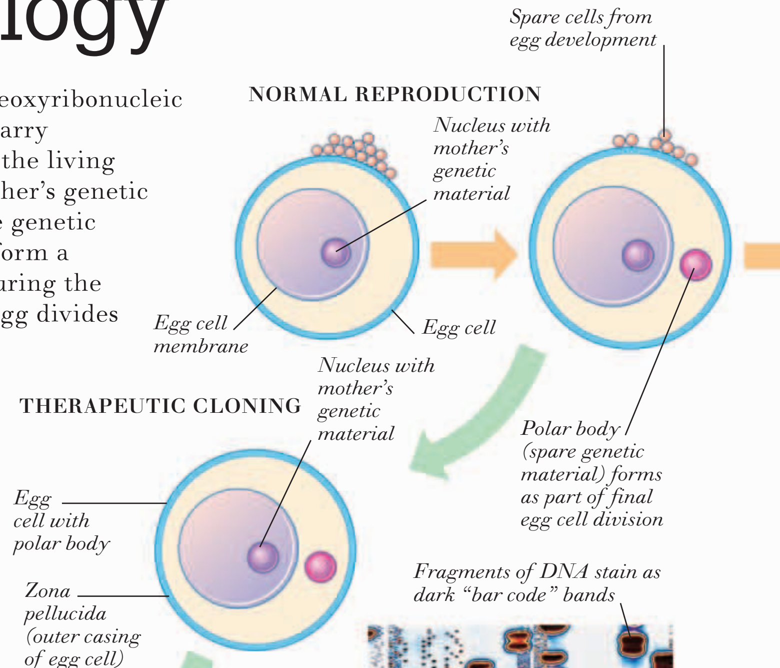
HOW A PHOTOVOLTAIC CELL WORKS

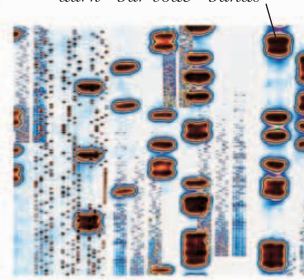


SOLAR PANEL

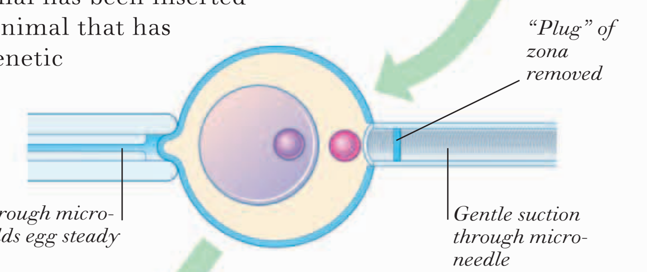
Cloning technology

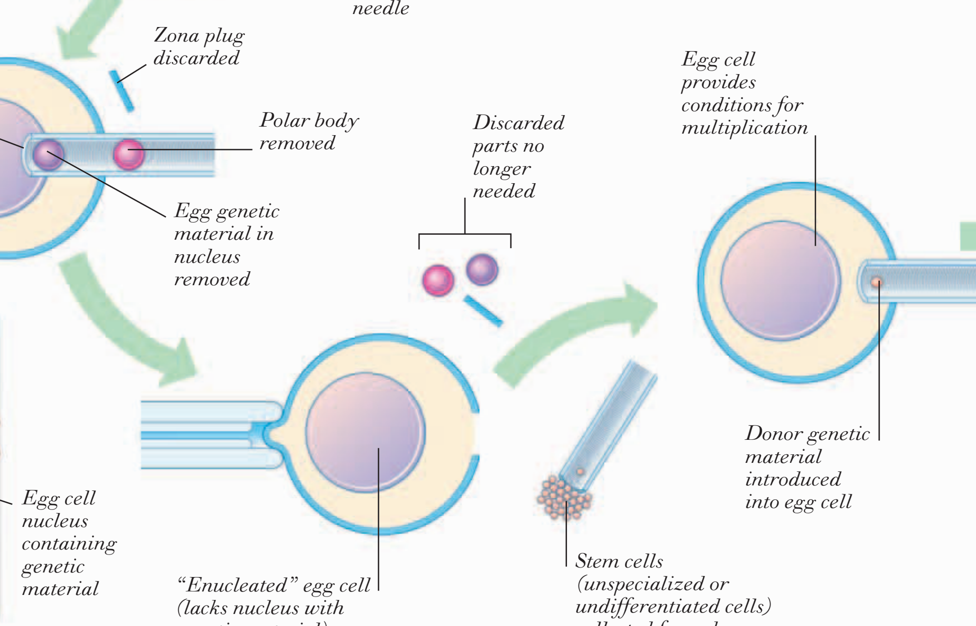
IN A LIVING CELL THE GENETIC MATERIAL DNA (deoxyribonucleic acid) contains thousands of units called genes that carry instructions for development, growth, and repair of the living creature. During normal reproduction, half the mother's genetic material contained in an egg cell joins with half the genetic material from the father carried in a sperm cell, to form a unique new genome (set of genes) for a new life. During the early stages of embryo development, the fertilized egg divides into stem cells, which have the potential to become specialized into the hundreds of cell types in a body. Through therapeutic cloning, stem cells can be produced in a laboratory. It is hoped that in the future this technology can be used to grow new tissue that can be transplanted back into the donor to treat illness, without fear of rejection—when the body recognizes a transplanted part as "foreign" because it has different genes, and tries to destroy it. In another form of cloning, performed experimentally using animals, genetic material from a donor animal has been inserted into an egg from another animal that has been emptied of its own genetic material, to produce an animal genetically identical to the donor.

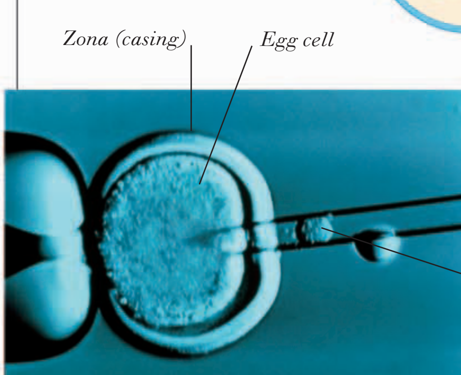




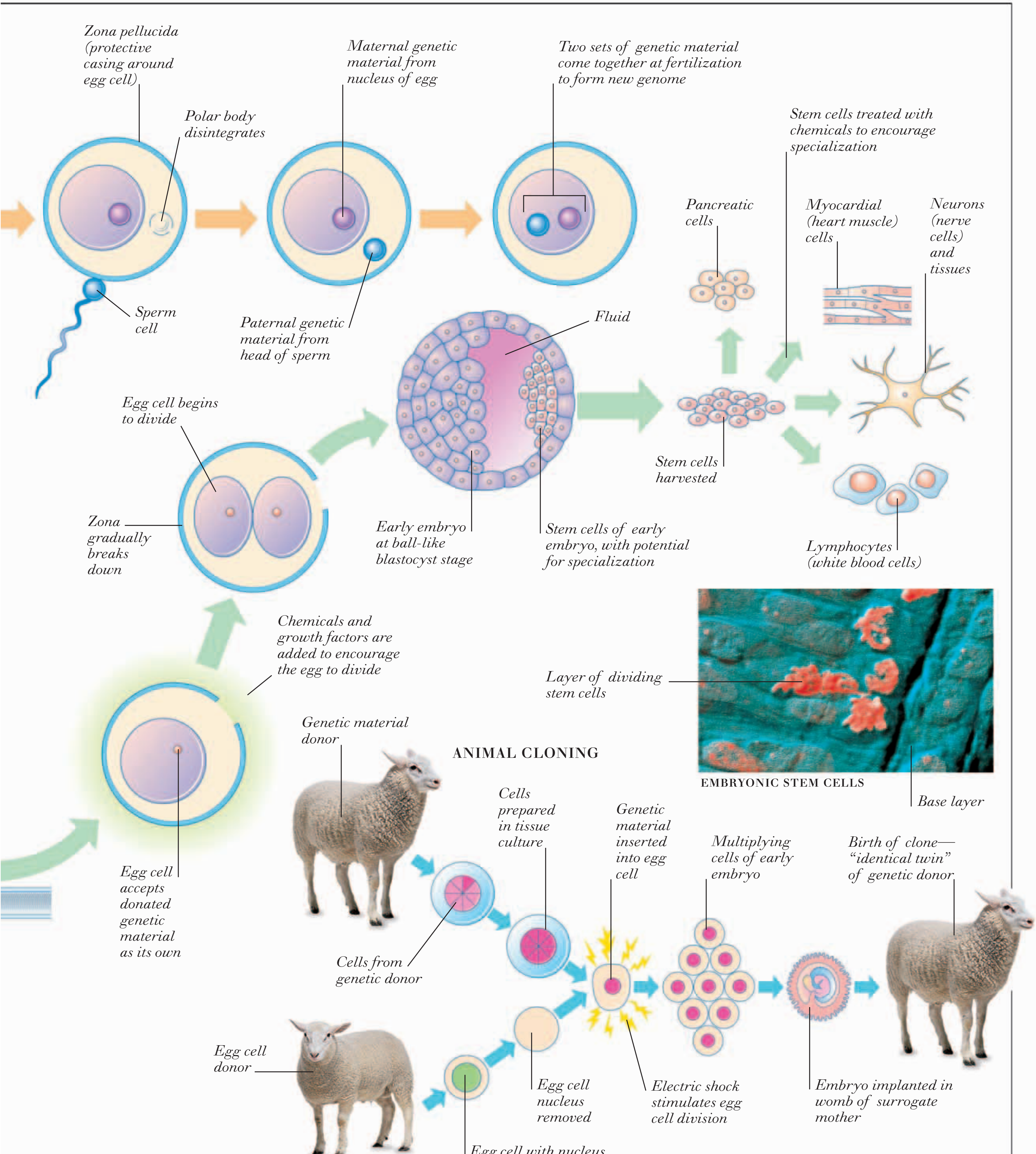
GEL IMAGE SHOWING DNA PROFILE





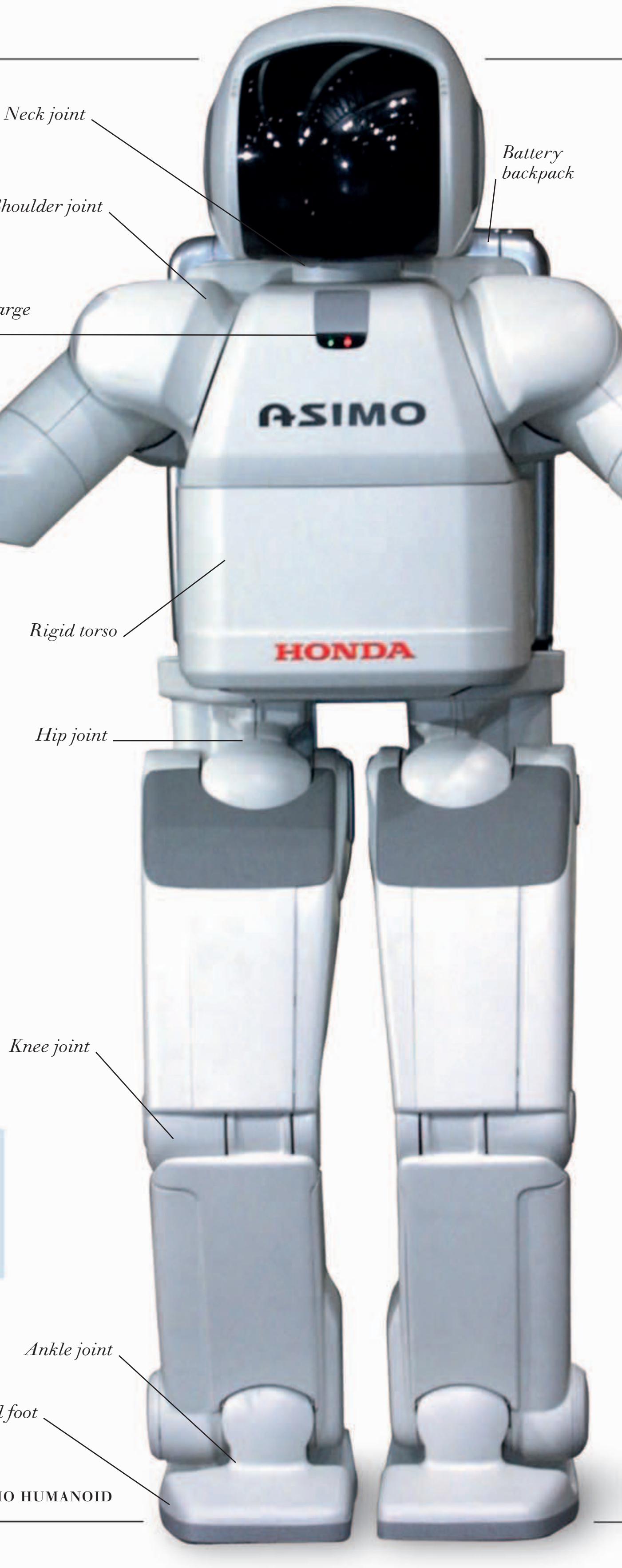


CENETIC MATERIAL REMOVED FROM EGG


Zona pellucida (protective casing around egg cell)
Polar body disintegrates
Maternal genetic material from nucleus of egg
Two sets of genetic material come together at fertilization to form new genome
Stem cells treated with chemicals to encourage specialization
Pancreatic cells
Myocardial (heart muscle) cells
Neurons (nerve cells) and tissues
Sperm cell
Paternal genetic material from head of sperm
Fluid
Egg cell begins to divide
Zona gradually breaks down
Early embryo at ball-like blastocyst stage
Stem cells of early embryo, with potential for specialization
Stem cells harvested
Lymphocytes (white blood cells)
Chemicals and growth factors are added to encourage the egg to divide
Layer of dividing stem cells
Egg cell accepts donated genetic material as its own
Genetic material donor
ANIMAL CLONING
EMBRYONIC STEM CELLS
Base layer
Cells prepared in tissue culture
Genetic material inserted into egg cell
Multiplying cells of early embryo
Birth of clone—“identical twin” of genetic donor
Cells from genetic donor
Egg cell donor
Egg cell nucleus removed
Electric shock stimulates egg cell division
Embryo implanted in womb of surrogate mother
Egg cell with nucleus

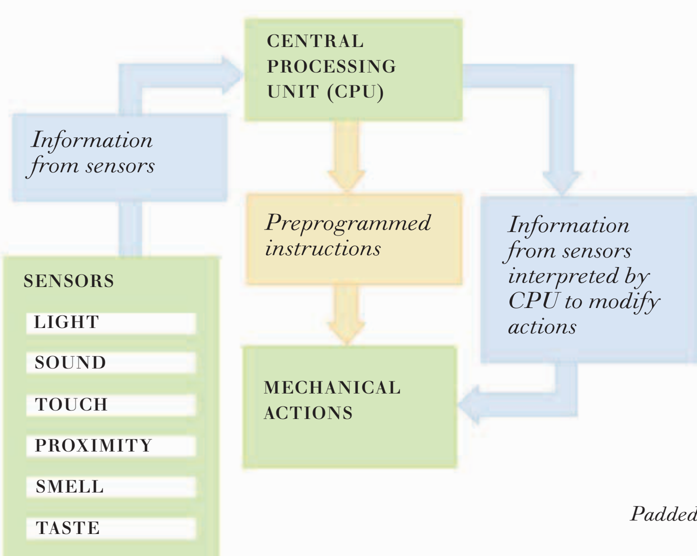
Robots

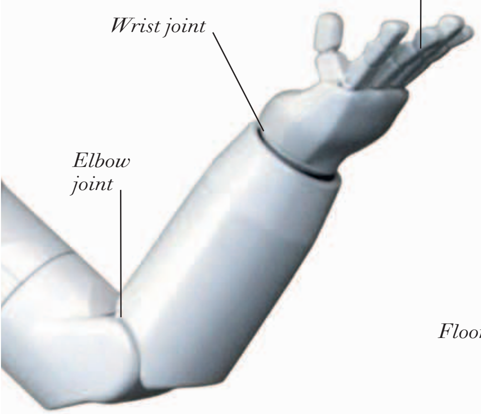
ROBOTS ARE MACHINES THAT CAN carry out a variety of tasks on their own, with little or no human control. Most robots are mechanical arms used to build things in factories. The end of the robot's arm can be equipped with different tools for gripping, drilling, cutting, welding, and painting. Robot toys have become popular, too. They incorporate sensors that respond to sounds and sometimes touch. Some of them can even understand spoken words. Scientists are also trying to create more advanced, humanlike robots that can see, hear, learn, and make their own decisions. ASIMO, a robot developed by the Japanese car manufacturer Honda, is one of these advanced humanoid robots. ASIMO stands for Advanced Step in Innovative MObility. It looks like a small astronaut wearing a backpack. ASIMO can walk, talk, carry things, recognize familiar faces, and respond to its name. It was the first robot that could walk independently and climb stairs. There are robot toys, too, in the shape of animals with simple artificial intelligence.

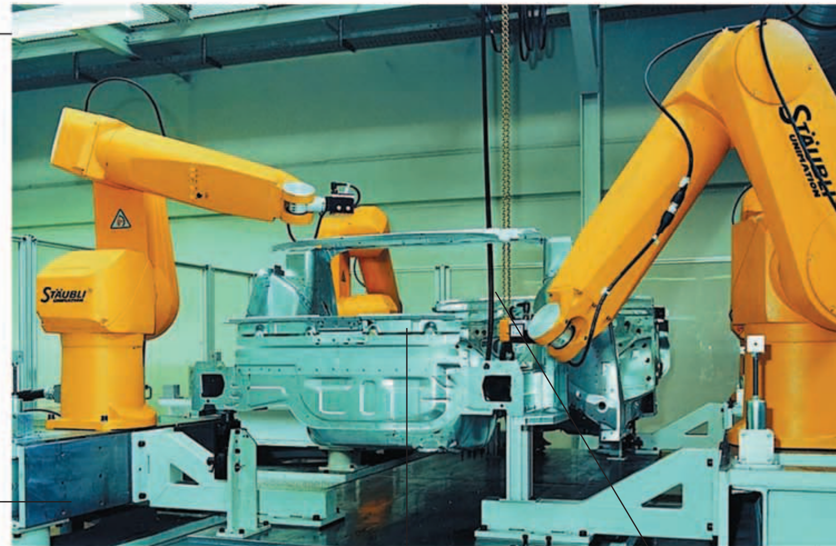


ASIMO HUMANOID

ELEMENTS OF ROBOT ACTION

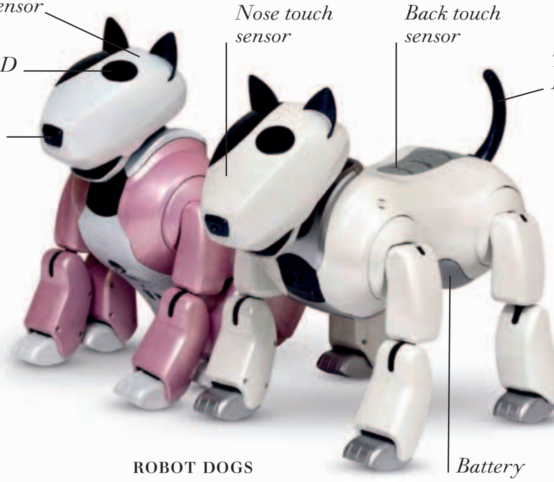






CAR-BUILDING ROBOTS

KAWASAKI INDUSRIAL ROBOT

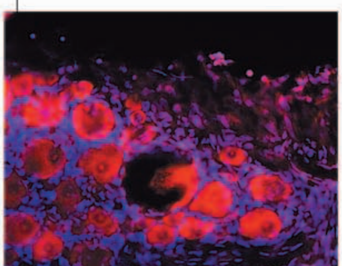


ROBOT DOGS

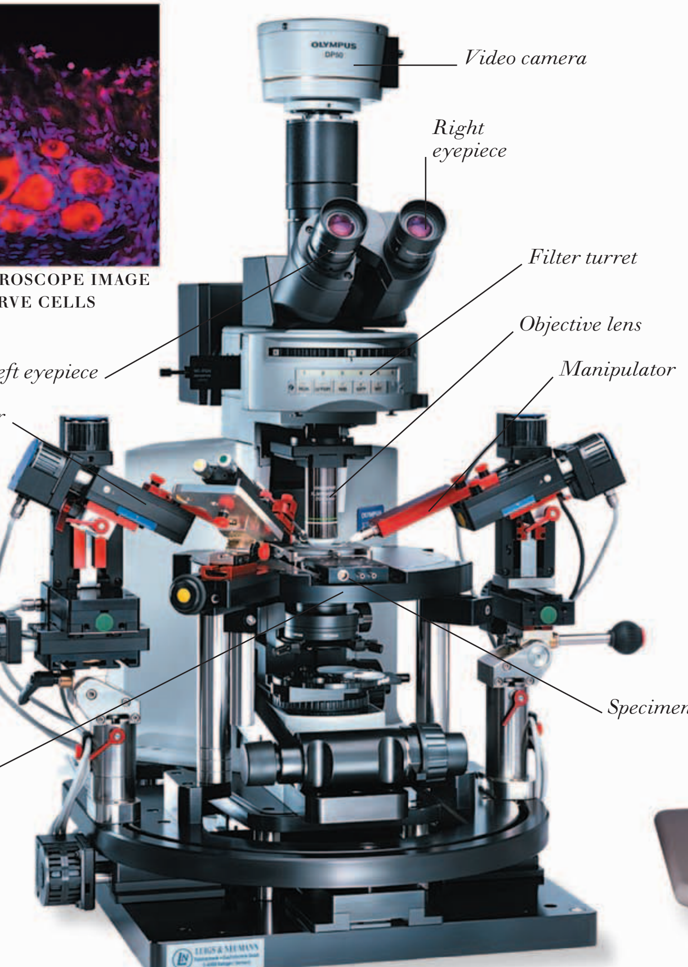
ROBOREPTILE

High-performance microscopes

OPTICAL MICROSCOPES FORM A MAGNIFIED image by using lenses to bend light. Some special-purpose optical microscopes used in industry and research are designed for observing particular materials, such as living cells. They produce magnifications of up to about 2,000. Electron microscopes produce magnifications of as much as 50 million, although 2 million is more typical. Their images are formed by means of electrons focused by magnetic lenses. There are two main types: scanning electron microscopes (SEMs) scan electrons back and forth across the surface of a specimen; transmission electron microscopes (TEMs) transmit electrons through a thin slice of the specimen.

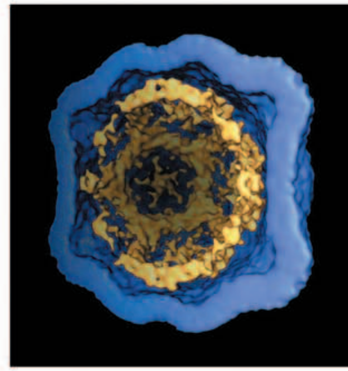


OPTICAL MICROSCOPE IMAGE OF DYING NERVE CELLS

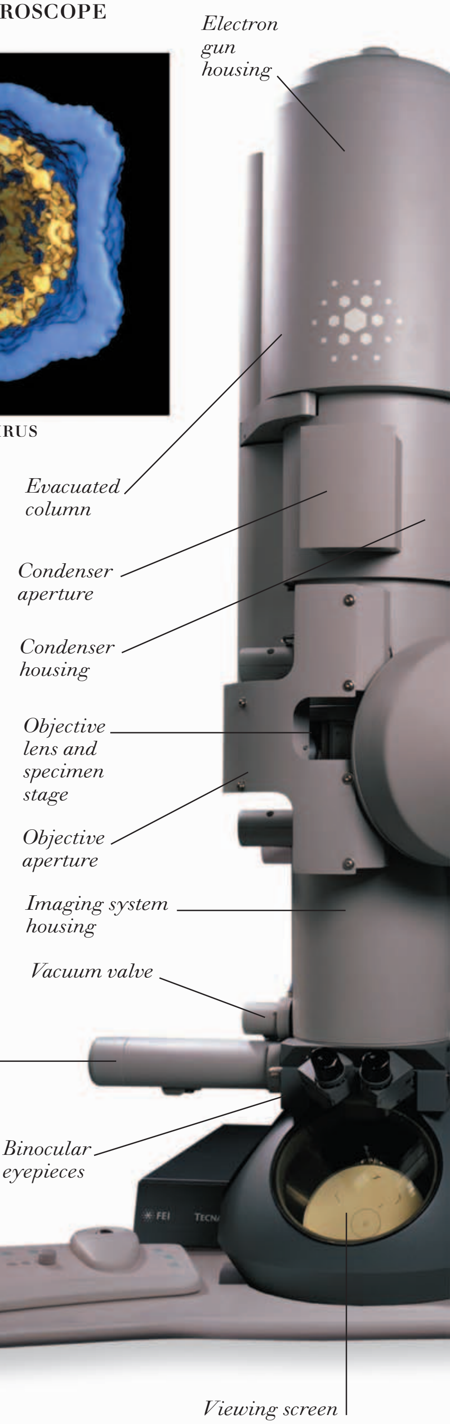


OLYMPUS BX51W1 OPTICAL MICROSCOPE

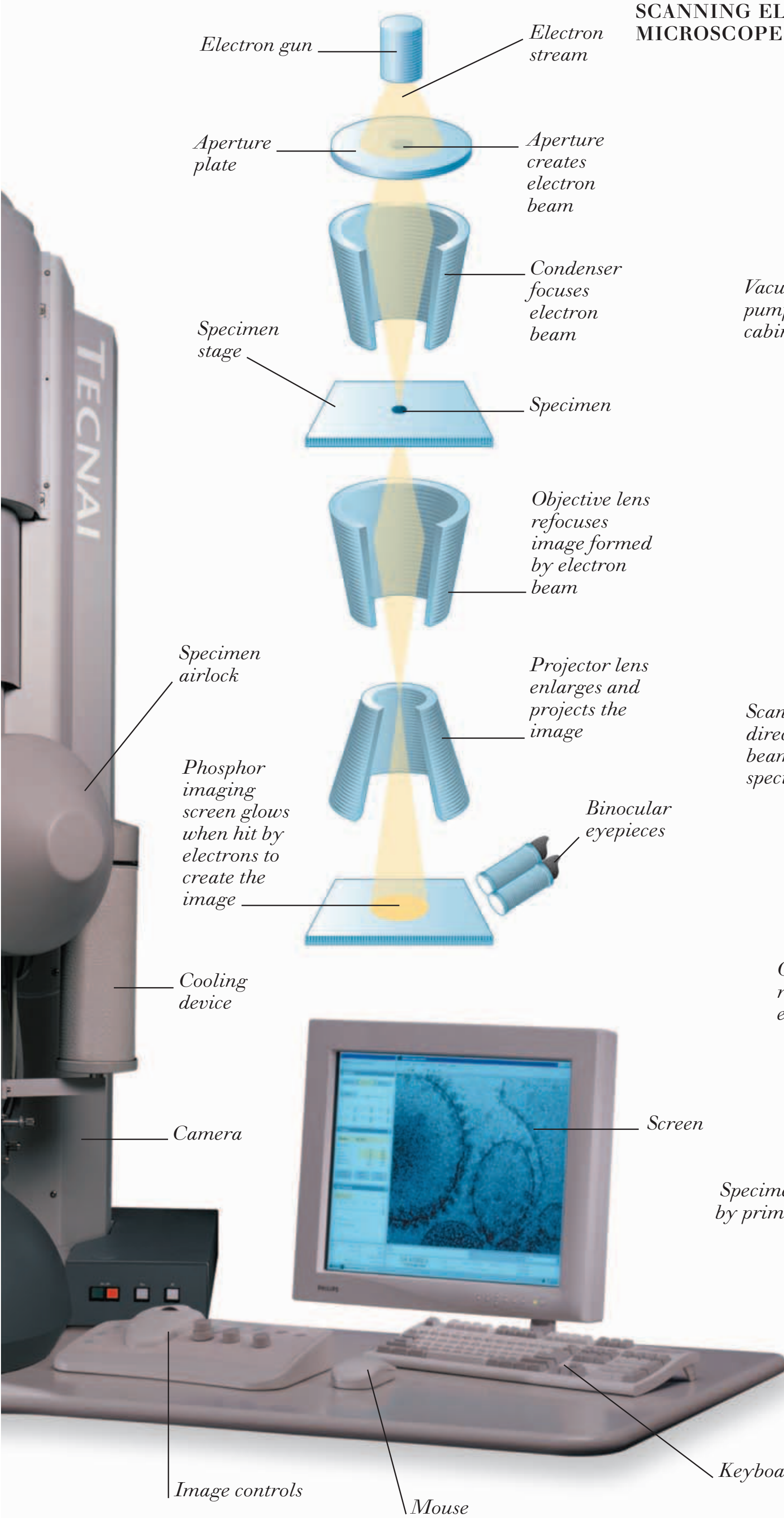
FEI TECNAI G² TRANSMISSION ELECTRON MICROSCOPE



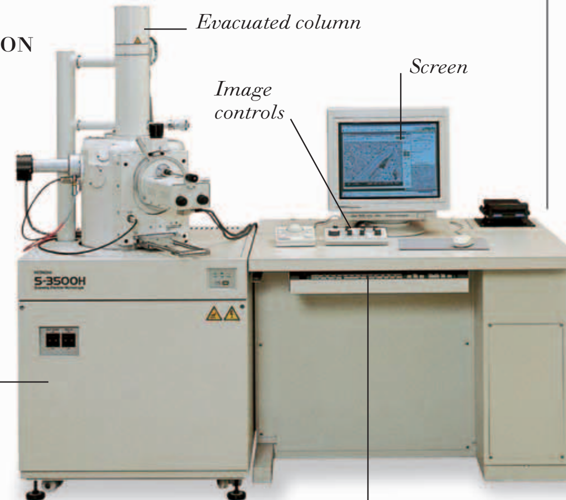
TEM IMAGE OF A VIRUS



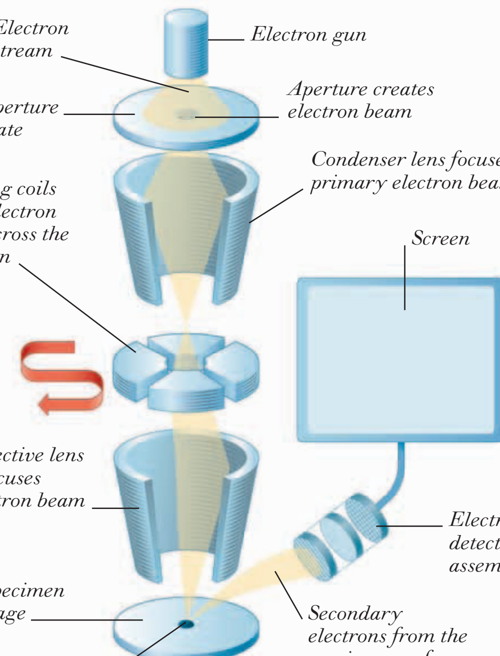
HOW A TEM WORKS

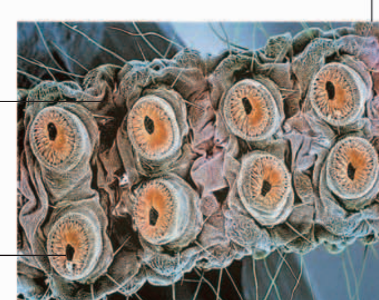


HITACHI S-3500H SCANNING ELECTRON MICROSCOPE



HOW A SEM WORKS





SEM IMAGE OF A CATERPILLAR

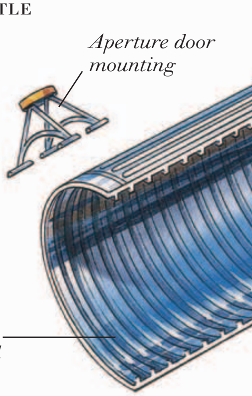
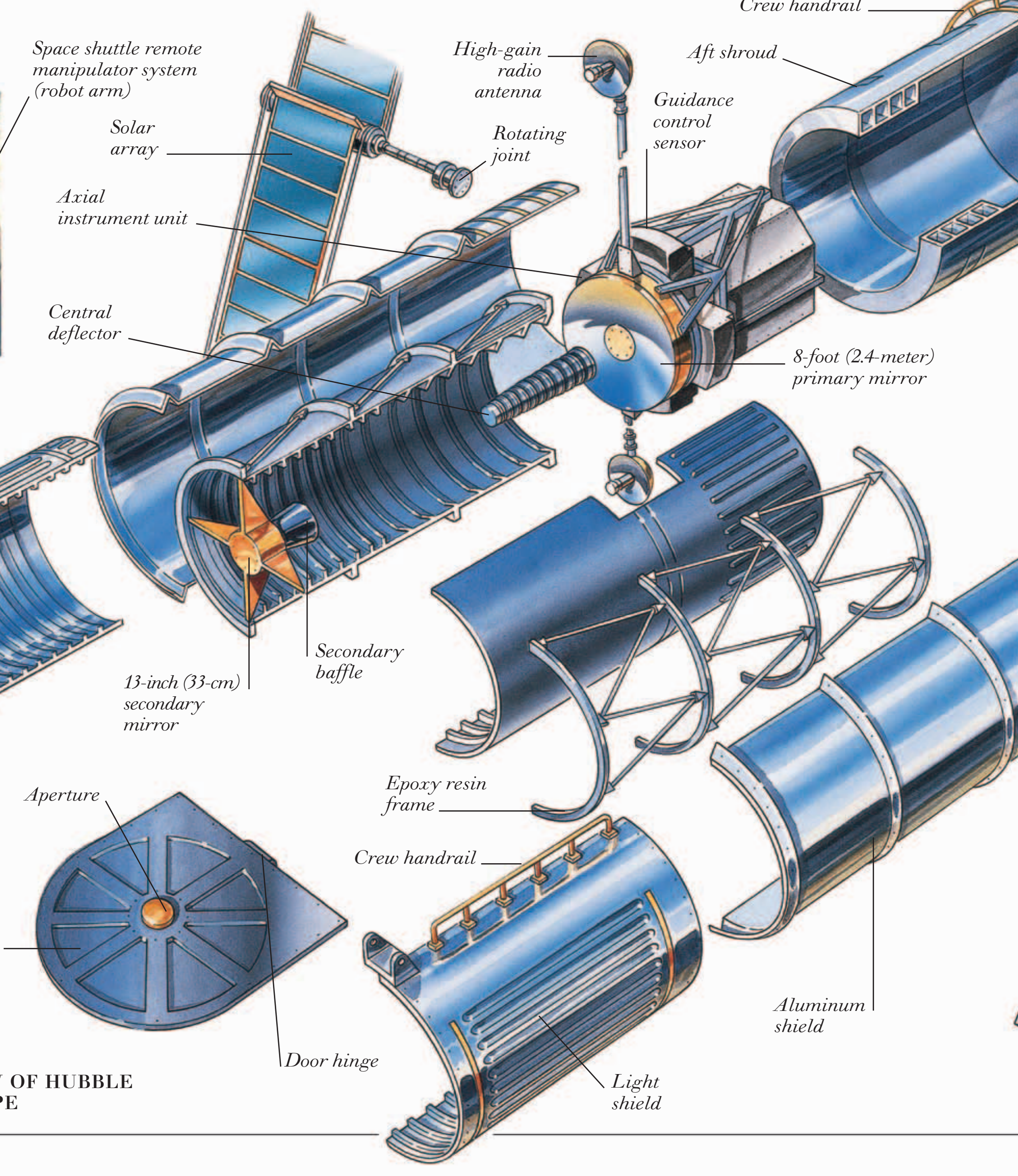
Space telescope

SPACE TELESCOPES ORBIT THE EARTH hundreds of miles above the ground, their instruments collecting light from stars and galaxies. Telescopes in space have a clearer view than those on Earth, because they are unaffected by the Earth's atmosphere, which absorbs or distorts much of this radiation. There are a variety of types of space telescope designed to observe different types of light. The Hubble Space Telescope observes infrared, ultraviolet, and visible light. It can detect objects that are 100 times fainter than those any telescopes on Earth can see. When this 12-ton (11,000-kilogram), 43-foot (13-meter) long telescope was launched by the Space Shuttle in 1990, it was found that its primary mirror was faulty and its images were blurred. Astronauts fitted extra optics to correct the problem in 1993.

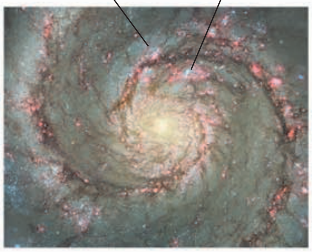
IMAGES TAKEN BY HUBBLE

CONE NEBULA

VIEW FROM COLUMBIA SPACE SHUTTLE

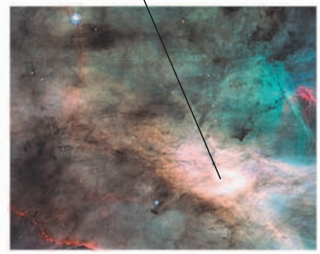



EXPLODED VIEW OF HUBBLE SPACE TELESCOPE

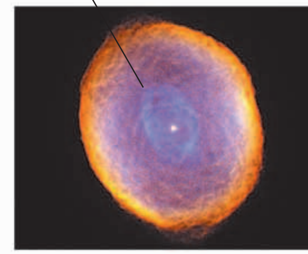


"WHIRLPOOL" GALAXY

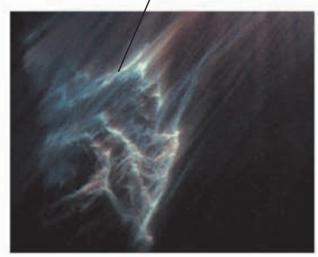
DRACO CONSTELLATION



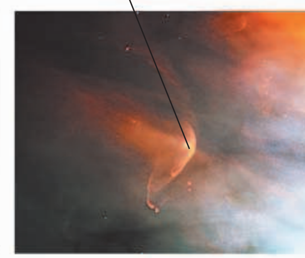
OMEGA NEBULA



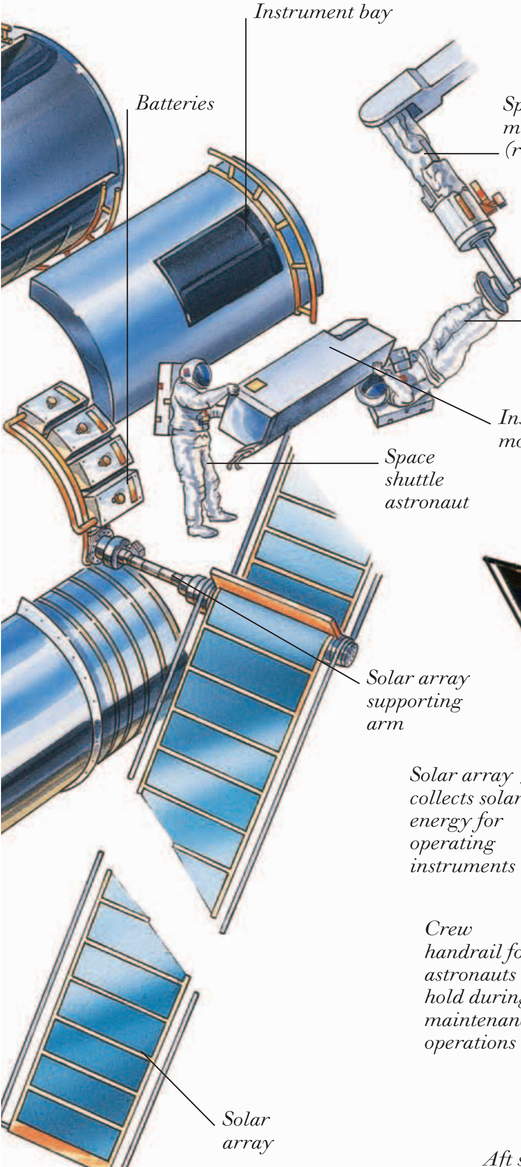
LEPUS CONSTELLATION



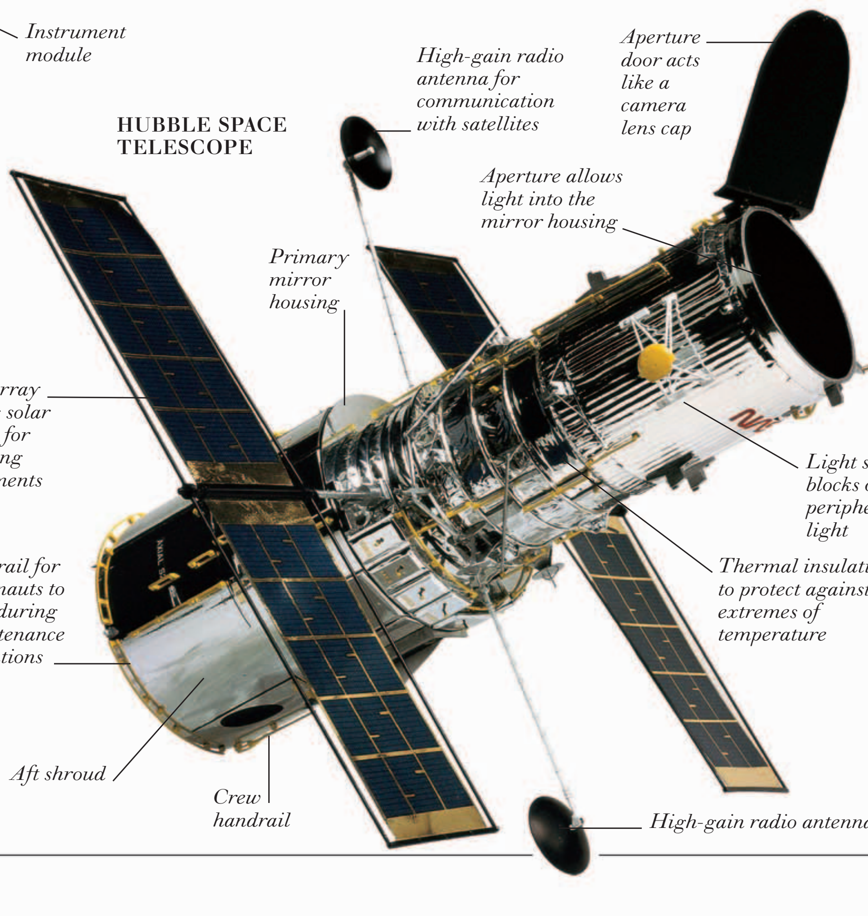
PLEIADES STAR CLUSTER



GREAT NEBULA, ORION

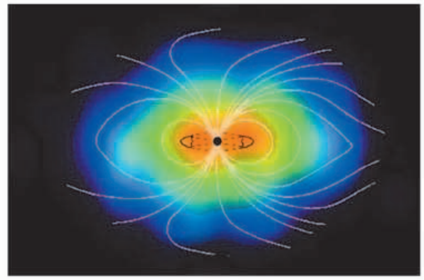


HUBBLE SPACE TELESCOPE

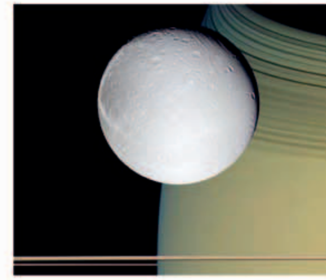


Probing the solar system

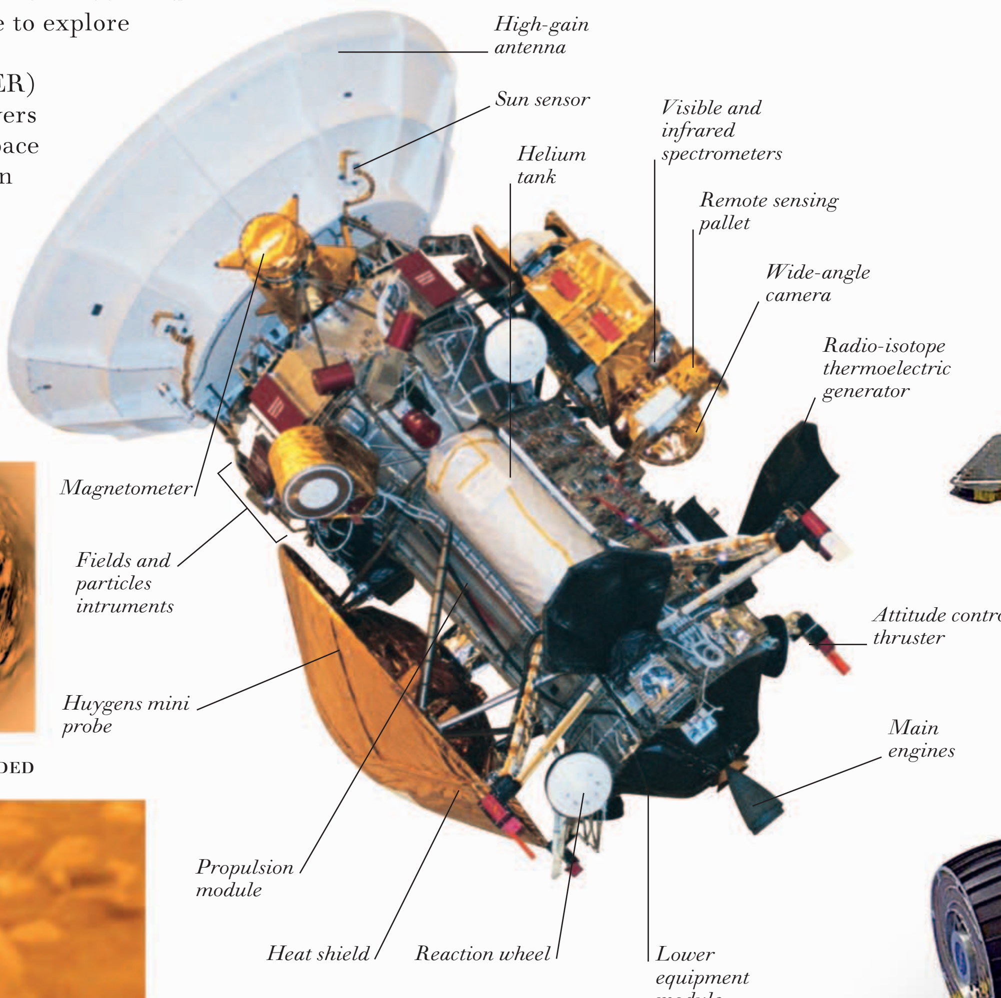
SPACE PROBES HAVE VISITED every planet in the solar system. They take photographs and gather data that cannot be collected using Earth-based equipment. Some probes fly past or orbit around planets or moons, while others land. Two Voyager space probes flew past the outer planets in the 1970s and 1980s. Two Viking spacecraft landed on Mars in 1976. The Magellan spacecraft orbited Venus from 1989 and mapped its surface. The Pathfinder spacecraft landed on Mars in 1997 and released a rover vehicle to explore the surface. The Mars Exploration Rover (MER) Mission landed two rovers in 2003. The Cassini space probe reached Saturn in 2004, and in 2005 its mini-probe, Huygens, landed on one of its moons, Titan, and became the first probe to land on a moon of another planet.



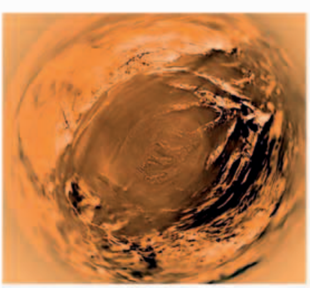
A MAP OF JUPITER'S VAST MAGNETIC FIELD PRODUCED BY CASSINI'S INSTRUMENTS



DIONE, ONE OF SATURN'S MOONS, ORBITING ABOVE THE "A" RING

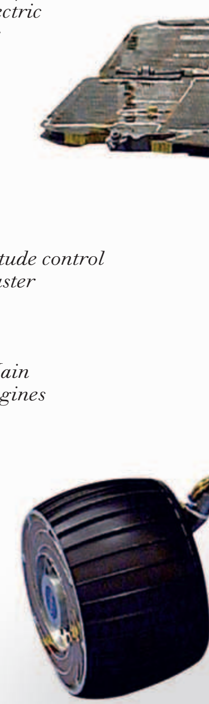


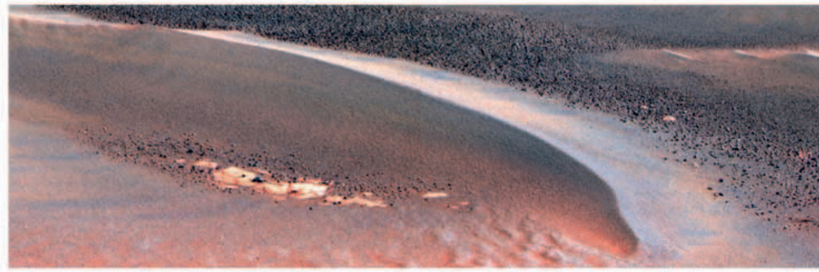
CASSINI SPACE PROBE AND HUYGENS MINI-PROBE



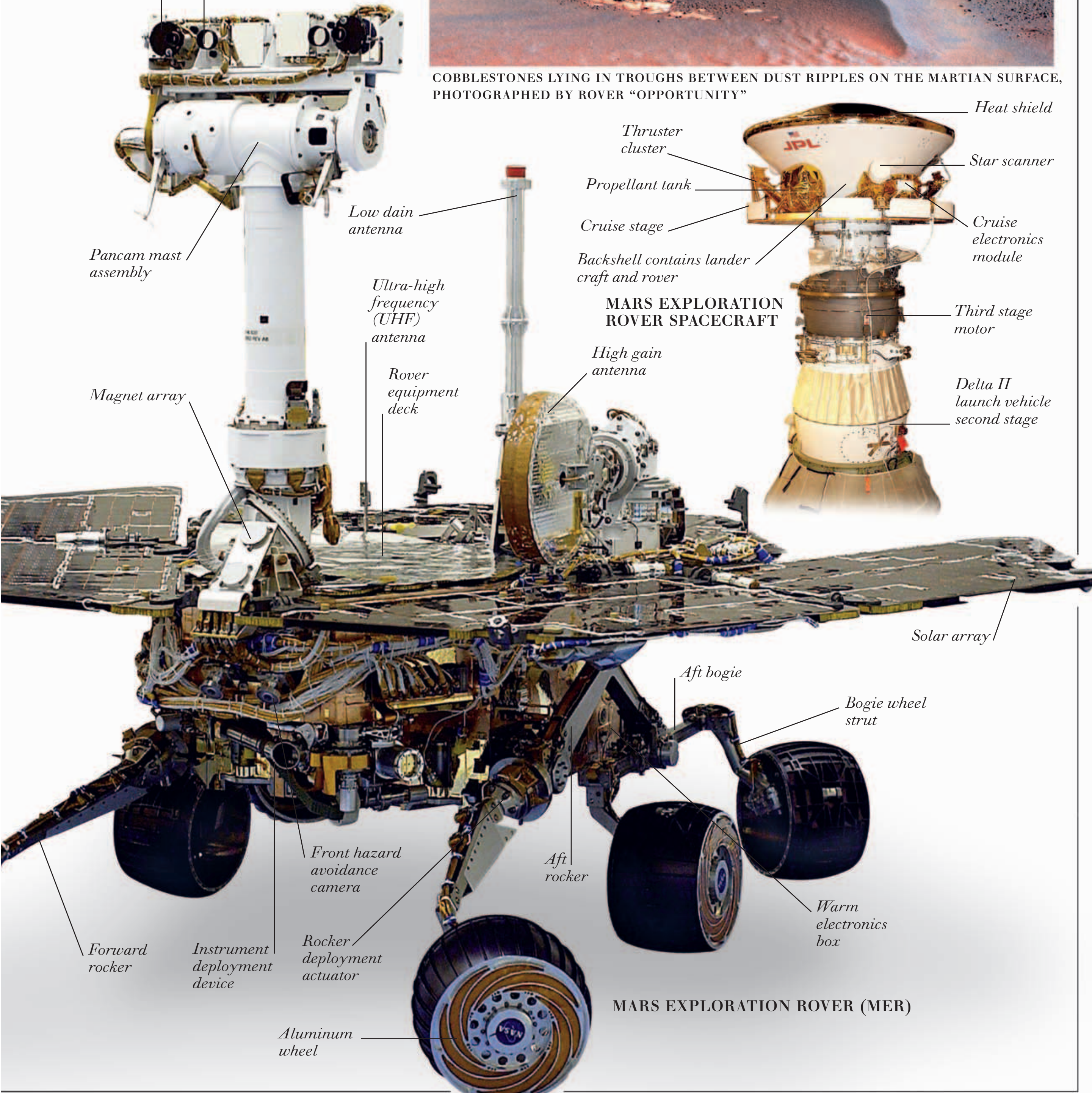
PANORAMIC VIEW OF TITAN TAKEN AS HUYGENS DESCENDED

THE ROCK-STREWN SURFACE OF TITAN, PHOTOGRAPHED BY HUYGENS





COBBLESTONES LYING IN TROUGHS BETWEEN DUST RIPPLES ON THE MARTIAN SURFACE, PHOTOGRAPHED BY ROVER "OPPORTUNITY"



MARS EXPLORATION ROVER SPACECRAFT

MARS EXPLORATION ROVER (MER)

Political map of the world

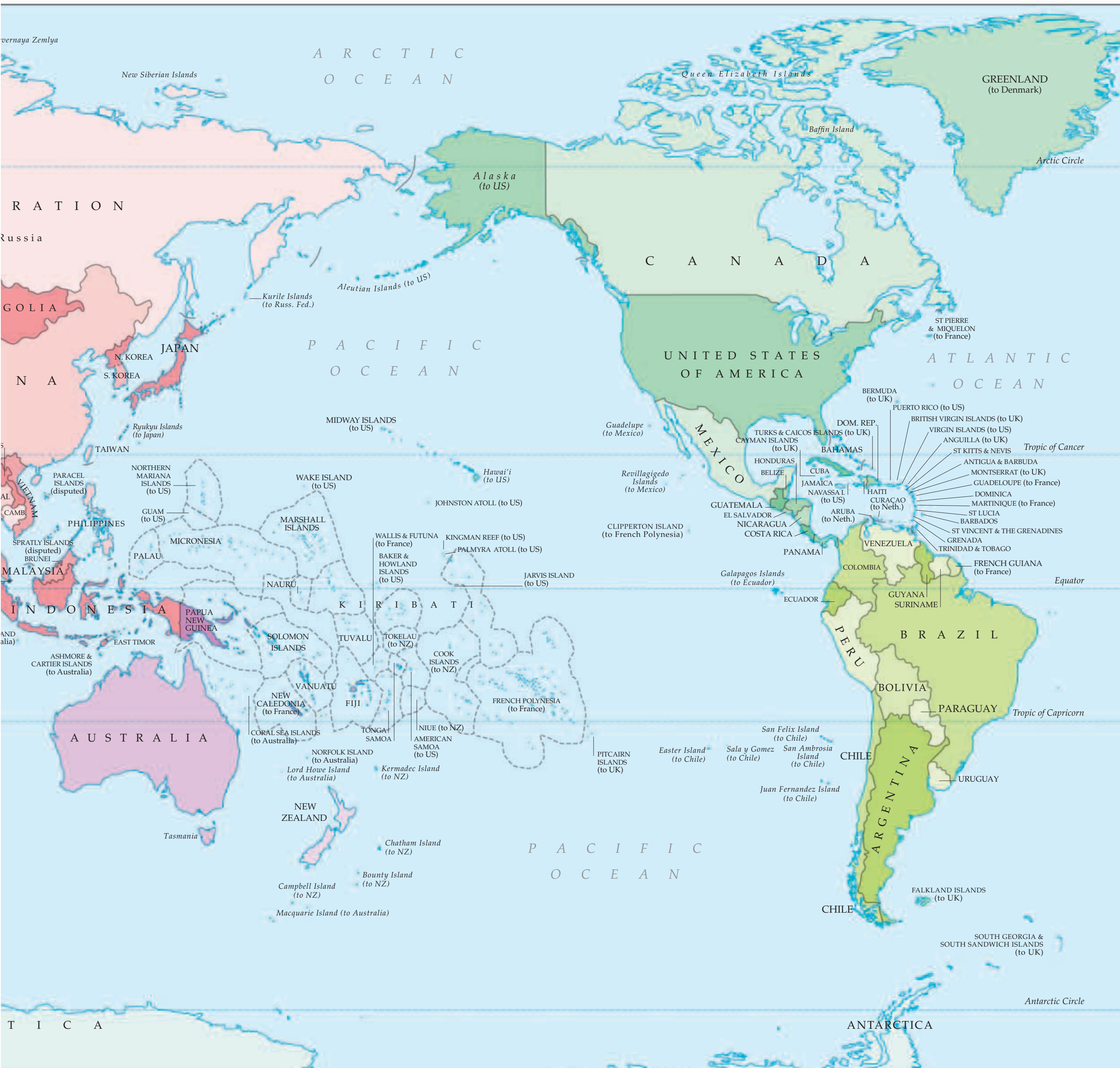
This map depicts the political boundaries of the world's nations. There are currently 196 independent countries in the world—a marked increase from the 82 that existed in 1950. With the trend toward greater fragmentation, most recently with the creation of Southern Sudan in July 2011, this figure is likely to increase. The largest country in the world is the Russian Federation, which covers 6,592,800 square miles (17,075,400 sq km), while the smallest is the Vatican City, covering 0.17 square miles (0.44 sq km). Under the Antarctic Treaty of 1959, no countries are permitted territorial claims in Antarctica.

ABBREVIATIONS

AFGH.	Afghanistan
ALB.	Albania
AUT.	Austria
AZ. OR AZERB.	Azerbaijan
B. & H.	Bosnia & Herzegovina
BELG.	Belgium
BELO.	Belorussia
BOTS.	Botswana
BULG.	Bulgaria
CAMB.	Cambodia
C.A.R.	Central African Republic
CRO.	Croatia
CZ. REP.	Czech Republic
DOM. REP.	Dominican Republic
EST.	Estonia
HUNG.	Hungary
KYRG.	Kyrgyzstan
LAT.	Latvia
LIECH.	Liechtenstein
LITH.	Lithuania
LUX.	Luxemburg
MACED.	Macedonia
MOLD.	Moldavia
MON.	Montenegro
NETH.	Netherlands
PORT.	Portugal
ROM.	Romania
RUSS. FED.	Russian Federation
SLVK.	Slovakia
SLVN.	Slovenia
S.M.	San Marino
SWITZ.	Switzerland
TAJ.	Tajikistan
THAI.	Thailand
TURKMEN.	Turkmenistan
U.A.E.	United Arab Emirates
UZBEK.	Uzbekistan
VAT. CITY	Vatican City
ZIMB.	Zimbabwe

KEY

CONTINENTS		LABEL STYLES	
Europe	North & Central America	E.g., Mexico	Independent state
Africa	South America	E.g., Faeroe Islands .... (to Denmark)	Self-governing territory (parent state)
Asia	Antarctica	E.g., *Andaman Islands* .... (*to India*)	Non self-governing territory (parent state)
Australasia & Oceania			



Time zones

The world is divided into 24 time zones, measured in relation to 12 noon Coordinated Universal Time (UTC), on the Greenwich Meridian (0°). Time advances by one hour for every 15° longitude east of Greenwich (and goes back one hour for every 15° west), but the system is adjusted in line with administrative boundaries. Numbers on the map indicate the number of hours that must be added to, or subtracted from UTC to calculate the time in each zone. Thus, the eastern United States (–5) is 5 hours behind UTC.

TYPES OF CALENDAR

GREGORIAN

The 365-day Gregorian calendar was introduced by Pope Gregory XIII in 1582 and is now in use throughout most of the Western world. Every four years (leap year) an extra day is added. Below are the names of the months (and number of days).

January (31)	July (31)
February (28, 29 in leap years)	August (31)
March (31)	September (30)
April (30)	October (31)
May (31)	November
June (30)	December (31)

JEWISH

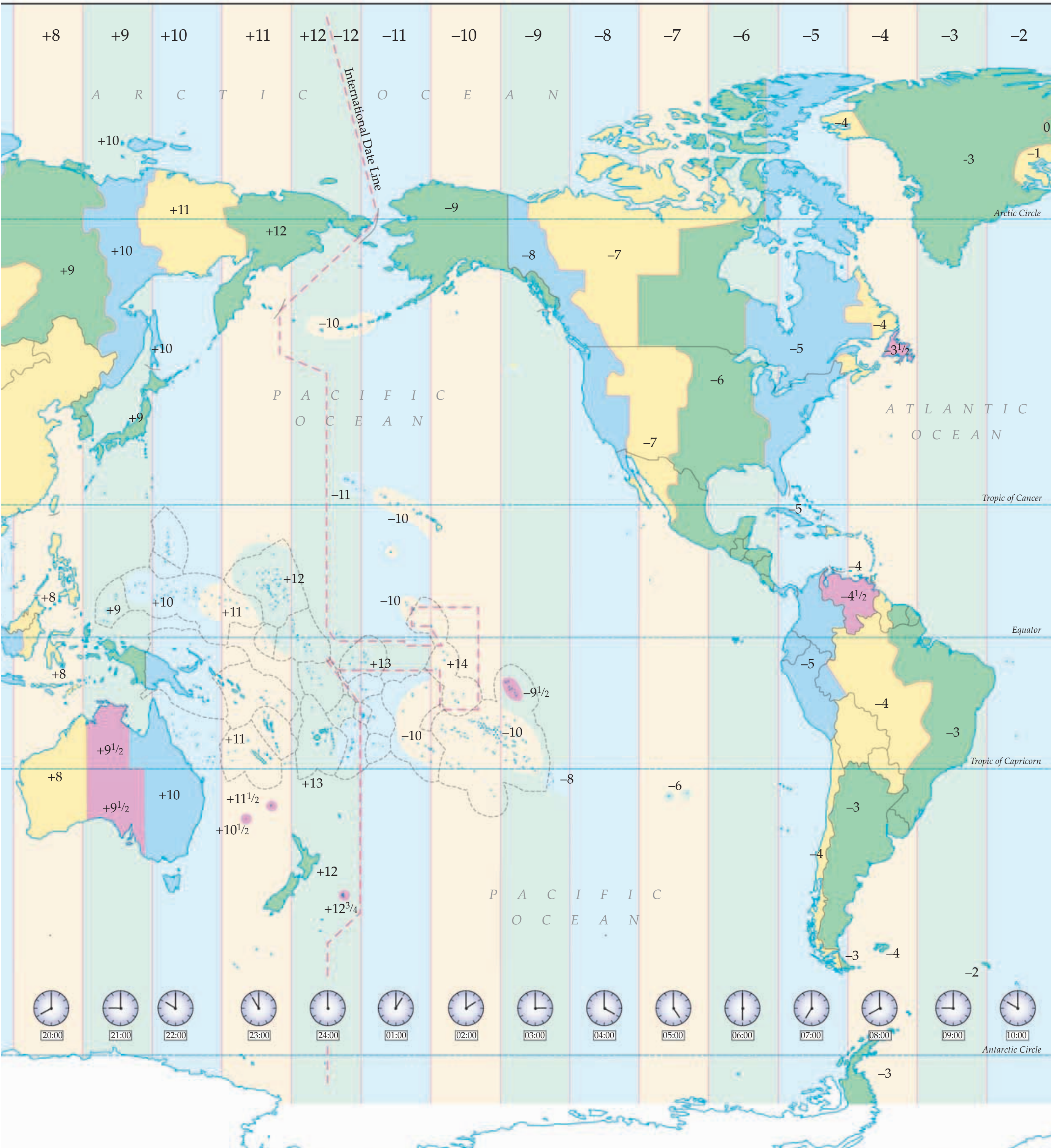
The Jewish calendar is a lunar calendar adapted to the solar year. It normally has 12 months but in leap years, which occur seven times in every cycle of 19 years, there are 13 months. The years are calculated from the Creation (which is placed at 3761 BC); the months are Nisan, Iyyar, Sivan, Thammuz, Ab, Elul, Tishri, Hesvan, Kislev, Tebet, Sebat, and Adar, with an intercalary month (First Adar) being added in leap years.

MUSLIM

The Muslim calendar is based on a year of 12 months, each month beginning roughly at the time of the New Moon. The months are Muharram, Safar, Rabi'I, Rabi'II, Jumada I, Jumada II, Rajab, Sha'ban, Ramadan, Shawwal, Dhu l-Qa'dah, and Dhu l-Hijja.

CHINESE

The Chinese calendar is a lunar calendar, with a year consisting of 12 months. Intercalary months are added to keep the calendar in step with the solar year of 365 days. Months are referred to by a number within a year, but also by animal names that, from ancient times, have been attached to years and hours of the day.


+8
+9
+10
+11
+12
–12
–11
–10
–9
–8
–7
–6
–5
–4
–3
–2
ARCTIC OCEAN
International Date Line
PACIFIC OCEAN
ATLANTIC OCEAN
PACIFIC OCEAN
Arctic Circle
Tropic of Cancer
Equator
Tropic of Capricorn
Antarctic Circle
0
–1
–3¹/₂
–4¹/₂
–9¹/₂
+9¹/₂
+11¹/₂
+10¹/₂
+12³/₄
+13
+14
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23:00
24:00
01:00
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Useful data

UNITS OF MEASUREMENT

METRIC UNIT	EQUIVALENT
Length	
1 centimeter (cm)	10 millimeters (mm)
1 meter (m)	100 centimeters
1 kilometer (km)	1,000 meters
Mass	
1 kilogram (kg)	1,000 grams (g)
1 metric ton (t)	1,000 kilograms
Area	
1 square centimeter (cm^2)	100 square millimeters (mm^2)
1 square meter (m^2)	10,000 square centimeters
1 hectare	10,000 square meters
1 square kilometer (km^2)	1,000,000 square meters
Volume	
1 cubic centimeter (cc)	1 milliliter (ml)
1 liter (l)	1,000 milliliters
1 cubic meter (m^3)	1,000 liters
Capacity (liquid and dry measures)	
1 centiliter (cl)	10 milliliters (ml)
1 deciliter (dl)	10 centiliters
1 liter (l)	10 deciliters
1 decaliter (dal)	10 liters
1 hectoliter (hi)	10 decaliters
1 kiloliter (kl)	10 hectoliters

IMPERIAL UNIT	EQUIVALENT
Length	
1 foot (ft)	12 inches (in)
1 yard (yd)	3 feet
1 rod (rd)	5½ yards
1 mile (mi)	1,760 yards
Mass	
1 dram (dr)	27.344 grains (gr)
1 ounce (oz)	16 drams
1 pound (lb)	16 ounces
1 hundredweight (cwt) (long)	112 pounds
1 hundredweight (cwt) (short)	100 pounds
1 ton (long)	2,240 pounds
1 ton (short)	2,000 pounds
Area	
1 square foot (ft^2)	144 square inches
(in^2)	1 square yard (yd^2)
9 square feet	
1 acre	4,840 square yards
1 square mile	640 acres
Volume	
1 cubic foot	1,728 cubic inches
1 cubic yard	27 cubic feet
Capacity (liquid and dry measures)	
1 fluidram (fl dr)	60 minims (min)
1 fluid ounce (fl oz)	8 fluidrams
1 gill (gi)	5 fluid ounces
1 pint (pt)	4 gills
1 quart (qt)	2 pints
1 gallon (gal)	4 quarts
1 peck (pk)	2 gallons
1 bushel (bu)	4 pecks

NUMBER SYSTEMS

ROMAN	ARABIC
I	1
II	2
III	3
IV	4
V	5
VI	6
VII	7
VIII	8
IX	9
X	10
XI	11
XII	12
XIII	13
XIV	14
XV	15
XX	20
XXI	21
XXX	30
XL	40
L	50
LX	60
LXX	70
LXXX	80
XC	90
C	100
CI	101
CC	200
CCC	300
CD	400
D	500
DC	600
DCC	700
DCCC	800
CM	900
M	1,000
MM	2,000

METRIC TO IMPERIAL CONVERSIONS

TO CONVERT	INTO	MULTIPLY BY
Length		
Centimeters	inches	0.3937
Meters	feet	3.2810
Kilometers	miles	0.6214
Meters	yards	1.0940
Mass		
Grams	ounces	0.0352
Kilograms	pounds	2.2050
Metric tons	long tons	0.9843
Metric tons	short tons	1.1025
Area		
Square centimeters	square inches	0.1550
Square meters	square feet	10.7600
Hectares	acres	2.4710
Square kilometers	square miles	0.3861
Square meters	square yards	1.1960
Volume		
Cubic centimeters	cubic inches	0.0610
Cubic meters	cubic feet	35.3100
Capacity		
Liters	pints	1.7600
Liters	gallons	0.2200

IMPERIAL TO METRIC CONVERSIONS

TO CONVERT	INTO	MULTIPLY BY
Length		
Inches	centimeters	2.5400
Feet	meters	0.3048
Miles	kilometers	1.6090
Yards	meters	0.9144
Mass		
Ounces	grams	28.3500
Pounds	kilograms	0.4536
Long tons	metric tons	1.0160
Short tons	metric tons	0.9070
Area		
Square inches	square centimeters	6.4520
Square feet	square meters	0.0929
Acres	hectares	0.4047
Square miles	square kilometers	2.5900
Square yards	square meters	0.8361
Volume		
Cubic inches	cubic centimeters	16.3900
Cubic feet	cubic meters	0.0283
Capacity		
Pints	liters	0.5683
Gallons	liters	4.5460

RULES OF ALGEBRA

EXPRESSION	COMMENTS	EXPRESSION BECOMES
a + a	Simple addition	2a
a + b = c + d	Subtract *b* from either side	a = c + d - b
ab = cd	Divide both sides by b	a = cd ÷ b
(a + b) (c + d)	Multiplication of bracketed terms	ac + ad + be + bd
a^2 + ab	Use parentheses	a(a + b)
$(a + b)^2$	Expand terms in parentheses	$a^2 + 2ab + b^2$
a^2—b^2	Difference of two squares	(a + b)(a-b)
1/a + 1/b	Find common denominator	(a + b)/ab
a/b ÷ c/d	Dividing by a fraction is the same as multiplying by its reciprocal	a/b × d/c

POWERS OF TEN USED WITH SCIENTIFIC UNITS

FACTOR	NAME	PREFIX	SYMBOL
10^{18}	quintillion	exa-	E
10^{15}	quadrillion	peta-	P
10^{12}	trillion	tera-	T
10^9	billion	giga-	G
10^6	million	mega-	M
10^3	thousand	kilo-	k
10^2	hundred	hecto-	h
10^1	ten	deca-	da
10^{-1}	one-tenth	deci-	d
10^{-2}	one-hundredth	centi-	c
10^{-3}	one-thousandth	milli-	m
10^{-6}	one-millionth	micro-	u
10^{-9}	one-billionth	nano-	n
10^{-12}	one-trillionth	pico-	p
10^{-15}	one-quadrillionth	femto-	f
10^{-18}	one-quintillionth	atto-	a

Note: The American system of numeration for denominations above one million is used in this book. In this system, each of the denominations above one billion (1,000 millions) is 1,000 times the preceding one.

BIOLOGY SYMBOLS

SYMBOL	MEANING
o	female individual (used in inheritance charts)
□	male individual (used in inheritance charts)
♀	female
♂	male
×	crossed with; hybrid
+	wild type
F_1	offspring of the first generation
F_2	offspring of the second generation

TEMPERATURE SCALES

To convert from Fahrenheit (F) to Celsius (C): C = (F—32) × 5 ÷ 9
To convert from Celsius to Fahrenheit: F = (C × 9 ÷ 5) + 32
To convert from Celsius to Kelvin (K): K = C + 273
To convert from Kelvin to Celsius: C = K - 273

Celsius	-20	-10	0	10	20	30	40	50	60	70	80	90	100
Fahrenheit	-4	14	32	50	68	86	104	122	140	158	176	194	212
Kelvin	253	263	273	283	293	303	313	323	333	343	353	363	373

PHYSICS SYMBOLS

SYMBOL	MEANING
α	alpha particle
β	beta ray
γ	gamma ray; photon
ε	electromotive force
η	efficiency; viscosity
λ	wavelength
μ	micro-; permeability
ν	frequency; neutrino
ρ	density; resistivity
σ	conductivity
c	velocity of light
e	electronic charge

MATHEMATICAL SYMBOLS

SYMBOL	EXPLANATION
+	addition
-	subtraction
×	multiplication
÷	division
=	equals
≠	does not equal
>	greater than
<	less than
≥	greater than or equal to
≤	less than or equal to
∞	infinity
%	percent
π	pi (3.1416)
°	degree
≈	is approximately equal to
∠	angle
∏	parallel to
∑	summation
u, u	vectors
f(x)	function
!	factorial
√	square root
ξ	universal set
A ∩ B	intersection
A ∪ B	unison
A ⊂ B	subset
Ø	null set

CHEMISTRY SYMBOLS

SYMBOL	MEANING
+	plus; together with
–	single bond
•	single bond; single unpaired electron; two separate parts or compounds regarded as loosely joined
=	double bond
≡	triple bond
R	group
X	halogen atom
Z	atomic number

SCIENTIFIC NOTATION

NUMBER	NUMBER BETWEEN 1 AND 10	POWER OF TEN	SCIENTIFIC NOTATION
10	1	10^1	1 3 10^1
150	1.5	10^2 (= 100)	1.5 3 10^2
274,000,000	2.74	10^8 (= 100,000,000)	2.74 3 10^8
0.0023	2.3	10^{-3} (= 0.001)	2.3 3 10^{-3}

TRIGONOMETRY

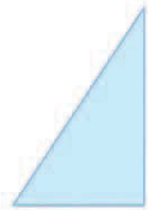
Angle A (degrees)	sin A	cos A	tan A
0	0	1	0
30	1/2	√3/2	1/√3
45	1/√2	1/√2	1
60	√3/2	1/2	√ 3
90	1	0	∞

Shapes: Plane

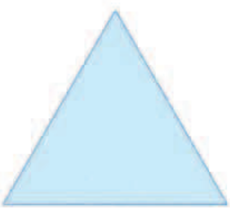
Two-dimensional shapes are termed plane (or flat) shapes. Plane shapes constructed with straight sides, as illustrated here, are called polygons. They are categorized according to the number of sides they have—for example, three-sided polygons are known as triangles. A polygon that has sides of equal length and internal angles of equal size, such as a square, is said to be regular.

SCALENE TRIANGLE
A triangle (three-sided polygon) with no equal sides or angles.

ISOSCELES TRIANGLE
A triangle with only two sides and two angles equal.

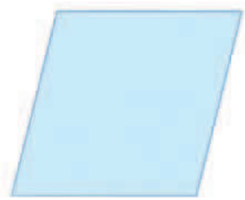


RIGHT-ANGLED TRIANGLE
A triangle with one angle as a right angle (90°).



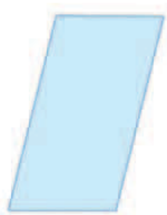
EQUILATERAL TRIANGLE
A regular triangle. All angles are 60°.

SQUARE
A regular quadrilateral. All angles are 90°.



RHOMBUS
A quadrilateral with all sides equal and two pairs of equal angles.

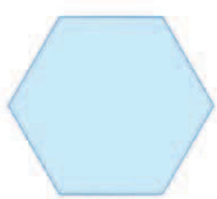
RECTANGLE
A quadrilateral with four right angles and opposite sides of equal length.



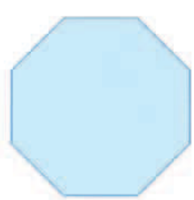
PARALLELOGRAM
A quadrilateral with two pairs of parallel sides.

TRAPEZIUM
A quadrilateral with one pair of parallel sides.

PENTAGON
A five-sided polygon. A regular pentagon is shown above.



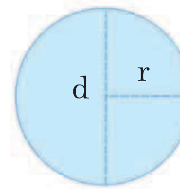
HEXAGON
A six-sided polygon. A regular hexagon is shown above.



OCTAGON
An eight-sided polygon. A regular octagon is shown above.

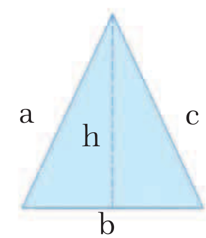
AREAS AND PERIMETERS

The formulae for calculating the areas and perimeters of simple plane shapes were devised by Classical Greek mathematicians.



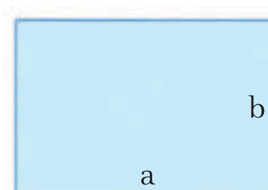
CIRCLE
r = radius
d = diameter = $2 \times r$

Circumference = $2 \times \pi \times r$
Area = $\pi \times r^2$
($\pi = 3.1416$)



TRIANGLE
Height = h
Sides = a, b, c

Perimeter = $a + b + c$
Area = $\frac{1}{2} \times b \times h$

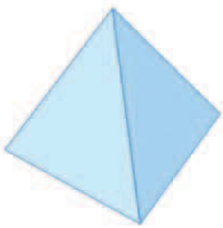


RECTANGLE
Sides = a, b

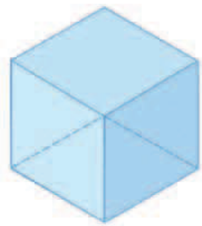
Perimeter = $2 \times (a + b)$
Area = $a \times b$

Shapes: Solid

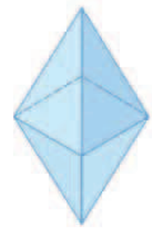
Three-dimensional shapes are known as solid shapes and include spheres, cubes, and pyramids. A solid shape with a polygon at each face is called a polyhedron.



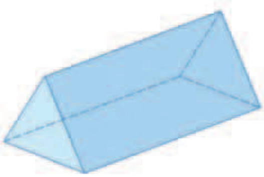
TETRAHEDRON
A four-sided polyhedron. A regular tetrahedron is shown.



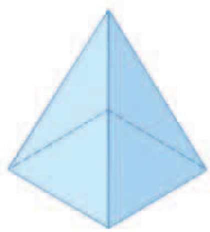
CUBE
A regular hexahedron. All sides are equal and all angles are 90º.



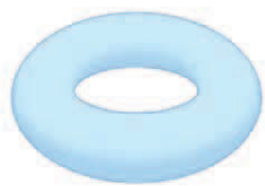
OCTAHEDRON
A polyhedron with eight sides.



PRISM
A polyhedron of constant cross-sections in planes perpendicular to its longitudinal axis.



PYRAMID
A polygonal base and triangular sides that meet at a point.



TORUS
A doughnutlike, ring shape.

SPHERE
A round shape, as in a ball or an orange.

HEMISPHERE
Formed when a sphere is cut exactly in half.

SPHEROID
An egg-shaped solid object whose cross-section is a circle or an ellipse.

CONE
An elliptical or circular base with sides tapering to a single point.

RIGHT CYLINDER
A tube-shaped, solid figure. A right cylinder has parallel faces.

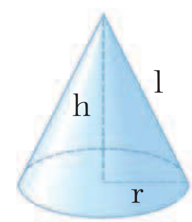
HELIX
A twisted curve. The distance moved in one revolution is its pitch.

SURFACE AREAS AND VOLUMES

Volume refers to the amount of space that a solid object occupies. Its surface area is the sum of the area of each of its faces.

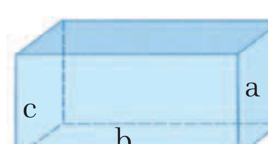
CYLINDER
Surface area = $2 \times \pi \times r \times h + 2\pi r^2$
Volume = $\pi \times r^2 \times h$

Height = h
Radius = r



CONE
Surface area = $\pi \times r \times l + \pi r^2$
Volume = $\frac{1}{3} \times \pi \times r^2 \times l$

Height = h
Radius = r
Side = l



RECTANGULAR BLOCK
Surface area = $2 (a \times b + b \times c + a \times c)$
Volume = $a \times b \times c$

Sides = a, b, c

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