MAN'S CONQUEST OF NATURE

LIFE AND LEISURE 5

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Man's conquest of nature

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1. THE END TO BE ACHIEVED

What is Nature? Quite an interesting book could be written about the word and its history. The *nature* of a thing is the Latin *natura*, a translation of the Greek *physis*, a word which means 'the way things are born and grow'; and so the word Nature, with a capital letter, is used to denote the condition that the world attains when the things in it fulfil their constitutional tendencies without the interference of man, who acts by intelligence and free-will and not merely by determined physical forces, by instinct and by habit. This distinction of Nature and Man begs a number of questions; but, whatever may be our beliefs concerning humanity, there is a real distinction between man as fulfilling his aims by intelligence and the rest of the world as the unintelligent material he seeks to modify. We need not here enter into the interesting question of why Nature has a capital N, is spoken of as *she* and portrayed in art as a big silly girl with no clothes on — though the discussion might not be altogether irrelevant to our story. When we talk of "unconquered Nature", we mean simply the totality of things apart from the influence of man's intelligence. Man himself, in his bodily and instinctive functions, may be included therein, but his functioning as an ethical and intelligent being is for our purpose excluded.

By the conquest of Nature we mean the process of causing the totality of things to function precisely as man desires; and by putting the matter in this brief way we may see that the total conquest of Nature is excessively improbable, and indeed has scarcely begun.

Nevertheless, as we look back across the known extent of human history, we see man shaping the world around him to his will, and of this process we can see neither the beginning nor the end. In the earliest ages to which we can trace our remotest forerunners we find that they did more to modify their environment than did any animal. They had fire, weapons, simple tools, clothing — and the antiquity of these is so vast that we cannot make any useful conjectures as to how these greatest of inventions were made. The primitive way of life with no more than these simple amenities is not something that belongs only to the remote past, for there are races in Africa and Melanesia that live in much that fashion today. We have no reason to say that these men are any less happy than ourselves, for happiness is a strange thing; we may find pleasure in winning some fresh conveniences for our lives, but the spring of joy rises from our human emotions rather than from the increase of our comforts. From the dawn of history, come down to the year 1770, when the modern industrial revolution was beginning, and the father of Hugh Miller, the stone-mason and geologist, was sailing about the Hebrides in search of kelp to be made into the soda that was needed in the bleaching of cloth:

"In the course of a protracted kelp voyage among the Hebrides, he had landed his boat, before entering one of the sounds of the Long Island, to procure a pilot, but found in the fisherman's cottage on which he had directed his course, only the fisherman's wife — a young creature of not more than eighteen, — engaged in nursing her child, and singing a Gaelic song, in tones expressive of a light heart, till the rocks rang again. A heath bed, a pot of baked clay, of native manufacture, fashioned by the hand, and a heap of fish newly caught, seemed to constitute the only wealth of the cottage; but its mistress was, notwithstanding, one of the happiest of women; and deeply did she commiserate the poor sailors, and earnestly wish for the return of her husband that he might assist them in their perplexity. The husband at length appeared. "Oh" he asked, after the first greeting, "have ye any salt?" "Plenty," said the master; "and you I see, from your supply of fresh fish, want it very much; but come, pilot us through the sound, and you shall have as much salt as you require." And so the vessel got a pilot, and the fisherman got salt; but never did my father forget the light-hearted song of the happy mistress of that poor Highland cottage."

There is a picture of unconquered Nature, of life without the effects of science. Such life was not all or always such as the sea-captain saw that day, but neither was it, as Hobbes thought, simply nasty, brutish and short.

Much of Nature man can never conquer. The universe stretches on every side much further than man could travel or transfer anything in a life-time, even at the speed of light; of the stellar world he can have knowledge and a mental conquest, but he can have no influence upon it. The planets man may some day reach, though we may doubt whether life could be maintained on any of them; the sun must remain forever unapproachable by one clothed in a perishable body of flesh.

But it is the earth and its inhabitants that man really seeks to conquer; yet even here it is unlikely that he will be able to modify the great movements of air, water and earth: the weather, the currents of the sea, and the commotions of the earth, — volcanoes and earthquakes. The reason is simple: a very small weather disturbance involves the moving of a thousand million tons of air, while the masses involved in the movements of the sea and earth are vastly greater. There seems at present to be no indication that man will ever have power sufficient to be lavished upon such works as moving the air-masses that condition weather, still less controlling the oceans. So at present we must think of earth, ocean, air and the stellar universe as conditions of man's conquest, but not as its object. Picture to yourself the life of a man in the state of nature, and the difficulty he experiences in fulfilling his natural desires. He is exposed to sun, rain, frost and wind. In his search for food he is thwarted by the agility of the animals he seeks as food; edible plants are few and in seasons of winter or drought may not be enough to keep him alive.

He is threatened by carnivorous animals, weakened by the larger parasites, such as intestinal worms, and subject to the ravages of the smaller, such as protozoa and bacteria. His journeyings are obstructed by rivers, hills, bogs, lakes and oceans. In his search for food and in his quarrels he has nothing to aid him but the sticks and stones he can pick up; for shelter he must resort to caves. Such would be the state of man in unconquered nature.

Look now to the result of this conquest. It is hard to guess what the men of the future will wish to have from nature, but, through the use of what science has already given or now promises to give, he need suffer almost none of the physical inconveniences of his fathers. The world can become his garden, farm and playground. Food can be plentiful and every animal be made his slave. Every disease may be conquered, nor need we despair of the prolonging of healthy life to ages that we cannot even guess. There need be no barriers to movement: the distance from any part of the world to any other may be numbered in minutes. All these things and more he might have if he wished them, but we do not know that he will wish them. Men are glad to have comfort, safety and convenience, but they fiercely desire danger, strife, and power; if they choose these, they need not lack for means of destruction.

We are apt to think that men of all ages and times wanted what we in twentieth-century England want, — to be well-fed, comfortable, healthy, clean, safe and long-lived. But, in fact, these have not been the chief desires of any age but the present, and we should not lightly assume they will be the aims of the future. All these things are good, and there is little doubt that the men of the future will some day have achieved them; but, even so, they may find their prime good in the fulfilling of some desires more characteristic of man and less of the animal. Man is on the way to conquering Nature, but he has still his own nature to overcome, and until he is the master in that conflict, the other can bring him little satisfaction.

2. THE WEAPON OF CRAFT

That man made great advances in the subduing of Nature, before he learned to write and so make records, is quite certain. Some of the very oldest remains of man-like creatures are accompanied by signs that they had the use of fire and simple tools of stone, while the men of the culture that preceded the beginnings of Egyptian civilisation possessed woven cloth, good pottery, basket-work, simple houses and boats. Naturally we ask how the earliest cultures developed into the later, but no very satisfactory answer can be given. We cannot trace the progress of a single community through the hundreds of centuries before civilisation began: but we find here and there the places where primitive men lived for a time and then died out or departed. There are men living today in a primitive fashion resembling that of the men before the beginning of the first civilisation and they may help us to form some idea of that distant past. The craftsmanship of these primitive peoples is often high but, as far as we can see from our comparatively short observation of them, is normally static. The crafts are handed on from old to young, often with some degree of ceremony, and we do not find new inventions being made. Such inventions must, however, have been made, and it seems probable that, as in civilised times, there were waves of invention initiating a new type of work, which was then sedulously and conservatively imitated by the community. We must, of course, refrain from thinking that our remote ancestors were of less potential mental capacity than ourselves. We have no evidence that the human brain has been evolving into more intelligent types, and it is reasonable to suppose that the ancestors of our race lived a full life, and that their lack of technical and verbal means of expression was compensated by their experience of complex relationships, human and religious. Their technical skill was far from low. The flint implements of the latest cultures could not be imitated today, and anyone who has attempted to handle that intractable and fickle material will realise the astonising craftsmanship that went to the making of the thin delicately-flaked curved knives, which were presumably made for sacrificial purposes. The art of these men could be extraordinarily brilliant. The drawings and sculptures of beasts in the caves of southern France and Spain have not in some respects been exceeded in the ten thousand years that have passed (Pl. I). We do not know why this ancient people made these works of art, which are found in dark caves, sometimes in positions in which it is almost impossible to see them. There are features which must make us suppose that their object was magical or religious, and that they were not made to give pleasure to those who saw them, nor yet to record events, but rather to bring about magical results. Magic, indeed, is, after craft, the earliest means of attempting to conquer Nature: its so-called laws are of the hoariest antiquity and even today do not lack their devotees.

We may wonder whether these cave-men cultivated other arts, song or poetry, to a similar standard, but here we are baffled by our complete ignorance of their speech. We do not even know whether they had names for things, but it seems certain that they were unable to write or to make any records.

So our curiosity about the distant forefathers of our civilisations must remain largely unsatisfied. We know that they began the work of subduing Nature and made several tremendous inventions. Fire and clothing enabled man to resist temperature-changes and so to penetrate into the northern regions of the world. Weapons of the chase relieved him from the need of continual wandering in order to gather food, and helped him to prey on animals and so to tide over the scarcities of the seasons of drought and winter, while pottery gave him the power to cook food and to store it, thereby further relieving his dependence on the food that could be gathered. The building of shelters and huts enabled him to live in regions where the climate was severe and where there were no natural caves. Finally agriculture, which comprises a great many important inventions, provided the means by which a large number of people could live together and be fed from an area which they could easily reach.

Thus even in the late neolithic period man had, as it were, fortified his environment against exposure and starvation, and had made it possible for small communities of men to establish themselves in any but the most unfavourable situations.

The outstanding reason why the conquest of Nature by primitive man was incomplete and precarious was that his knowledge and skill were not permanent, far less cumulative. The potter had to learn his trade from another potter and there was no way of recording what should be done. The great craftsmen could not teach their special excellences to their successors, and so the common stock of craft increased but very slowly. But increase it did, and finally led, we do not know how, to three inventions that ushered in civilisation, namely, the smelting of metals, the use of writing, and the social organisation of large communities.

3. THE WEAPON OF ORGANISATION

There are three great centres, in each of which civilisation began at much the same period — namely, Egypt, Mesopotamia and the valley of the Indus. The records of Egypt are for climatic reasons much better preserved and therefore much more complete and much more thoroughly investigated than the others. Here it seems clear that in the thousand years between 4,000 and 3,000 B.C. the standard of living greatly improved and that at the same time separate village communities became organised into petty kingdoms, which were finally unified as a single kingdom of Egypt. In this millennium also there began the smelting of copper and the art of writing. Society became organised, and we find an increasing differentiation of function between members of the community. In very primitive societies there is sometimes no differentiation, every man turning his hand to hunting, building, pottery or whatever might be required at the moment. Less primitive communities differentiate a few skilled occupations, and among the earliest of these is the priest, shaman, witch-doctor — the man who knows what ordinary men do not and can do what they cannot. This man may or may not be the ruler of the society. With the increase in size of human communities we find the emergence of a ruling class and also a learned class, whose members are the originators of systematic knowledge. The man we call 'priest' in early Egypt was the man who knew difficult things such as medicine, metallurgy, architecture, astronomy, and the relation of man to the supernatural, and who could record these things by means of the new art of writing, which was a monopoly of his class. The priesthood was an organised and continuing corporation which preserved and accumulated the knowledge of successive centuries. Thus the crafts of healing, metal-working, building, mathematics, measuring of time and influencing the gods, became the property of the priesthood; they became the subject of written documents and therefore also became matters of learning. The documents concerning these learned crafts enabled them to transcend the limits of a man's memory and to survive bad times when learning could not flourish. The achievements of these early civilisations are familiar enough to us; we must judge them, however, not by comparison with our own culture, which stands upon their shoulders, but by the standards of the primitive men who went before. Chief among their achievements were the State, a multitude of men working in concert to a single end, and writing, dead walls and pillars which could speak like living men. What stupendous inventions! Then the recognition and naming of the organs of man's body; the description and diagnosis of disease; the power to *design* a vast structure such as a temple or pyramid, to fix it by marks on a wall or papyrus and then bring it into being; above all, the ability to predict cosmic events, the risings of stars, the flood of the Nile, and even eclipses of the sun-god, — small wonder that the power to achieve such things was treated as a sacred gift and made a part of the business of those who knew divine things.

In these ages, between about 3,500 and 600 B.C., there accumulated in Egypt and Mesopotamia, and perhaps in India also, something that could be called natural science — recorded information about Nature. But it is a very different science from what we know to-day, being simply a collection of facts, — or supposed facts, — together with empirical rules and recipes. Egyptian arithmetic is a collection of '*tips*' for computation, Egyptian medicine a collection of *rules* for treating ailments. Their astronomy consists of *records* of positions of stars and coincidences of heavenly events with earthly (such as the rising of the Nile and the events of agriculture.) There is nothing in this that we can call theory, scarcely any attempt at explanation of natural phenomena. The Egyptian sciences are practical, and are intended to help men to *do* things, to build, heal, farm, buy and sell. There is no evidence that their sciences were regarded as learning to be pursued for the pleasure of knowing. The later Assyrian civilisation shows signs of something more. Their mathematics, which is recorded on clay tablets and has only recently been interpreted, shows examples of calculations which involve the solution of quadratic equations and even something very like the notion of logarithms. Nevertheless, even here we have not found anything like a systematic treatment starting with simple axioms and building up by rational proofs a system of mathematics; as far as we can see, in Assyria as in Egypt, mathematics was an *art*, the *art* of calculation, not a *science* of reasoning about quantity. Comparing some three thousand years of Egyptian and Mesopotamian science with three hundred of our own, we find it to be curiously unprogressive. Gigantic progress was made in the period just before and after 3,000 B.C., yet it seems that the Egyptians of the time of the Great Pyramid (c. 2780 B.C.) were nearly as advanced in their conquest of Nature as were any of their descendants until the time when these were influenced by the Greek culture, which became important in Egypt in the third century B.C. Much the same is true of Assyria, though here there seems to have been much activity in scientific matters in the eighth century B.C., an activity which may have been a starting-point for the great flowering of the human intellect in the Greek world.

These first civilisations brought man much nearer to the conquest of Nature. It was no longer individual men that made their contributions with the little armoury of wit and skill they carried in their individual heads and hands, contributions perhaps to be remembered, perhaps forgotten: man had constructed in the written word a new impersonal memory, which did not die and lasted as long as the material in which it was constructed. Men had organised themselves into a super-organism, with rulers to direct, learned men to give instructions, skilled craftsmen to carry them out and slaves or labourers to do the things that needed no learning and little skill. Where had this brought man by, let us say, 700 B.C.? The conquest of Nature had now come near to removing the threat of starvation. Agriculture was systematised. The motion of the stars told men when to sow and to reap; they owned their fields and irrigated their land. They built large and solid granaries where they could store food over a whole season of scarcity. Ships could be steered by the stars, and caravans traversed trade routes to distant lands, exchanging superfluities for needs.

Man had also begun the conquest of matter. No longer was he confined to working the stone and wood and clay he found about him, for he had begun to study the strange transformations of things, the rudiments of a chemistry. He had learnt to know the ores of the metals — silver, gold, copper, tin, iron and lead — and had learnt how to work them for beauty and use. He had made saws, chisels, axes, adzes, files, and used them to make all manner of new things in stone and wood. Coloured glazes, glass, pigments, dyes, drugs, were known and the means of making them were recorded. He had learnt to brew beer and wine, to tan skins. And with the organisation of nations came war, culminating in the use of the horse and chariot, and of iron and steel weapons.

It seems to us that by the seventh century B.C. the ancient cultures were beginning to decline, though their activity was not altogether spent before the beginning of the Christian era. Shortly after 600 B.C. there burst on the world a wholly new attitude to Nature, the theoretical approach to the understanding of her ways, and we therefore turn to the new weapon wielded by the Greeks, the weapon of abstract throught.

4. THE WEAPON OF ABSTRACT THOUGHT

Even primitive nations are prone to ask the question "why?" Why does the sun rise? Why do plants come in spring and die in autumn? Man's first experience of cause and effect is in himself — I went out into the sun because I felt cold; I hit my wife because I was angry. Man brings about changes in response to felt needs, and that is his first explanation of the changes of the outer world. So primitive people attribute to natural phenomena some sort of life analogous to their own life. The sun, moon and planets are gods and move because they are alive, and even after their regularities have been chronicled this notion persists. The first Greek philosophers had such ideas. Thales, who flourished about 600 B.C., spoke of the world as full of gods; the magnet had a *soul* because it attracted iron. This might have been explanation enough for the earlier peoples, but the Greeks asked for something more — the explanation of these things in terms of common experience. Where the more primitive thinker would answer the question as to the motion of the sun by identifying it with a sentient being rowing himself round the liquid heavens in a boat, the Greek scientist sought a non-sentient analogy — the sun goes goes round 'like a wheel' or 'as if on an eccentric sphere'. They were in fact the originators of the idea of a *machina mundi*, an explanation of the world in terms of simple bodies and mechanical processes that we can visualise. This is not to say that the Greeks excluded the operation of mind from the changes of its universe (though this was the tendency of the atomists) but rather that they pushed it back to the position of original mover or designer of the universe. They did not regard mind and matter as being so completely different and mutually exclusive as most of us now suppose. A breath or influence from the Divine mind, something living, grosser than soul but more subtle than matter, seemed to them to be infused through matter and to direct it, yet all according to *law* — a notion which we here meet for the first time.

It sometimes seems as if the Greeks had not done much to conquer Nature — that the men of 100 A.D., after the force of Greek science was spent, had little more mastery over Nature than had the Assyrians before them; this view indeed is strongly supported by many whose positivist philosophy or political creed inclines them to regard technical achievements as the only ones worthy of note. Actually the Greeks in Hellas, and later in the Near East, made, as it were, a mental conquest of Nature. They arrived at the idea of giving scientific explanations of phenomena — even though their explanations were not always the true ones; and even more, they understood that in mathematics, the science of quantity, was the key to the prediction of natural phenomena, exact prediction in quantitative terms. The Greek scientific genius was for mathematical theory. We do not know how or why it came to interest them, but even in the time of Thales and Pythagoras they began to seek logical proofs in mathematics instead of empirical methods of calculating. Here we see the pattern of a science for the first time. Data→reasoning→conclusion: conclusions→reasoning→further conclusions, — all to be verified by the facts. Argument of this kind showed e.g., that there were five regular figures, that the circumference of a circle was less than $3^1/_7$ and more than $3\frac{10}{71}$ times its diameter, and these things proved by argument were found to be really true in fact. So the Greeks tried to build a system of the world in the same kind of way that they had built a system of geometry. Now their geometry started from a few simple definitions and axioms which seemed to be evidently known as true without any need for verification; but in astronomy or physiology they did not find their axioms ready made, and they never fully understood how much care was required in order to obtain facts accurate enough to be the foundation for the reasonings of science. Nor had they altogether disentangled their minds from the animistic explanations of earlier times. They did not confine their science to observation and reasoning about it, but allowed their ideas of what was 'fitting' to influence their opinions as to the nature of things.

The Greek learning after 300 B.C. spread widely over the near East and civilised Europe, and it is almost true to say that the science of the ancient world was Greek, whether it was written or practised in Athens, Alexandria, Rome, or Byzantium, and that we can look on the thousand years of science from c. 600 B.C. to 400 A.D. as Greek in spirit. How far, then, did this thousand years bring man towards his goal? We must first remember that the Greeks were the originators of science and therefore indirectly of much of the conquest of Nature. They set themselves the goal of scientific explanation of unknown phenomena in terms of familiar experiences. They invented logic, the science of knowing true reasoning from false, and mathematics, the way of abstract reasoning about quantities. Anything they did in the other sciences is unimpressive beside this, but even so their contribution was not small. By their weapon of mathematical reasoning, applied to astronomy, they arrived at not altogether absurd results for the distances and sizes of the sun and moon, and they made schemes of the positions of the heavenly bodies by which their motions could be predicted. One of their astronomers, Aristarchus of Samos, even arrived at the modern theory of the positions of the bodies of the solar system which we call after Copernicus. This astronomical work enabled them to determine the latitude and in favourable circumstances the longitude of places, and so to map the known world and measure its size.

Their anatomy, medicine and surgery were far ahead of those of the Egyptians and Babylonians. They described the general features of the body pretty accurately and had a general idea of the purpose of the principal organs and their function in the animal economy. Physiology was, of course, beyond them, because its basis is a complex chemistry about which they knew nothing. The best of Greek medicine and surgery was at least free from superstition; it was based partly on experience, which put them on the right road, and partly on unfounded theories of the body's working, which were responsible for the ferocious bleedings and purgings which killed so many patients before better practices prevailed in the nineteenth century.

The Greeks made some study of the more mathematical parts of physics, principally statics and optics, but their studies had little effect on their practice. Ancient engineering, which reached a high level in Alexandria and Rome, probably derived from theoretical physics in part and indirectly, but the connection is not easily traced.

Of chemistry these ancients made but slight studies. They practised chemical trades, such as metallurgy, ceramics, dyeing, tanning and the like, but they had no useful theories to guide them. The Greek idea that all matter was composed of four "elements" served to explain the changes in things in a vague manner, but was of no practical assistance to the manipulator of materials. Nevertheless in the years from 100 A.D. onward, we find the first chemical laboratories, well-equipped with furnaces, crucibles, flasks, mortars, stills, and indeed most of the equipment that was found in the laboratory of the seventeenth or eighteenth century. These were however directed to the winning of a victory over Nature, which by their theories seemed practicable but needed far more knowledge, skill and, above all, power than they possessed, — namely, the transmutation of base metals into gold.

To sum up the thousand years of Greek science, we may say that it taught man how to reason logically about things, and especially about quantities; a mode of thinking which has in recent times proved to be the key to the conquest of Nature, but which, in ancient times, largely failed of that object, because the scientists were more interested in reasoning than in obtaining accurate information to reason about.

5. THE RELIGIOUS APPROACH

As the classical civilisation gradually disintegrated and communications became more difficult, we find a growing, and finally almost complete, severance between the Greek-speaking world of the East and the Latin-speaking world of the West. The scientific works of antiquity were for the most part written in Greek and never translated into Latin, so that the knowledge of science was far better preserved in the Eastern Empire than in the West. But throughout the civilised world a great change had taken place. The greatest event of human history, the life and death of Jesus Christ, led to the foundation of the Christian religion, which brought new life to supplant the dying civilisation of Europe. The discovery of the implications of the Christian faith and the interpretation of the Scriptures occupied the best minds of the first millennium of our era. It was fashionable some seventy years ago to belittle this period as one of retrogression in which the world was occupied with unpractical subtleties. In fact, however, it was occupied with no less than the building up of a Christian society and there is not a day in the lives of pagan and Christian alike when we do not experience, consciously or otherwise, the blessing of its work. Nor is the intellectual quality of these theologians to be doubted, as the reading of the works of such a man as St. Augustine, Bishop of Hippo, will soon convince us. It is true that in the West the scientific knowledge of the years from 500 to 1100 A.D. was very small, and indeed practically negligible; none the less, hard clear theological reasoning was building a new civilisation, and, incidentally, equipping the men of the so-called Dark Ages to tackle any other intellectual problems that might be presented to them.

In the East the situation was very different. Byzantium retained its Greek culture until the time of the Crusades and even later; the works of Greek science were read and studied, but nevertheless, the Eastern interest was always in theology and Eastern scientific studies were mere learned exercises. But Byzantium sent out waves of learned men, expelled from it for theological reasons, into Syria and Persia; and these set up in the Near East their schools and universities, where the sciences were studied in a more practical way. These exiles translated the Greek scientific manuscripts into Syriac and Persian, and many of them preserved a knowledge of Greek in their distant settlements. In the seventh century Islam conquered Syria, Persia, Arabia, Egypt, North Africa, Sicily, Southern Italy and most of Spain. From about 750 A.D. the world of Islam became enamoured of Greek learning. It procured the translation into Arabic of the Greek texts — especially those of science — and learned everything that the Greeks could teach them. This great age of Arabic learning, from c. 750 to 1250 A.D., added but little to what the Greeks had known, the principal advance being in the introduction of algebra and the use of what we call the Arabic numerals. We must think of the Arabs chiefly as preservers of and commentators upon the science of the Greeks.

But this preservation was vastly important. During the twelfth century, in the Mediterranean frontier regions of Southern Italy, Sicily and Spain, there was not a little contact between Latin Europe, Islam, Jewry and the Greek culture of Byzantium. The Latin

West became aware of the treasures of science and philosophy possessed by the Arab masters. Translations into Latin were made and circulated through Europe, and a swift and glorious revival of learning ensued. The West possessed a well-defined and clear theology, unquestionable by a Catholic. Islam and the East possessed the science and philosophy of Greece. After some hesitation by the more conservative, the Church accepted the glorious task of making a synthesis of learning — an account and view of the world accommodated at once to Christian doctrine and Greek philosophy.

Nothing was to be excluded. God, man and matter were alike to be seen in their mutual relationship. The mutual relation of man and God was, it is true, very much more interesting than the relationships of matter, but Nature was always there in the background of the picture, like the landscape behind the Madonna in an Italian primitive. All things were to serve man who was to serve God. So when the men of the middle ages thought about Nature they were chiefly concerned to discover how her various manifestations demonstrated the existence of God and his providence, how they illustrated His workings and how they served His plan. They were not very much interested in discovering the quantitative relationships of things that make up modern science. On the whole they failed. They did not know enough about things to discover their true workings, and so they often exhibited some false scientific theory as an illustration of a theological principle, which has tended to the disedification of those who have read their works in later years. We need not think their quest — to show the workings of God in Nature — to be an impossible or useless one. Their science was insufficient in extent or accuracy: ours is insufficient in scope (being mainly quantitative), but we need not disregard the possibility that a future age may find that the full study of Nature with every faculty is a means of coming to understand something of God.

This was the main trend of mediaeval science and it led to some hard and clear thinking. Thus one of the standard proofs of the existence of God starts from the statement that 'everything that is moved is moved by something else.' This statement, when considered by the philosophers of the fourteenth and fifteenth centuries, such men as Jean Buridan, Albert of Saxony and Nicholas Oresmes, led to the beginning of dynamics and the verbal figuring out of principles of motion that were later enunciated mathematically by Galileo and Newton. But the same attitude led the mediaeval men of science into some strange by-ways. They believed that God, as source of all motion, had ordained angelic powers to operate the motions of the planets, which in turn operated all changes upon earth, and this belief led to an enormous cultivation of astrology, which, except in so far as it encouraged the study of astronomy, proved fruitless. Again, the religious approach to the nature of matter led to alchemy, the central idea of which is the death of matter and its resurrection to a glorified state, the Philosopher's Stone, which, they believed, would have the power of transmuting all bodies to the greatest perfection of their own kind; and alchemy, being an impossible quest, based on a view of matter which science does not confirm, could not lead to the conquest of Nature, except accidentally through the encouragement of chemical technique.

The greatest advances, indeed, towards the conquest of Nature in the middle ages were by the use of the oldest weapon — that of craftsmanship. We find quite a number of important inventions, all of a practical and valuable kind. Rarely have we any idea, and in no case can we be sure, of the identity of the men who made these advances, but the inventors were probably practical craftsmen and certainly do not seem to have been any of the scientific writers. Among these discoveries (some of which may be introductions from the Eastern world) are the mariner's compass, the windmill, gunpowder and ordnance, mechanical clocks and sand-glasses, the distillation of alcohol for consumption as medicine or beverage, and the distillation of the mineral acids. In a less obviously scientific field we find the visible triumphs of the middle ages, their buildings and their art. Their cathedrals and castles show a steady conquest of Nature in the empirical engineering which made it possible to shape from stone these noble fabrics, which far exceed the productions of antiquity; in the field of art, the composition and manipulation of colours and mediums to make possible the representation of a Nature more perfect than that we see was another great triumph. It is remarkable how little we know of the men who brought about these practical advances, yet, unknown as they are, no men of their age, save a few of the greatest writers, are to be rated higher.

6. THE WEAPON OF OBSERVATION

The standard mediaeval view of the world was at fault because it was founded on information about Nature which was insufficient and unreliable. The foundations of a world-view, as of a cathedral, need to be strong and true. Mediaeval cathedrals whose foundations were imperfect (as was often the case) demonstrated the fact by falling down, but the mediaeval world view touched practical everyday life at so few points that its unsoundness was very slowly discovered.

The untutored human eye does not see and record Nature with any precision, as appears from the mistakes that we make when we try to describe anything exactly from memory. A lesson which was only very slowly learned in the centuries between 1250 and 1650 A.D. was that only observations of certain kinds, made and recorded in certain ways, are sufficiently reliable to be the material of a science capable of making correct predictions and therefore of practical use.

Everyone, of course, knew that all our knowledge of individual objects was obtained through our senses—that is, by observation—but, for all that, the mediaeval followers of Aristotle gave little or no attention to whether the facts they adduced had been correctly observed, and sometimes made general assertions about natural laws which seemed to go beyond what had been observed. Such a principle as 'every moving body is impelled by another' was put forward, not as something induced from particular observations of moving bodies, but as something that was known intuitively and did not require proof.

The first striving for a higher standard of observation is to be found in the works of Albertus Magnus (1206-1280), and more especially of Roger Bacon (1214-1294), who was the nearest mediaeval approach to a modern man of science. The scientific works of Albertus Magnus deal principally with the natural history of living things and of minerals, and he at least distinguishes clearly between what he himself has seen and what he had read or been told by others. Roger Bacon's favourite science was physics, and especially optics; he is never tired of preaching the need to observe phenomena under laboratory conditions, and it is certain that he carried out extensive researches on these matters. His friend, Peter Peregrine, has left us a most practical little book, *Epistola de Magnete* (1269), concerning the properties of magnets, and in it emphasises the need to *use our hands* in the discovery of their properties. Roger Bacon, moreover, is emphatic concerning the importance of mathematics to natural science. It may well be that these men were all stimulated by contact with the science of Islam, which was certainly more practical and more mathematical than that of the West. However, this movement towards more careful observation did not survive the thirteenth century, and was not reborn before the fifteenth. By the middle of the fifteenth century Aristotelianism had become somewhat arid and unpractical: new translations from the Greek and contact with the Greek philosophers from Constantinople had led to a revival of Neo-platonism, with a consequent interest in mathematics and willingness to investigate other systems than that of Aristotle. Craftsmanship in the wealthy countries of North Italy and Germany had reached a high order. Mathematics and craftsmanship were what science then needed.

So in the early fifteenth century we find speculations concerning the system of the world, and doubts as to whether the Aristotelian closed spherical universe with the earth at its centre (Pl. II) was the only possibility. In Germany a great step was taken in the middle of the fifteenth Century when Georg Peurbach and J. Müller (Regiomontanus) began to make new observations of the heavens with the best instruments that the German craftsmen could make for them. They began to accumulate new facts — observations of star-positions which they recorded, both in writing and on a celestial globe, observations which were reliable enough to test the ancient theories of the heavens. Their work was used by Copernicus, who carried out observations between

1507 and his death in 1543, and took the tremendous step of putting forward the hypothesis that these theories were wrong, maintaining that the sun was the centre of the universe, that the planets revolved about it, and that the seemingly stable earth was one of these revolving planets. This tremendous effort of scientific imagination cannot be sufficiently admired, yet it is to be remembered that Copernicus did not succeed in bringing the motions of the planets into harmony with the simple circular motions he proposed, but had to retain the idea of a combination of circular motions such as was used by Ptolemy. Copernicus made very numerous observations, but his apparatus was, like all the instruments of the time, very crudely made, and his best observations of angles were in error by 10′ or more. Tycho Brahe, in the last quarter of the sixteenth century, saw the extreme importance of accurate observation and re-designed the current astronomical instruments so that his necessary errors of observation were less than a tenth of those that had formerly prevailed. He made a far more accurate star-map and he was enabled to measure the distance of some of the nearer heavenly bodies. The result was typical of the science of the sixteenth century; by more accurate observation the ancient theories were proved wrong, but nothing better was put in their place. Tycho's work showed that neither the Aristotelian, the Ptolemaic, nor the Copernican theory, as then held, could explain the motions of the planets that his more accurate observations had revealed. The same thing happened in another field, that of anatomy. Dissection of human bodies was practised in the middle ages, but rather as a means of demonstration of the contents of the anatomy-books of the ancient masters than as a weapon of research. In the fifteenth and sixteenth centuries many artists made dissections; thus Leonardo da Vinci dissected more than thirty bodies. They did not publish their findings but Andreas Vesalius, among others, made most careful dissections and recorded his results in a famous book, *On the Fabric of the Human Body*, which was illustrated by a series of brilliant engravings. The invention of printing and the illustration of books added enormously to the power of the scientist to record his observations, in this field and in every other.

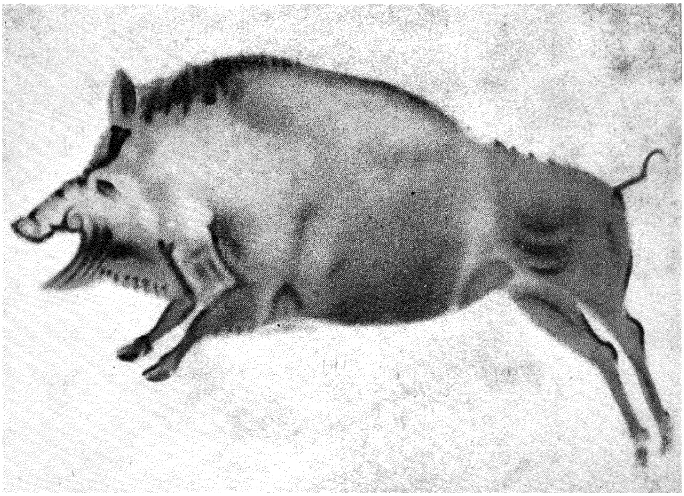
The work of these anatomists, led to no important new theories but was valuable, both as providing material and as proving the ancients wrong in many respects. Anatomical beliefs essential to the ancient physiology, such as the existence of pores in the septum of the heart, the origin of nerves from the heart and of veins from the liver, and the existence of the "*rete mirabile*" in the brain, were demonstrated to be false, and the way was thereby laid open for something new.

So in chemistry also, there was a great deal of new observation and record, most of it based upon the technical processes of the druggist and metallurgist, and this likewise afforded material for the theories of later times. The Aristotelians had contributed but little to chemistry save the four-element theory of matter, and a theory of chemical combination based on the principles of matter and form and the celestial influences. These theories were in fact of no use to practical chemists and although other theories which were propounded by sixteenth-century authors were little better, the free discussion of them opened the way for the atomic theory of matter once more to be brought forward in the early seventeenth century.

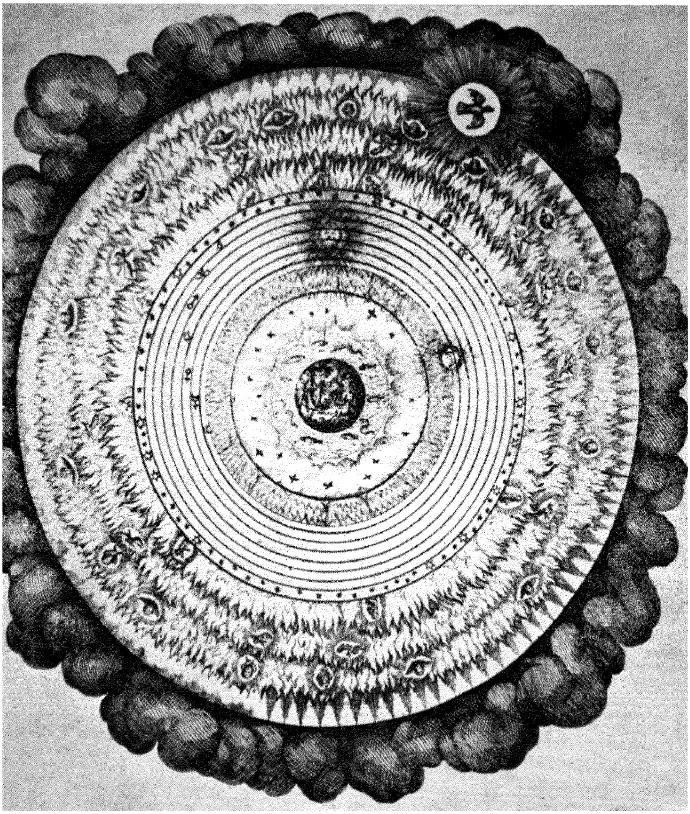
In the biological sciences something of the same kind appeared. Animals and plants were described and beautifully drawn by artists. It became apparent that the mediaeval natural histories contained a great deal that was not verifiable by observation, and moreover that the world contained a great deal that was not in those histories. The ancient learning was discredited and a good deal of true knowledge was provided by means of which the next century could begin to build up a scientific natural history.

Thus observation in the fifteenth and sixteenth centuries principally availed to discredit the older sources, to interest people in the vast variety of unexplained phenomena, whether in industry or in nature, and so to provide both the interest and the material by means of which sciences, in our modern sense, could be constructed. By the year 1600, then, there was a strong interest in natural phenomena, and a highly cultivated society whose craftsmen were capable of making scientific and industrial apparatus of a simple kind; numerous books describing natural phenomena and industrial processes had appeared. The natural histories still tended to minister to the appetite for the marvellous and were on the whole uncritical; but some of the technical works, such as Agricola's famous work on mining or Neri's on glassmaking, were unexceptionable in their objective approach to their subject.

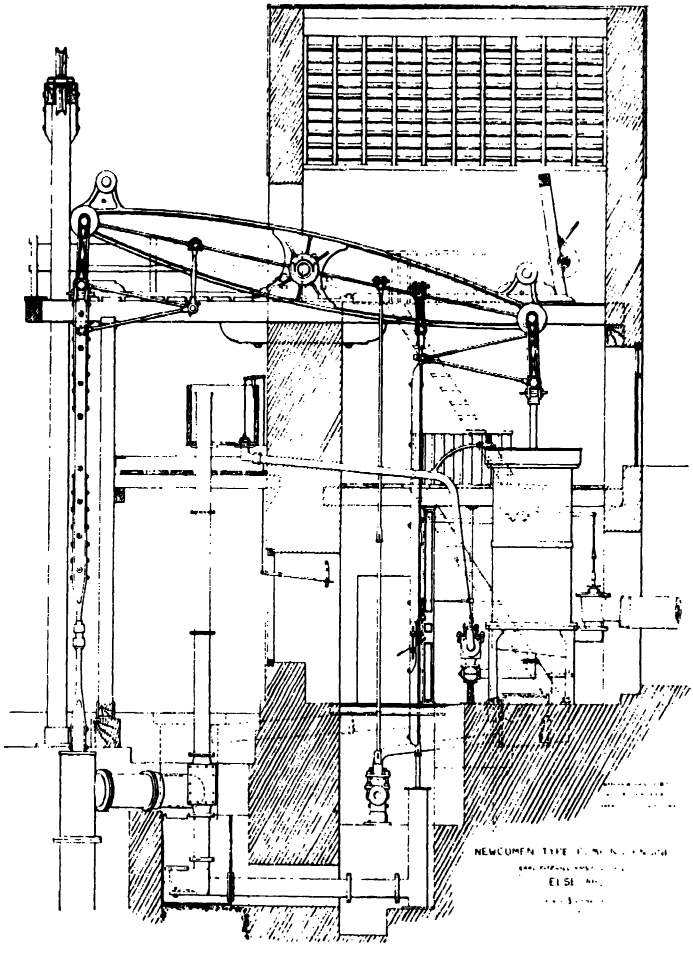
By observation with our unaided senses we learn very little about things and are enabled to give only an approximate description of them. To say a thing is "large" is much less informative than saying it is 3.507 metres in length; to say it is "green" tells us less than saying that it reflects light of wavelengths between 5200 A.U. and 5300 A.U.; to say it is "bright" is less useful than telling us that it reflects 85% of the light that falls on it. The biological sciences got on pretty well for a long time with the verbal kind of description, but the physical sciences got nowhere until men took the all-important step of supplementing observation by *measurement.*



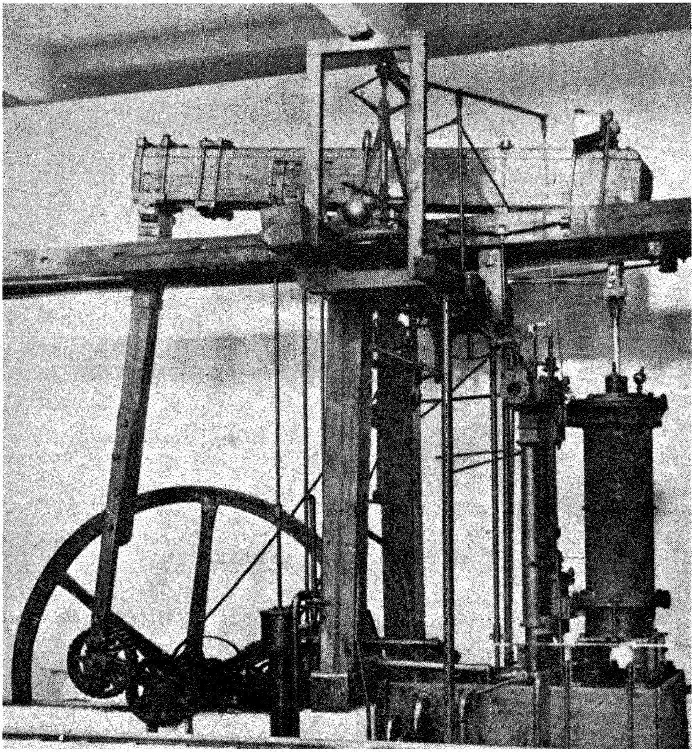
1. Copy of a painting of a running Wild Boar
in the cave of Altamira,
executed perhaps ten thousand years ago. (p. 12)
British Museum.



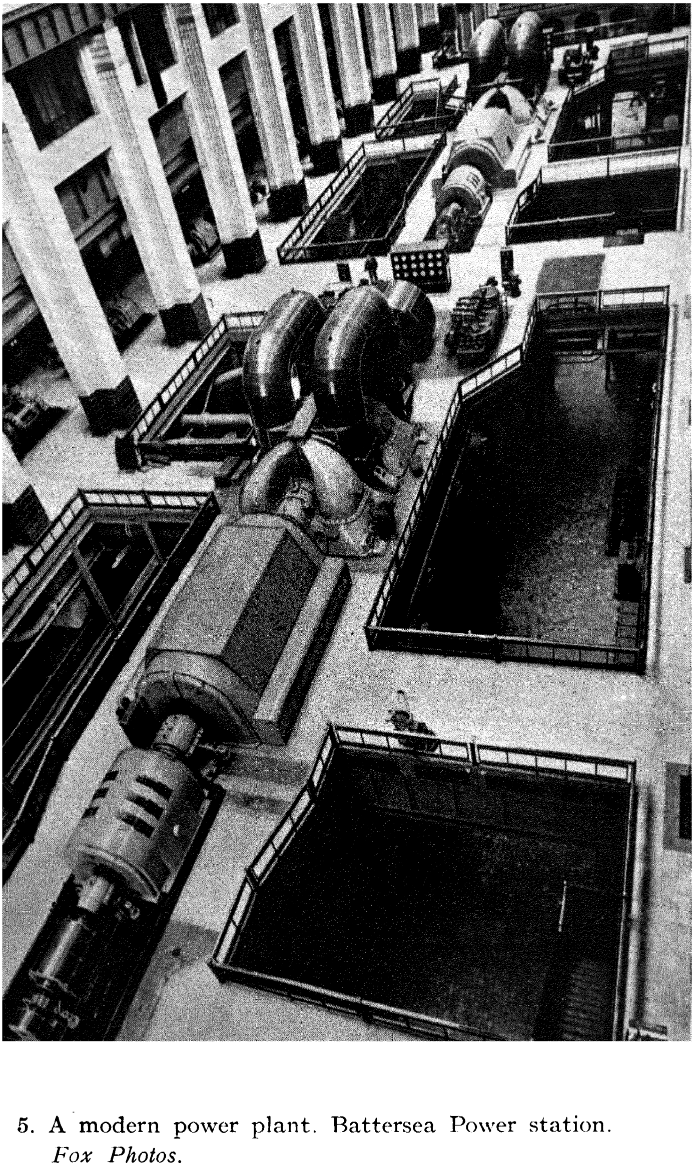
2. The mediaeval notion of the universe.
The earth is at the centre,
surrounded by spheres of water, air and fire.
This terrestial world is surrounded by a celestial world.
Sun, moon, and planets and fixed stars
operate the generation of all earthly things,
but receive their impulse from intelligences:
outside the sphere of fixed stars is the empyrean,
the local heaven, and outside this is chaos.
from Flud's *Utriusque Cosmi Historia*. 1617. (p. 29)



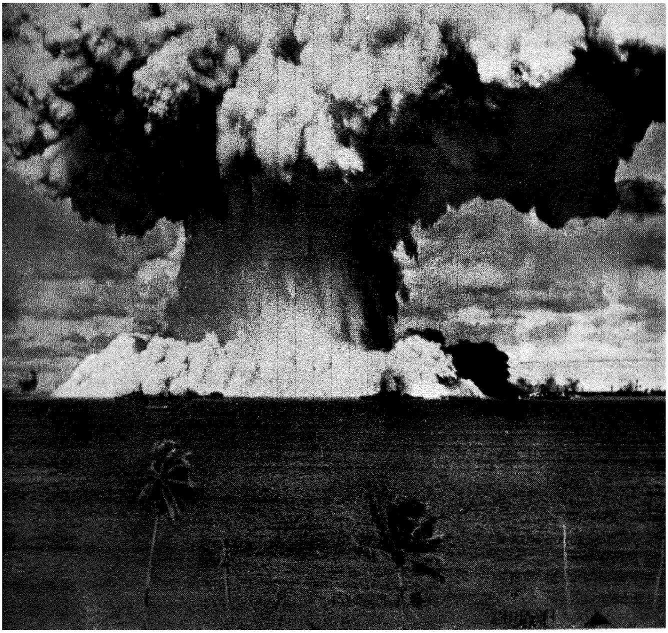
3. Diagram showing the working of an atmospheric pumping engine of the Newcomen type. (p. 63) *Science Museum*.



4. Boulton and Watt's rotative beam-engine, 1797.
Such engines as these were the first sources of power for the mechanization of industry. (p. 63)
Science Museum.

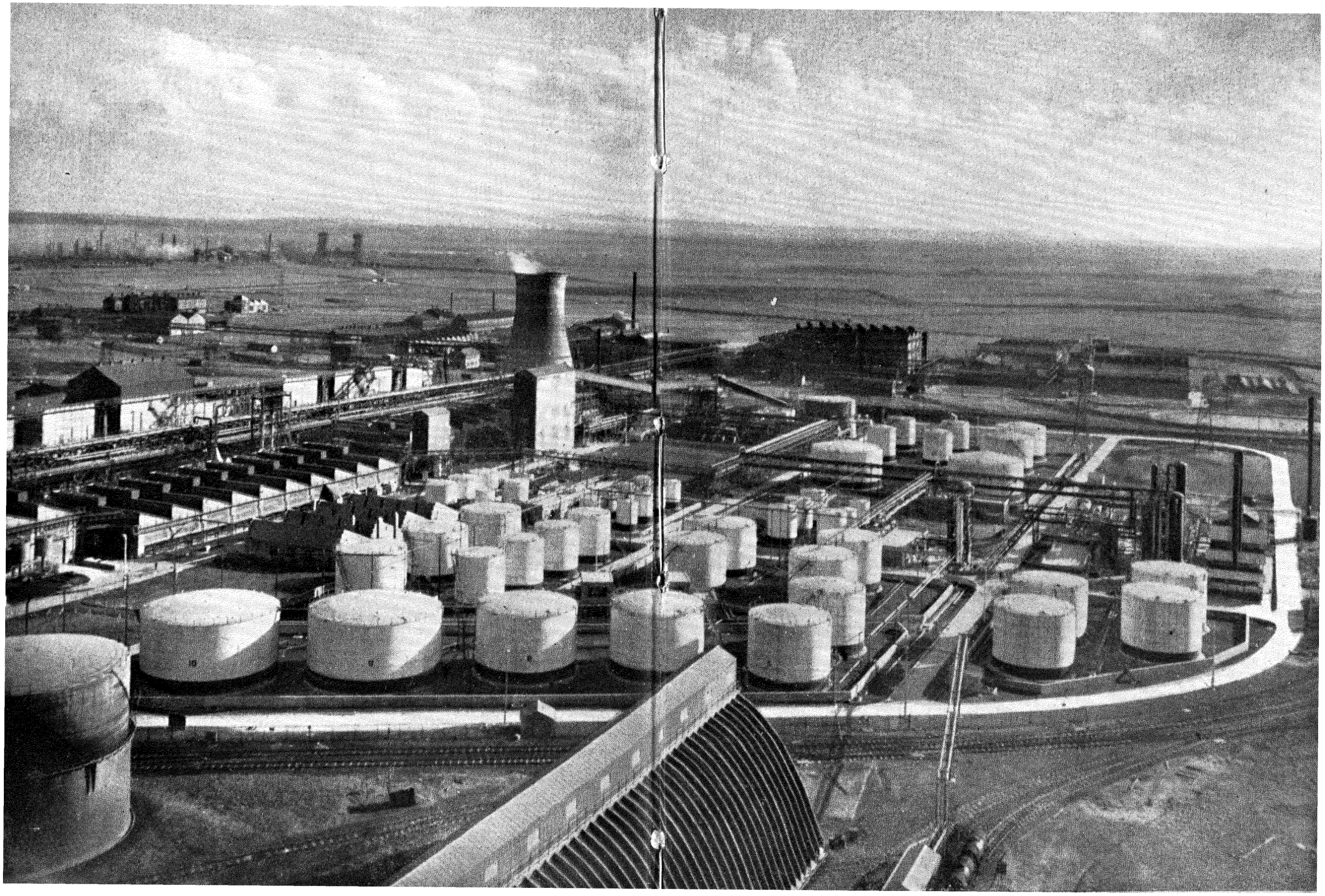


5. A modern power plant. Battersea Power station.
Fox Photos.



6. Explosion of an atomic bomb
during the underwater test at Bikini Lagoon.
The picture shows a column of water,
2,000 feet across at its base,
boiling 5,000 feet into the sky,
driven by the blast below the surface of the lagoon. (p. 65).
Keystone Press.

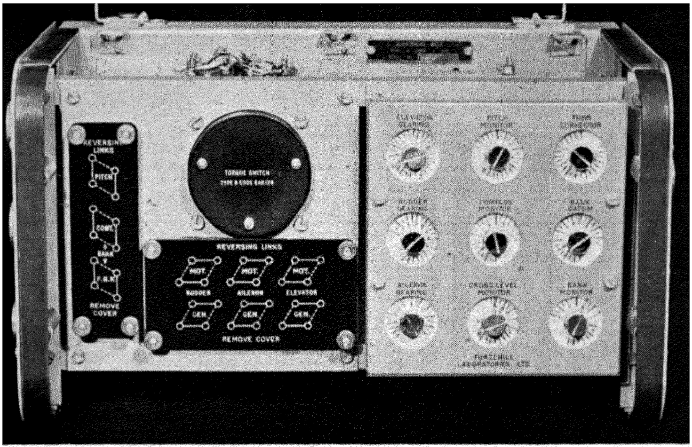
Opposite
7. The vast air-conditioned silo
in which ammonium sulphate (used as a fertiliser)
is stored at the I.C.I. works, Billingham. (p. 78)
Imperial Chemical Industries.

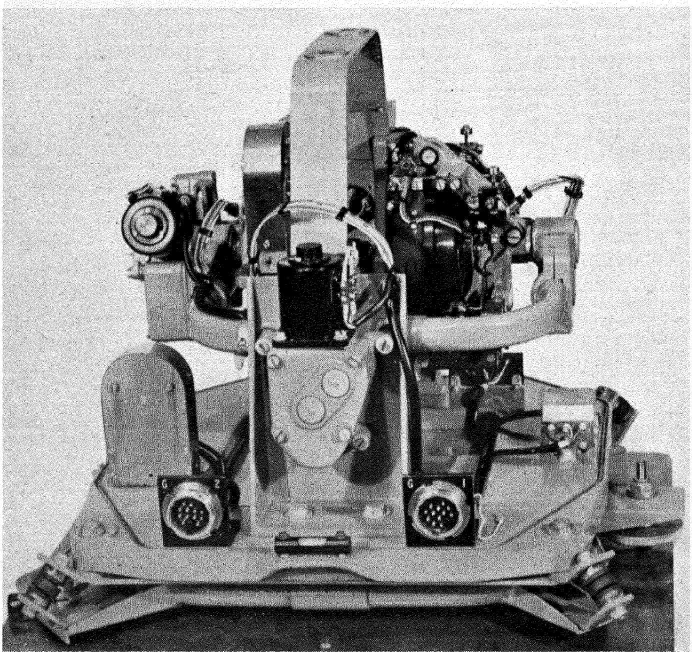


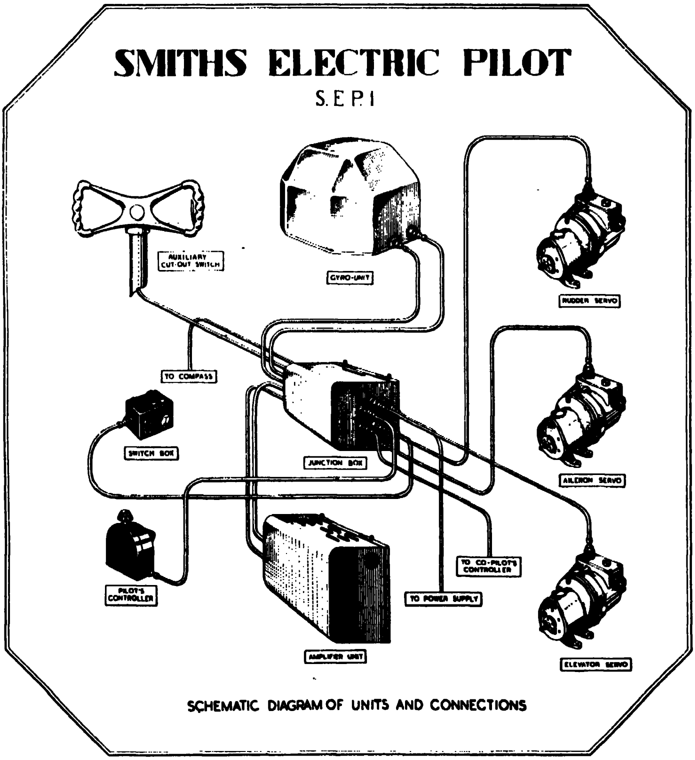
8. The modern chemical factory. The I.C.I. petrol plant at Billingham. (p. 78) *Imperial Chemical Industries.*

9. Illustrating the wide range of objects made from different types of plastic. (p. 79) *Imperial Chemical Industries.*

Alkathene: cables, films and toothpaste caps
Perspex: various transparent objects
Nylon: comb, bristles and filaments
Diakon: telephone
Kallodent and *Kallodentine:* dentures
Welvic: (plasticised polyvinyl chloride) shoe

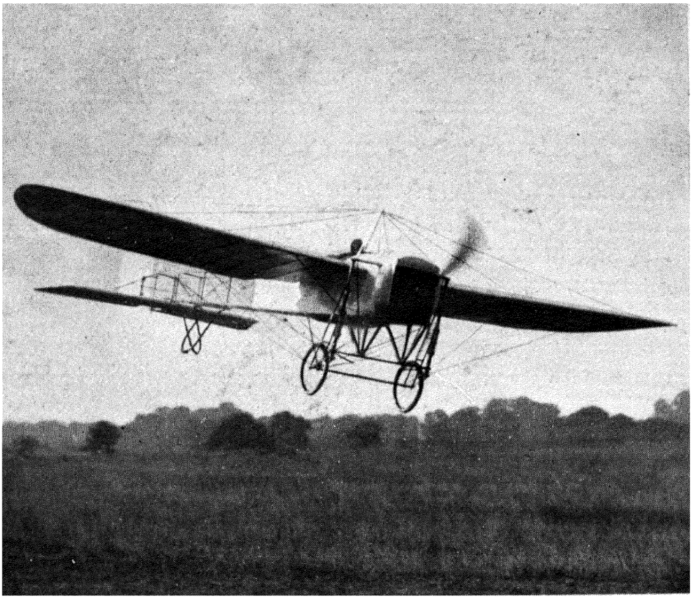

REVERSING LINKS
PITCH
REMOVE COVER
REVERSING LINKS
MOT.
MOT.
MOT.
RUDDER
AILERON
ELEVATOR
GEN.
GEN.
GEN.
REMOVE COVER
CROSS LEVEL MONITOR
BANK MONITOR



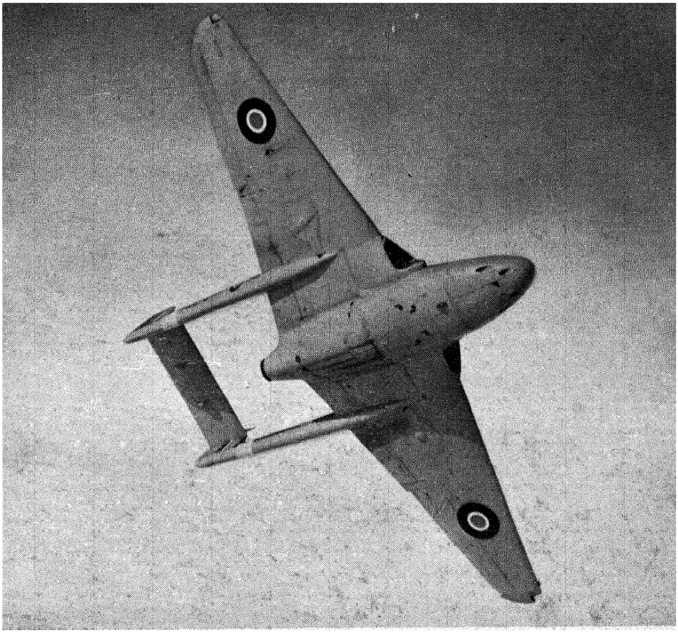


Smith's Electric Pilot.
This instrument pilots an aeroplane
on a steady course and
removes the need for occupying the human pilot with the continual semi-mechanical operations required. (p. 83)
Smith's Aircraft Instruments Ltd.

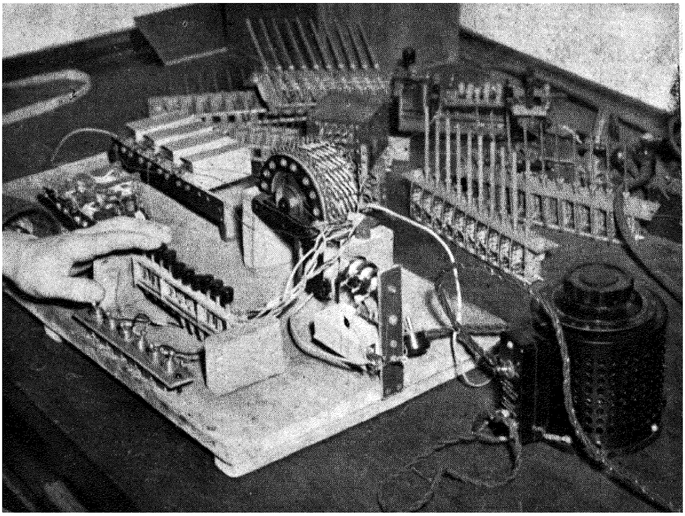
10. Junction Box.
11. Gyro Unit.
12. General Lay-out.



13. Bleriot in his monoplane, 1909. (p. 91)
Flight.



14. The aeroplane today: De Havilland Vampire. (p. 91)
Flight.



a.

15. Part of the so-called Electronic Brain; an elaborate calculating machine which can perform complex calculations required in scientific research in a fiftieth of the time required by the human computator.

a) One of the calculating key-boards.
b) The main multiplying and dividing units. (p. 109)
Associated Press.

Furthermore most of the phenomena we observe — such as the growing of a plant or the combustion of a candle—are influenced by so many environmental factors that mere observation can tell us little or nothing about their causes, unless the phenomenon be artificially arranged so that it may be observed under known conditions which can be varied in a known manner. This kind of observation we call *experiment*. *Measurement* and *experiment* were the two weapons which were lacking in the sixteenth century. The addition of these by the founders of modern quantitative experimental science completed the armoury of science and so enabled men to accumulate with unprecedented speed that knowledge of Nature which has enabled us to conquer her.

7. THE WEAPON OF MEASUREMENT

Some sciences had been conducted from the most ancient times by measurement — notably astronomy, optics, statics, and hydrostatics — though even at the end of the sixteenth century these last three sciences had made but little progress.

Aristotle was not much of a mathematician and his discussions of motion and physical changes were for the most part metaphysical, and when they descended to statements that could be numerically interpreted these were generally wrong. His explanations of things were in terms of qualities. But in the fifteenth and sixteenth centuries, as we have seen, the keenest minds reverted to Platonism and contemplated a mathematical view of the world, expecting everywhere to find geometrical relationships and simple mathematical laws. Some of the ancient writings on physics, such as those of Archimedes, Heron and Philon, became available in printed books, and their attempts to build up physics by means of measurement were an example to the men of the time. In the sixteenth century there were new studies and correspondingly great advances in mathematics — especially in algebra — and by the end of the century there were many who were able to perform fairly complex calculations.

Almost the first and much the greatest of those who attempted to treat physical science by measurement and calculation was Galileo Galilei, who was followed by René Descartes and very soon by a host of others. Aristotle had attached great importance to the phenomena of falling bodies, but he had allowed himself to conclude (probably merely from the observation that light bodies, such as leaves, fell more slowly than heavy bodies, such as stones) that the speed of a falling body was proportional to its weight — and so the world generally believed for some two thousand years. Then Simon Stevin, the Dutch mathematician and physicist, tried the simple experiment of simultaneously dropping two weights, one ten times heavier than the other, on to a board, thirty feet below, and, hearing only one crack when they hit it, concluded that one did not fall ten times faster than the other, and thereby proved Aristotle wrong. This was the test of experiment. Galileo, who performed similar experiments, probably without any knowledge of Stevin's work, took a further step. Falling bodies moved too fast to be timed by the instruments of the early seventeenth century, so he timed a bronze ball rolling down a groove in a sloping beam. He timed it over different lengths of the groove and at various inclinations. These measurements revealed a simple law: that the distance travelled was proportional to the square of the time of descent. These and other experiments convinced him that bodies moved in accordance with simple mathematical laws, and he found that calculations applied to measurements were so successful in predicting how bodies would behave, that he, and also all later scientists, tried to express all the changes they observed in terms of measurements that could be handled mathematically. For that veason principally, they adopted the atomic view of matter, which alone could make this goal attainable. Let us examine this further. When we observe, let us say, a piece of sealing-wax, we can define its size, its position and its motion in terms of *quantities* — centimetres and seconds. But we also perceive concerning the sealing-wax that it has a red colour and an aromatic odour, that it melts easily and burns brightly, and these qualities are not at first sight to be related to numbers. The holders of the atomic theory proposed the view that the wax was made of atoms, of such-and-such size and shapes, arranged in a certain fashion or moving in a certain way. Considering the redness of the wax, they would say that the sensation we call redness is in *us* and not in the *wax*, and that what we call redness in the wax was simply the fact that the atoms of the wax were of such sizes, such shapes and so arranged as to reflect the kind of light which should give us the sensation of red. If this view is accepted, then the possession of any sensible qualities whatever can be explained in terms of the size, shape and arrangement of the atoms; and size, shape and arrangement are matters which can be treated by mathematics.

Thus the men of the seventeenth century believed, correctly but on very inadequate grounds, that much of our knowledge of bodies could be expressed in terms of number, weight and measurement — and this has been the aim of science ever since that time, and has met with much success. It is true that mathematics and measurement cannot *explain* redness in the sense of telling us why certain wavelengths of light give the sensation we know as red and not, for example, that which we know as green; but it can connect together the behaviour of red bodies, and in some cases it can predict that when a hitherto unknown chemical substance of a particular molecular structure has been made, it will appear red.

Not only on earth were exact mathematical relationships found, but also in the heavens. Johan Kepler, between 1609 and 1619, was the first to formulate simple mathematical laws which predicted the motions of the planets precisely, as far as the instruments of the period would show. Very impressive was his discovery of the laws that the planets describe ellipses about the sun which is in one focus of the ellipse; that they move so that the line joining the sun to the planet sweeps out equal areas of the ellipse in equal times; and, above all, the simple mathematical law that the squares of the periodic times of the planets are proportional to the cubes of the major axes of their elliptical orbits. These laws clearly demonstrated that exact and simple mathematical relationships obtained in the heavenly regions. The work of Kepler above and of Galileo below indicated then that the world was formally mathematical. They did not go far towards suggesting any cause for this, except that God had so ordained it — nor, indeed, perhaps can we.

Be this as it may, this view of science — that the book of Nature is written in the mathematical language and cannot be understood without it — naturally gave the strongest impulse to the construction of instruments of measurement; and the idea that many of the properties of bodies depend on their fine structure led to attempts to make instruments to discover that structure. In the sixteenth century the only measuring instruments were rulers, compasses, various arrangements of graduated arcs and sights for measuring angles, measuring-vessels, the balance, sundials, sand- and water-glasses and very inaccurate clocks.

The seventeenth century shows the widest contrast. The vernier-scale (1631) and micrometer-screw (1638) gave an accurate way of measuring lengths. The latter was applied to astronomical telescopes and to microscopes, and both were applied to quadrants and the like for measuring angles. Clocks were made accurate by the use of the pendulum and balance-spring (c.1660). Thermometers were discovered and used to measure temperatures, barometers and manometers to measure pressures, photometers to measure light, and even simple electrometers to measure electric charges. And this work has never ceased. Scientists have never ceased to endeavour to make instruments to measure every quantity that they study. In this way they express the properties of bodies in terms of numbers, and so can use the powerful methods of mathematics upon them; to a large extent they also get rid of the personal element in their records, for their sense-observation is reduced thereby to reading the position of a pointer on a scale. The records of the physicist and chemist today, then, are mostly in the form of numbers or geometrical structures; the biologists have also moved in this direction, for statistical treatment of biological units has proved extremely valuable, but much of biology is not yet amenable to mathematical treatment. The structure, for example, of a human arm is a spatial one, the muscles, bones, nerves, arteries being arranged in a certain spatial relationship which varies, however, over rather wide limits. Thus a human arm can be described spatially, but the valuable description of an arm is in terms of its function and the relations of the parts that compose it. No doubt the most significant scientific description of it would be in terms of the physical cause of the relative arrangement of its parts em dash and to thatscience has not as yet attained.

8. THE WEAPON OF EXPERIMENT

At the end of the sixteenth century the books which purported to deal with scientific subjects contained an extraordinary collection of odd information. The author's first care was to collect and set down without discrimination every written word he could find on the subject. Aristotle, Pliny and the Bible, magical stories, travellers' tales, the author's own experience: all went in together and the reader could choose what he wished to believe, or if he had the generous ration of credulity common in the sixteenth century, he could believe it all. No matter in what department of science, the same trouble prevailed; the books were full of unreliable information.

In the first quarter of the seventeenth century Francis Bacon made it his task to try to set out a method by which truths about Nature could be discovered and the power of man thereby increased. He saw that the conquest of Nature depended on the understanding of the causes of phenomena, and that the understanding of these causes must await the knowledge of the phenomena themselves. The first requisite for this task was therefore a *natural history* — a true account of natural phenomena. First of all, nothing that could be ascertained by observation was to be accepted on the word of any authority, however famous. The scientist was to see for himself, and wherever possible to arrive at conclusions by experiments. The experiments which Bacon proposed or, more rarely, performed were for the most part simple tests designed to give the answer "yes" or "no", and thereby much inferior to those of Galileo, which employed specially constructed apparatus and were intended to give numerical results from which mathematical relationships could be inferred. But the essential idea was the same, the arrangement of conditions for the occurrence of a phenomenon in such a way that its cause or mechanism might be discovered. Thus Bacon says

> " .... Again, in the very stock of mechanical experiments there is a great want of such as principally conduce to the information and the understanding. For the mechanic, being in no way concerned about the discovery of truth, applies his mind, and stretches out his hand, to nothing more than is subservient to his work; but we may then rationally expect to see the sciences farther advanced, when numerous experiments shall be received and adopted into natural history, which of themselves are useless, and tend only to the discovery of causes and Axioms [1]; those being what we call experiments of light to distinguish them from experiments of profit. And they have this wonderful property that they never deceive or frustate the expectation: for being used, not in order to effect any work, but for disclosing natural causes, in certain particulars; let them fall which way they will, they equally answer the intention, and solve the question."

Thus by personal observation (for experiment is only a refined form of observation) exact information was to be obtained and recorded. The work of Bacon was extremely influential, especially in England, and by the sixteen-sixties our men of science had a pretty clear idea of what should be admitted as scientific data. The standard of record was at first low. There

[1] The word *Axiom* in Bacon's terminology means a generalisation or rule expressing some truth about a number of phenomena.

were no scientific journals before the sixteen-sixties and men of science published their work from time to time, when they had enough matter for a book. They did not as a rule give exact details of the experiments they had performed, but were often content to record only the method and the general outline of results.

A great advance was made when the Royal Society began to publish its *Philosophical Transactions* (1665) and thereby set a standard for the recording of results and a means for their speedy publication.

Bacon's plan of campaign was deficient in that he laid too much stress on collecting evidence concerning Nature in the form of descriptions or statements in words and sifting these to find general principles. His scrutiny of Nature took a form rather like that of a legal enquiry; William Harvey justly said of him that he wrote philosophy like a Lord Chancellor.

Descartes, on the continent, erred in the opposite direction by trying to investigate Nature by long chains of mathematical reasonings based on what were, in fact, insufficiently certain data. Like Bacon, he made men believe in the value of the scientific method, and his insistence on the power of mathematical reasoning in science was complementary to Bacon's insistence on the collection of trustworthy fact. His influence became important in this country in the years after 1650. The two methods (Baconian and Cartesian) met in the work of the greatest of men of science, Isaac Newton (1642-1727), who had at once the respect for observation and experiment that Bacon showed and inculcated, and also Descartes' facility in the free use of mathematical reasoning. In Newton's work, then, the present scientific method is recognisable and all its principles are to be found. Since his time, however, the development of what we may call the tools of investigation, physical and mental, has been enormous. Mathematical methods have progressed, and generally quicker than science has required, so that the mathematicians have usually been working out methods that the scientists of half a century later have found useful. Instruments have been developed out of all recognition: the discovery of the electric battery in 1800 opened the way to the designing of an enormous variety of electrical instruments applicable to every grade of scientific work, and the development of engineering technique and automatic-machine-tools (pp. 63—64) have made much more perfectly finished and therefore far more accurate instruments available.

It may be said, then, that from the middle of the seventeenth century to the present day, scientific research has been following a steady course towards its unattainable end, namely the observation, measurement and investigation by experiment of every aspect of the material universe, and the description of the relationships between all classes of phenomena in terms of mathematical expressions. It is to be noted that science is not a mere record of facts about individual things, which would be impossibly bulky and of no value for the main purpose of science, the prediction of phenomena. Science classifies all the observables into a hierarchy of classes and expresses in the concisest form the properties of those classes. By this process the record of science is made useful. The scientist carries in his mind a picture of what he believes to be the realities indicated by science, and is conscious of the general principles of his own department of science and its more important facts. Confronted with some particular problem, his knowledge is enough to indicate to him where the relevant information is to be found. He consults bibliographies and indexes and so obtains references to the original papers of those who have worked on this or similar problems, and reads these up in one of the greater libraries which house the thousands of volumes of scientific periodicals that have been published in the last hundred years. He is then in possession of all the relevant knowledge; this may solve his problem, but, if not, he must investigate the problem for himself in the laboratory. Up to this point the work needs nothing but taking pains, but once laboratory research begins he has to use all his wits. There is no rule for laboratory research. Every possible analogy to the problem in hand is thought of, every possible explanation of the phenomenon considered and experiments whose results may decide between possible explanations are devised. A sharp eye is kept on the results of these, for an experiment based on a wholly false theory may give a result that indicates the true one. The essential process of research is generally an intuitive one, the forming, by no conscious rational method, of hypotheses, or well-formed guesses at laws, that may express the relationships between the phenomena that are under investigation, followed by a reasoned study of these guesses in order to discover whether they agree with the known facts and, if so, whether they will predict hitherto unknown phenomena which experiment can confirm. The guess that passes these tests is taken to be the true law and is incorporated into the structure of science, until the time, if it ever comes, when new facts for which it does not account require it to be replaced by a new or modified hypothesis. By this process science is built up. Its matter is a mass of well-tested fact, and its form is the laws of science. But science is really more flexible and living than a building, and more like a growing organism, for it is continually modified. Even the facts are continually renewed. No chemist or physicist would use data that were a century old, for all the reproducible facts of science are continually being observed more perfectly, and with greater certainty and accuracy; so that the observations of Berzelius, Gay-Lussac, Regnault or any of the great masters, though they determined the form of science of the day, and through it, of our own, have yet been discarded and replaced by the more accurate work of the lesser men that stood on their shoulders.

Not only the matter but the form of science continually shifts; scarcely any law stands in the form which it held in, let us say, the year 1870: for, although the science of 1870 was an admirable account of nature, our present science is not only fuller, in that we know more, but wider and deeper, in that we understand wider principles underlying those laws, principles derived from a deeper analysis of phenomena.

So science will go on, like a man endowed with eternal youth — always the same person, but ever self-renewing and self-renewed.

9. THE WEAPON OF POWER

The development of the sciences about which we have been writing gave the knowledge that was the key to the conquest of Nature which is the subject of the latter part of the book, but the practical part of that conquest consists for the most part in mechanical operations — mining, digging, draining, working of metal, and the like, all of which require power. Man is a quarter-horse-power engine, horses are of a little less than a horse-power; if there is time, sufficient horses and men can bring about great results, as is shown by the works of antiquity. But a thousand horse-power in living organisms is very heavy, very bulky and uses a great deal of expensive fuel in the form of food. During the greater part of man's civilised existence the only power available was that of men and animals, and consequently only those tasks could be performed that did not require a prime mover of more than a low power. Agriculture was developed on this basis, the tendency naturally being to the sub-division of land into small units. All other operations had likewise to be sub-divided into units within a man's strength.

It is remarkable how much men could do by their strength and ingenuity, but what was *possible* differed a great deal from what was practicable. All the king's horses and all the king's men could dig canals or raise palaces for kings, but the goods and services that ordinary men were to have and use had, then as now, to be produced by a quantity of labour comparable with that which ordinary men were able to perform. Thus in the seventeenth century it was possible and practicable to bring water into the towns that needed it by means of aqueducts; it was possible but not practicable to pump it into the towns, because this needed too much labour. Again it was practicable to sink shallow mines and keep them free from water by hand pumping; but as the mines became deeper, the cost in labour of raising the ore and the water became too great. Many other trades were limited to a low rate of production through this lack of power. Thus all the metal-shaping trades, carried out by hammer and anvil, file and saw and treadle-lathe, turned out goods at a cost in labour very high compared with their modern mechanical equivalent, and the quantity of metal goods available for each person was therefore small. Finally there were a great many tasks that could not be done at all without a source of power with a smaller ratio of weight and bulk to output than a man or horse. Transport at a continuous speed of over twelve miles an hour is an example: the forging of a piece of metal weighing fifty tons or so is another.

Let us then consider what kind of prime mover man required to aid him in fulfilling his desires. Any kind of prime mover that can do what horses and men can not is better than none at all, but in order that the use of power should develop to any considerable extent prime movers had to be developed in the direction of giving:

1. Maximum power from an engine of given weight and bulk.
2. Maximum power from a given amount of fuel.
3. Maximum power from a given expenditure of human labour in tending and maintaining the engine.

In other words engines had to become light, small, economical and automatic; and this was a long process, not even now complete.

Before the eighteenth century the only sources of power were wind and water and the muscles of men and animals. The first two sources could be used in mills, which commonly gave 10-12 h.p., though water-mills of much greater power could be constructed. In fact, however, before the middle of the eighteenth century mills were rarely used for any purpose except the grinding of corn and occasionally the pumping of water. The faults of mills as sources of industrial power are obvious. Windmills depend on that least dependable of powers — the wind; and water-mills can only be operated where there is a supply of water with sufficient velocity or fall; furthermore, they are liable to interruption by frost, drought or flood.

The raising of water against the force of gravity is a true conquest of Nature, and one which man has always sought to make. Among the earliest of machines is the shadoof, the bucket hung on a pivoted rod and counterpoised by a heavy weight; pumps and bucket-wheels, sometimes moved by a source of flowing water, were early expedients for irrigation and town-supply. But in the sixteenth century the need became more urgent, because the increase of wealth and craftsmanship increased the need for metals, and therefore for mining and the raising of water from mines. In the seventeenth century, man's increasing, though still not very conspicuous, habits of cleanliness required more water for the ever-growing towns, the increasing cleanliness of which further increased their population by lowering the death-rate. At this time men of science had begun systematic studies of the properties of gases and steam, especially of atmospheric pressure and the vacuum; and so those who were acquainted with science had the knowledge that was required in order to devise the first attempts at steam-engines.

Without going into details, and omitting abortive or unsuccessful attempts, we may say that the first practicable pumping engine operated by steam was in use in 1698. This engine, invented by Thomas Savery, operated without a piston, the steam acting directly upon the water to be moved. A strong copper vessel was filled with steam, which condensed, leaving a partial vacuum, which was filled by water from the mine-sump. Steam was then forced into this vessel, now full of water, driving this water out through a valve and up to the top of the mine shaft, very much as in the pulsometer pump of today. This engine worked very well and did the work of a dozen men, but it went out of use because the technique of handling steam at comparatively high pressures was not developed and consequently danger and trouble were caused by leakages from imperfect joints.

The atmospheric engine, first constructed by Newcomen about 1705, is the ancestor of the modern steam engine. It had a low-pressure tank-boiler, steam from which was led into a very large vertical cylinder. This steam was then condensed by a jet of cold water, and the atmospheric pressure forced down the piston, tipping the rocking-beam and so operating the pumps attached to the other end. (Pl. 3). It was a reliable and quite powerful engine, but although improvements were made in it, it remained very large and heavy for its power. But its chief fault was the great quantity of steam that was wasted in heating the heavy cylinder from air-temperature to boiling-point at every stroke, which necessitated the use of a great quantity of fuel to produce a given quantity of power.

James Watt between 1769 and 1784 made the steam engine as we know it. His improvement of keeping the cylinder always hot and condensing the steam in a separate condenser which was always cold, enormously reduced the quantity of fuel used per horse-power. His introduction of double action (steam-pressure on one side of the piston and vacuum on the other) greatly reduced the bulk and weight of the engine; finally his sun-and-planet device attached to the rocking-beam provided a rotary engine capable of driving machinery. (Pl. 4). He also invented the plan of dispensing with a condenser and using high-pressure steam, though he did not adopt it in practice: it was this plan that enabled Trevithick and others to build light-weight engines that could be used as locomotives.

James Watt's improvements therefore mark an enormous advance towards the conquest of Nature. They opened the way to three great lines of development.

The first of these was *mechanical engineering* — the use of power to build engines, machines and accessories by far more accurate, efficient and rapid methods than had been possible with the use of none but hand-tools. Mechanical engineering opened up the whole engineering progress of the nineteenth and twentieth centuries, by which, in turn, much of the conquest of nature has been made possible.

The second line of development was improved *transport*, steamships, railways and locomotives of all kinds, which we shall consider as contributing to the war against distance.

The third development was *mechanisation*, the application of power-driven machinery to the trades that had been conducted by handicrafts and which, therefore, turned out a comparatively small quantity of goods per man-hour, which goods were therefore expensive in terms of the prevalent wages.

Steam was the source of the power which was the means of carrying out the enormous industrial expansion of the nineteenth century, and it is still today the chief means of producing power, whether directly or in the form of electricity.

Other sources of power became important only at the end of the nineteenth century. Even in its most improved forms the steam engine remained heavy; it emitted a great deal of heat together with unpleasant or poisonous smoke and gases; furthermore, the power it gave could not be applied at any great distance from the engine itself without serious loss through friction in the driving gear. The difficulties of obtaining a light source of power were overcome, in principle at least, in the eighteen-eighties, by the invention of light oil-burning internal-combustion engines; and the difficulty of transmission was overcome by the development of electric supply.

The internal combustion engine found its most important uses in, and indeed revolutionised, all known forms of transport on land or sea, and was the determining factor in making transport by air practicable. Of this more will be said.

Electric supply has solved the problem of providing small units of power. An electric motor is small, cool, and emits no fumes, and it can be instantly switched on or off; consequently it has made the use of power possible in homes and all manner of places in which a steam-engine would be obviously inadmissible. In the factory, likewise, it has gone far towards doing away with belting and shafting, source of so many accidents, and has rendered possible the use of power on even the smallest of tasks. Furthermore electric supply has opened up the great possibilities of water-power, which was little used in the nineteenth century because of the difficulty of transmitting it to the factories where it was needed: and it at least offers the possibility of the use of the tides.

These three means of applying power, the steam engine, the internal-combustion engine and the electric motor, are the means by which man now applies his knowledge, gained by science, to the conquest of Nature. To these we may add, in parenthesis, explosives, which have been for a long time man's method of shaping nature's hardest and heaviest of materials, the rocks. The development of nuclear fission has added gigantically to the possibilities of using explosives to perform vast works and has also opened the way to the possibility of generating power from a new source. (Pl. 6).

No one can yet say how this power will be developed, but at present it looks as if its utilisation as a source of power will require very heavy plant and will therefore be restricted to the generation of electric power for distribution. But it is far too soon to prophesy. Who lives (and that may be fewer of us than formerly seemed likely) will see.

Part II

INTRODUCTORY

We have hitherto considered the weapons of thought and means of action with which man has equipped himself throughout the ages, and we now turn to see what he has done and what he is doing by their aid. It is well to consider at this stage the factors that determine the strategy of man's conquest of his environment. These factors are the desires which he seeks to satisfy.

Very broadly we may divide man's life into an active and a contemplative part. In his active life man seeks to act upon his external environment, and is correspondingly acted upon by it, both in the realm of matter and motion, and in that of thought. This inter-action with nature and his fellows is enjoyed by him, and the desire of active man may be summed up as the making of that inter-action more extensive in space and time and more intense in quality of experience.

The feature of man's environment which has through the ages become ever more obvious is the extreme smallness of his own extension and duration in comparison with the extension and duration of the external world. He seeks therefore to find means to conquer his smallness and impermanence, and his first objective is to be able to be effectively present at any point of space or time with the least expenditure of time and trouble. By effective presence I mean either actual bodily presence or presence through some means of communication; which communication may be by reproduction of the distant event to the senses, as in the cinema, radio, or television, but can also be attained through the symbols of words apprehended by the intellect. But not only does man desire to extend his domain; he strives to render it more enjoyable. This involves the provision of all that we may class as comforts and things of beauty, and also the arrangement of his life so that he may have the opportunity to enjoy them. All this has been brought about, for the most part, by a great increase of productivity per man-hour, as a consequence of which he is enabled to receive both more goods and services and more time in which to enjoy them. But when productivity has given all it can, life and health are needed to enjoy that all; and the third of man's desires is, therefore, to be healthy and to live long. Lastly, he must conquer his own nature, so as to avoid the usual state of man in which a few steal from the many the enjoyment of the products of Nature and art, and to this end he must find a state of social and international peace.

The fulfilling of men's active desires may perhaps then be summed up as the war against space and time, the war against poverty, the war against death, and the war against his own nature.

Yet, were all these wars brought to a successful end, man would still be dissatisfied, for all the objects that he seeks lose their savour once they are enjoyed, and become mere commonplace comforts, taken for granted. It is a great thing to be cured of our illness, but who takes any active pleasure in being well? So we are not to forget that there is another way of life which depends not at all on the conquest of any Nature but man's own, and that only as a means to an end. The men who have lived a life of love for God or man, independent of natural enjoyments, are, oddly enough, those that the world most praises and least imitates. But it is not my task to tell of this way of living but rather to describe the conquest of Nature — the still continuing wars against severing distance, impassable Time, stubborn matter, sickness, death and the folly of man.

10 THE WAR AGAINST POVERTY

Man in the hypothetical state of nature is poor. He possesses very few things and has the benefit of no services except perhaps those of his marriage partner. Throughout his history he has, with intermissions, been progressing towards a state of wealth in which he possesses or has the use of many and various kinds of goods and services, clothes, houses, food-stuffs, medical attention, defence, and so on through all the list of material amenities that are supplied by the modern industrial civilisation.

These goods and services do not for the most part imply the possession or use of natural products only, but are the result of their development. The resources of Nature are radiation, air, water, the rocks, and living organisms: these have been wrought by man's knowledge and skill and power of organisation into the goods and services he now enjoys.

Every process of this kind has three chief requisites — power, materials, and machinery — all developed by human skill and labour from natural resources.

Power. Power is nothing more than supply of energy, the most valuable and necessary of natural resources. We have already said something as to the development of prime movers, contrivances for transforming the energy of natural resources into useful power, but not so much concerning these same natural resources. The energy which is the source of man's power cannot be made, and almost all of it is in some sense a transformation of the radiant energy of the sun. The radiation from the sun is the means by which the green plant builds up carbon dioxide and water into the various compounds in its tissues; when these are broken down again to carbon dioxide and water the energy reappears. If the plant tissues are burned in a fire this energy appears as heat; if they are digested and oxidised in the body of an animal the products are heat, the chemical energy that builds up the tissues of the animal, and the mechanical energy of the animal's external and internal movements. Fuels are, as far as we know, plant or animal products, coal being mummified plant-remains, and oil, in all probability, the result of the action of heat, pressure and time upon some low forms of marine animal life. When these fuels burn they return to the carbon dioxide and water which was the material of the primitive plants, and therefore of the primitive animals that fed on them, and the energy they absorbed from the sun reappears after hundreds of millions of years of imprisonment. All water-power is likewise derived from the energy of the sun; for it is the heating of the air that causes the air-currents which carry moisture, evaporated from the seas, to the tops of the hills. The work done by the sun in raising the water, we recover by using the falling water in our mills and turbines. Windmills take their power from the same source, but tidemills (which have as yet been little developed) use the earth's and moon's energy of rotation as their source, and this energy, in all probability, was originally derived from the sun. Even the energy of the uranium atoms which is employed in nuclear fission was probably derived from the intense heat and pressure of the centre of the sun in which these atoms were built up. Thus all our utilisation of power consists, in very roundabout ways, of using the sun's radiation. The direct use of this energy is difficult but not impossible. The solar energy daily imparted to the earth amounts to two hundred and fifty billion horse-power, and the energy of the sun's rays falling on the Sahara alone could, if utilised, supply the earth with all the power it needs. The obvious difficulty is the very great cost of the enormous area of plant needed to intercept and utilise this energy. Tubular steam-boilers onto which sunlight is focused by ranges of mirrors have been used in tropical countries, but the possibility of interruption of working by cloud or dust-storms, as well as the impossibility of operating at night, have hitherto restricted their use.

This general survey shows us the limitations of man's use of power. The power that is derived from energy stored in the past (from coal and oil) is obviously limited in quantity, for there is no evidence that at the present time coal or oil is being laid down at all, let alone at the rate at which we are using them. The time that these stores will last is not known, but at any rate it is small compared with human history; and though we who are now living will not exhaust these stores, our descendants will ultimately so far deplete them that the only remaining coal and oil will be so difficult of access as to be no longer worth working. But at present, while accessible stores of fuel still exist, the effective limitation to their use is the quantity of man-power directly or indirectly required to transfer the fuel and the energy made from it to the place where the power is needed. Any diminution of the man-hours needed to win a horse-power hour of energy from the earth, whether by mechanisation of mining or by simplifying the transport of the fuel or the energy made from it, will increase the horse-power hours available for each member of the community, and so increase its wealth. Plans for generating electricity in coalmining districts or, as in a Russian experiment, gasifying the coal underground without mining it, are designed to meet this end.

On the other hand, any increase of this man-power per horse-power, or the decrease of available man-power to the point where sufficient energy to supply the needs of the community can no longer be generated, makes other means of generating power, which require less man-power than the mining and burning of fuel, seem more attractive. All methods of generating power, however, present the same essential problem of using the least quantity of man-power to generate a horse-power. Thus utilisation of water-power, whether of rivers or tides, requires the building and upkeep of dams or barrages; atomic power, it seems, needs very elaborate plant to prepare the materials and utilise the energy, and in fact all these works require power to bring them into existence, though the labour they require for maintenance is much less than is needed for example, in the mining of coal and its use to make electricity. A shortage of power in a community is therefore peculiarly difficult to meet, because every method of meeting it requires large supplies of that very power which is lacking. It would seem, then, that the only remedy is to divert power from inessential uses and to employ it in accomplishing the mechanisation of the means of generation of power, which in its turn makes further supplies of power available.

Materials. The kinds of matter found in nature are air, water, the rocks and the tissues of living organisms, and these can be developed by the use of power into those materials of which are made the myriad things an industrial civilisation uses. The making of these materials requires the use of power, and the generation of power requires the use of these materials; consequently the use of power and the development of materials have gone hand in hand.

The science by which we study the ways of making new kinds of matter is chemistry, and all the chief classes of matter found in nature have been made the subjects of the chemists' investigation and practical arts.

Air and water, of which the chemical composition was discovered less than two hundred years ago, are now the source of many other materials. Air is separated into oxygen, nitrogen and the inert gases (helium, argon, neon, etc.). Water is made to combine with carbon (coke) and give hydrogen and carbon dioxide. The oxygen from air is used in cutting and welding metals. The nitrogen is made to combine with hydrogen, made from water, and gives ammonia, which in turn is made into fertilisers or oxidised to nitric acid, an essential material for the making of explosives, fertilisers, dyes, drugs and all manner of organic compounds.

Minerals are the source of almost all the inorganic elements and their compounds, and, above all, of the metals. All our metals are the products of the application of chemical energy to minerals. The smelting of iron and steel requires the burning of vast quantities of coal; the manufacture of aluminium requires the use of electricity; no metal can be had without energy, and no energy can be utilised without metals. These metals and their compounds give rise to a vast variety of materials — pigments, glazes, enamels, mordants, drugs and materials of industrial use. Another great industry springs from salt, which is converted into soda, caustic soda, chlorine, hydrochloric acid or other products; another from clays, which are converted into bricks, pottery, porcelain, and which with chalk give cement; another is the conversion of sulphur or iron pyrites into sulphuric acid, required in almost all the chemical industries, amongst which may be mentioned the making of superphosphate and similar fertilisers from phosphate rock.

The tissues of plants and animals and their remains, coal and oil, are the source of quite a different range of materials. They provide man's food — his first necessity — and can be worked up into any of the million or so known organic compounds. Agriculture is the means of producing plant and animal material and its beginnings precede the dawn of history. It is, indeed, the most obvious conquest of Nature, and that conquest has proceeded by an increase of the quantity, and an alteration of the quality, of the material produced. The plant, and therefore indirectly the animal, is made from air, water and certain mineral salts — notably nitrates, phosphates, and potassium salts — by the agency of light; moreover the life-process of each species can only proceed within a certain range of temperature. From these considerations we can see the limitations of agriculture. Air is unlimited, but the supply of water is deficient over much of the earth's surface. Man uses power to carry out irrigation works, but these will only be worth carrying out if the food-values produced are at least enough to provide the needs of those directly or indirectly engaged on the work. The soil commonly contains enough salts, nitrates, phosphates and potash, etc., to support plant life, but in artificial cultivation the plant material is removed together with the salts it has taken up; the soil is thereby impoverished and the yield falls. The nitrates and phosphates in this food travel down the sewers to the sea and are effectively lost. If fertility is to be maintained, these salts must be replaced. Nitrates, or some nitrogenous material that will be converted thereto in the soil, have to be put back, and the making of these from air, water and coal, or their transport from the dwindling nitrate-deposits of Chile, requires power, on which, therefore, even our food depends. Phosphates also have to be put back; these are taken from deposits of phosphate rock or the slag of phosphatic iron ores — both being sources that can be exhausted; potash likewise comes from mineral deposits. So at present it appears that we are conquering the limitations of production of plant-food by the expenditure of non-replaceable resources; yet it must be remembered that the powers of science will have become much greater before any of these resources are near exhaustion, and that it may be then possible to extract the necessary salts from rocks that contain them only in quantities that today do not repay our labour. The need for light, as the source of the power by which a plant builds itself, means that agriculture has to be carried out in such way that the plant receives a full supply of light; and, consequently, although the productivity of a given area can be much increased by giving the optimum supply of water and salts (as in the soil-less culture known as hydroponics), a given area cannot synthesise more plant-tissue than corresponds to the energy of the light that falls on it. Lastly, the production of food-stuff is limited by temperature-conditions, so that cultivation becomes more difficult and finally ceases at high altitudes or as the Arctic and Antarctic regions are approached. A further limitation to production is the struggle of a vast variety of animals and plants to devour or compete with those we seek to produce. Every living thing is food for other living things — animals, fungi, bacteria, viruses — that in a state of nature live upon it and limit its numbers; these the agriculturist seeks to eliminate by various means, such as poisons, or the encouragement of their living enemies. His success in this respect has been enormous. Furthermore, by scientific breeding he alters the characters of the living organisms he cultivates, intensifying their productiveness and their resistance to their enemies. Biology is at a far more elementary stage than physics or chemistry, and an enormous field for improvement of agriculture awaits the research worker.

It appears then that the theoretical limitations of production of plant and animal materials have scarcely begun to be felt. Furthermore, the world could produce far more food than it does — witness the enormous uncultivated areas of Africa and Brazil; yet it has, and always has had, vast populations near the famine-level. The cause of this anomaly has occupied the pens of countless economists and politicians, and it would seem that our failure is due not so much to an inability to subdue nature as to our imperfect organisation for the use of labour and the distribution of products. Thus there are countless agriculturists in India and China who have not enough land, nor the means to make what they possess fully productive. On the other hand, we have had farmers producing foodstuffs that they cannot sell and have had to destroy. Be this as it may, it is clear that the world's production of plant and animal material could be very greatly increased so as to support a population perhaps double that alive to-day.

Yet we have to remember that the population of the world has already doubled in a period of little more than a century, mainly as a consequence of improved public-health measures. These measures have as yet had very little effect among the inhabitants of India, China and the parts of Africa which have not been influenced by European civilisation. The result of the influence of medical services upon these countries could be that quadrupling of the population which happened in Japan during the past century. As these peoples appear to be very fertile we may reasonably expect that the food supply of the world will need to be even more than doubled if there comes a century of scientific progress unobstructed by the devastation of war. Could we in such a case contemplate the chemical preparation of food from new sources? There are two possibilities here. The first is the conversion of non-edible plants into food. All plants contain cellulose, and cellulose can be fairly easily made into sugar, which could be used directly as a foodstuff or to supplement animal rations. In this way all manner of plants, including those adapted to very unfavourable climates, could be used to make food, and the refuse of plants grown for the making of some other product could be used in the same way. The second possibility is the synthesis of foodstuffs from non-living matter. Some foodstuffs can be synthesised from air, water and coal, though at present the cost of doing this would be much greater than the cost of growing food. But there is little doubt that half-a-century's progress might bring us to the large-scale production of carbohydrates, and of amino-acids, the chief material of protein. Whether the arts of the chemist could make these materials palatable is less certain, but they could certainly be used as feeding-stuffs for animals.

The products of agriculture are either used in the crude state, or are in some way preserved, or are worked up into various chemical products. The preservation of foodstuffs has been one of man's most important conquests, removing as it does some of the dangers of starvation. The chief causes of decay of foodstuffs are fungi and bacteria, and at a remote period it was discovered that this decay was prevented by drying, salting or smoking moist food-stuffs. But these methods were not perfect, retarding decay rather than preventing it, and they yielded foodstuffs that were often unpalatable. It was the invention of canning, which became reliable in the 'seventies and 'eighties and has since been perfected, that enabled foodstuffs to be safely stored in quantity.

The chemical uses of plant and animal products are legion, but we may note a few of the most important ways in which we have modified their former use. Plants contain a high proportion of carbohydrates, of which the most important are cellulose, starch and sugar. Cellulose, in the fibrous form in which it exists in the plant, is the chief constituent of cotton, linen, paper and wood, but in the last hundred years it has been chemically treated and converted into other products. By treatment with sulphuric and nitric acids it gives the high explosive, nitrocellulose (gun cotton), a form of which, mixed with camphor, gives celluloid, from which sprang the film industry; by several different processes cellulose has been chemically modified, dissolved and spun into 'artificial silk' or dissolved in other solvents and used as paints or lacquers.

Starch is converted into glucose, and this is fermented to alcohol, from which a great number of chemicals are derived. It can also be converted by other types of fermentations into solvents. Sugars can be treated in the same way, but are mostly consumed as food-stuffs. Both animals and plants yield oils and fats which, in their crude state or after conversion into margarine, are used as food-stuffs. They are also converted into soaps and glycerine, into lubricants, paints, linoleum and many other products. Many other classes of material are separated from animal and plant products — *e.g.* rubber, camphor, essential oils, dyes, alkaloids and the like.

The molecules of all these substances are built up of many atoms of a few of the elements — carbon, hydrogen, oxygen, nitrogen, etc. Accordingly the greater part of these substances have been, and all probably some day will be, synthesised by the chemist — that 's to say, they can or will be made by a series of chemical processes from simpler compounds, or even from the chemical elements. Thus the chemist may start from some plentiful material containing carbon — coal, or possibly cellulose or starch — and, with the help of chemicals derived from air, water and minerals, build up such complex substances as rubber or indigo. Sometimes this process is cheaper than growing these compounds, or yields a better product; but sometimes it is too expensive for practical use. It is important to remember that if we prefer to make a substance by chemical synthesis rather than by growing it, none the less we do not make it out of nothing. We require materials, numerous chemicals, and extensive plant (Pl. 7—8) all of which have been made by the use of power, and the making of these materials into the final product also requires a good deal of power. So a change from the agricultural to the synthetic way of making a substance means taking carbon from coal and power from coal, instead of taking carbon dioxide from the air and power from sunlight.

Coal, then, the remains of mummified plants, is not only the chief source of power, but the chief source of synthetic organic compounds. Coal, distilled in the gas-works, gives us coke, gas, ammonium salts and tar. Tar gives us pitch for roads, and benzene, toluene, phenol, cresol, naphthalene, and anthracene, which can be converted into an enormous variety of compounds. In brief, the greater part of our drugs, our dyes, our explosives and our plastics originate from coal-tar. Even if coal becomes supplanted as a source of power it will probably still be necessary to mine and distil it to obtain the substances which are the sources of synthetic carbon compounds.

Petroleum is a lesser source of these materials. The greater part of it is burned as fuel in internal combustion engines, but a certain amount, especially of the low-boiling hydrocarbons that cannot be easily used for fuel, is converted into chemicals.

Thus man is ever perfecting new materials. Materials of which only a small quantity per person is needed can as a rule be made by expensive processes, that is by the expenditure of much skilled labour, but materials needed in very large quantity must be made by simpler processes. There is no theoretical limit to the number and variety of substances that chemists might prepare; but certain practical limitations are unavoidable. Thus there are no indications that new elements will ever be made except at a very high cost, and as the metals are elements we are unlikely to have new metals. Nor are metals likely to be displaced by any compound materials, for they are unequalled in the combination of low cost, strength, hardness, toughness, electrical conductivity, etc. In the field of organic materials, however, (for example, plastics), continuous development is likely, but the results will almost certainly fall short of metals in strength, hardness and heat-resistance; and they will be relatively costly, although they will have other merits such as lightness, transparency and ease of working. It seems unlikely, then, that the progress of science will greatly alter the prime constructional materials, nor greatly lower their production costs; nevertheles the design of new materials for specialised purposes will greatly increase (Pl. 9).

Manufactured goods. Given materials and power, man makes machinery, which enables him to modify his environment in ways and at a speed utterly impossible for man unaided. What then are the conditions for making machinery, and when did these come into being? A machine is an assembly of fixed and moving parts, designed to cause some piece of metal to move in an *exactly pre-determined* way, and the more complex the machine, the smaller must be the deviation of its moving parts from the path assigned to them by the designer. The parts of a machine are commonly required to move in contact with each other at a high speed, and in order that these high-speed parts may move rapidly in contact without wasting energy in destroying themselves and in generating heat and vibration, they must be of exact geometrical form—smooth and of the shape needed to ensure perfect balance. The use of high-speed accurate machinery had therefore to wait for the invention of machines capable of making precisely-shaped metal parts, and these machines themselves had to be of exact construction. How was this seeming *impasse* broken? The eighteenth-century metal-worker used hammer and anvil, saw and file and the crude treadle-lathes of his time to shape machine-parts as well as he could — which was not very well. But the best craftsmen of the early nineteenth century managed to make lathes with slide-rests, screw-cutting lathes, and planing-machines which, although they were not accurate, were good enough for the making of lathes and planing-machines better than themselves; and so by a series of inventions and improvements modern machine-tools were constructed. All through the last two centuries there has been a steady trend towards the fully automatic machine. We begin with craftsmen who by wonderful skill and much labour make fine (and beautiful) things with the simplest of tools, and we have ever since been transferring this skill from the operative to the designer — the unattainable end of this process being the production of a perfect article without any human intervention. The first condition for the growth of this mechanisation of industry has been the scientific progress which has led to the ability to make more perfect machines, and, especially, the adoption of electrical machinery, so well adapted to automatic control; but there have been other conditions of a more human character. When labour is very cheap and plentiful, there is no financial motive for designing a machine to do something that workers can and will do at lower cost, and it was the coincident trend of the humanitarian legislation and the workers' own efforts towards higher wages that necessitated the replacement of men by machines. A visit to any large factory today will show how many processes have been transferred from human manipulation to machine operation, and it is certain that a great many purely mechanical tasks for which human labour is still employed could be and will be given to the machine. This process seems to be an admirable one. Two hundred years ago most things were shaped by the craftsman, who took a pride in his work and enjoyed making things well. But with the advent of the machine, the making of things was subdivided into a number of operations, lacking in human interest because mechanically performed and not visibly leading to anything complete and perfect. The craftsman became replaced by two different classes of worker, the machine-maker and the machine-minder. The first was still a craftsman and even the fitter who kept the machines in order had a job which was interesting because it continually presented problems to be solved. The machine-minder, however, has a job of no interest in itself, though the companionship of fellow workers and the opportunity to ruminate while earning money may make it acceptable to some. The present tendency of industry is clearly to reduce the proportion of machine-minders, and rises in wage-costs must hasten the process. Ultimately we might envisage the almost wholly automatic factory in which the goods are made and packed without any manipulation, and in which the employees are all engineers of various grades and only the minimum of unskilled labour remains. This process would obviously increase productivity per employee, though the increase of productivity per person living and the consequent increase of wealth might be much less. It would in fact cause an increase in the total stock of leisure. At one time such a process meant full employment for a few and unemployment and consequent penury for the remainder, but in a sensibly organised community it should be possible to ensure the reasonable distribution of wealth produced by a few.

How has it been possible to produce machines to perform many tasks for which men were formerly required? A human being, considered only as a machine-minder, is a receiver of light-, sound- and contact-signals which lead him to perform certain movements appropriate to the information given by those signals; in many cases this response is stereotyped and requires little or no judgement. The machine in its early days was an excellent performer of movements, but was not, or was only to a small extent, a receiver of signals, except by the fairly vigorous contact required to move handles or levers. Electrical machinery is far more adapted to the reception of signals. Photo-electric cells can receive light-signals, microphones sound-signals, and very light contacts can energise electric circuits; thus the electrical machine is well adapted to take action on receiving a signal and to respond only to a particular type of signal. Furthermore, electrical relays afford an excellent means of procuring a sequence of operations to be performed on the same object. Thus electricity has afforded the means of making what has aptly been called robot-machinery — machinery which performs some operation which was formerly done by a human being who had only to make certain determinate motions appropriate to certain determinate sense-impressions. Thus the automatic pilot of a plane (Pls. 10—12) automatically keeps the plane on a predetermined course, and relieves the human pilot from acting for hours together as a piece of mechanism. Its limitation is that it cannot exercise judgment. If an emergency arises which was not foreseen by its designer, then the human pilot who can think — *i.e.*, can originate new actions in response to new stimuli — has to take over.

It is remarkable how many of our daily actions, at home or at work, are in fact automatic. The replacement of men and women by machines to do such work is sure to continue; the distance it will go is determined first of all by the general degree of aversion to or liking for routine work, secondly by the quantity of plant that can be supplied to each member of the community and kept serviced, thirdly by the quantity of power available to each of us. No doubt a breakfast-making machine could be devised, which could be set off by a clock and automatically deliver cups of tea and plates of eggs-and-bacon, but will the quantity of labour, materials and power ever be sufficient to let every household have one?

The disadvantage of increasing the complexity of a machine is the increase of the possibilities of breakdown. A wheelbarrow almost never breaks down: a car not infrequently, especially if driven by those who do not understand it. Mechanical complexity and social complexity are alike in this respect. The small primitive community stood in danger of extinction by starvation through failure of crops, or by plague, and was continually hampered by the vagaries of the weather and the attacks of animals great and small upon its food. We have eliminated these dangers by greatly increasing the size and complexity of the social organism, but we have introduced the new danger of dependence upon the co-operation of a great number of men. Our system of production and exchange of goods is based on the assumption of a world co-operating for the mutual advantage of every part. The production of goods is divided among the various countries of the world; half-a-dozen countries produce the raw materials, which are combined and manufactured into goods in another country, which goods are sold to half-a-dozen others. Without free exchange and sufficient transport, the production of these goods must be retarded. The services required to gather the materials, transport them, manufacture them, export them, buy them and sell them, are performed by many groups of human beings with different interests and desires. It has become painfully obvious that the conquest of Nature will never come near to completion while it is sought by forces which are much more interested in maintaining their own interests than in combining to the common good.

11. THE WAR AGAINST DISTANCE

The objective of the war against distance is the ability of every man to be effectively present anywhere in the briefest possible time.

Man has approached this object in two ways, by moving himself or his goods from place to place or by sending and receiving signals, which two modes of minimising distance we can call transport and communications. All his recent successes in the acceleration of transport have of course depended on the availability of power, materials and machinery, so that his conquest of distance depends in the first place on that capture of Nature's resources which we have discussed in the preceding chapter.

Man's power of moving his body and his goods can be looked at in three ways — from the point of view of speed, of availability and of cost in terms of the labour expended on providing both the means of transport and the power required to work it. The speed of transport depends on the ingenuity and skill of those who use their knowledge of Nature to devise locomotive machines; the availability and cost of transport depend also on the utilisation of our natural resources so as to obtain the greatest amount of motion (reckoned according to both mass and speed) for the least expenditure of labour. Thus transport may be lacking because we have not provided transport through lack of will or organisation; it may also be lacking because the labour needed to provide it is not recompensed by the transport provided; it may also be impossible to us because we have not yet found out how to make it possible.

So our men of science have enabled man to be conveyed safely from London to New York in ten hours; this was a matter of application of scientific knowledge and experimental investigation to a particular problem. But in fact this mode of transport requires the expenditure of so much labour that only a few thousand Englishmen, selected for their services to the community, can so travel each year; and the problem of moving the greatest number at the highest speed that can be provided in return for their services is considerably more important than moving a few Very Important People at a very high speed.

The maximum speed of transport depends upon the exertion of man's knowledge and skill upon the problem. In 4000 B.C., before the discovery of transport animals, a four-hundred mile journey can rarely have taken less than a couple of months. In the early nineteenth century the mail-coach from London to Edinburgh managed the journey in $42\frac{1}{2}$ hours. In 1900 the express train made the journey in $8\frac{1}{2}$ hours and today the regular air services take only $2\,^1/_4$ hours. A war-plane might cut this down to 1 hour. Can this process be indefinitely extended? Is there any necessary lower limit to the time required for a 400-mile journey? Obviously we can set no upper limit to the speed of a projectile, save that of the velocity of light, but we must remember that in passenger transport it is a human body that has to be conveyed. Uniform speed has no effect on a body, for I am now travelling (relatively to the sun) at a pace of 18 miles a second without noticing it. But though speed has no effect on a body, acceleration has, for it necessarily exerts on every part of it a force equal to the mass multiplied by the acceleration. The study of diving aeroplanes shows that the accelerations of 100 to 160 feet per second per second have such an effect in moving the blood relatively to other tissues that they are accompanied by grave discomfort and even unconsciousness. So if we take 100 feet per second per second as the greatest acceleration or deceleration that could be made tolerable for even a short period, and suppose that our vehicles are accelerated at this rate for the first half of the journey and decelerated at this rate for the other half, we can calculate that the quickest journey we could tolerate from a state of rest in London to a state of rest in Edinburgh would occupy two and a half minutes. With increasing distance the average speed becomes much higher; thus the shortest time for a journey of 6,400 miles, say from Stockholm to Cape Town, that could be tolerated under the above conditions would be ten minutes. Whether man will ever construct mechanisms capable of transporting him at such accelerations cannot of course be predicted but it does not seem at all impossible that rocket-craft should be able to accomplish it. It does not seem to matter much to the ordinary man whether it becomes possible or not. Most of us could now spare a couple of days to get to Australia, or ten hours to New York; but, in fact, we can't afford the fare and, if we could, much less than a thousandth of us could obtain passages. The real conquest in respect of transport must be thought to be the general availability of reasonably fast transport provided by steam and oil on sea and land.

The principle that lies behind the improvement in transport is simple enough. There must be some motive power — muscles, an engine, a rocket or what not — that exerts a certain force upon the vehicle. Any force applied to a mass causes its velocity to increase in the direction of that force, and the less the mass and the greater the force, the greater is the acceleration. But as the velocity increases so does the friction, both between the internal moving parts of the engine and the vehicle, and also between the vehicle and the ground, water, air or whatever it touches. This friction increases very rapidly with increasing velocity and finally exerts a force opposing the motion of the vehicle equal to the force exerted by the engine driving it. When this occurs the vehicle no longer accelerates but moves at a steady pace.

So all increases of the speed of transport consist in either the application of greater power to moving a vehicle of a given mass or the diminishing of the friction involved in its motion. These are the essentials that must always enter into the problem; other limiting factors, such as the destruction of the engine or vehicle by vibration or by overturning, or the avoidance of such unnecessary increases in the driving force as are caused by taking the load up and down hills, are only matters of design. Design can prevent a motor-car shaking itself to bits or a locomotive from being derailed, but no design can make a low-powered engine move a heavy mass at a high speed over a rough surface.

All this seems simple to the point of naivety, but it took the world a long time to decide to act upon it, and it was not until the second half of the eighteenth century that its importance for transport was grasped. At that time no engine other than a horse was light enough to be used for transport. But, as soon as the principle of diminishing friction was acted on by building smooth roads, horses became capable of transporting coaches full of human beings at twelve miles an hour instead of at three to five. Moreover it was found that when vehicles were set on level iron rails a horse could draw some forty tons, and when the load was floated on water in a barge, the same horse could draw sixty or seventy tons for long periods.

These improvements awoke men to the possibilities of accelerating transport and, when Watt's inventions (p. 63) made possible the construction of an engine of reasonable power-weight ratio, many inventors set to work to construct power-driven transport both for sea and land. Their first idea was not so much to move men at high speeds as to overcome the obvious defects of the transport of the time. On land the urgent need was to move heavy goods in quantities greater than a horse-wagon could handle, and at a lower cost; at sea to provide a passenger-ship which could make its voyages at fixed dates, and in an approximately known period, irrespective of unfavourable winds.

Land-transport was the more troublesome to achieve. The years from 1801 to 1805 may be regarded as the experimental period of the locomotive. From 1805 to 1830 it was a useful means of hauling a great weight of coal-trucks at a slow speed, but the opening of the

Liverpool and Manchester railway in 1830, and the unprecedented speed of 35 miles per hour attained by George Stephenson's Rocket, convinced the world of the value of the locomotive for rapid passenger transport. The spread of railways all over the world continued for a century and has not ceased, and for the large-scale movement of men and goods overland the railway had no rival until after 1920. From an early period high speeds on the railway were possible, the limiting factor being not so much the design of the locomotives as the lack of safety of the track and the inability to stop a train within a reasonable distance. The strength and smoothness of the track were greatly increased by adoption of steel rails, in place of iron, and the ability to stop within a reasonable distance was attained through the Westinghouse brake, both of which improvements were brought into use in the eighteen-seventies. Subsequent progress has been more in the direction of providing larger and more comfortable trains and longer non-stop runs, than in increase of speed.

Mechanical road transport made a start in the eighteen forties when steam road-carriages enjoyed a brief popularity. They soon died out, however, not so much because of the vigorous opposition of the coach-owners and other interested parties, which could not have prevailed against a strong public demand, but because the steam-carriage was very heavy and hot, produced unpleasant black smoke and (since it had solid tyres and the roads were rough) could not travel much faster than the horse-drawn vehicles without breaking itself to bits. In no country, in fact, did the steam-carriage become popular, and we must not attribute its downfall and disuse only to unfair opposition and legislation. The combined inventions of the petrol-burning internal combustion engine (1887) and the pneumatic tyre (1889) gave a fast, light, and smooth-running vehicle which, after some twenty-five years of teething-troubles, became the reliable motor-car we know today. The motor-car and motor-coach on ordinary roads are slower than the railway, but their outstanding advantage is that of providing door-to-door transit, which makes them generally the most rapid means of locomotion for short distances and for longer distances in countries where railroads are few. The effect of the motor-car in conquering the difficulties of transport in tropical countries is most notable. Africa, for example, is sparsely traversed by railroads, but today all the more settled areas are intersected by roads that can be used by cars, so greatly reducing the isolation of the farmers and settlers. Of the increase in mobility that the automobile has given to the population of England and America, the reader has the material to judge for himself.

From the eighteen-eighties electrified transport, trams and trains, began to develop. Its obvious limitation is the cost of track or overhead wires. But it made underground travel tolerable and so increased the mobility of the inhabitants of great cities; it was the first means of rapid and cheap street-transport and so allowed the worker to escape from the overcrowded centres of the towns. Finally the electric motor gives the most rapid acceleration for a given weight of machinery and is particularly suitable for suburban railways where there is much stopping and starting.

So we find steam, electricity and petrol as the present means of conveying human beings and their possessions overland at a maximum average speed of about seventy miles an hour, through generally at a much lower rate.

At sea the rate of progress is even slower. The steamship brought reliability; before its advent, a journey of a thousand miles by water might take one week or six according to the wind and weather. Steam meant that the time of a voyage was predictable within small limits. The speed of the steamship steadily increased. The fastest Atlantic crossing in 1839 took 19 days; in 1846, 14 days; in 1880, a week, and now 3 days 20 hours. The power of engines cannot be indefinitely increased without requiring much space and weight to be unprofitably employed for the carriage of machinery and fuel, and even the most careful design will not reduce the friction of the water indefinitely; consequently really high-speed sea transport is very unlikely.

An entirely new departure towards higher speed was taken with the development of the aeroplane. The friction of air is far less than that of any arrangements of solids or liquids; furthermore, the vast expanse of air allows of far higher speeds without fear of collision. The progress of aircraft has been through the increase of power and decrease of friction, the former being attained through engine design, the latter by adoption of smoother surfaces and above all of streamline forms calculated to impart the least quantity of energy to the air they traverse (Pls. 13—14). Air speeds have steadily climbed, as the following table of records shows.

AIR SPEED RECORD

Year		Record up to that year to nearest mile per hour.
1906		37
1914		125
1926		233
1936		424
1946		616
1956	Speed to be expected on the basis of former increase	*c.* 1,000

The further increase of these speeds can only come about by the same means—greater power and diminished friction. The former can be and is being brought about by rocket-propulsion, which affords the highest ratio of power for weight which can at present be visualised; the latter both by refinement of streamline design and, most notably, by flying at a height where air is scanty and therefore causes little friction. No one can predict the results of such developments, but having regard to the manner in which air-speeds have developed and to wartime essays towards rocket projectiles, it appears that air-travel may in 25 to 50 years reach the stage outlined at the beginning of this chapter, where the construction of the human body becomes the factor limiting speed. Of course a very great number of problems have to be solved before then, especially those of landing high-speed projectiles, but these, being problems of design, will doubtless be solved if men so desire.

Nuclear fission and the release of atomic energy is often invoked as a possible means of obtaining light motors of much greater power than even the rocket, and as bringing within our reach that final triumph over distance, inter-planetary travel. Of this very little can be said. At the time of writing, nuclear fission can either give the intense explosion of the atomic bomb or large quantities of low-grade heat; and it does not appear to have been adapted to producing that rapid, intense but controllable evolution of energy which is required to operate a motor of high power-weight ratio. Experiments on these lines are known to be in progress. The most potent objection to inter-planetary travel seems to be the danger of collision with small meteorites. The velocity of these seems to range around ten or twenty times that of a rifle bullet; the inter-planetary vehicle that will have to meet them would seem to require to be of a very strong and therefore heavy construction and so to require enormous power to accelerate it. The probability of encountering one of these meteorites seems at present to be beyond calculation; but doubtless if the inter-planetary vessel can be made, men will be found to try their luck.

Air vehicles, then, may attain enormous speeds, but unless they can take off from any given place and land at any other, the over-all speed of the human being travelling from door to door will remain comparatively low. It may therefore prove that the future of high-speed travel, as apart from the provision of vehicles capable of very high speeds, lies with the helicopter, or some similar machine, which can rise and alight in limited areas and travel short distances at higher than road-speeds. If a helicopter could rise from my garden in Oxford and take me to London Airport in a quarter of an hour, where I should transfer to a stratosphere plane and be projected to La Guardia, whence another helicopter would instantly take me to my friends' back garden in Downsville, N.Y., that would be high-speed travel. But if I have to spend three hours each end in getting to and from the air-port and two or three more in receiving the attentions of passport officers, immigration officers, customs officers, not to mention a great deal of waiting about and doing nothing — why, then, it matters very little whether my actual trip to New York from London takes ten hours or five.

Lastly, we have to look not only at the conquests we have made through high-speed travel but at the reverses we have undergone. The important difference between the wars of the nineteenth century and those of the twentieth century can be summed up as *mobility*. No one needs a lecture on modern warfare, for we have all been the toads beneath the harrow. We know that it is the aeroplane, the tanks and the rocket that make modern war; even the terror of the atomic bomb would not exist were there not these means of conveying it to its wretched victims. As speeds increase, so defence measures become more difficult, and it will probably be impossible to use any of the normal means of defence against atomic rocket-projectiles because the time available for action will be less than human reaction-times. Whether effective automatic defence machinery can be evolved remains to be seen. Would God we might believe it will never be needed!

Communications. In considering the conquest of distance through communications we must distinguish two aspects, first, the ability of any one person to communicate with any other, or with all others; secondly, the increase of speed of those communications.

A wonderful conquest of man's perishable memory was made by the unknown inventor or inventors of the pictorial arts and of the art of writing, for thereby the ever-shifting body of memorised tradition was replaced by the permanence of picture and the written word, which could communicate itself to those he had never seen. Comparable thereto is the art of printing, whereby the information formerly contained in MSS, copied by the dozen, was made available in books, printed by the thousand. The speed of printing made the newspaper possible; steam-printing, introduced in 1814, made large circulations possible; the railway made easy the nation-wide distribution of papers, and to-day we have the Press—and who dare say how much of his mental equipment he owes to it?

But the modern forms of communication from one to many—newspapers, broadcasting, television and the films — are also communications at high speed, and to this development of speed we now turn.

The final limit of speed for the actual movement of our signals has already been reached, for radio in all its forms travels at the maximum possible speed, that of light. Indeed that limit was effectively reached more than a century ago, when the electric telegraph service was established; for, although the signals conveyed by an electric current do not traverse a wire at the speed of light, they travel so rapidly that the human senses could scarcely detect the time taken by a message from the other side of the earth. Before the electric telegraph, the normal speed of communication was that of transport and was the highest speed at which a letter could be carried, although signals were occasionally used for the most urgent messages. Thus the chain of hill beacons, each lighted as soon as its neighbour was seen, could warn a whole country within a few hours, but it could not send any message other than that which had already been agreed as the meaning of the signals. The African drum-messages are commonplaces of romance, though no-one seems to know how the messages are read. The word "telegraph" was first applied (1792) to a system of visual signalling from one high point to another by means of a post with moveable arms in the style of the modern semaphore. The speed of the message depended, of course, on the number of times it had to be re-transmitted.

But these methods were available only for emergency, and the electric telegraph and ocean cable (1851) gave the first means by which every civilised country could be aware of what was happening in any other within a matter of hours. The political effect of this was enormous, and it became further accentuated when the overseas telephone came into use (1891).

The telegraph, then, provided communications in the time needed to take a message from the sender to the office, to transmit it and to carry the reply to the recipient — a few seconds for the message, a few hours for the rest. In the case of ocean cables the demand was often such that there was an appreciable delay between the receipt of the message and its despatch.

The telephone, which came into use from c. 1880 in this country, but which became a national habit only in the first decade of the twentieth century, was a great advance over the telegraph, a reduction of the time of communication from several hours to a couple of minutes or less. Further small reductions might be envisaged through the increased use of automatic devices at the exchanges, but it may be said that, as between telephone subscribers, communications have almost reached perfection in principle, though in practice improvements in reliability can be expected.

The perfection of communication is for any person, at any time, to be able to communicate reciprocally with any other; whether this is desirable or whether it would be an intolerable burden will be a matter for man to decide when science has made it possible. That there will be a time when we shall all carry a little box, and by dialling a number make communication with anyone else with such a box, seems obvious to the writers of scientific romances about the future, but closer consideration gives us reason to doubt its possibility. The only medium we can conceive for such communication is radio and there are nothing like enough different wave-lengths to allow a thousand, let alone a million, people to converse simultaneously without interference. So perhaps we may dismiss the idea of communications more perfect than would exist in a world where everyone was on the telephone.

But though everyone cannot talk at once, everyone can listen and look at once, and perhaps the greatest of all conquests of distance has been the development of broadcasting (1921) and television (1936), devices by which a few persons may communicate with almost every civilised person. Here again the reader may assess for himself the value and significance of these devices. They have obviously raised almost everybody's standard of information and musical appreciation. They have at the same time tended to impose a uniformity of speech and culture, and have proved capable of being made into sinister agents of propaganda.

Radar is perhaps not a means of communication from one man to another, but is to be thought of as a sort of extension of the senses, by which we can discover material objects, without the aid of light and through some media which do not transmit light signals, such as fog or cloud. Transport has hitherto been almost entirely suspended wherever man's power of sight has become obstructed; but radar, when developed, promises the conquest of another of Nature's limitations on human movement.

Photography, developing into the illustrated journal on the one hand and into the cinema on the other, may also be treated as a means of communication from the few to the many, and in these forms has many of the same merits and defects as broadcasting and television.

It is obvious that all our advances in transport, communications and the aiding of our senses lend themselves alike to the convenience and the destruction of man; but, be this as it may, our purpose is to consider the conquest of Nature, not the character of the servitude to which man has subdued her; and the conquest of that physical nature of man that isolates him on an earth of some two hundred million square miles, which he can traverse unaided only at a rate of some three miles an hour, has been more effectively conquered than any other restrictive aspect of his natural endowment.

12. THE WAR AGAINST DEATH

That man should be well and long-lived has never been regarded as other than a good — not necessarily a supreme good but always a good. Yet despite this desire and the antiquity of the physician's profession, it must seem to us, as we survey the mode of living of the men of the past, that throughout most of human history extremely little that was effective was done to prevent disease or to cure it. Something might have been done, by careful experiment and record, to connect the occurrence of a disease with the conditions surrounding the patient, or to discover the factors which led to recovery, but we must not forget the extreme difficulty of singling out the real causes of disease from the mass of possibilities, and of collecting accurate statistics about treatment and cure. The crying need was for a knowledge of the causes of the different types of disease and of the mode of operation of the various parts of the body, and until this knowledge began to be appreciable, which did not occur until the mid-nineteenth century, both hygiene and medicine were ineffective. Surgery, moreover, could make little progress because the mortality from sepsis made it always dangerous or, in many regious of the body, impossible. One may doubt, indeed, whether the mortality rates in the seventeenth century or earlier would have been appreciably greater had there been no profession of medicine at all. So, in a general survey of public health before the nineteenth century, there is no great need to consider what was said or done by the doctors, for the variation in man's degree of health was the result in great measure of changes in his habits of living, changes which were not directly dictated by any knowledge of their connection with, or probable effect upon, disease.

Reliable statistics as to death-rates and causes of death before the year 1840 are not available but there is strong evidence that health had been improving steadily and quite rapidly for at least three centuries before that date. The health of the community can be fairly well expressed by the expectation of life of its members — that is to say, the average age to which a new-born baby survives. This seems steadily to have risen in civilised European countries from about 8 in the sixteenth century to about 41 in the eighteen-forties. An expectation of life of 8 does not of course mean that most or many people died at that age, but that there was an enormous mortality among the young and especially among infants. Very little of the improvement between 1540 and 1840 can be attributed to anything that was done by the doctors; its cause was almost certainly a steady improvement in the standards of personal and domestic cleanliness and of the housing both of the rich and of the poor. We must therefore look on this period in England and most European countries as a very great period of progress in public health, though that improvement was no more than an accidental result of growing wealth and refinement of manners. Strange as it may seem, it is true that in nineteenth-century England this improvement ceased, and the expectation of life remained almost stationary until the eighteen-eighties. The cause of this arrest in the improvement of public health was almost certainly the great increase in the proportion of the population who were factory-hands and were therefore compelled to dwell in large towns, in highly overcrowded and insanitary conditions, often six or more in a room, scantily supplied with sewage-infected water. So, although the conditions of living of the middle-classes certainly improved in the first three-quarters of the nineteenth century, the same cannot be said of the conditions of living of the workers, who represented the greater part of the population. Progress in public health consists in preventing the preventable diseases and in postponing the death of every member of the population to the latest possible date. It is therefore obvious that the most important factor in the improvement of public health is the prevention or cure of those diseases which kill or disable the young and those who are still in the years of activity. Nearly all of these are what we may call germ-diseases, conditions that result from the multiplication of some living organism in our bodies; and consequently the most important and effective part of the war against death has been the prevention of the invasion of our bodies by these organisms. The fact that many human diseases are caused by such organisms was rarely considered as a possibility until near the year 1865, and not generally accepted until the years round 1880. The organisms that cause disease — protozoa, bacteria or virus particles — are very small and very much alike, and only a very expert microscopist could demonstrate the smaller bacteria with the microscopes in use before the eighteen-sixties. Their study became practicable for the ordinary research-worker only after Pasteur had shown how to isolate and cultivate bacteria in liquids, after Koch had shown how to grow them on jelly and stain them with aniline dyes, and after the great improvements in the optical system of the microscope that were made between 1870 and 1880. The story of the tremendous discovery of the rôle of germs in the causation of disease has often been told. First came Louis Pasteur's proofs (1856-1864) that fermentation and putrefaction are caused by minute organisms, then Joseph Lister's conjecture (1865) that surgical sepsis was a sort of putrefaction of the fluids around the wound and therefore attributable to these organisms in the air or on the surgeon's hands, instruments, dressings and whatever might come in contact with a wound. Lister's technique of destroying and excluding these organisms led to triumphs of surgery scarcely dreamed of in previous ages, but it was not for some twelve or fifteen years that organisms were suspected and convicted of being the cause of human diseases other than surgical sepsis. In the years round 1880 came the discoveries of bacteriological technique that have been mentioned above, and the research-workers of the decade 1880-90 proved the germ-theory to the hilt. The result was that the cause of infectious diseases was then known to be not, as formerly supposed, a subtle gaseous emanation or *miasma* — in plain words, a stink — but solid living particles, which could be recognised by culture and staining, and whose mode of transport from the sick to the healthy could be studied and interrupted. Researches showed that these organisms could be killed by heat or by certain poisons, which we call disinfectants. From these researches sprang the two great precautions against the spread of disease, namely the killing of bacteria and the closing of their routes of transfer. Thus it became obviously necessary to sterilise surgical requisites and articles that have had contact with infected matter, to chlorinate drinking-water suspected of containing disea e germs, etc. But the most effective precautions lay in the interception of the bacteria *en route* from the sick to the healthy. It was realised that infectious diseases were transmitted by solid or liquid matter from the patients' bodies, and the isolation of the infectious, concerning the value of which many doctors had been sceptical, was seen to be necessary. Sewage was shown to be swarming with bacteria, including those of typhoid and cholera if patients suffering from those diseases or tolerating the bacteria were present in the community; accordingly sewage was prevented from entering drinking-water, a precaution which almost abolished the occasional attacks of cholera and the ever-present typhoid, one of the chief killing diseases of past ages. It was further realised that droplets of saliva or mucus, expelled by coughing or sneezing, were the means of transmitting a number of diseases, and this knowledge helped to enforce the drive against that overcrowding which favours this transfer, and to encourage ventilation which prevents it. The transmission of the germs of malaria, yellow fever, typhus, plague and other diseases by biting insects was later recognised, and in some instances these diseases have been locally arrested or abolished by extirpation of these insects.

It would take too long to indicate all the modes of transfer of disease germs, but half-a-century of public consciousness of their danger has led to such a revolution in habits of cleanliness and such a revulsion against dirt as has never been known before.

Not all germ-diseases can be arrested by detecting and closing the avenues of transfer. Parts of our bodies are always inhabited by bacteria; various *streptococci* dwell in our noses and throats, *staphylococci* in our skins, and *bacillus coli* in our large intestines. It is impossible to get rid of these, but they do not give trouble unless they gain access to some other part of the body and multiply excessively. Thus the *streptococcus pneumoniae* and *streptococcus pyogenes* from our throats and noses, may give rise to pneumonia or to "blood-poisoning". Diseases caused by our ever-present bacterial population cannot be radically prevented. The body has its own technique of prevention and cure by means of the white cells that clear up stray bacteria, and the production of "anti-bodies" destructive to them; but these defences often break down. The bacteria may increase more rapidly than the white cells destroy them, and the speed and effectiveness of the production of anti-bodies is often insufficient to destroy the bacteria before their toxins have destroyed the patient. From the earliest period of bacteriology efforts were made to aid these natural defence-mechanisms by serums, vaccines, anti-toxins, which contain these anti-bodies or provoke their formation; and in some diseases, such as diphtheria, success was very considerable. For most diseases, however, serum therapy was uncertain in its effects, while for many diseases no serum could be prepared.

A very great advance was therefore made when chemo-therapy, the destruction or arrest of development of bacteria in the body by means of drugs, became practicable. The first great success in this field was the discovery of salvarsan (1910) by Ehrlich, which revolutionised the treatment of syphilis and yaws. Christopherson's discovery of the antimony treatment for *kala-azar* saved the lives of hundreds of thousands of sufferers from this deadly tropical fever. But the greatest triumphs have been those of the sulphonamide drugs, initiated by Domagk in 1935, and greatly developed by others since that date; and of penicillin, discovered by Sir Alexander Fleming in 1929 and developed as a curative agent by Sir Howard Florey and others after 1939. Among the germ-diseases that can be effectively cured by these agents are the septic conditions caused by streptococci, staphylococci and some other bacteria, including surgical sepsis, puerperal fever (the cause of most of the deaths in childbirth), erysipelas, and what the public calls "blood-poisoning"; it further includes pneumonia, cerebrospinal meningitis, many intestinal affections, and the venereal diseases. Among the major killing diseases the only ones that are at present uninfluenced by chemotherapy are tuberculosis and the virus diseases, such as small-pox and measles.

The germ-theory of disease has revolutionised not only medicine, but also surgery. In the first place it indicated the means of excluding the bacteria which had given every major operation a mortality of one death in two or three cases and had made operations on the brain, thorax or belly-cavity impossible. Surgery has thus been enabled to save life by removing diseased organs and to restore function in many cases of deformity or damage. The chief successes in the war against cancer have been surgical, and these have been rendered possible only by the precautions against sepsis which followed from the germ-theory of disease. The surgery of organs in which bacteria are already present, whether by nature or accident, (the bowel, organs affected by bacterial disease, infected wounds etc.,) has been revolutionised by chemotherapy, which in many cases enables operations to be undertaken with the same confidence as if the organs were uninfected. The part played in diagnosis by X-rays and various scientific instruments must likewise be mentioned. Abnormal conditions can usually be recognised without exploratory operations and the surgeon to-day has usually a fair idea of what he is going to find before he opens the patient.

Second only to the germ-theory are the scientific studies of nutrition. Before the latter part of the nineteenth century we neither knew how much to eat nor what to eat in order to preserve health. This did not matter very much to those who were in a position to eat plenty of what they liked, for the appetite was an excellent guide; but when diets were dictated by poverty or scarcity disaster could follow. This had two causes. The first was deficient quantity. Everyone, of course, knew that starvation ensued from underfeeding, but they had no evidence as to what constistituted underfeeding. Only in the years around 1880 was it possible to define with some accuracy the minimum quantities of carbohydrates, fats and proteins that were required to preserve life over a long period, and thus to show that many institutional diets were in fact slow starvation. The second was deficient quality. In the years after 1912 the great discovery of the vitamins was worked out, and the reason for a mass of ill-health was thereby discovered. Not only were the deficiency diseases of scurvy, rickets, pellagra and beriberi made preventable but a great deal of obscure mal-nutrition, particularly among children, has been prevented. The ill-effects of the starvation-diets imposed by the results of war upon many European peoples have been mitigated by a supply of artificial vitamins which prevent the addition of deficiency diseases to the results of hunger.

Man is not disabled from the attainment of his desires only by sickness and death, but also by infirmity of mind. The possibilities of the conquest of man's mental nature we have still to consider in the next chapter, but here we may glance at the conquest of the diseases and abnormalities to which his mental nature is liable. Before the twentieth century not very much was done for the mentally infirm. Those who could be allowed to remain at large were exhorted with small effect; those who had to be confined in asylums were treated by various means, which, as time went on, became less brutal. Beyond attempts to improve the general health of the patients — sometimes a successful measure — very little was done for them. In this century much activity has been directed upon mental disease, not only in its gross forms, but also in those which manifest themselves as lesser abnormalities, especially of an anti-social character. Infinite trouble is taken to discover the causes of these abnormalities and to dispel them, and it is difficult to doubt that an enormous amount of potential crime and unhappiness has been banished by the psychiatrist. Even the intractable cases, who formerly spent their lives in the asylum, are assailed by a variety of energetic therapies, which have produced a certain percentage of remissions. There seems at least to be good hope that the proportion of those who are misfits in human society through other than deliberate choice will be diminished, not only by the aid of the psychologist's guidance, but also as the result of the increasing public awareness of the conditions which breed and foster neuroses.

In all this we can see a certain conquest of Nature — the preservation and improvement of the life of man by the exercise of his knowledge, skill and organisation — but in no department of practical science does so much remain to be discovered and to be done. In a vast area of Asia populated by some 1,000,000,000 people the mortality from preventable diseases is as high as it was in this country a century ago and we have not, or cannot spare, the resources and means of organisation needed to cure them. Of a number of killing diseases, notably tuberculosis, we know the cause, but cannot find an effective means of prevention or cure. Of many other killing diseases and conditions — cancer, many forms of heart disease, arteriosclerosis, and above all the decay of old age — we do not know the cause or mechanism, and we therefore cannot tell how far they are avoidable or curable.

We may feel reasonably sure that the next fifty years will put us in possession of resources against all germ-diseases, but we must feel less sure about these others; for, as long as the fundamental mechanism of life, the intracellular chemical and physical processes, remain largely unknown, we cannot hope for much understanding of the profounder kinds of derangement of function. Let these be discovered, and we shall surely very soon be able to know the powers and limitations of applied science in the promotion of health and the prolongation of life.

The war against death could be extended from the individual to the race. As far as we can tell, three hundred years ago the inhabitants of this country were at least twice as fertile as they are now, and in the general opinion the use of contraceptives does not afford a complete explanation of this decline. We are still very ignorant concerning the causes of the fertility of some persons or races and the relative sterility of others. These matters are receiving study, and their importance is paramount, for what is the use of man's conquest of Nature if he is to die out through failure to generate? These studies are at an elementary and early stage, and we may have good hope that some means at least of increasing the fertility of human beings may be found.

It is interesting to speculate on the possibilities of the investigation of the mechanism of human heredity, the study of which is also at present in a very early stage. The differences between individuals are certainly not merely external; and what is summed up by the phrase 'a good constitution' is probably a combination of a great many hereditary factors, inherited along mendelian lines. It may well be that susceptibility to many diseases is inherited, and that some day a technique of ascertaining the hereditary make-up of individuals may be discoverable and that it may, theoretically at least, be possible to discover and perpetuate strains of human beings free from some diseases — as we to-day breed strains of potatoes immune to wart-disease; though I would prefer to think that my fellow men and women will not submit to any compulsory process of breeding, even though it might lead to the elimination of disease and enfeebling conditions from the human race.

13. THE WAR AGAINST MAN'S NATURE

We have said much about the possibility and limitations of the conquest of Nature. In talking of these possibilities we are apt to think of the victorious progress of science as an impersonal process, continuing and accelerating as a result of some necessary law. We have to remind ourselves occasionally that the motive force of all that has been done is the will of man to do it, that the means of doing it has been man's intelligence, and that the conquest of Nature is as much conditioned by the nature of man as by the nature of things.

We may consider in this respect two aspects of man's nature, his powers and his desires.

Man's powers are limited. His physical strength he can supplement by the power of the sun transformed by his engines, but it is not this physical strength but his mental powers that have enabled him to conquer Nature. Are we to envisage the limitations of those powers as limitations to his conquest of Nature? These limitations are obvious enough, so obvious that we scarcely think of them. Our memories are very limited and we supplement them by books. Our imaginations are extremely deficient, so that we can hold in our minds at one time only the much simplified version of any natural problem, which we have therefore to analyse, sometimes in a misleading manner, into very simple elements which are not really contained in Nature at all. Our reasoning marches only one step at a time; but we have overcome this by writing our successive reasonings and checking them successively. Can any other artifices help us to overcome any of these limitations? Is there some mechanical substitute for the thinking mind? We have certainly devised mechanical means of performing calculations — slide-rules, integrating machines, and such devices. These enable men to carry out in practice what they have already understood in the theory by which they devised the machine, and even to arrive at results impossible to attain without it. But at the root of human thinking is a process of intuitive guessing of the right conclusion, which is usually preliminary to the rigid reasoning by which it is established, and we cannot believe that this intuition can be exercised by anything but a living mind. We have heard talk of "electronic brains", but this phrase should not be taken seriously, and a sensible man should prefer the plain word "calculating-machine" (Pl. 15).

Now the exercise of this intuition requires a knowledge of the subject in question, for no inexperienced person ever makes a sound contribution to any science. But the sciences are always increasing in bulk, and it is often asked whether the science of the future will be slowed down by the difficulty of acquiring the preliminary knowledge which the man of science requires in order to carry out research and form sound judgments about it. At present this does not seem to be a serious difficulty, for men still do excellent research within a year or two of taking their degrees. The result of the increase of the quantity of knowledge needed by the research worker is likely to be a narrowing of the field of research cultivated by each man, but the time when it will become difficult to acquire the equipment for research lies far ahead.

Man's desires are even more remote from the study and aid of science than are his mental powers.

Science can tell us very little about the conscious life of man. It can describe his anatomy and physiology; it has chronicled a good deal of information and some generalities about sensation and the emotional life, especially of the unconscious mind; but it can tell us extremely little about the specially human part of our mental functioning. Science can only deal with the relationship of well-defined *classes* of events; and the events that occur in the conscious workings of the human mind are so difficult to describe and classify, and are influenced by such a vast number of associations stored in the human brain, that even if these events occurred according to a determined sequence it would be next to impossible to form a useful science capable of predicting mental responses. But all the evidence goes to show that mental responses are not determined in the way that physical phenomena are determined but are subject to a process of choice, of which we are conscious and which we describe as "free-will". Thus the desires of mankind are not wholly predictable, though physiology and history can indicate to us some that will always be present. We may presume that man will wish to fulfil the desires that spring from physiological needs — to eat, to drink, to generate, to be at a comfortable temperature, to be in health, to escape death. But experience teaches us that, in addition to these merely physiological desires, man has other conscious desires that are sometimes strong enough to over-ride even the satisfaction of the most fundamental physiological needs. Men will forgo food, drink, sexual pleasure and even life itself to fulfil some of their conscious desires, both for ignoble ends, such as popular esteem, or for higher, such as the love of country, of humanity, or of God.

What has all this to do with with the conquest of Nature? Very much. The conquest of Nature we have so far made has had the practical results of fulfilling our physiological needs for food and health, decreasing pain, lengthening life and increasing our enjoyment by giving us more goods and services and more opportunity to enjoy certain of the arts. It could give us more leisure, but in fact has not done so. It has greatly increased our knowledge of physical things, and it has likewise enormously increased our power to do anything that can be accomplished by physical means.

How far, then, could this conquest of Nature, wisely applied, succeed in fulfilling the desires of man? Suppose that its success was such that everybody had enough to eat, a good education, a comfortable house, and a life of ninety years of perfect health during which only four hours a day were occupied in work; would not this be a good thing? Undoubtedly, a very good thing! But it would not be the completion of man's desires or a guarantee of happiness. Man can have all these and still quarrel with his wife, hate his children, be jealous of his neighbours, suffer from fits of boredom and depression, and be oppressed by the emptiness of human existence. He can still scheme to get more than he already has, however ample; amuse himself by seducing his neighbour's wife; band together with his fellows to subjugate some other human beings. In fact the conquest of Nature relieves man of none of his innate potentialities for experiencing and causing unhappiness. Indeed, anyone who has a circle of friends including both poor and wealthy is not likely to maintain that those who have a superfluity of goods and time are more happy and better members of the community than those who have not. Man's own nature is, in fact at least as great an obstacle to his happiness as is external Nature.

Furthermore, man's nature being as it is, the conquest of Nature adds opportunities for its worst manifestations. Man desires to slay: here is the aeroplane and plutonium. Men wish to deceive other men into becoming their unconscious slaves: here is printing, transport, radio. Man wishes to save his fellows from disease and starvation: here is medicine, scientific agriculture, transport. It works both ways; but unfortunately it is much easier to break than to make, much easier to get short-term results by lies than by truth, — so much so that today we are beginning to wonder whether the conquest of Nature is such a good thing after all. Obviously some advance from the primitive is to be desired; but obviously the world at present owes its devastation, at least as a cause *sine qua non,* to the conquest of Nature. It may be thought, then, that man is happiest when his degree of conquest of Nature is duly proportioned to his degree of conquest of his own mental nature. That conquest, in itself and alone, is capable of abolishing the misery that man would continue to suffer even if Nature were fully conquered.

We want, then, to find a process by which mankind shall, collectively and individually, enjoy happiness. Philosophers and religious men have been looking for this process from antiquity; men of science have only recently, through psychological methods, begun the attempt.

We are not encouraged by the record of the past to suppose that a millennium of happiness on earth is ever to be obtained. Most of us, whether believers in God or otherwise, would agree that a life in accordance with Christian ethics, lived in the consciousness of God's presence and the hope of eternal life, would be a happy life and one that would promote the happiness of others; and that such a life can be led appears from the experience of the past. To the fundamental and essential happiness arising from this way of living could be added the accidental relief from unhappiness that the conquest of Nature can give — relief from sickness, hunger, cold, separation, bereavement. Furthermore, the psychologist will be able to play an increasing part by severing the bonds of the neuroses that cause so much incidental misery. It may well be that when mankind has discovered by experience that nothing else but God can give rest to their unquiet hearts, we may have again an age of faith, from which will flow a public opinion opposing the evils we now suffer, a public opinion so strong as to make it impossible for the wicked individual to gain a dangerous following. Then only will it be safe for the conquest of Nature to be carried to the limits of physical possibility. Yet we may wonder whether, in the event of man finding his inner happiness, the conquest of Nature would be further pursued. For man, when at peace, finds in himself a sympathy with Nature unconquered and a power of understanding her, seeing upon her the sign manual of God's creation. Man's progress will be proportioned to his desires, and if the overmastering desire of man were the greater knowledge of God, I do not think he would worry very much about telephones and tin-openers. Civilisation would probably be greatly simplified, though it could never return to the disease-ridden squalor of the past. Whether science would progress it is hard to say, for man has hardly begun to consider the relationship between the knowledge that science gives and the knowledge of God. It may be that our study would be upon the knowledge of things not so much in their quantitative relationships as in their psychological significance —

that natural science would relate to our whole knowledge of Nature and not merely to the shapes, sizes and movements of things.

This would be the way of the world's salvation and I can visualise no other. If man's nature is not transformed, we must see ever-increasing power seized by the scoundrels to whom power is all, and through their efforts an increasing degradation of man. Man's nature can be transformed, and I have yet to be convinced that there is any means of transforming it except the grace of God.

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