THE EVOLUTION OF WORLDS

LOWELL

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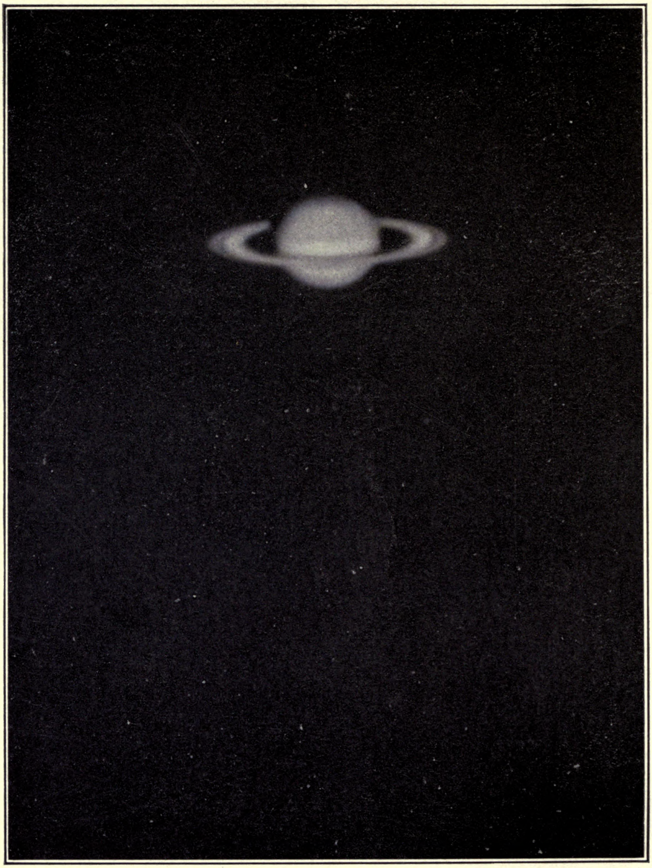

SATURN — PHOTOGRAPHED AT THE LOWELL OBSERVATORY
BY MR. E. C. SLIPHER. SEPTEMBER, 1909.

THE EVOLUTION OF WORLDS

BY

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To

THE PRESIDENT OF THE MASSACHUSETTS INSTITUTE

OF TECHNOLOGY

TO MY COLLEAGUES THERE

AND TO ITS STUDENT BODY

TO WHOSE INTEREST AND ATTENTION THESE

LECTURES ARE INDEBTED

THEY ARE APPRECIATIVELY INSCRIBED

"Si je n'étais pas devenu général en chef et l'instrument du sort d'un grand people, j'aurais couru les bureaux et les salons pour me mettre dans la dépendance de qui que ce fût, en qualité de ministre ou d'ambassadeur? Non, non! je me serais jeté dans l'étude des sciences exactes. J'aurais fait mon chemin dans la route des Galilée, des Newton. Et puisque j'ai réussi constamment dans mes grandes entreprises, eh bien, je me serais hautement distingué aussi par des travaux scientifiques. J'aurais laissé le souvenir de belles découvertes. Aucune autre gloire n'aurait pu tenter mon ambition."

— NAPOLEON I^ER^, QUOTED BY ARAGO.

THE substance of the following pages was written and presented in a university course of lectures before the Massachusetts Institute of Technology — in February and March of this year. The kind interest with which the lectures were received, not only by the students and professional bodies, but by the public, was followed by an immediate request from The Macmillan Company to issue them in book form, and as such they now appear.

PERCIVAL LOWELL.

BOSTON, MASS., May 29, 1909.

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THE EVOLUTION OF WORLDS

CHAPTER I

BIRTH OF A SOLAR SYSTEM

ASTRONOMY is usually thought of as the study of the bodies visible in the sky. And such it largely is when the present state of the universe alone is considered. But when we attempt to peer into its past and to foresee its future, we find ourselves facing a new side of the heavens — the contemplation of the invisible there. For in the evolution of worlds not simply must the processes be followed by the mind's eye, so short the span of human life, but they begin and end in what we cannot see. What the solar system sprang from, and what it will eventually become, is alike matter devoid of light. Out of darkness into darkness again: such are the bourns of cosmic action.

The stars are suns; past, present, or potential. Each of those diamond points we mark studding the heavens on a winter's night are globes comparable with, and in many cases greatly excelling, our own ruler of the day. The telescope discloses myriads more. Yet these self-confessed denizens of space form but a fraction of its occupants. Quite as near, and perhaps much nearer, are orbs of which most of us have no suspicion. Unimpressing our senses and therefore ignored by our minds, bodies people it which, except for rare occurrences, remain forever invisible. For dark stars in countless numbers course hither and thither throughout the universe at speeds as stupendous as the lucent ones themselves.

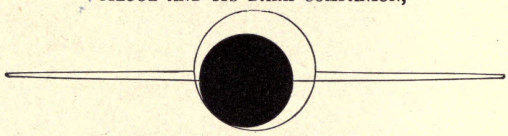
Had we no other knowledge of them, reasoning would suffice to demonstrate their existence. It is the logic of unlimited subtraction. Every self-shining star is continually giving out light and heat. Now such an expenditure cannot go on forever, as the source of its replenishing by contraction, accretion, or disintegration is finite. Long to our measures of time as the process may last, it must eventually have an end and the star finally become a cold dark body, pursuing as before its course, but in itself inert and dead; an orb grown *orbéd*, in the old French sense. So it must remain unless some cosmic catastrophe rekindle it to life. The chance of such occurrence in a given time compared with the duration of the star's light-emitting career will determine the number of dark stars relative to the lucent ones. The chance is undoubtedly small, and the number of dark bodies in space proportionally large. Reasoning, then, informs us first that such bodies must exist all about us, and second that their multitude must be great.

Valid as this reasoning is, however, we are not left to inference for our knowledge of them. There is a certain star amid the polar constellations known as Algol, — el Ghoul, the Arabs called it, or The Dæmon. The name shows they noticed how it winked its eye and recognized something sarcastically sinister in its intent. For once in two days and twenty hours its light fades to one-third of its usual amount, remains thus for about twenty minutes, and then slowly regains its brightness. Seemingly unmoved itself, its steady blinking from the time man first observed it took on an uncanniness he felt. To untelescoped man it certainly seemed demoniacal, this punctual recurrent wink. Spectroscoped man has learnt its cause.

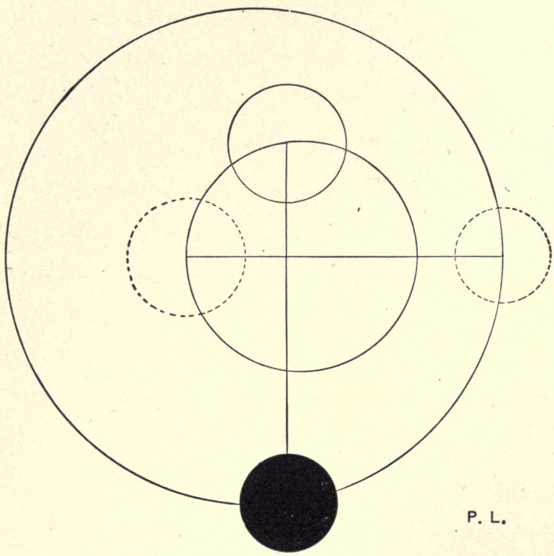
Goodricke in 1795 divined it, and research since has confirmed his keen intuition. Its loss of light is occasioned by the passing in front of it of a dark companion almost of its own size revolving about it in a close elliptic orbit. That this is the explanation of its strange behavior, the shift of its spectral lines makes certain, by showing that the bright star is receding from us at twenty-seven miles a second seventeen hours before the eclipse and coming towards us at about the same rate seventeen hours after it; its dark companion, therefore, doing the reverse.

Algol is no solitary specimen of a mind-seen invisible star. Many eclipsing binaries of the same class are now known; and considering that the phenomenon could not be disclosed unless the orbital plane of the

ALGOL AND ITS DARK COMPANION,



AS SEEN FROM THE EARTH,



AS SEEN FROM ABOVE ORBIT.

pair traversed the observer's eye, an unlikely chance in a fortuitous distribution, we perceive how many such in truth there must be which escape recognition for their tilt.

But if dark stars exist in connection with lucent ones, there must be many more that travel alone. Our own Sun is an instance in embryo. If he live long enough, he will become such a solitary shrouded tramp in his old age. For he has no companion to betray him. The only way in which we could become cognizant of these wanderers would be by their chance collision with some other star, dark or lucent as the case might be. The impact of the catastrophe would generate so much light and heat that the previously dark body would be converted into a blazing sun and a new star make its advent in the sky.

Star births of the sort have actually been noted. Every now and then a new star suddenly appears in the firmament — a nova as it is technically called. These apparitions date from the dawn of astronomic history. The earliest chronicled is found in the Chinese Annals of 134 B.C. It shone out in Scorpio and was probably the new star which Pliny tells us incited Hipparchus, "The Father of Astronomy," to make his celebrated catalogue of stars. From this time down we have recorded instances of like character.

One of the most famous was the "Pilgrim Star" of Tycho Brahe. That astronomer has left us a full account of it. "While I was living," he tells us, "with my uncle in the monastery of Hearitzwadt, on quitting my chemical laboratory one evening, I raised my eyes to the well-known vault of heaven and observed, with indescribable astonishment, near the zenith, in Cassiopeia, a radiant fixed star of a magnitude never before seen. In my amazement I doubted the evidence of my senses. However, to convince myself that it was no illusion, and to have the testimony of others, I summoned my assistants from the laboratory and inquired of them, and of all the country people that passed by, if they also observed the star that had thus suddenly burst forth. I subsequently heard that in Germany wagoners and other common people first called the attention of astronomers to this great phenomenon in the heavens, — a circumstance which, as in the case of non-predicted comets, furnished fresh occasion for the usual raillery at the expense of the learned."

The new star, he informs us, was just like all other fixed stars, but as bright as Venus at her brightest. Those gifted with keen sight could discern it in the daytime and even at noon. It soon began to wane. In December, 1572, it resembled Jupiter, and a year and three months later had sunk beyond recognition to the naked eye. It changed color as it did so, passing from white through yellow to red. In May, 1573, it returned to yellow ("the hue of Saturn," he expressly states), and so remained till it disappeared from sight, scintillating strongly in proportion to its faintness.

Thirty-two years later another stranger appeared and was seen by Kepler, who wrote a paper about it entitled "The New Star in the Foot of the Serpent." It shone out in the same sudden manner and faded in the same leisurely way.

Since 1860 there have been several such apparitions, and since 1876 it has been possible to study them with the spectroscope, which has immensely increased our knowledge of their constitution. Indeed, this instrument of research has really opened our eyes to what they are. Nova Cygni, in 1876, Nova Aurigæ, in 1892, and Nova Persei, in 1901, besides several others found by Mrs. Fleming on the Arequipa plates, were excellent examples, and all agreed in their main features, showing that novæ constitute a type of stars by themselves, whose appearing in the first place and whose behavior afterwards prove them to have started from like cause and to have pursued parallel lines of development.

As a typical case we may review the history of Nova Aurigæ. On February 1, 1892, an anonymous postcard was received by Dr. Copeland of the Royal Observatory, Edinburgh, that read as follows: "Nova in Aurigæ. In Milky Way, about 2° south of χ Aurigæ, preceding 26 Aurigæ. Fifth magnitude slightly brighter than χ." The observatory staff at once looked for the nova and easily found it with an opera-glass. They then examined it through a prism placed before their 24-inch reflector and found its spectrum. It proved to be that of a "blaze star."

Dr. Thomas D. Anderson turned out to be the writer of the anonymous post-card — his name modestly self-obliterated by the nova's light. He had detected the star on January 24, but had only verified it as a new one on the 31st. Harvard College Observatory then looked up its archived plates. The plates showed that it had appeared sometime between December 1 and 10. Its maximum had been attained on December 20, after which it declined, to record apparently another maximum on February 3 of the 3.5 magnitude. From this time its light steadily waned till on April 1 it was only of the 16th magnitude or $\frac{1}{100000}$ of what it had been. In August it brightened again and then waned once more.

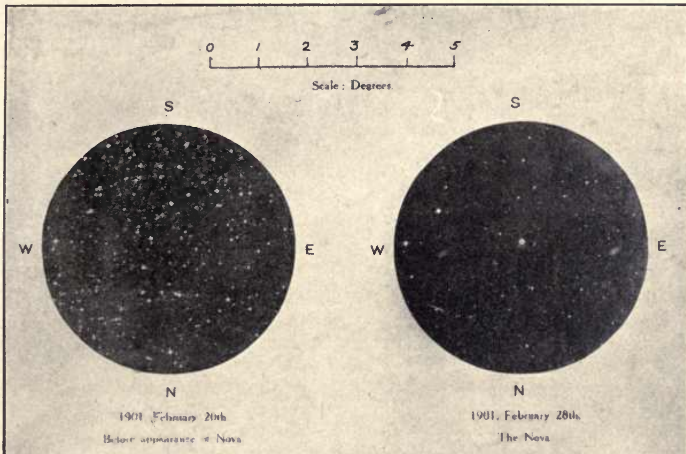
Meanwhile its spectrum underwent equally strange fluctuations. At first it exhibited the bright lines characteristic of the flaming red solar prominences, the calcium, hydrogen, and helium lines flanked by their dark correlatives upon a continuous background, showing that both glowing and cooler gases were here concerned. The sodium lines, too, appeared, like those that come out in comets as they approach the furnace of the Sun. An outburst such as occurs in miniature in the solar chromosphere or outermost gaseous layer of the Sun was here going on upon a gigantic scale. A veritable spectral chaos next supervened, staying until the star had practically faded away. Then, on its reappearance, in August, Holden, Schaeberle, and Campbell discovered to their surprise not what had been at all, but something utterly new: the soberly bright lines only of a nebula. Finally, ten years later, January, 1902, Campbell found its spectrum had become continuous, the body having reverted to the condition of a star.

Now how are we to interpret these grandiose vicissitudes, visually and spectrally revealed? That we witnessed some great catastrophe is clear. The sudden increase of light of many thousand fold from invisibility to prominence shows that a tremendous cataclysm occurred. The bright lines in the spectrum confirm it and imply that vast upheavals like those that shake the Sun were there in progress, but on so stupendous a scale that, if for no other reason, we must dismiss the idea that explosions alone can possibly be concerned. The dark correlatives of the bright lines have been interpreted as indicating that two bodies were concerned, each travelling at velocities of hundreds of miles a second. But in Nova Aurigæ shiftings of the spectral lines implying six bodies at least were recorded, if such be attributed to motion in the line of sight, and Vogel was minded to throw in a few planets as well — as Miss Clerke pithily puts it. There is not room for so many on the stage of the cosmic drama. Other causes, as we now know, may also displace the spectral lines. Great pressure has been shown to do it, thanks to the labors of Humphreys and Mohler at Baltimore. "Anomalous refraction" may do it, as Professor Julius of Utrecht has found out. Finally, changes of density may produce it, as Michelson has discovered. To these causes we may confidently ascribe most of the shiftings in the stellar spectrum, for just such forces must be there at work.

Mr. Monck suggested the idea that new stars are the result of old dark stars rushing through gaseous fields in space and rendered luminous by the encounter. Seeliger revived and developed this idea, which in certain cases is undoubtedly the truth. Probably this occurred to the new star of 1885 which suddenly blazed out almost in the centre of the great nebula in Andromeda. It behaved like a typical nova and in due course faded to indistinguishability. Something like it happened, too, in the nova of 1860, which suddenly flared up in the star cluster 80 Messier, outdoing in lustre the cluster itself, and then, too, faded away.

But just as psychology teaches us that not only do we cry because we are sorrowful, but that we are sorrowful because we cry, so while a nova may be made by a nebula, no less may a nebula be made by a star.

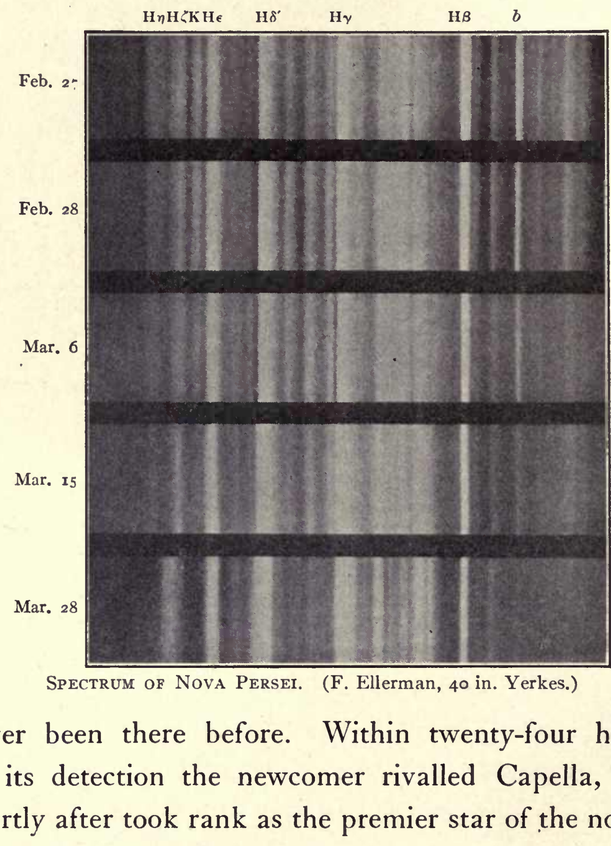
Let us see how this might be brought about and what sign manuals it would present. Suppose that the two bodies actually grazed. Then the disruption would affect the star's cuticle, first raising the outer parts, consisting rather of carbon than of the metals, since that substance is the lighter, to intense heat and the gases about it at the same time. The glowing carbon would be intensely bright, and at first its light would overpower that from the gases, and not till its great glow had



NOVA PERSEI. Photographs by A. STANLEY WILLIAMS, Hove, Sussex.

partially subsided would theirs be seen. Then the gases, hydrogen, helium, and so forth, would make themselves evident. Finally only the most tenuous ones, those peculiar to a nebula, would remain visible. After which the more solid particles due to the disruption would fall together and light up again by their individual collisions. Much the same would result if without striking the stars passed close.

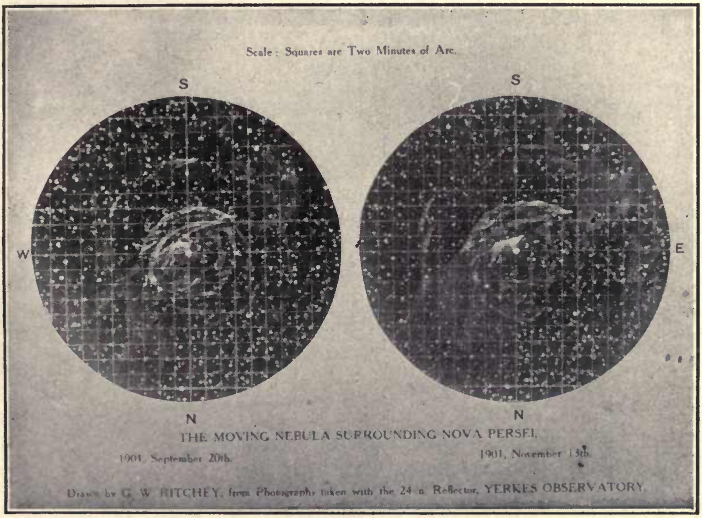
Now to put this theory to the proof. In the early morning of the 22d of February, 1901, Dr. Anderson, the discoverer of Nova Aurigæ, perceived that Algol had a neighbor, a star as bright as itself, which had



Spectrum of Nova Persei. (F. Ellerman, 40 in. Yerkes.)

never been there before. Within twenty-four hours of its detection the newcomer rivalled Capella, and shortly after took rank as the premier star of the northern hemisphere. Its spectrum on the 22d was found at Harvard College Observatory to be like that of Rigel, a continuous one crossed by some thirty faint dark lines.

On the 24th, however, *so soon as it began to wane*, the bright lines of hydrogen were conspicuous with their dark correlatives, just as they had been with Nova Aurigæ and other novæ. At the same time each particular spectral line proved a law unto itself, some shifted more than others, thus negativing motion as



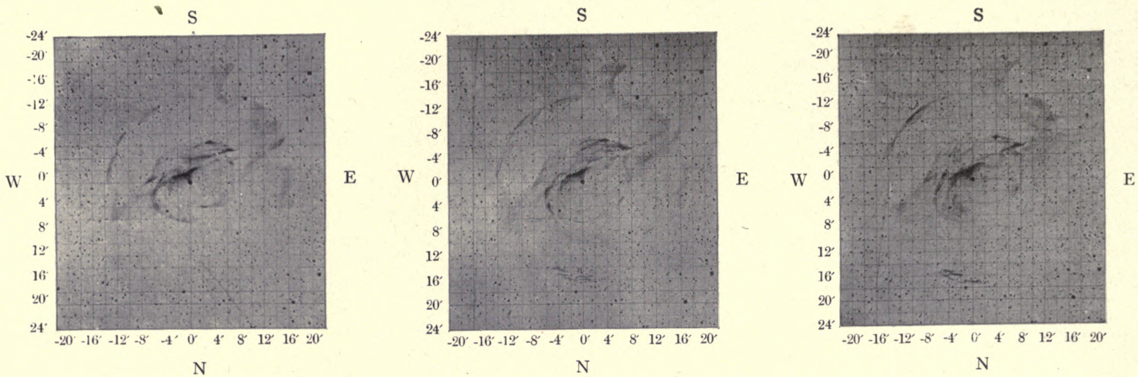
THE MOVING NEBULA SURROUNDING NOVA PERSEI.

their only cause and indicating change of pressure or density as concerned concomitants of the affair. Blue emissions like those of Wolf-Rayet stars next made their appearance; then a band, found by Wright at the Lick to characterize nebulæ, shone out, and finally in July the change to a nebular spectrum stood complete.

Then came what is the most suggestive feature in the whole event. On August 22 and 23 Dr. Wolf at

Königstahl took with his then new Bruce objective some long exposure plates of the nova, and on them found, to his surprise, wisps of nebulous matter to the southeast of the star. On September 20 Ritchey, with a two-foot mirror of his own constructing exposed for four hours, brought the whole formation to light. It turned out to be a spiral nebula encircling and apparently emanating from the star. Its connection with the nova was patent. But there was more to come. Later plates taken at the Lick on November 7 disclosed the startling fact that the nebula was visibly expanding, uncoiling outward from the star. A plate by Ritchey on November 13 confirmed this, and still later plates by him in December, January, and February showed the motion to be progressive. At the same time the star showed no parallax, and the speed of the motion seemed thus to be indicated as enormous. Kapteyn suggested to account for it that appearance, not reality, was here concerned; that the nebula had always existed, and was only shown up by the light from the conflagration travelling outward from the nova at the rate of one hundred and eighty-six thousand miles a second. This would make the catastrophe to have occurred as far back as the time of James I, of which the news more truthful but less timely than that of the morning papers had only just reached us.

But a little of that simple reasoning by which Zadig



December 14, 1901.　　January 7 and 9, 1902.　　February 8, 1902.

THE MOVING NEBULA SURROUNDING NOVA PERSEI—AFTER RITCHEY.

recovered the lost horses of the Sultan, and which from its unaccustomedness in the affairs of men got him suspected of having stolen them and very nearly caused his death, will show the untenableness of this idea and help us to a solution. In the first place we note that the star holds the very centre of the nebular stage, a remarkable prominence if the star has no creative right to the position. Then the same knots and patches of the nebulous configuration are visible in all the photographs, in the same relative positions, turned through corresponding angles as one will see for himself, all having moved symmetrically from one date to another. At the truly marvellous mimicry implied if different objects were concerned common sense instinctively shies, and very properly, as the chances against it are millions to one. Clearly it was not a mere matter of ethereal motion, but a very material motion of matter, which was here concerned. Something corpuscular emanating from the nova spread outward into space.

Clinching this conclusion is the result of a search by Perrine for traces of the nebula on earlier plates. For on one taken by him on March 29 (1901) he found the process already started in two close coils, its conception thus clearly dating from the time of the star's outburst. In Nova Persei, then, we actually witnessed a spiral nebula evolved from a disrupted star.

What was this ejectum and what drove it forth? Professor Very regarded it as composed of corpuscles such as give rise to cathode rays discharged from the star under the stress of light pressure or electric repulsion. But I think we may see in it something simpler still; to wit, gaseous molecules driven off by light pressure alone — the smoke, as one may say, of the catastrophe — akin exactly to the constituents of comet's tails. The mere light of the conflagration pushed the hydrogen molecules away. This would explain their presence and their exceeding hurry at the same time. They were started on their travels by domestic jars and kept going by the vivid after-effects of that infelicity.

The fairly steady rate of regression from the nova observed may be explained by the observed decrease in the light of the repellent source. Such combined with the retarding effect of gravity might make the regression equable. This is the more explanatory as the speed was certainly much less than that of light, though greatly exceeding any possible from the direct disruption. At the same time both the bright and the dark lines of hydrogen seen in the spectrum stand accounted for; the colliding molecules, at their starting on their travels from the star, shining through their sparser fellows farther out. An interesting biograph of the levity of light!

Nova Persei thus introduces us at its birth to one of a class of most interesting objects comparatively re-

GREAT NEBULA IN ORION — AFTER RITCHEY.

cently discovered and of most pregnant import, — the spiral nebulæ.

In 1843 when Lord Rosse's giant speculum, six feet across, was turned upon the sky, a nebula was brought to light which was unlike any ever before seen. It was

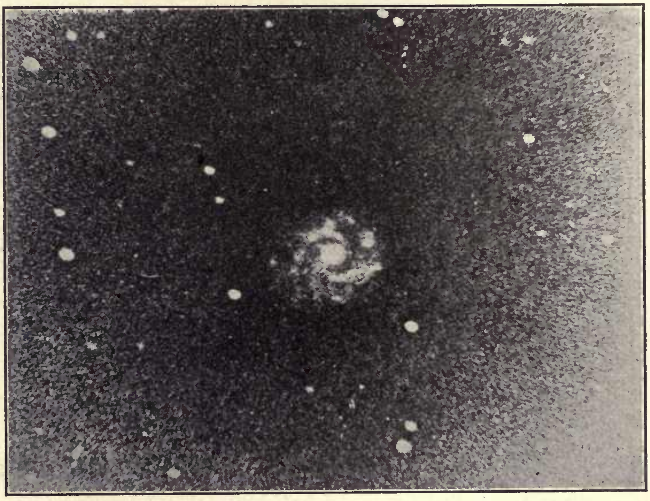
GREAT NEBULA IN ANDROMEDA — AFTER RITCHEY.

neither irregular like the great nebula in Orion nor round like the so-called planetary nebulæ, — the two great classes at that time known, — but exhibited a striking spiral structure. It proved the forerunner of a remarkable revelation. For the specimen thus disclosed has turned out to typify not only the most interesting form of those heavenly wreaths of light, but by far the commonest as well. As telescopic and especially photo-

NEBULA M. 100 COMÆ — AFTER ROBERTS.

graphic means improved, the number of such objects detected steadily increased until about thirteen years ago Keeler by his systematic discoveries of them came to the conclusion that a spiral structure pervaded the great majority of all the nebulæ visible. Their relative universality was outdone only by the invariability of their form. For they all represent spirals of one type:

two coiled arms radiating diametrically from a central nucleus and dilating outward. Even nebulæ not originally supposed spiral have disclosed on better revelation the dominant form. Thus the great nebula in Andromeda formerly thought lens-shaped proves to be



NEBULA ♅ I. 226 URSÆ MAJORIS — AFTER ROBERTS.

a huge spiral coiled in a plane not many degrees inclined to the plane of sight.

As should happen if the spirals are unrelated, left-handed and right-handed ones are about equally common. In Dr. Roberts' great collection of those in which the structure is distinctly discernible, nine are right-handed, ten left-handed, showing that they partake of the ambidextrous impartiality of space.

Lastly the spirals are evidently thicker near the centre, thinning out at the edge, and when the central nucleus is pronounced, it seems to have a certain globularity not shared by the arms, and more or less detached from them. This appears in those cases where

NEBULA ♅ V. 24 COMÆ — AFTER ROBERTS.

Showing globular structure.

they are shown us edgewise, and it has been thought perceptible in the great nebula of Andromeda. The difficulty in establishing the phenomenon comes from the impossibility of both features showing at their best together. For the globularity to come out well, the spiral must be presented to us nearly in the plane of sight; for the spirality, in a plane at right angles to it.

Much may be learnt by pondering on these peculiarities. The widespread character of the phenomenon points to some universal law. We are here clearly confronted by the embodiment of a great cosmic principle, causing the helices it is for us to uncoil. It is a problem in mechanics.

In the first place, a spiral structure denotes action on the face of it. It implies a rotation combined with motion out or in. We are familiar with the fact in the sparks of pin-wheel pyrotechnics. Any rotating fluid urged by an outward or an inward impulse must take the spiral form. A common example occurs in the water let out of a basin through a hole in the centre when we draw out the plug. Here the force is inward, and because the bowl and orifice are not perfectly symmetric, a rotation is set up in the water trying to escape, and the two combine to give us a beautiful conchoidal swirl. In this case the particles seek the centre, but the same general shape is assumed when they seek to leave it.

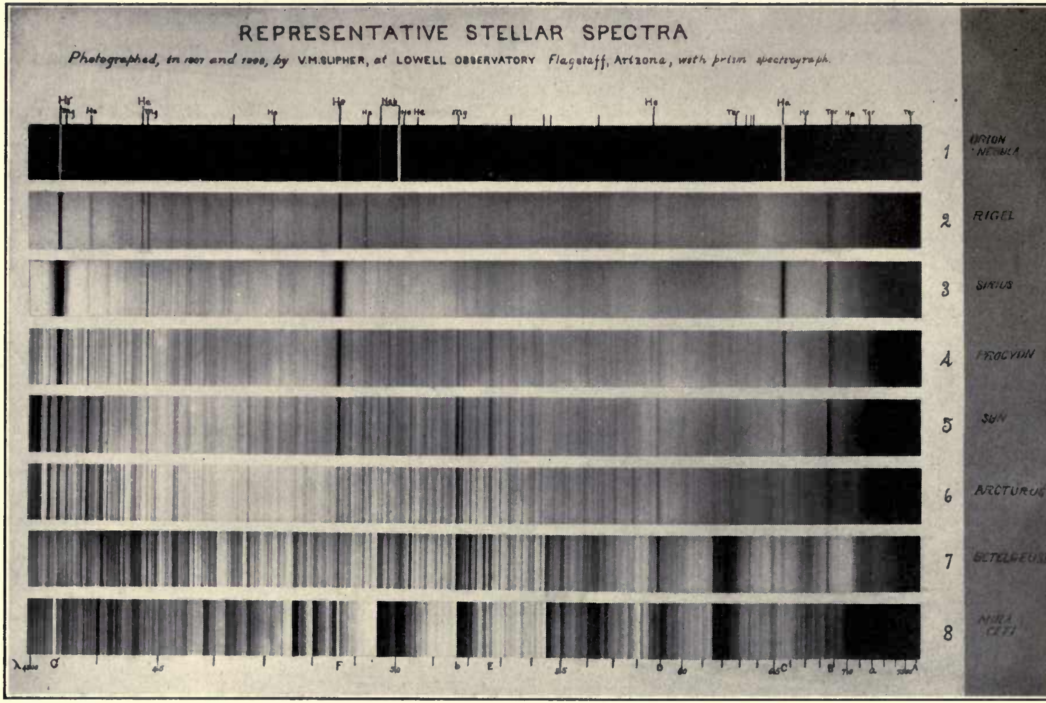
Another point to be noticed is that a spiral nebula could not develop of itself and subsist. To continue it must have outside help. For if it were due to internal explosive action in the pristine body, each ejectum must return to the point it started from, or else depart forever into space, for the orbit it would describe must either be closed or unclosed. If the former, it would revisit its starting-point; if the latter, it would never return. Explosion, therefore, of itself could not

NEBULA M. 101 URSÆ MAJORIS — AFTER RITCHEY.

have produced the forms we see, unless they be ephemeral apparitions, a supposition their presence throughout the heavens seems effectually to exclude.

The form of the spiral nebulæ proclaims their motion, but one of its particular features discloses more. For it implies the past cause which set this motion going. A distinctive detail of these spirals, which so far as we know is shared by all of them, are the two arms which leave the centre from diametrically opposite sides. This indicates that the outward driving force acted only in two places, the one the antipodes of the other. Now what kind of force is capable of this peculiar effect? If we think of the matter, we shall realize that tidal action would produce just this result. We see it daily in the case of the Moon; when it is high tide in the open ocean hereabouts, it is high tide also at the opposite end of the Earth. The reason is that the tide-raising body pulls the fluid nearest it more strongly than it pulls the Earth as a whole, and pulls the Earth as a whole more than it pulls the fluid at the opposite extremity.

Suppose, now, a stranger to approach a body in space near enough; it will inevitably raise tides in the other's mass, and if the approach be very close, the tides will be so great as to tear the body in pieces along the line due to their action; that is, parts of the body will be separated from the main mass in two antipodal directions. This is precisely what we see in the spiral nebula. Nor is there any other action that we know of which would thus handle the body. If it were to disintegrate under


REPRESENTATIVE STELLAR SPECTRA
Photographed, in 1907 and 1908, by V.M.SLIPHER, at LOWELL OBSERVATORY Flagstaff, Arizona, with prism spectrograph.
1 ORION NEBULA
2 RIGEL
3 SIRIUS
4 PROCYON
5 SUN
6 ARCTURUS
7 BETELGEUSE
8 MIRA CETI

increased speed of rotation due to contraction upon itself, parts of its periphery should be shed continually and a pinwheel of matter, not a two-armed spiral, be thrown off. If explosion were the disintegrating cause, disruption would occur unsymmetrically in one or more directions, not symmetrically as here.

As the stranger passed on, his effect would diminish until his attraction no longer overbalanced that of the body for its disrupted portions. These might then be controlled and forced to move in elliptic orbits about the mass of which they had originally made part. Thence would come into being a solar system, the knots in the nebula going to form the planets that were to be.

Before proceeding to what proof we have that it actually did occur in this way we may pause to consider some consequences of what we have already learned. Thus what brought about the beginning of the system may also compass its end. If one random encounter took place in the past, a second is as likely to occur in the future. Another celestial body may any day run into the Sun, and it is to a dark body that we must look for such destruction, because they are so much more numerous in space.

That any of the lucent stars, the stars commonly so called, could collide with the Sun, or come near enough to amount to the same thing, is demonstrably impossible for æons of years. But this is far from the case for a dark star. Such a body might well be within a hundredth of the distance of the nearest of our known neighbors, Alpha Centauri, at the present moment without our being aware of it at all. Our senses could only be cognizant of its proximity by the borrowed light it reflected from our own Sun. Dark in itself, our own head-lights alone would show it up when close upon us. It would loom out of the void thus suddenly before the crash.

We can calculate how much warning we should have of the coming catastrophe. The Sun with its retinue is speeding through space at the rate of eleven miles a second toward a point near the bright star Vega. Since the tramp would probably also be in motion with a speed comparable with our own, it might hit us coming from any point in space, the likelihood depending upon the direction and amount of its own speed. So that at the present moment such a body may be in any part of the sky. But the chances are greatest if it be coming from the direction toward which the sun is travelling, since it would then be approaching us head on. If it were travelling itself as fast as the Sun, its relative speed of approach would be twenty-two miles a second.

The previousness of the warning would depend upon the stranger's size. The warning would be long according as the stranger was large. Let us assume it the mass of the Sun, a most probable supposition.

Being dark, it must have cooled to a solid, and its density therefore be much greater than the Sun's, probably something like eight times as great, giving it a diameter about half his or four hundred and thirty thousand miles. Its apparent brightness would depend both upon its distance and upon its intrinsic brightness or albedo, and this last would itself vary according to its distance from the Sun. While it was still in the depths of space and its atmosphere lay inert, owing to the cold there, its intrinsic brightness might be that of the Moon or Mercury. As its own rotation would greatly affect the speed with which its sunward side was warmed, we can form no exact idea of the law of its increase in light. That the augmentation would be great we see from the behavior of comets as they approach the great hearth of our solar system. But we are not called upon to evaluate the question to that nicety. We shall assume, therefore, that its brilliancy would be only that of the Moon, remembering that the last stages of its fateful journey would be much more resplendently set off.

With these data we can find how long it would be visible before the collision occurred. As a very small telescopic star it would undoubtedly escape detection. It is not likely that the stranger would be noticed simply from its appearance until it had attained the eleventh magnitude. It would then be one hundred and forty-nine astronomical units from the Sun or at five times the distance of Neptune. But its detection would come about not through the eye of the body, but through the eye of the mind. Long before it could have attracted man's attention to itself directly its effects would have betrayed it. Previous, indeed, to its possible showing in any telescope the behavior of the outer planets of the system would have revealed its presence. The far plummet of man's analysis would have sounded the cause of their disturbance and pointed out the point from which that disturbance came. Celestial mechanics would have foretold, as once the discovery of another planet, so now the end of the world. Unexplained perturbations in the motions of the planets, the far tremors of its coming, would have spoken to astronomers as the first heralding of the stranger and of the destruction it was about to bring. Neptune and Uranus would begin to deviate from their prescribed paths in a manner not to be accounted for except by the action of some new force. Their perturbations would resemble those caused by an unknown exterior planet, but with this difference that the period of the disturbance would be exactly that of the disturbed planet's own period of revolution round the Sun.

Our exterior sentinels might fail thus to give us warning of the foreign body because of being at the time in the opposite parts of their orbits. We should then be first apprised of its coming by Saturn, which would give us less prefatory notice.

It would be some twenty-seven years from the time it entered the range of vision of our present telescopes before it rose to that of the unarmed eye. It would then have reached forty-nine astronomical units' distance, or two-thirds as far again as Neptune. From here, however, its approach would be more rapid. Humanity by this time would have been made acquainted with its sinister intent from astronomic calculation, and would watch its slow gaining in conspicuousness with ever growing alarm. During the next three years it would have ominously increased to a first magnitude star, and two years and three months more have reached the distance of Jupiter and surpassed by far in lustre Venus at her brightest.

Meanwhile the disturbance occasioned not simply in the outer planets but in our own Earth would have become very alarming indeed. The seasons would have been already greatly changed, and the year itself lengthened, and all these changes fraught with danger to everything upon the Earth's face would momentarily grow worse. In one hundred and forty-five days from the time it passed the distance of Jupiter it would reach the distance of the Earth. Coming from Vega, it would not hit the Earth or any of the outer planets, as the Sun's way is inclined to the planetary planes by some sixty degrees, but the effects would be none the less marked for that. Day and night alone of our astronomic relations would remain. It would be like going mad and yet remaining conscious of the fact. Instead of following the Sun we should now in whole or part, according to the direction of its approach, obey the stranger. For nineteen more days this frightful chaos would continue; as like some comet glorified a thousand fold the tramp dropped silently upon the Sun. Toward the close of the nineteenth day the catastrophe would occur, and almost in merciful deliverance from the already chaotic cataclysm and the yet greater horror of its contemplation, we should know no more.

Unless the universe is otherwise articulated than we have reason to suppose, such a catastrophe sometime seems certain. But we may bear ourselves with equanimity in its prospect for two mitigating details. One is that there is no sign whatever at the moment that any such stranger is near. The unaccounted-for errors in the planetary theories are not such as point to the advent of any tramp. Another is, that judged by any scale of time we know, the chance of such occurrence is immeasurably remote. Not only may each of us rest content in the thought that he will die from causes of his own choosing or neglect, but the Earth herself will cease to be a possible abode of life, and even the Sun will have become cold and dark and dead so long before that day arrives that when the final shock shall come, it will be quite ready for another resurrection.

CHAPTER II

EVIDENCE OF THE INITIAL CATASTROPHE IN OUR OWN CASE

BY quite another class of dark bodies than those we contemplated in the last chapter is the immediate space about us tenanted. For that, too, is anything but the void our senses give us to understand. Could we rise a hundred miles above the Earth's surface we should be highly sorry we came, for we should incontinently be killed by flying brickbats. Instead of masses of a sunlike size we should have to do with bits of matter on the average smaller than ourselves but hardly on that account innocuous, as they would strike us with fifteen hundred times the speed of an express train. Only in one respect are the two classes of erratics alike, both remain invisible till they are upon us. Even so, the cause of their visibility is different. The one is announced by the light it reflects, the other by the glow it gives out on its destruction. These last are the meteorites or shooting-stars. They are as well known to every one for their commonness as, fortunately, the first are rare. On any starlight night one need not tarry long before one of these visitants darts across the sky, a brilliant thread of fire gone almost ere it be descried.

Usually this is all of which one is made aware. Silent, ghostlike, the apparition comes and goes, and nothing more of it is either seen or heard. But sometimes there is a good deal more. Occasionally a large ball of flame shoots through the air, a detonation like distant thunder startles the ear, and a luminous train, persisting for several seconds, floats slowly away. Finally if one be fortunate to be near, — but not too near, — one or more masses of stone are seen to fall swiftly and bury themselves in the ground. These are meteorites: far wanderers come at last to rest in graves they have dug themselves.

A great revolution has taken place lately in our ideas concerning meteorites. Indeed, it was not so very long ago, since modern man admitted their astronomic character at all. He looked as askance at them as he did at fossils. It was the fall at Aigle, in Switzerland, April 26, 1803, that first opened men's eyes to the fact that such falls actually occurred. It is more than a nine days' wonder at times how long men, as well as puppies, can remain blind. To admit that stones fell from heaven, however, was not to see whence they came. Their paternity was imputed to nearly every body in the sky. They were at first supposed to have been ejected from earthly volcanic vents, then from volcanoes in the Moon. That they are of domestic manufacture is, however, negatived by the paths they severally pursue. Nor can they for like reason have been ejected from the Sun.

The Earth was not their birthplace. It is alien ground in which they lie at last and from which we transfer them to glass cases in our museums. This fact about their parentage they tell by the speed with which they enter our air. They become visible 100 miles up and explode at from 20 to 10, and their speed has been found to be from 10 to 40 miles a second, which is that of cosmic bodies moving in large elliptic orbits about the Sun, — a speed greater than the Earth could ever have imparted.

Four classes of such small celestial bodies tenant space where the planets move: sporadic shooting-stars, meteorites, meteor-streams, and comets. The discovery of the relation of each of these to the solar system and then to each other forms one of the latest chapters of astronomic history. For they turn out to be generically one.

It was long, however, before this was perceived. The first step was taken simultaneously by Professor Olmstead of Yale and Twining in 1833 from reasoning on the superb November meteor-shower of that year. All the shooting-stars, "thick as snowflakes in a storm," had a common radiant from which they seemed to come.

Thus they argued that the meteors must all be travelling in parallel lines along an orbit which the previous shower, of 1799, showed to be periodic. This was the first recognition of a meteor-swarm.

The next advance was when Schiaparelli, in 1862, pointed out the remarkable connection between meteor-swarms and comets. On calculation the August meteor-stream and the comet of 1862 proved to be pursuing exactly the same path. Soon other instances of like association were discovered, and we now know mathematically that meteor-streams can be, deductively that they must be, and observationally that they are, disintegrated comets. More than one comet has even been seen to split.

Then came the recognition that comets are not visitors from space, as Sir Isaac Newton and Laplace supposed, but part and parcel of our own solar system. Without going into the history of the subject, which includes Gauss, Schiaparelli, and finally Fabry's great Memoir, much too little known, the proof can, I think, be made comprehensible without too much technique, thanks to the fact that the Sun is speeding through space at the rate of eleven miles a second.

Orbits described by bodies under the action of a central force are always conic sections, as Sir Isaac Newton proved. There are two classes of such curves: those which return into themselves, such as the circle and ellipse, and those which do not, the hyperbolæ. If a body travel in the first or closed class about the Sun, it is clearly a member of his family; if in the second, it is a visitor who bows to him only in passing and never returns. Which orbit it shall pursue depends at a given distance solely upon the speed of the body; if that speed be one the Sun can control, the body will move in an ellipse; if greater, in an hyperbola. Obviously the Sun can control just the speed he can impart. Now a comet entering the system from without would already possess a motion of its own which, when compounded with the solar-acquired speed, would make one greater than the Sun could master. Comets, therefore, if visitors from space, should all move in hyperbolæ. None for certain do; and only six out of four hundred even hint at it. Comets, then, are all members of the solar family, excentric ones, but not to be denied recognition of kinship for such behavior.

Still, admittance to the solar family circle was denied to meteorites and shooting-stars. Thus Professor Kirkwood, in 1861, had considered "that the motions of some luminous meteors (or cometoids, as perhaps they might be called) have been decidedly indicative of an origin beyond the limits of the solar system." Here cometoid was an apt coinage, but when comets were later shown not to be of extra-solar origin, the reasoning carried luminous meteors in its train.* Finally Schiaparelli, in 1871, concluded an able Memoir on the subject with the decision that "a stellar origin for meteorites was the most likely and that meteorites were identifiable with shooting-stars." † A pregnant remark this, though not exactly as the author thought, for instead of proving both interstellar, as he intended, both have proved to be solar bound.

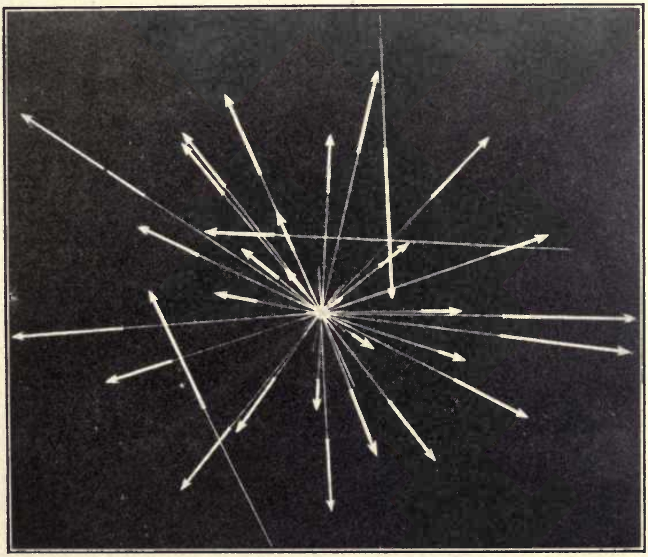
It was Professor Newton, in 1889, who first showed that meteorites were pursuing, as a rule, small elliptic orbits about the Sun, and that their motion was direct. He, too, was the first to surmise that meteorites are but bigger shooting-stars.

Now, as to their connection. Of direct evidence we have little. A few meteors have been observed to come from the known radiants of shooting-stars. Two instances we have of the fall of meteorites during star showers. One in 1095, when the Saxon Chronicle tells us stars fell "so thickly that no man could count them, one of which struck the ground and when a bystander cast water upon it steam was raised with a great noise of boiling." The second case was the fall of a siderite, eight pounds' worth of nickel-iron, at Mazapil during the Andromede shower of 1885, which was by

* "Mem. del Reale Inst. Lombardo," Vol. XII. III della serie III.

† Quoted in "Luminous Meteors," Committee's Report for 1870–1871, p. 48.

many supposed to be a part of the lost Biela comet. It contained graphite enough to pencil its own history, but unfortunately could not write. The direction from

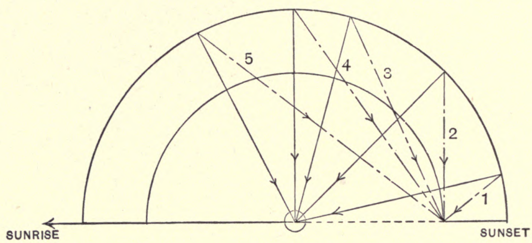


THE RADIANT OF A METEORIC SHOWER, SHOWING ALSO THE PATHS OF THREE METEORS WHICH DO NOT BELONG TO THIS SHOWER — AFTER DENNING.

which it came was not recorded, and so the connection between it and the comet not made out.

If our direct knowledge is thus scanty, reasoning affords surer ground for belief. For at this point there steps in a bit of news about the family relations of shooting-stars from a source hardly to have been anticipated. Indeed, it arose from the thought to examine a qualitative statement in Young's "Astronomy" quantitatively. Mathematics is simply precise reasoning, applied usually to the discovery that a pet theory will not work. But sometimes it presents one with an unexpected find. This is what it did here.

It is an interesting fact of observation that more meteors are visible at six o'clock in the morning than at six o'clock at night in the proportion of 3 to 1. This



METEORS
Diagram explaining their proportionate visibility.
——————— *denotes true paths.*
——— - ——— " *apparent paths.*
- - - - - - - " *Earth's path.*

seeming preference for early rising is due to no matutinality on the part of the meteors, but to the matin aspect then presented by the Earth combined with its orbital motion round the Sun. For at six in the morning the observer stands on the advancing side of the Earth, at the bow of the airship; at six at night he is at the stern. He, therefore, runs into the meteors at sunrise and slips away from them at sunset. He is pelted in the morning in consequence. Just as a pedestrian facing a storm gets wetter in front than behind.

So far the books. Now let us examine this quantitatively according to the direction in which the meteors themselves may be moving before the encounter. Suppose, in the first place, that they were travelling in every possible direction, with the average velocity of the most erratic members of the family, the great comets. On this supposition calculation shows that we ought to meet 5.8 times as many at six in the morning as at six at night. If their orbits were smaller than this, say, something like those of the asteroids, we should find 7.6 to 1 for the ratio.

Suppose, however, that they were all travelling in the same sense as the Earth, direct as it is called in contradistinction to retrograde, and let us calculate what proportion in that case we should meet at the two hours respectively. It turns out to be 2.4 to 1 for the parabolic ones, 3.3 to 1 for the smaller orbited, or almost precisely what observation shows to be the case.[1]* Here, then, a bit of abstract reasoning has apprized us of a most interesting family fact; to wit, that the great majority of shooting-stars are travelling in the same orderly sense as ourselves. Furthermore, as some must be moving in smaller orbits than the mean, others must be journeying in greater; or, in other words, shooting-stars are scattered throughout the system. In short, these little bodies are tiny planets themselves, as truly planets as the asteroids, — asteroids of a general instead of a localized habit.

* Numerals refer to notes at end of book.

Thus meteorites and shooting-stars are kin, and from the fact that they are pursuing orbits not very unlike our own we get our initial hint of a community of origin. Indeed, they are the little bricks out of which the whole structure of our solar system was built up. What we encounter to-day are the left-over fragments of what once was, the fraction that has not as yet been swept up by the larger bodies. And this is why these latter-day survivors move, as a rule, direct. To run counter to the consensus of trend is to be subjected to greater chance of extermination. Those that did so have already been weeded out.

From the behavior of meteorites we proceed to scan their appearance. And here we notice some further telltale facts about them. Their conduct informed us of their relationship, their character bespeaks their parentage.

Most meteorites are stones, but one or two per cent are nearly pure iron mixed with nickel. When picked up, they are usually covered with a glossy thin black crust. This overcoat they have put on in coming through our air. Air-begotten, too, are the holes with which many of them are pitted. For entering our atmosphere with their speed in space is equivalent to immersing them suddenly in a blowpipe flame of several thousand degrees Fahrenheit. Thus their surface is burnt and fused to a cinder. Yet in spite of being warm to the touch their hearts are still cosmically cold. The Dhurmsala meteorite falling into moist earth was found an hour afterwards coated with frost. Agassiz likened it to the Chinese culinary *chef d'œuvre* "fried ice." It is the cold of space, 200° or more Centigrade below zero, that they bear within, proof of their cosmic habitat.

THE MART IRON.
(*Proc. Wash. Acad. of Sci.* vol. II. plate VI.)

That they are bits of a once larger mass is evident on their face. Their shape shows that they are not wholes but parts, while their constitution bespeaks them anything but elementary. Diagnosis of it yields perhaps their most interesting bit of news. For it shows their origin. Their autopsy proves them to contain thirty known elements, and not one that is new. The list includes all the substances most common on the Earth's surface, which is suggestive; but, what is still more instructive, these are combined into minerals which largely differ from those with which we are superficially familiar. Professor Newton, whose specialty they were, has said: "In general they show no resemblance in their mechanical or mineralogical structure to the granitic and surface rocks of the Earth. One

SECTION OF METEORITE SHOWING WIDMANNSTÄTTIAN LINES.
(Field Columbian Museum, Chicago.)

condition was certainly necessary in their formation, viz. the absence of free oxygen and of enough water to oxidize the iron." Thus they are not of the Earth earthy; nor yet, poor little waifs, of the upper crust of any other body.

In them prove to be occluded gases, which can be got out by heating in the laboratory, and which must have got in when the meteorites were still subjected to great heat and pressure. For only thus could these gases have been absorbed. Both such heat and such pressure accuse some great solid body as origin of this flotsam of the sky. Fragments now, they owe to its disruption their present separate state. This parent mass must have been much larger and more massive than the Earth, as the great amount of occluded hydrogen, sometimes one-third the volume at 500° C., of the meteorite seems to testify.

METEORITE, TOLUCA.
(Field Columbian Museum, Chicago.)

The two classes of meteorites, the stone and the iron, show this further by the very differences they exhibit between themselves. For both the amount and the proportions of the occluded gases in the two prove to be quite distinct. In the stones the quantity of gas is greater and the composition is diverse. In the stones carbonic acid gas is common, carbon monoxide rare; in the irons the ratio is just the other way. Thus Wright found in nine specimens of the iron meteorites: —

CO_2	CO	H	CH_4
11.5 %	32.4 %	54.1 %	00 % of the total;

in ten of stone: —

CO_2	CO	H	CH_4
60.1 %	3.4 %	32.0 %	2.1 %

The stones are much lighter than the iron, their specific gravities being as 3 to 7 or 8 for the metallic. The stones, therefore, came from a more superficial layer of the body torn apart than the iron, and the composition of their occluded gases bears this out. Those in the stones are such as we may conceive absorbed nearer the surface, those in the iron from regions deeper down.

Here, then, the meteorites tell us of another, an earlier, stage of our solar system's history, one that mounts back to before even the nebula arose to which we owe our birth. For the large body to whose dismemberment the meteorites were due can have been no other than the one whose cataclysmic shattering produced that very nebula which was for us the origin of things. The meteorites, by continuing unchanged, link the present to that far-off past. And they tell us, too, that this body must have been dark. For solid, they inform us, it was, and solidity in a heavenly body means deficiency of light.

That such corroborative testimony to a cataclysmic origin is forthcoming in the sky we shall see by turning again to the spiral nebulæ.

Of the two classes of nebulæ which we contemplated in the last chapter, the amorphous and the structural, there is more to be said than we touched on then.

Not only in look are the two quite unlike, but the spectroscope shows that the difference in appearance is associated with dissimilarity of character. For the spectrum of the amorphous proves to consist of a few bright lines, due to hydrogen and nebulium chiefly, in

NEBULA ♅ V. 14 CYGNI — AFTER ROBERTS.

the green, whence the name green nebulæ. That of the spirals, on the other hand, is continuous, and therefore white. The great nebula in Andromeda was one of the first in which this was recognized; and the perception was pregnant, for no nebula defies resolution more determinedly than it. We may, therefore, infer that it is not made up of stars, certainly big enough for us to see. On the other hand, from the fact that its spectrum is continuous it must be solid or liquid. Young pointed out that this did not follow, because a gas under great pressure also gives a continuous

NEBULA N. G. C. 1499 PERSEI — AFTER ROBERTS.

spectrum. But he forgot that here no such pressure could exist. A nebula of compressed gas could not have an irregular form and would have, in the case of the Andromeda nebula, a mass so enormous as to preclude supposition. Continuity of spectrum here means discontinuity of mass. The spectral solidity of the nebula speaks of a *status quo ante*, not of a condition of condensation now going on.

Advanced spectroscopic means reveals that the spectra of these "white" nebulæ are not simply con-

NEBULA N. G. C. 6960 IN CYGNUS — AFTER RITCHEY.

tinuous. Thus that of the Andromeda nebula shows very faint dark lines crossing it, apparently accordant with those of the solar spectrum and faint bright ones falling near and probably coincident with those of the

Wolf-Rayet stars, due to hydrogen, helium, and so forth. These later observations make practically cer-

NEBULA M. 51 CANUM VENATICORUM — AFTER RITCHEY.

tain what earlier ones permitted us just now only to infer: that it is not composed of stars, but of something subtler still; to wit, of meteorites. The reasoning is interesting, as showing that if one have hold of a true idea, the stars in their courses fight for him.

Although Lockyer has long been of opinion that the nebulæ are composed of meteorites, the present argument differs from his. The way in which their spectra establish their constitution may be outlined as follows: the white nebulæ are from their structure evidently in process of evolution, and if they are in stable motion, as we suppose them to be, their parts are moving round their common centre of gravity. As the white nebulæ resist resolution as obstinately as the green, these parts must be not only solid but comminuted (composed of small particles). Now this would be the case were they flocks of meteorites such as we have seen composed our own system once upon a time. Though all are travelling round the centre of gravity of the flock, each is pursuing its own orbit slightly different from, and intersecting those of, its neighbors. Collisions between the meteors must therefore constantly occur, and the question is, are these shocks sufficient to cause light. Let us take our own system and consider two meteorites at our distance from the Sun, travelling in the same sense, the one in an ellipse, the other in a circle, with a major axis five per cent greater and meeting the other at aphelion. This would be no improper jostle for such heavenly bodies. If we calculate the speeds of both and deduct the elliptic from the circular, we shall have the relative speed of collision. It proves to be a half a mile a second or 30 times the speed of an express train. As such a train brought up suddenly against a stone wall would certainly elicit sparks, we see that a speed 30 times as great, whose energy is 900 times greater, is quite competent to a shock sufficient to make us see stars *en masse*. But, indeed, there must be collisions much more violent than this; both because the central mass is often much greater and because the orbits differ much more, and the effect would increase as the square of the speed. The heat thus generated would cause the meteorites to glow, and at the same time raise the temperature of the gases in and about them. Furthermore, the light would come to us through other non-affected portions of gas between us and the scene of the collision. Thus all three peculiarities of the spectra stand explained: we have a continuous background of light due to heated solid meteorites, the bright lines of glowing gases, and dark lines due to other gases not ignited, lying in our line of sight.

In addition we should perceive another result. Collisions would be both more numerous and more pronounced toward the centre of the nebula, for it must speedily grow denser toward its core owing to the falling in of meteorites, in consequence of shock. Being denser in the centre, the particles would there be thicker and be travelling at greater speed. The nebulæ, therefore, should be brightest at their centres, which is accordant with observation.

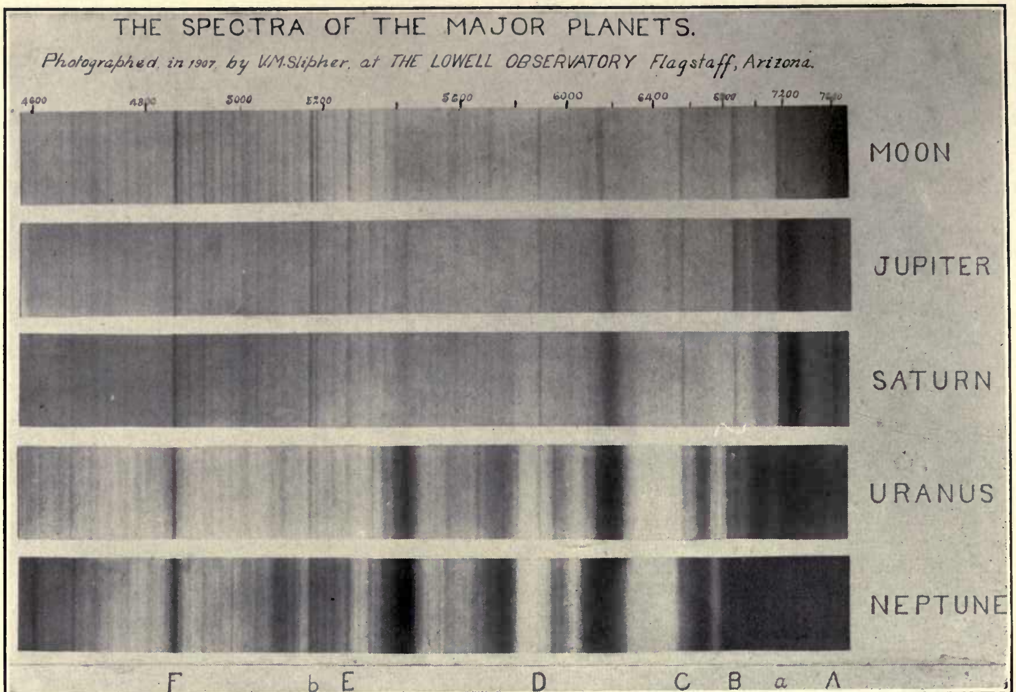
Thus from having offered themselves exemplars of the way in which our own system came into being, the white nebulæ assert their present constitution to be that from which we know our system sprang.

Another suggestive fact about the present members of our solar system which has something to say about a past collision is the densities of the different planets. The average density of the four inner planets, Mars, the Earth, Venus, and Mercury is nearly four times that of the four outer ones Neptune, Uranus, Saturn, and Jupiter.[2] The discrepancy is striking and cannot be explained by size, as the smallest are the most massive, and if all were primally of like constitution, should be the least compressed. Nor can it be explained simply by greater heat tending to expand them, for Neptune and Uranus show no signs of being very hot. The minor differences between members of each group are probably explicable in part by these two factors, mass and heat, but the great gulf between the two groups cannot so be spanned. We are then driven to the supposition that the materials composing the outer ones were originally lighter. Now this is precisely what should happen had all eight been formed by disruption of a previous body. For its cuticle would be its least dense portion, and on disruption would travel farthest away, not because of being lighter, but because of being on the outside. Parts coming from deeper down would remain near, and be denser intrinsically.

What the present densities of the planets enable us to infer of the cataclysm from which they came, a remarkable set of spectrograms taken not long ago by Dr. V. M. Slipher, at Flagstaff, seems to confirm.

The spectrograms in question were made possible by his production of a new kind of plate. His object was to obtain one which should combine sufficient speed with great photographic extension of the spectrum into the red. For it is in the red end that the absorption lines due to the planets' atmospheres chiefly lie. With the plates heretofore used it was impossible to go much beyond the yellow, the C line marking the *Ultima Thule* of attent. Not only was it advisable to get more particularity in the parts previously explored, but it was imperative to go beyond into parts as yet unknown. After several attempts he succeeded, the plates when exposed showing the spectra beyond even the A band. Of their wealth of depiction it is only necessary to say that in the spectrum of Neptune 130 lines and bands can easily be counted between the wave-lengths 4600 $\mu\mu$, 7600 $\mu\mu$. Of these 31 belong to the planet, which compares with 6 found by Huggins, 10 by Vogel, and 9 by Keeler in the part of its spectrum they were able to obtain.

The result was a revelation. The plates exposed a host of lines never previously seen; lines that do not appear in the spectrum of the Sun, nor yet in the added


THE SPECTRA OF THE MAJOR PLANETS.
Photographed in 1907 by V.M. Slipher, at THE LOWELL OBSERVATORY Flagstaff, Arizona.
4600
4800
5000
5200
5600
6000
6400
6800
7200
7600
MOON
JUPITER
SATURN
URANUS
NEPTUNE
F
b
E
D
C
B
a
A

spectrum of the atmosphere of the Earth, but are due to the planets' own envelopes. But this was only the starting-point of their disclosures. When in this manner he had taken the color signatures of Jupiter, Saturn, Uranus, and Neptune, an orderly sequence in their respective absorption bands stood strikingly confessed. In other words, their atmospheres proved not only peculiar to themselves and unlike what we have on Earth, but progressively so according to a definite law. That law was distance from the Sun. When the spectra were arranged vertically in ordered orbital relation outward from the Sun, with that of the lunar for comparison on top, a surprising progression showed down the column in the strange bands, an increase in number and a progressive deepening in tint. The lunar, of course, gives us the Sun and our own air. All else must therefore be of the individual planet's own. Beginning, then, with Jupiter, we note, besides the reënforcement of what we know to be the great water-vapor bands '*a*,' several new ones, which show still darker in the spectrum of Saturn. The strongest of these is apparently not identifiable with a band in the spectra of Mira Ceti in spite of falling near it. Passing on to Uranus, we perceive these bands still more accentuated, and with them others, some strangers, some solar lines enhanced. Thus the hydrogen lines stand out as in the Sirian stars. All deepen in Neptune, while further newcomers appear.

Thus we are sure that free hydrogen exists in large quantities in the atmospheres of the two outermost planets and most so in the one farthest off. Helium, too, apparently is there, and other gases which in part may be those of long-period stars, decadent suns, in part substances we do not know.

From the fact that these bands are not present in the Sun and apparently in no type of stars, we may perhaps infer that the substances occasioning them are not elements but compounds to us unknown. And from the fact that free hydrogen exists there alongside of them, and apparently helium, too, we may further conclude that they are of a lighter order than can be retained by the Earth.

But now, we may ask, why should these lighter gases be found where they are? It cannot be in consequence simply of the kinetic theory of gases from which a corollary shows that the heaviest bodies would retain their gases longest, because the strange gases are not apportioned according to the sizes of their hosts. Jupiter, by all odds the biggest in mass, has the least, and Saturn, the next weightiest, the next in amount. Nor can title to such gaseous ownership be lodged in the planet's present state. For though Jupiter is the hottest and Saturn the next so, the increased mass more than makes up in restraint what increased temperature adds in molecular volatility — as we perceive in the cases of the Sun and Earth.

No; their envelopes are increasingly strange because their internal constituents are different, and as hydrogen is most abundant in Neptune, the lightest of all the gases, it is inferable that this planet's material is lighter. As distance from the Sun determines their atmospheric clothing, so distance decides upon their bodies, too. It was all a case of primogeniture. The light strange matter that constitutes them was so because it came from the outer part of the dismembered parent orb. Neptune the outermost, Uranus the next, then Saturn and Jupiter came in that order from the several successive layers of the pristine body, while the inner planets came from parts of it deeper down. The major planets were of the skin of the dismembered body, we of its lower flesh.

Very interesting the study of these curious spectral lines from the outer planets for themselves alone; even more so for what one would hardly have imagined: that they should actually tell us something of the genesis of our whole solar system. They corroborate in so far what the meteorites have to say.

That the meteorites are solid and, except for their experiences in coming through our air, bear no marks of external heat, is a fact which is itself significant. It seems to hint not at a crash as their occasioning but at disruptive tidal strains. The parent body appears to have been torn apart without much development of heat. Perhaps, then, we had no gloriously pyrotechnic birth, but a more modest coming into existence. But about this we must ourselves modestly be content to remain for the present in the dark.

Not the least important feature of the theory I have thus outlined is that it finishes out the round of evolution. It becomes a conception *sapiens in se ipso totus, teres atque rotundus.* To frame a theory that carries one back into the past, to leave one there hung up in heaven, is for inconclusiveness as bad as the ancient fabulous support of the world, which Atlas carried standing on an elephant upheld by a tortoise. What supported the tortoise we were not told. So here, if meteorites were our occasioning, we must account for the meteorites, starting from our present state. This the present presentation does.

Thus do the stones that fall from the sky inform us of two historic events in our solar system's career. They tell us first and directly of a nebula made up of them, out of which the several planets were by agglomeration formed and of which material they are the last ungathered remains. And then they speak to us more remotely but with no less certainty of a time antedating that nebula itself, a time when the nebula's constituents still lay enfolded in the womb of a former Sun.

Man's interest in them hitherto has been, as with other things, chiefly proprietary. Greed of them has grown so keen that legal questions have been raised of the ownership of their finding, and our courts have solemnly declared them not "wild game" but "real estate," and as such belonging to the owner of the land on which they fall.

But to the scientific eye their estate is something more than "real," for theirs is the oldest real estate in the solar system. They were what they are now when the Earth we pride ourselves in owning was but a molten mass.

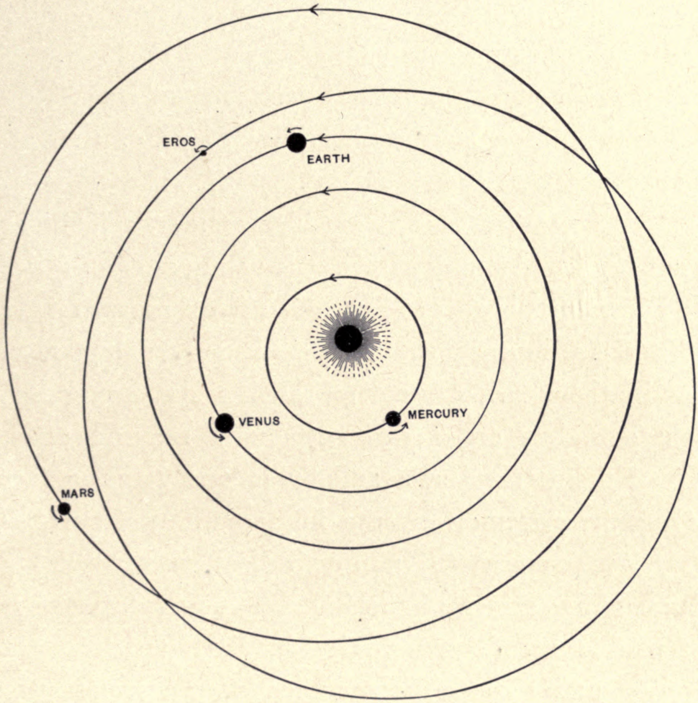
So that when in future you see these strange stones in rows upon a museum's shelves, regard them not as rarities, in which each museum strives to outdo its neighbors by the quantity it can possess, but as rosetta stones telling us of an epoch in cosmic history long since passed away — of which they alone hold the key. Look at them as the literary do their books, for that which they contain, not as the bibliophile to whom a misprint copy outvalues a corrected one and by whom "uncuts" are the most prized of all.

CHAPTER III

THE INNER PLANETS

WHEN we recall that the Ptolemaic system of the universe was once taught side by side with the Copernican at Harvard and at Yale, we are impressed, not so much with the age of our universities, as with the youth of modern astronomy and with the extraordinary vitality of old ideas. That the Ptolemaic system in its fundamental principle was antiquated at the start, the older Greeks having had juster conceptions, does not lessen our wonder at its tenacity. But the fact helps us to understand why so much fossil error holds its ground in many astronomic text-books to-day. That stale intellectual bread is deemed better for the digestion of the young, is one reason why it often seems to them so dry.

Before entering upon the problem of the genesis and career of a world, it is essential to have acquaintance with the data upon which our deductions are to rest. To set forth, therefore, what is known of the several planets of our solar system, is a necessary preliminary to any understanding of how they came to be or whither they are tending; and as our knowledge has been vitally affected by modern discoveries about them, it is imperative that this exposition of the facts should be as near as possible abreast of the research itself. I shall, therefore, give the reader



Orbits of the Inner Planets.

in this chapter a bird's-eye view of the present state of planetary astronomy, which he will find almost a different part of speech from what it was thirty years ago. It is not so much in our knowledge of their paths as of their persons that our acquaintance with the planets has been improved. And this knowledge it is which has made possible our study of their evolution as worlds.

Could we get a cosmic view of the solar system by leaving the world we live on for some suitable vantage-point in space, two attributes of it would impose themselves upon us — the general symmetry of the whole, and the impressively graded proportions of its particular parts.

Round a great central globular mass, the Sun, far exceeding in size any of his attendants, circle a series of bodies at distances from him quite vast, compared with their dimensions. These, his principal planets, are in their turn centres to satellite systems of like character, but on a correspondingly reduced scale. All of them travel substantially in one plane, a fact giving the system thus seen in its entirety a remarkably level appearance, as of an ideal surface passing through the centre of the Sun. Departing somewhat from this general uniformity in their directions of motion, and also deviating more from circularity in their paths, some much smaller bodies, a certain distance out, dart now up now down across it at different angles and from all the points of the compass, agreeing with the others only in having the centre of the Sun their seemingly never attained goal of endeavor. These bodies are the asteroids. Surrounding the whole, and even penetrating within its orderly precincts, a third class would be visible which might be described for size as cosmic dust, and for display as heavenly pyrotechnics. Coming from all parts of space indifferently they would seem to seek the Sun in almost straight lines, bow to him in circuit, and then depart whence they came. For in such long ellipses do they journey that these seem to be parabolas. These visitants are the comets and their associates the meteor streams.

Although for purposes of discrimination we have labelled the several classes apart, an essential fact about the whole company is to be noted: that no hard and fast line can be drawn separating the several constituents from one another. In size the members of the one class merge insensibly into the other. Some of the planets are hardly larger than some of the satellites; some of the satellites than some of the asteroids; some of the asteroids than comets and shooting stars. In path, too, we find every gradation from almost perfect circularity like the orbits of Io and Europa to the very threshold of where one step more would cease to leave the body a member of the Sun's family by turning its ellipse into an hyperbola. Finally, in inclination we have every angle of departure from orthodox platitude to unconforming uprightness. This point, that heavenly bodies, like terrestrial ones, show all possible grades of indistinction, is kin to that specific generalization by which Darwin revolutionized zoölogy a generation ago. It is as fundamental to planets as to plants. For it shows that the whole solar system is evolutionarily one.

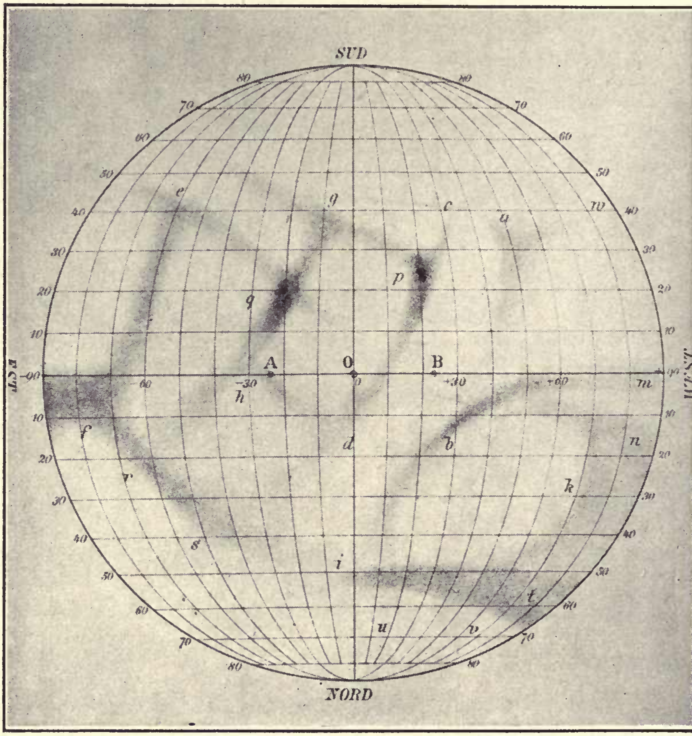
A second point to be noticed in passing is that undue inclination and excessive eccentricity go together. The bodies that have their paths least circular have them, as a rule, the most atilt. And with these two qualities goes lack of size. It is the smallest bodies that deviate most from the general consensus of the system. With so much by way of generic preface, the pregnancy of which will become apparent as we proceed, we come now to particular consideration of its members in turn.

Nearest to the Sun of all the planets comes Mercury. So close is he to that luminary, and so far within the orbit of the earth, that he is not a very common object to the unaided eye. Copernicus is said never to have seen him, owing, doubtless, to the mists of the Vistula. By knowing when to look, however, he may be seen for a few days early in the spring in the west after sunset, or before sunrise in the east in autumn. He is then conspicuous, being about as bright as Capella, for which star or Arcturus he is easily mistaken by one not familiar with the constellations.

His mean distance from the Sun is thirty-six million miles, but so eccentric is his orbit, the most so of any of the principal planets, that he is at times half as far off again as at others. Even his orbital behavior is the least understood of any in the solar system. His orbit swings round at a rate which so far has defied analysis. It may be a case of reflected perturbation, one, that is, of which the indirect effect from another body becomes more perceptible than would be the direct effect on the body itself. As yet it baffles geometers.

As to his person, our ignorance until lately was profound. It is only recently that such fundamental facts about him as his size, his mass, and his density have been reached with any approach to precision. This was because he so closely hugs the Sun that observations upon his full, or nearly full, disk had never been attempted. When I say that his volume was not known to within a third of its amount, his mass not closer than one-half, while his received density was nearly double what we now have reason to suppose the fact, some idea of the depth of our nescience may be imagined. This, of course, did not prevent text-books from confidently misinstructing youth, or Nautical Almanacs from misguiding computers with figures that thus almost achieved immortality, so long had they passed current in spite of lacking that perfection which is usually assigned as its warrant.

Schiaparelli first put astronomy on the right track. By attempting daylight observations of the planet, not



Sulla Rotazione di Mercurio — Di G. V. Schiaparelli.

toward night, but actually at midday, he made some remarkable discoveries, and though he did not detect the hitherto erroneous values of the volume, the mass, or the density, his method of observation paved the way for their ascertainment. What he sought, and found, was evidence of markings upon the disk by which the planet's time of rotation might be determined. Up to then, Schroeter's value of about twenty-four hours had been accepted, on very slender evidence indeed, and passed into all the books. But when the planet came to be observed by noon, very definite markings stood out on its face, which showed its rotation to take place, not in twenty-four hours, but in eighty-eight days. By a persistence equal to his able choice of observing time, he established this beyond dispute. He proved the revolutionizing fact that Mercury's periods of rotation and of revolution were the same.

He detected, too, the evidence in the position of the markings of the planet's great libratory swing due to the eccentricity of its orbit, a result as remarkable as a feat of observation as it was conclusive as a proof.

If Schiaparelli had never done any other astronomical work, this study of Mercury would have placed him as the first observer of his day. For the observations are so difficult that the planet not only baffled all his predecessors, but has foiled many since who are credited with being observers of eminence.

In 1896 the study of Mercury was taken up at the Lowell Observatory in Arizona along the same lines that had proved so successful with Schiaparelli, but without using his observations as guide. Indeed, his papers had not then been read there. The two conclusions were, therefore, independent of one another.

The outcome was a complete corroboration and an extension of Schiaparelli's work. We shall begin with the consideration of the most fundamental point. In the clear and steady air of Flagstaff, permitting of measurement of his disk up to within a few degrees of the Sun, Mercury was found to be much larger than previously thought.

Instead of a diameter of three thousand miles he proved to have one of thirty-four hundred, making his volume nearly half as large again as had been credited him. These measures bore intrinsic evidence of their trustworthiness in an interesting manner, and at the same time produced internal testimony that accounted for the smallness of previous determinations. Measures heretofore had been made, usually if not invariably, either when the planet transited the Sun or when it exhibited a pronounced phase. Now in both these cases the planet looks smaller than it is. In the first case this is due to irradiation, the surrounding disk of the Sun encroaching both to the eye and to the camera upon the silhouette of Mercury. And this inevitable effect had not been allowed for in the measures. In the second case the horns of the planet never seem to extend quite to their true position. This was rendered evident by the Flagstaff series of measures, which began when the planet was a half-moon and continued till it was almost full. As it did so, the values for the diameter steadily increased, even after irradiation was allowed for, although this against the brilliant background of the noonday sky must have been exceeding small, and tended in part to be diminished as the planet attained the full, because of its consequent nearing of the Sun. The measures thus explained themselves and vouched for their own accuracy.*

Then came a curious bit of unexpected proof to corroborate them. In his "Astronomical Constants,"† published but a short time before, Newcomb had detected a systematic error in the right ascensions of Mercury which he was not able to explain. By diligent mousing that eminent computer had discovered that Mercury was registered by observers too far from the Sun on whichever side of him it happened to be, and in proportion roughly not to its distance off but to the phase the planet exhibited. When the disk was a crescent the discrepancy between observation and theory was large, and thence decreased as the planet passed to the full. He suspected the cause, and would have found it had he not considered the diametral measures of the planet too well assured to permit of doubt. As it was, he neglected a factor which has

* New Observations of the Planet Mercury, *Memoirs Amer. Acad.* 1897. Vol. XII, No. 4.

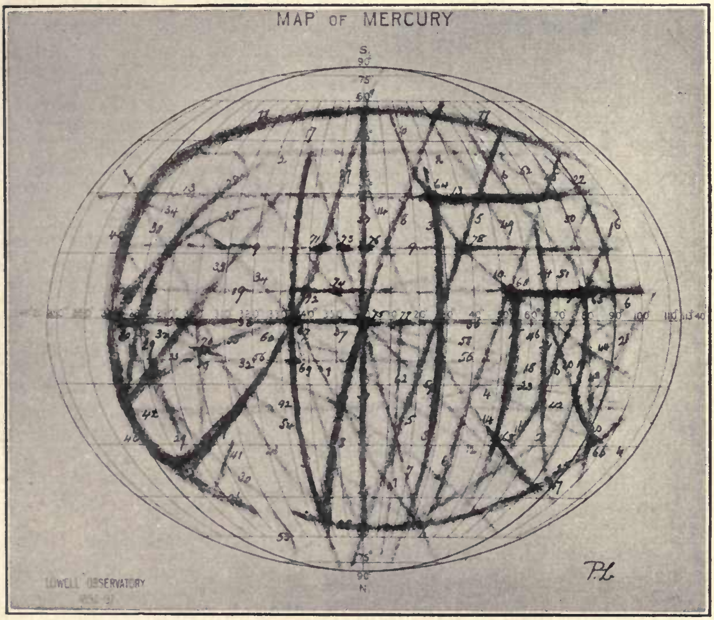
† "Astronomical Constants," 1895, pp. 67, 68.

vitiated almost all the observations made on the planets up to within a few years, the correction for irradiation. This was the case here. The received measures, beginning with Bradley and ending with Todd, had almost without exception been made in transit, and, as no regard had been paid to the contracting effect of irradiation, had been invalidated in consequence. The new method supplied almost exactly the amount needed to explain the right ascensions, a second of arc, and in precise accordance with the place which the discrepancy demanded.

About the mass there has been, and still is, great uncertainty. This is because it can only be found from the perturbing effect it has on Venus, the Earth, or Encke's comet. Modern determinations, however, are smaller than the older ones; thus Backlund in 1894 got from the effect on Encke's comet only one-half the mass that Encke had, fifty-three years before. Probably the most reliable information comes from Venus, which Tisserand found to give for Mercury $\frac{1}{7100000}$ of the mass of the Sun, or $\frac{1}{21}$ of the mass of the Earth. If we take $\frac{1}{7000000}$ as the nearest round number, we find the planet's density to be 0.66 that of the Earth.

The same observations that disclosed at Flagstaff the planet's size revealed a set of markings on his face so definite as to make the rotation period unmistakable.

It takes place, as Schiaparelli found, in eighty-eight days, or the time of the planet's revolution round the Sun. The markings disclosed the fact, as Schiaparelli had also discovered, in a most interesting manner, for



the ellipticity of the planet's orbit stood reflected in the swing of the markings across the face of the disk, a definiteness in the proof of a really surprising kind. What this means we shall see in a subsequent chapter when we take up the mechanical problem of the tides. Another result that issued from the positions of the markings was the determination of the planet's pole. Except for the libration above noticed, the markings kept an invariable longitudinal position upon the illuminated disk, showing that the planet turned always the same face to the Sun; but latitudinally a difference was noticeable between their place in October–November, 1896, and in February–March, 1897, the latter being 4° farther north. Now this is just what the orbital position should have caused, if the pole stood vertically to it. Thus a difference of 4° from perpendicularity should have been discernible, had it existed,—a very small amount in such a determination. We may, therefore, conclude that the axis stands plumb to the orbit, and this is what theory demands.

The state of things this introduces to us upon that other world is to our ideas exceeding strange. It is not so much the slowness of the diurnal spin, eighty-eight times as long as our own, which is surprising, as the fact that this makes its day infinite in length. Two antipodal hemispheres divide the planet, the one of which frizzles under eternal sun, the other freezes amid everlasting night. The Sun does not, indeed, stand stock-still in the sky, but nods like some huge pendulum to and fro along a parallel of latitude. In consequence of libration the two great domains of day and night are sundered by a strip of debatable ground 23½° in breadth on either side, upon which the Sun alternately rises and sets. Here there is a true day, eighty-eight of our days in length from one sunrise to the next. But its day and night are not apportioned alike. The eastern strip has its daylight briefer than its starlight hours; the western has them longer. Nor are different portions of the strips similarly circumstanced in their sunward regard. Only the edge next perpetual day has anything approaching an equal distribution of sunlight and shade. The farther one just peeps at the Sun for a moment every eighty-eight days, and then sinks back again into obscurity.

The transition from day to night is equally instantaneous and profound. For little or no twilight here prolongs the light; since the air, if there be any at all, is too thin to bend it to service round the edge to illuminate the night. When the libratory Sun sets, darkness like a mantle falls swiftly over the face of the ground. No evidence of atmosphere has ever been perceived, and theory informs that it should be nearly, if not wholly, absent.

In consequence of the rigid uprightness of the planet's axis, seasons do not exist. Their nearest simulacrum comes from the seeming dilatation of the Sun during half the year, and its apparent contraction during the other half. It expands so much between its January and its July as to receive more heat in the ratio of nine to four. A seasonless, dayless, and almost yearless planet, it is better to look at than to look from; but its study opens our eyes to the great diversity which even one of our nearest neighbors exhibits from what we take as matters of course on Earth.

That what we take offhand to be purely astronomic phenomena should turn out to be so essentially of the particular world, worldly, clarifies vision of what these really are, and how dependent on and interwoven with everyday life astronomy is. Or, we may consider it turned about and realize how purely astronomic relations, such abstract mechanical matters as rotations and revolutions, result in completely changing the very face and character of the globe concerned. Mercury to-day stares forever at the Sun. The markings we see have stereotyped this stare to its inevitable result. For they seem to mark a globe suncracked. At such a condition the curious crisscross of dark, irregular lines certainly hints, accentuated and perfected as it is by a bounding curve where the mean sunward side terminates to the enclosing them as by the carapace of a tortoise. Though they cannot probably be actual cracks, however much they may resemble such, yet they may well owe their existence to that fundamental cause.

In color the planet is ghastly white; of that wan hue that suggests a body from which all life has fled. Far whiter than Venus in point of fact, the rosy tint with which it sparkles in the sunset glow is all borrowed of the dying day and vanishes when the planet is looked at in the uncompromising light of noon. Seen close together once at Flagstaff it was possible directly to compare the two; when Mercury, although lit by the Sun two and a half times as brilliantly as Venus, was, surface for surface, more than twice as faint. Müller has found its intrinsic brightness about that of our Moon, which in some respects it resembles, though it apparently departs widely from any similarity in others. The bleached bones of a world; that is what Mercury seems to be.

Venus comes next in order outward from the Sun. To us her incomparable beauty is partly the result of propinquity: nearness to ourselves and nearness to the Sun. Relatively so close is she to both that she does not need the Sun's withdrawal to appear, but may nearly always be seen in the daytime in clear air if one knows where to look for her. Situate about seven-tenths of our own distance from our common giver of light and heat, she gets about double the amount that falls to our lot, so that her surface is proportionately brilliantly illuminated. Being also relatively near us, she displays a correspondingly large surface.

But though part of her lustre is due to her position, a part is her own. Direct visual observation, as we remarked above, shows her intrinsic brightness to be more than five times that of Mercury, square mile to square mile of surface for the two. Now this has been determined very carefully photometrically by Müller at Potsdam. The result of his inquiry was to indicate that Mercury shines with 0.17 of absolute reflection, Venus with 0.92. So high a value has seemed to many astronomers impossible, because so far surpassing that which has tacitly been taken as the *ne plus ultra* of planetary brightness, that of cloud, 0.72.

Now, one of the direct outcomes of the study of Venus at the Lowell Observatory was an explanation of this seemingly incredible phenomenon. When the planet came to be critically examined there under conditions of seeing which permitted discovery, markings very faint, but nevertheless assurable, stood presented on the planet's face. These markings, of which we shall have more to say in a moment, had this of pertinency to our present point, that they kept an invariable position to one another. They thus betrayed themselves to be surface features. Furthermore, their dimness was as invariable an attribute of them as their place. They were not obscured on some occasions and revealed at others, but stayed, so far as one might judge, permanently the same. They were thus neither clouds themselves nor subject to the caprice of cloud.

The old idea that Venus was a cloud-wrapped planet and owed her splendor to this envelope, vanished literally into thin air.

It is precisely because she is not cloud-covered that her lustre is so great. She "clothes herself with light as with a garment" by a physical process of some interest. As becomes the Mother of the Loves, this is gauze of the most attenuated character, and yet a wonderful heightener of effect. For it consists solely of the atmosphere that compasses her about. It is well known that a substance when comminuted reflects much more light than when condensed into a solid state. Now an atmosphere is itself such a comminuted affair, and, furthermore, holds in suspension a variety of dust. This would particularly be the case with the atmosphere of Venus, as we shall have reason to see when we consider the conditions upon that planet made evident by study of its surface markings. To her atmosphere, then, she owes four-fifths or more of her brilliancy. And this stands corroborated by the low albedo of both Mercury and the Moon, which have no atmosphere, and by the intermediate lustre of Mars, which has some, but little.*

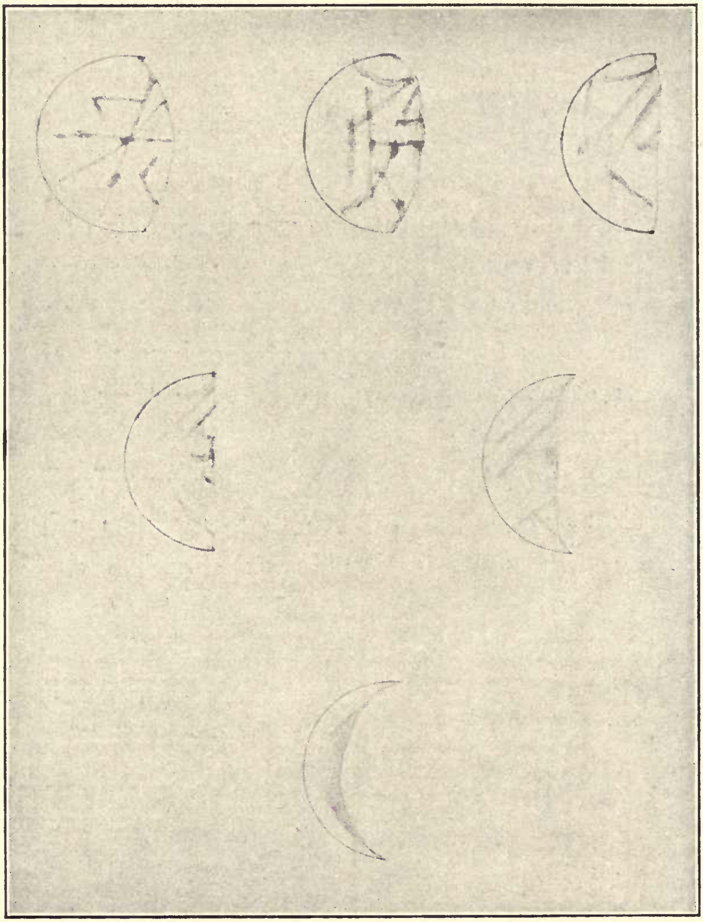
The rotation time of Venus, the determination, that is, of the planet's day, is one of the fundamental astronomical acquisitions of recent years. For upon it

* *Astr. Nach.* No. 3406. Monthly Notices R. A. S., March, 1897.

turns our whole knowledge of the planet's physical condition. More than this, it adds something which must be reckoned with in the framing of any cosmogony. It is not a question of academic accuracy merely, of a little more or a little less in actual duration, but one which carries in its train a completely new outlook on Venus and sheds a valuable sidelight upon the history of our whole planetary system.

Unconsciously influenced, one is inclined to think, by terrestrial analogies, astronomers for more than a couple of centuries, ever since the time of the first Cassini in 1666, deemed the day of Venus to be just under twenty-four hours in length. So well attested was its determination, and so precisely figured to the minute, that it imposed itself upon text-books which stated it as an acquired fact down to the last second. Nevertheless, Schiaparelli was not so sure, and proceeded to look into the matter. He first looked for himself, and then looked up all the old observations. His chief observational departure was observing by day as near to noon as possible; because then the planet was highest, to say nothing of the taking off from its glare by the more brilliant sky. From certain dark markings around two bright spots near the southern cusp, of one of which spots the detection dates from the time of Schroeter, and from a long, dark streak stretching thence well down the disk, he convinced himself that no such period as twenty-four hours could possibly be correct, inasmuch as whenever he looked, the markings were always there. His notes read, "Same appearance as yesterday," day after day, until he would really have saved ink and penmanship had he had the phrase cut into a die and stamped. He concluded that the rotation was at least six months long, and was probably synchronous with the planet's time of revolution. This was in 1889. In 1895 he became still more sure, and showed how the older observations were really compatible with what he had found.

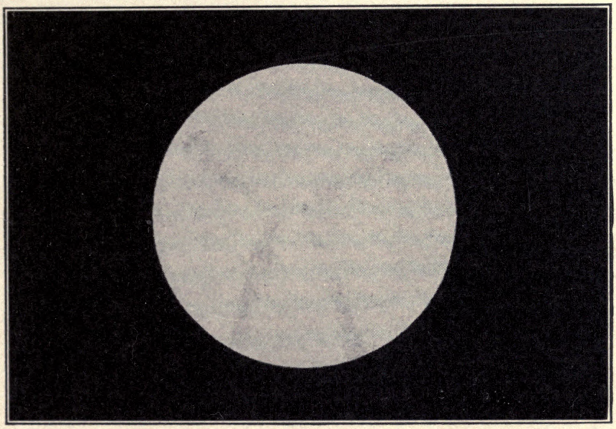
In 1896 the subject was taken up at Flagstaff. Very soon it became evident there that markings existed on the disk, most noticeable as fingerlike streaks pointing in from the terminator, faint but unmistakable from the identity of their successive presentation. Schroeter's projection near the south cusp was also clearly discernible as well as two others, one in mid-terminator, one near the northern cusp. Schiaparelli's dark markings also came out, developing into a sort of collar round the southern pole. Other spots and streaks also were discernible, and all proved permanent in place. By watching them assiduously it was possible to note that no change in position occurred in them, first through an interval of five hours, then through one of days, then of weeks. Care was taken to guard against illusion. It thus became evident



VENUS. OCTOBER, 1896–MARCH, 1897 — DRAWINGS BY DR. LOWELL.

that they bore always the same relation to the illuminated portion of the disk. This illuminated part, then, never changed. In other words, the planet turned always the same face to the Sun. The fact lay beyond a doubt, though of course not beyond a doubter.*

The years that have passed since these observations were made have brought corroboration of them. Sev-



VENUS. APRIL 12, 1909, 3H 26M–4H 22M — BY DR. LOWELL.

eral observers at Flagstaff have seen and drawn them and added discoveries of their own, among whom are especially to be mentioned, of the observatory staff: Miss Leonard, Dr. Slipher, and Mr. E. C. Slipher.†

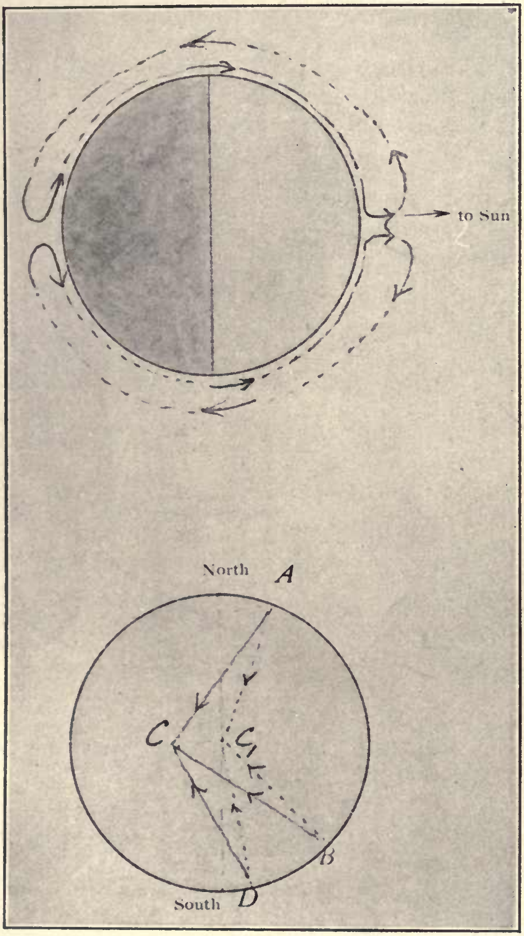
In character these markings were peculiar and distinctive. In addition to some of more ordinary char-

* Monthly notices R. A. S., March, 1897.

† Lowell Observatory Bulletin 6.

acter were a set of spokelike streaks which started from the planet's periphery and ran inwards to a point not very distant from the centre. The spokes started well-defined and broad at the edge, dwindling and growing fainter as they proceeded, requiring the best of definition for their following to their central hub.

The peculiar symmetry thus displayed, a symmetry associated with the planet's sunrise and sunset line, or, strictly speaking, what would be such did the Sun for Venus ever rise or set, would seem inexplicable, except for that very association. When we reflect, however, upon what this means, a very potent cause for them becomes apparent, so potent that surprise is turned into appreciation that nothing else could well exist. That Venus turns on her axis in the same time that she revolves about the Sun, in consequence of which she turns always the same face to him, must cause a state of things of which we can form but faint conception, from any earthly analogy. One face baked for countless æons, and still baking, backed by one chilled by everlasting night, while both are still surrounded by air, must produce indraughts from the cold to the hot side of tremendous power. A funnel-like rise must take place in the centre of the illuminated hemisphere, and the partial vacuum thus formed would be filled by air drawn from its periphery, which, in its turn, would draw from the regions of the night side. Such winds would sweep the sur-



I

Showing convection currents in the planet's atmosphere.

II

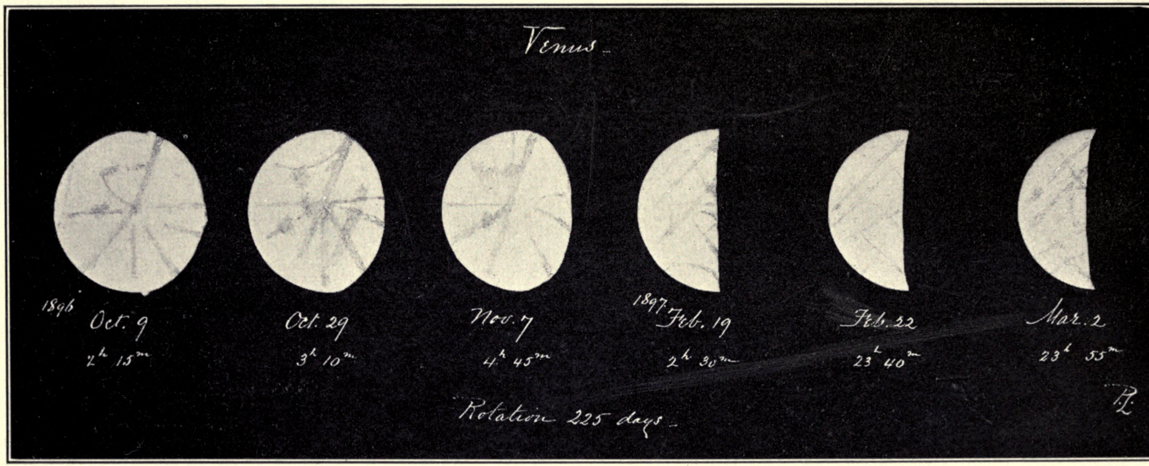
Showing shift in central barometric depression due to rotation of the planet affecting the winds.

VENUS.

face as they entered, becoming less superficial as they advanced, and the marks of their inrush might well be discernible even at the distance we are off. Deltas of such inroad would thus seam the bounding circle of light and shade.

Another result of the aërial circulation would be the removal of all moisture from the sunward face, and its depositing in the form of ice upon the night one. For the heated air would be able to carry much water in suspension, which, on cooling, after it had reached the dark hemisphere would unload it there. In the low temperature there prevailing, this moisture would all be frozen, and so largely estopped from return. This process continuing for ages would finally deplete one side of all its water to heap it up in the form of ice upon the other.

Now it is not a little odd that a phenomenon has been observed upon Venus which seems to display just this state of things. Many observers have noted an ashen light on the dark side of her disk. Some have tried to account for it as Earth shine, the same earth-reflected light that makes dimly visible the old moon in the new moon's arms. But the Earth is too far away from Venus to permit of any such effect; nor is there any other body that could thus relieve its night. But if the night hemisphere of Venus be one vast polar sheet, we have there a substance able to mirror the stars to a ghostlike gleam which might be discernible even from our distant post.


Venus
1896 Oct. 9
2h 15m
Oct. 29
3h 10m
Nov. 7
4h 45m
1897 Feb. 19
2h 30m
Feb. 22
23h 40m
Mar. 2
23h 55m
Rotation 225 days
P.L.

Thus when we reason upon them we see that the peculiar markings of the planet lose their oddity, becoming the very pattern and prototype of what we should expect to view. Interpreted, they present us the picture of a plight more pitiable even than that of Mercury. For the nearly perfect circularity of Venus' orbit prevents even that slight change from everlasting sameness which the libration of Mercury's affords. To Venus the Sun stands substantially stock-still in the sky, — a fact which must prove highly reassuring to Ptolemaic astronomers there, if there be any still surviving from her past. No day, no seasons, practically no year, diversifies existence or records the flight of time. Monotony eternalized, — such is Venus' lot.

What visual observations have thus discovered of the rotation time of Venus, with all that follows from it, the spectroscope at Flagstaff has confirmed. At Dr. Slipher's hands, spectrograms of the planet have told the same tale as the markings. It was with special reference to this point that the spectrograph there was constructed, and the first object to which it was directed was Venus.*

The planet's rotation time was to be investigated by means of the motion it brought about in the line of sight. Visual observation, telescopically, reveals motion

* Lowell Observatory Bulletin No. 3.

thwart-wise by the displacement it produces in the field of view; spectroscopic observation discloses motion to or from the observer by the shift it causes in the spectral lines due to a stretching or shortening of their wave-lengths.

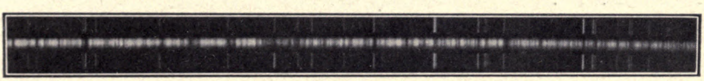
The spectroscope is an instrument for analyzing light. Ordinary light consists of light of various wave-lengths. By means of a prism or grating these are dispersed into a colored ribbon or band, the longer waves lying at the red end of the spectrum, as the ribbon is called, the shorter at the violet. Now the spectroscope is primarily such a prism or grating placed between the image and the observer, by means of which a series of colored images of the object are produced. In order that these may not overlap and so confuse one another, the light is allowed to enter the prism only through a narrow slit placed across the telescopic image of the object to be examined. Thus successive images of what is contained by the slit are presented arranged according to their wave-lengths. In practice the rays of light from the slit enter a small telescope called the collimator, and are there rendered parallel, in which condition they fall upon the prism. This spreads them out into the spectrum and another small telescope focusses them, each according to its kind, into a spectral image band which may then be viewed by the eye or caught upon a photographic plate.

Now, if an object be coming toward the observer, emitting or reflecting light as it does so, each wave-length of its spectrum will be shortened in proportion to the relative speed of its approach as compared with the speed of light, because each new wave is given out by so much nearer the observer and in reflection the body may also meet it. Reversely it will be lengthened if the object be receding from the observer or he from it. This would change the color of the object were it not that while each hue moves into the place of the next, like the guests at Alice's tea-party in Wonderland, some red rays pass off the visible spectrum, but new violet rays come up from the infra-violet and the spectrum is as complete as before. Fortunately, however, in all spectra are gaps where individual wave-lengths are absorbed or omitted, and these, the lines in the spectrum, tell the tale of shift. Now if a body be rotating, one side of it will be approaching the observer, while the opposite side is receding from him, and if the slit be placed perpendicular to the axis about which the spin takes place, each spectral line will appear not straight across the spectrum of the object, but skewed, the approaching side being tilted to the violet end, the receding side to the red.

This was to be the procedure adopted for the rotation of Venus. By placing the slit parallel to the ecliptic, or, more properly, to the orbit of Venus, which is practically the same thing, it found itself along what we have reason to suppose the equator of the planet. Even a considerable error on this point would make little difference in the rotational result. In order that there might be no question of illusion or personal bias, photographs instead of eye observations of the spectrum were made. For reference and check side by side with that of Venus were taken on either hand the spectra of iron, made by sparking a tube containing the vapor of that metal. The vapor, of course, had no motion with regard to the observer, and therefore its spectral lines could have no tilt, but must represent motional verticality.

Dr. Slipher chose his time astutely. He selected the occasion when Venus was passing through superior conjunction, or the point in her orbit as regards us directly beyond the sun. At first sight this might seem to be the worst as well as the most impracticable of epochs, inasmuch as the planet is then not only at her farthest from the Earth, but in a line with the Sun, and so drowned in his glare. But in point of fact any tilt of the spectral lines is then, owing to phase, twice what it is at elongation, and exceeds still more what it is when Venus has her greatest lustre.[3] In his purpose he was abetted by the Flagstaff air, which enabled the planet to be spectrographed much nearer the sun than would otherwise have been the case. He thus selected the best possible opportunity. To guard against any subsequent bias on the part of the examiner of the plates, after the spectroscope had taken a plate it was then reversed, and the process repeated on another one, the iron being sparked as before. What had been the right side of Venus with regard to the red end of the spectrum thus became the left one, and *vice versa.* In this manner, when the plates came to be measured for tilt, the measurer would have no indication from the spectrum itself which way the lines might be expected to tilt; he could, therefore, not be influenced either consciously or unconsciously in his decision.

Eight plates with their comparison ferric spectra were thus secured; four with the spectroscope direct, four with it reversed. They were then shuffled, their numbers hidden, and given to Dr. Slipher to measure. The spectral lines told their own story, and without prompting. All the plates agreed within the margin

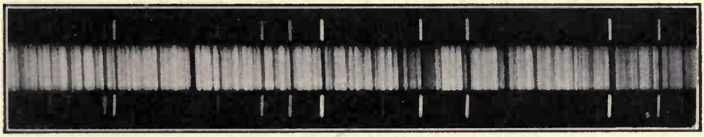


SPECTROGRAM OF VENUS, SHOWING ITS LONG DAY — V. M. SLIPHER, LOWELL OBSERVATORY, 1903.

of error accordant with their possible precision, a precision some thirty times that of Belopolski's experiment on the same lines, — a result not derogatory of that investigator, but merely illustrative of superior equipment. They showed conclusively that a rotation of anything like twenty-four hours was out of the question. They yielded, indeed, testimony to a negative rotation of three months, which, interpreted, means that so slow a spin as this was beyond their power to precise.

For Dr. Slipher was at no less care to determine just what precision was possible in the case, although a speed corresponding to a spin of twenty-four hours on a globe the size of Venus is well known to be spectroscopically measurable. It would mean a motion toward us of one thousand miles an hour, or about a third of a mile a second. The tilt occasioned by this speed is well within the spectroscope's ability to disclose. Not content with this, however, by two special investigations, he proved the spectroscope's actual limits of performance to be far within the quantity concerned. One of them was the determination by the same means and in like manner of the rotation time of Mars, the length of that planet's day, which in other ways we know to the hundredth of a second, and which is $24^h\ 37^m\ 23^s.66$. Now Mars offers a test nearly twice as difficult as Venus, even supposing the apparent disks of the two the same, because his diameter being less in the proportion roughly of one-half, the actual speed of a particle at his edge is less for the same time of rotation in the like proportion, and it is only with the speed in miles, not in angular amount, that the spectroscope is concerned. Nevertheless, when a like number of plates were tried on him, they indicated on measurement a rotation time within an hour of the true. This corresponds to half an hour on Venus. We see, therefore, that had Venus' day been anywhere in the neighborhood of twenty-four hours, Dr. Slipher's investigation would have disclosed it to within thirty-one minutes.

This result was further borne out by a similar test made by him of Jupiter. Inasmuch as the diameter of



Spectrogram of Jupiter, giving the length of its day by the tilt of its spectral lines — V. M. Slipher, Lowell Observatory.

Jupiter is twelve times that of Venus, while the rotation time is $9^h\ 50^m.4$ at the equator, the precision attained on Venus should here have been about a minute. And this is what resulted. Slipher found the rotation time spectrographically $9^h\ 50^m$, or in accordance with the known facts, while previous determinations with the spectroscope had somehow fallen short of it.

The care at Flagstaff with which the possibility of error was sought to be excluded in this investigation of the length of Venus' day and the concordant precision in the results are worthy of notice. For it is by thus being particular and systematic that the accuracy of the determinations made there, in other lines besides this, has been secured.

In size, Venus of all the planets most nearly approaches the Earth. She is 7630 miles in diameter to the Earth's 7918. Her density, too, is but just inferior to ours. And she stands next us in place, closest in condition and constitution in the primal nebula. Yet in her present state she could hardly be more diverse. This shows us how dangerous it is to dogmatize upon what can or cannot be, and how enlightening beyond expectation often is prolonged and systematic study of the facts.

The next planet outward is our own abode. It is one of which most of us think we know considerable from experience and yet about which we often reason cosmically so ill. If we knew more, we should not deem ourselves nearly so unique. For we really differ from other members of our system not more than they do from one another. Much that appears to us fundamental is not so in fact. Thus many things which seem matters of course are merely accidents of size and position. Our very day and night upon which turn the habits of all animals and, even in a measure, those of plants, are, as we have seen, not the possession of our nearest of cosmic kin. Our seasons which both vegetally and vitally mean so much are absent next door. And so the list of our globe's peculiar attributes might be run through to the finding of diversity to our familiar ways at every turn. But, as we shall see later, these differences from one planet to the next are not only not incompatible with a certain oneness of the whole, but actually help to make the family relationship discoverable. Analogy alone is a dangerous guide, but analogy crossed with diversity is of all clews the most pregnant of understanding. The very fact that we can tell them apart when we see them together, as the Irishman remarked of two brothers he was in the habit of confusing, points to their brotherly relation.

Proceeding still further, we come to Mars at a mean distance of one hundred and forty-one million miles. Smaller than ourselves, his diameter is but a little over half the Earth's, or forty-two hundred miles, his mass one-ninth of ours, and his density about seven-tenths as much. Here, again, but in a different way, we find a planet unlike ourselves, and we know more about him than of any body outside the Earth and Moon. So much about him has been set forth elsewhere that it is enough to mention here that no oceans diversify his surface, no mountains relieve it, and but a thin air wraps it about, — an air containing water-vapor, but so clear that the surface itself is almost never veiled from view.

About the satellites Mars possesses, Deimos and Phobos, we may perhaps say a word, as recent knowledge concerning them exemplifies the care now taken to such ascertainment and the importance of considering factors often overlooked. Soon after they were discovered in 1877, they were measured photometrically, with the result of giving a diameter of six miles to Deimos and one of seven miles to Phobos, and these values unchallenged entered the text-books. When the satellites came to be critically considered at Flagstaff, it was found that these determinations were markedly in error, Phobos being very much the larger of the two, the actual values reaching nearer ten miles for Deimos and thirty-six for Phobos.

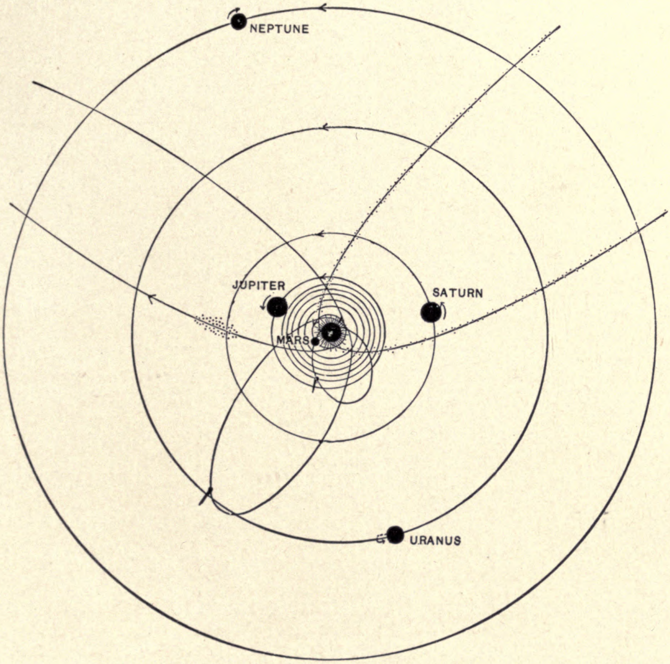
In getting the Flagstaff values, the size to the eye of the satellite was corrected for the background upon which it shone; for the background is all-important to the brilliancy of a star. In the case of a small star near a planet, the swamping glare of the planet is something like the inverse cube of its distance away. Furthermore, the Flagstaff observations indicated how the previous error had crept in. For before correction for the differing brilliancies of the field of view, the apparent size of the satellites judged by conspicuousness was about six to seven. The photometric values must have been taken just as they came out, no correction apparently having been made for the background. Now the background is a fundamental factor in all photometric determinations, a factor somewhat too important in this case to neglect, since it affected the result 2500 per cent.

CHAPTER IV

THE OUTER PLANETS

BEYOND Mars lies the domain of the asteroids, a domain vast in extent, that, untenanted by any large planet, stretches out to Jupiter. Occupied solely by a host of little bodies agreeing only in lack of size, even this space seems too small to contain them, for recent research has shown some transgressing its bounds. One, Eros, discovered by De Witt, more than trenches on Mars' territory, having an orbit smaller than that of the god of war, and may be considered perhaps the forerunner of more yet to be found between Mars and the Earth. On the other side, three recently detected by Max Wolf at Heidelberg have periods equal to that of Jupiter, and in their motions appear to exemplify an interesting case of celestial mechanics pointed out theoretically by Lagrange long before its corroboration in fact was so much as dreamt. Achilles, Patroclus, and Hector, as the triad are called, so move as always to keep their angular distance from Jupiter unaltered in their similar circuits of the Sun.

Before considering these bodies individually, we may well look upon them *en bloc*, inasmuch as one attribute of the asteroids concerns them generically rather than specifically, and is of great interest both from a mechani-



ORBITS OF THE OUTER PLANETS.

cal and an historical point of view. For, in fact, it is what led to their discovery. Titius of Wittenburg, about the middle of the eighteenth century, noticed a curious relation between the distances from the Sun of the then known planets. It consisted in a sort of regular progression, but with one significant gap. Bode was so struck by the gap that he peopled it with a supposed planet, and so brought the relation into general regard in 1772. In consequence, it usually bears his name. It is this: if we take the geometrical series, 3, 6, 12, 24, 48, 96 and add 4 to each term, we shall represent to a fair degree of precision the distances of the several planets, beginning with Mercury at 4 and ending with Saturn at 100, which was the outermost planet then known. All the terms were represented except 24 + 4, or 28 — a gap lying between Mars and Jupiter. When Uranus was discovered by Sir William Herschel in 1781 and was found to be travelling at what corresponded to the next outer term 192 + 4, or 196, the opinion became quite general that the series represented a real law and that 28 must be occupied by a planet. Von Zach actually calculated what he called its analogical elements, and finally got up in 1800 a company to look for it which he jocularly described as his celestial police. Considering that Bode's law is not a law at all, but a curious coincidence, as Gauss early showed in its lack of precision and in its failure to mark the place of Mercury with any approach to accuracy, and as the discovery of Neptune amply bore out, it was perhaps just in fate that the honor of filling the gap did not fall to any of the "celestial police," but to an Italian astronomer, Piazzi, at the time engaged on a new star chart. An illness of Piazzi caused it to be lost almost as soon as found. In this plight an appeal was made to the remarkable Gauss, just starting on his career. Gauss undertook the problem and devised formulæ by which its place was predicted and the planet itself recovered. It proved to fit admirably the gap. But it had hardly been recovered before another planet turned up equally filling the conditions. Ceres, the first, lay at 26.67 astronomical units from the Sun; Pallas, the second, at 27.72. Two claimants were one too many. But the inventive genius of Olbers came to the rescue. By a bold hypothesis he suggested that since two had appeared where only one was wanted, both must originally have formed parts of a single exploded planet. He predicted that others would be detected by watching the place where the explosion had occurred, to wit: where the orbits of Ceres and Pallas nearly intersected in the signs of the Virgin and the Whale.

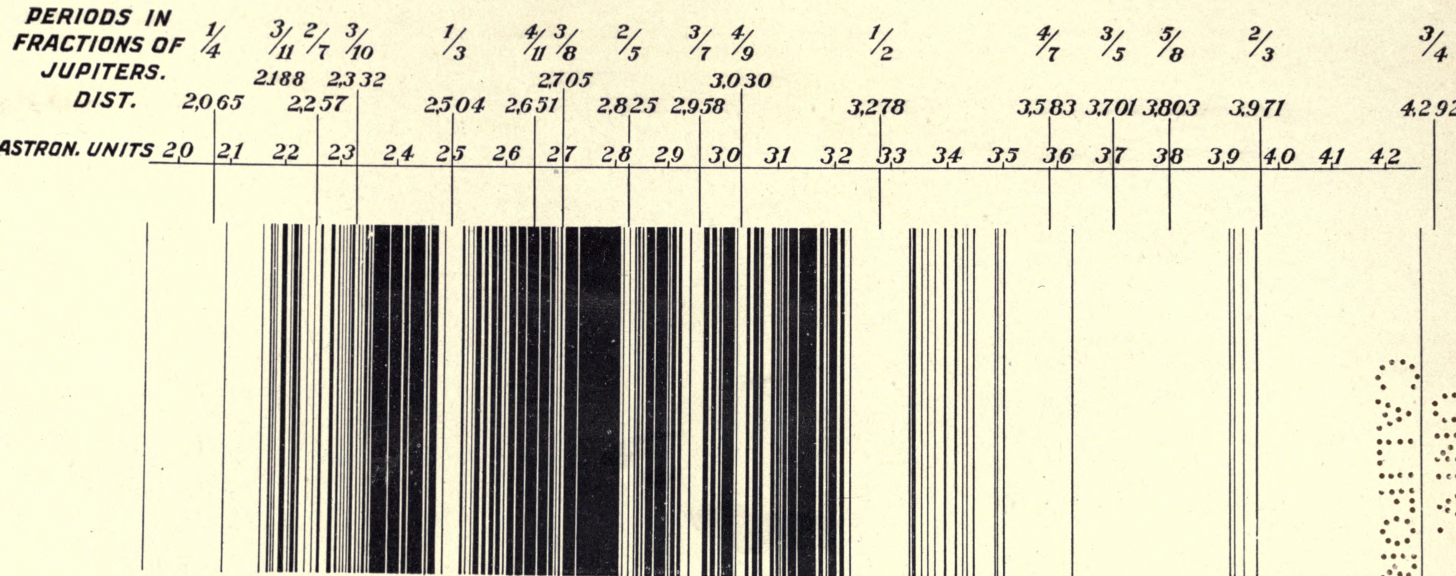
For in the case of an explosion the various parts, unless perturbed, must all return in time to the scene of the catastrophe. By following his precept, two more were in fact detected in the next two years, Juno and Vesta. His hypothesis seemed to be confirmed. No new planets were discovered, and the old fulfilled fairly what was required of them. Lagrange on calculation gave it his mathematical assent.

Nevertheless, it was incorrect, as events eventually showed, though for forty years it slept in peace, no new asteroids being found. We now know that this was because the rest were all much smaller, and for such nobody looked. It was not till 1845 that Hencke, an ex-postmaster of Driessen in Prussia, after fifteen years of search detected another, Astræa, of the 11th magnitude. After this discoveries of them came on apace, until now more than six hundred are known, and their real number seems to be legion. But those discovered are smaller each year on the average, showing that the larger have already been found. Their orbits are such that they cannot possibly ever have all formed part of a pristine whole. The idea, not the body, was exploded. For they are now recognized as having always been much as they are to-day.

They prove to be thickest at nearly the point where Bode's law required, the spot where Ceres and Pallas were found. The mean of their distances is less, being 2.65 instead of 2.8 astronomical units, probably simply because the nearer ones are easier discovered. The fact that they are clustered most thickly just inside 2.8 astronomical units implies that there of all points within the space between Mars and Jupiter a planet would have formed if it could. A definite reason exists for its failure to do so — Jupiter's disturbing presence. Throughout this whole region Jupiter's influence is great; so great that his scattering effect upon the particles exceeds their own tendency to come

ASTEROIDS.

MAJOR AXES OF ORBITS.



P. L. 1907.

together. We see this in the arrangement of the orbits. If we plot the orbits of the asteroids, we shall be struck by the emergence of certain blanks in the ribbon representing sections of their path. It is the woof of a plaid of Jupiter's weaving. The gaps are where asteroids revolving about the Sun would have periods commensurate with his, $\frac{2}{5}$, $\frac{1}{2}$, $\frac{3}{5}$, $\frac{4}{7}$, and the like. Such bodies would return after a few revolutions, five of theirs, for instance, to Jupiter's two, into the same configurations with him at the same points of their orbits. Thus the same perturbation would be repeated over and over again until the asteroid's path was so changed that commensurability ceased to exist. And it would be long before perturbation brought it back again. Thus the orbits are constantly swinging out and in, all of them within certain limits, but those are most disturbed which synchronize with his. In this manner he has fashioned their arrangement and even prevented any large planet from forming in the gap.

Such restrictive action is not only at work to-day in the distribution of the asteroids and in the partitions of Saturn's ring, but it must have operated still more in the past while the system was forming. To Professor Milham of Williamstown is due the brilliant suggestion that this was the force that fashioned the planetary orbits. For a planet once given off from a central mass would exercise a prohibitive action upon any planet trying to form within. In certain places it would not allow it to collect at all. The evolution of the solar family would resemble that of some human ones in which each child brings up the next in turn. So that the planetary system made itself, as regards position, a steadily accumulative set of prohibitions combining to leave only certain places tenantable.

In this manner we may perhaps be brought back to Bode's law as representing within a certain degree of approximation a true mechanical result, although no such exact relation as the law demands exists. That a relation seemingly close to it is necessitated by the several successive inhibitions of each planet upon the next to form, is quite possible.

One other general trait about their orbits is worth animadversion. In spite of being eccentric and inclined, they are all traversed in the same sense. Every one of the asteroids travels direct like the larger planets. In this they differ from cometary paths, which are as often retrograde as direct. Thus in more ways than one they hold a mid-course in regularity between the steady, even character of the planets proper and what was for long deemed the erratic behavior of the cometary class of cosmic bodies. Very telling this fact will be found with regard to the genesis of the solar family, as we shall see later.

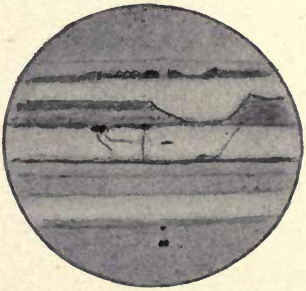
With regard now to their more individual characteristics, the asteroids may be said to agree in one point — their diversity, not only to all the larger members of the solar family, but to one another. For they travel in orbits ranging in ellipticity all the way from such as nearly approach circles to ellipses of cometary eccentricity. They voyage, too, without regard to the dynamical plane of the system, or, what is close to it, the ecliptic; departing from the general level often 30° and, in one instance, that of the little planet dubbed W. D., by as much as 48°. This eccentricity and inclination put them in a class by themselves. It is associated and unquestionably connected mechanically with another trait which likewise distinguishes them from the planets more particularly called — their diminutive size. Only four — Vesta, Ceres, Pallas, and Juno — out of the six hundred odd now known exceed a hundred miles in diameter, and the greater number are hardly over ten or twenty miles across. Very tiny worlds indeed they would seem, could we get near enough to them to discern their forms and features. Curiously enough, reasoning on certain light changes they exhibit has enabled us to divine something of their shapes, and even character. Thus it was soon perceived that Eros fluctuated in the light he sent us, being at times much brighter than at others. In February and March, 1901, the changes were such that their maximum exceeded three times their minimum two hours and a half later. Then in May the variation vanished. More than one explanation has been put forward, but the best so far, because the most simple, is that the body is not a sphere but a jagged mass, a mountain alone in space, and that as it turns upon its axis first one corner and then another is presented to our view or throws a shade upon its neighbor. When the pole directly faces us, no great change occurs, especially if it also nearly faces the Sun. Yet even this fails to explain all its vagaries.

Eros is not alone in thus exhibiting variation. Sirona, Hertha, and Tercidina have also shown periodic variability, and it is suspected in others. Indeed, it would be surprising did they not show change. For they are too small to have drawn their contents into symmetry, and so remain as they were when launched in space. Mammoth meteorites they undoubtedly are.

With the asteroids we leave the inner half of the Sun's retinue and pass to the outer. Indeed, the asteroids not only mark in place the transition bound between the two, but stamp it such mechanically. In their own persons they witness that no large body was here allowed to form. The culmination of coalition was reached in Jupiter, and that very acme of accretion prevented through a long distance any other.

In bulk, the major planets compared with the inner or terrestrial ones form a class apart; and among the major

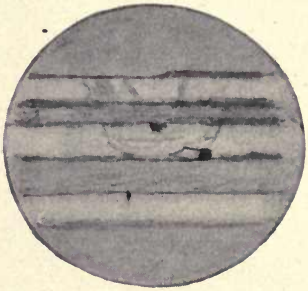
Jupiter is by all odds first. His mass is 318 times the Earth's and his volume nearly 1400 times hers. From this it appears that his density is very much less. Indeed, his substance is only fractionally denser than water. This and its tremendous spin, carrying a point at its equator two hundred and eighty thousand miles round in less than ten hours, flatten it to a very marked oval with an ellipticity of $\frac{1}{15.5}$. Not the least beautiful of the revelations of astronomy are the geometrical shapes of the heavenly bodies, proceeding from nearly perfect spheres like the Sun or Moon to marked spheroids like Jupiter or Saturn. So enormous are the masses and the forces concerned that the forms assumed under them are mechanically regular. They are the visible expression of gravitation, and so delight the brain while they satisfy the eye.



DRAWING OF JUPITER BY DR. LOWELL. APRIL 12, 1907.

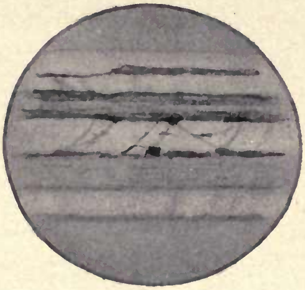
It is to appreciation of the detail visible on Jupiter's disk that modern advance in the study of the planet is indebted. Examination has shown its features to be of great interest. To Mr. Stanley Williams of Brighton, England, much of our knowledge is due, and Mr. Scriven Bolton has also made some interesting contributions. The big print of the subject, read long ago, is that the planet's disk is noticeably banded by dark belts. Two characteristics of these belts are important. One is that they exhibit a regular secular progression with the lapse of years, the south tropical belt being broader and more salient for many years in succession, and then gradually fading out while the northern one increases in prominence. It has been suspected that the rhythm of their change is connected with that of sun spots. The second is that the belts do not preserve in their several features the same relation in longitude toward one another. They all rotate, but at different speeds. There could be no better proof that Jupiter is no solid, but a seething mass of heavy vapors boiling like a caldron. Tempered by distance we can form but a faint idea of the turmoil there going on. Further indication of it is furnished by its glow. For all the dark belts are a beautiful cherry red, a tint extending even to the darkish hoods over the planet's caps. This hue comes out well in good seeing, and best, as with all planetary markings, in twilight, not at night, because the excessive brightness of the disk is then taken off, preventing the colors from being swamped.

This brings us to the planet's albedo, which Müller at Potsdam has found to be 75 per cent. Now the interest attaching to this determination is twofold, that it bespeaks cloud and that it seems to imply something else. The albedo of cloud is 72 per cent of absolute whiteness. What looks like cloud, then, is such, on that distant disk. But Jupiter surpasses cloud in lustre, since his albedo exceeds 72 per cent. Yet a large part of his surface is strikingly darker than that. The inference from this is that he shines by intrinsic light, in part at least. The fact may not be stated dogmatically, as there is no astronomic determination so uncertain as this one of determining albedoes, and therefore Herr Müller's results must be accepted with every reserve, but they suggest that Jupiter is still a semi-sun, to be recognized as such by light as well as heat, though his self-luminosity, if it exist at all, can hardly exceed a dull red glow.



I.

JUPITER AND ITS WISPS. — A DRAWING BY DR. LOWELL, APRIL 11, 1907.



II.

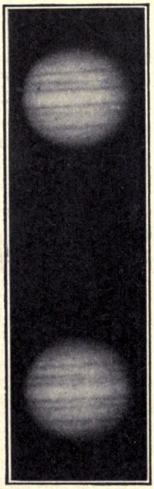
JUPITER AND ITS WISPS. — A DRAWING BY DR. LOWELL, APRIL 11, 1907.

A modern detection on Jupiter's disk has been that of wisps or lacings across the bright equatorial belt, a detail of importance due to Mr. Scriven Bolton.

Requested to look for them, the observatory at Flagstaff was not long in corroborating this interesting phenomenon. The peculiarity about them pointed out by Mr. Bolton is that they traverse the belt at an angle of about 45° to the vertical, proceeding from caret-shaped dark spots projecting into the bright belt from the dark ones on either side. They exist all round the equator and are found indifferently dextrous or sinister—sometimes vertical. For there are others that go straight across. Nor are they confined to the bright equatorial belt, but are to be seen traversing all of the bright belts both north or south up to the polar hoods. From its sombreness it seems that we are here regarding a phenomenon in the negative; remarking it by what it has left behind, not by what it has accomplished. For the wisps are not wisps of cloud, since they are dark, not light, but gaps strung out in the clouds themselves.

Recently photographs of Jupiter have been secured at Flagstaff, by the new methods there of planetary photography, showing a surprising amount of detail. The wisps come out with certainty, and the white spots, which are such a curious feature of the disk, have also left their impress on the plate. Not the least of the services thus rendered by the camera is the accurate positioning of the belts made possible by it. Micrometric measures are all very well when nothing better is attainable, but any one who has made such upon a planet's disk swinging like a lantern in the field of view under a variety of causes instrumental and optical, knows how encumbered they inevitably are with error. To have the disk caught and fixed on a plate where it may be measured at leisure and as often as one likes, is a distinct advance toward fundamental accuracy. Measures thus effected upon the Jupiter images of 1909 proved the bright equatorial belt to lie exactly upon the planet's equator when allowance was made for the tilt of the planet's axis toward the Earth. This showed that the aspect of the planet toward the Sun had no effect upon the position of the belt. Jupiter's cloud formation, therefore, is not dependent, as all ours are, upon the solar heat.

S.



N.

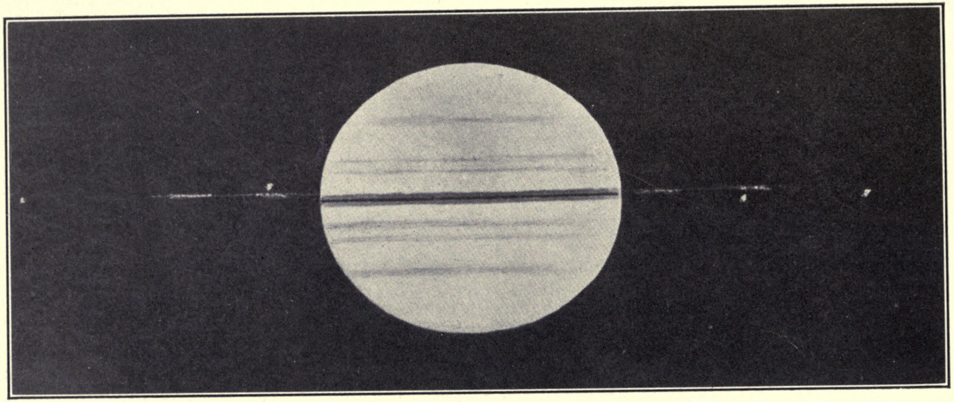
PHOTOGRAPH OF JUPITER, 1909.
P. L.

A like indifference to solar action is exhibited in the utter obliviousness of the belts to day or night. To them darkness and light are nugatory alike. They reappear round the sunrise edge of the disk just as they left it when they sank from sight round the sunset one, and they march across its sunlit face without so much as a flicker on their features.

Yet this seeming immobility from moment to moment takes place in what is really a seething furnace, the fiery glow of which we catch below the vast ebullition of cloud in the cherry hue of its darker portions. Distance has merged the turmoil into the semblance of quiescence and left only its larger secular changes to show. Even so the Colorado River from the brink of the Grand Cañon is seen apparently at rest, the billows of its rapids so stereotyped to stability one takes the rippled sand bank for the river and the billows of the river for the ripple marks of its banks.

At twice the distance of Jupiter we cross the orbit of Saturn. Here the ringed planet, with an annual sweep of twenty-nine and a half of our years, pursues his majestic circuit of the Sun. Diademed with three or more circlets of light and diamonded by ten satellites, he rivals in his cortège that of his own lord. In some ways his surpasses the Sun's. For certainly his retinue is the more spectacular of the two; the more so that it is much of it fairly comprised within a single glance. Very impressive Saturn is as, attended thus, he sails into the field of view.

In our survey we may best begin with his globe. If Jupiter's compression is striking, Saturn's is positively startling when well displayed. This happens but at rare intervals. As the plane of his equator is almost exactly that of the rings, the flattening is conspicuous only on those occasions when the rings disappear because their



Saturn — A drawing by Dr. Lowell, showing agglomerations.

plane passes through the line of sight. Seen at such times the effect of the discrowned orb is so strange as to suggest delusion. This occurred two years ago in 1907, and when the planet was picked up by its position and entered the field unheralded by its distinctive appendage, it was almost impossible to believe there had not been some mistake and a caricatured Jupiter had taken its place. For the flattening outdoes that of Jupiter as 3 to 2, being $\frac{1}{10}$ of the equatorial diameter. Such a bulging almost suggests disruption and is due to the extreme lightness of the planet's substance, which is actually only 0.72 of that of water. Like Jupiter, the disk exhibits belts, though very much fainter, and, like his, these are of a cherry red. As the planet's albedo is even greater, 0.78 of absolute whiteness, as deduced from H. Struve's measures of the diameter, the same suspicion of shining, at least in part, from inherent light, applies equally to him. But it is practically certain that in neither case does this light equal that of the planet's clouds, or add anything to them. Both planets are red-hot, not white-hot. The determination of the albedo depends upon that of the diameter, and an increase in the latter would lower the albedo to that of cloud.

His most unique possession are his rings. Broad, yet tenuous, they weigh next to nothing, being, as Struve has dubbed them, "Immaterial light." Nevertheless, it is not their lightness but their make-up that prevents from lying uneasy the head that wears this crown.

The mechanical marvel was not appreciated by early astronomers, who took it for granted that they were what they seemed, solid, flat rings, all of a piece. Even Laplace considered it sufficient to divide them up concentrically to insure stability. To Edouard Roche of Montpellier, as retiringly modest as he was penetratingly profound, is due the mathematical detection that to subsist they must be composed of discrete particles, — brickbats, Clerk Maxwell called them, when, later, unaware of Roche's work, he proved independently the same thing in his essay on Saturn's rings. Peirce, too, in ignorance of Roche, had half taken the same step a little before, showing that they must at least be fluid. Then in 1895 Keeler ingeniously photographed the spectrum of both ball and rings to the revealing of velocities in the line of sight of the different portions of the spectrum exactly agreeing with the values mechanics demanded.

The rings have usually been considered to be flat. At the time of their disappearance, however, knots have been seen upon them. It is as if their filament had suddenly been strung with beads. At the last occurrence of the sort in 1907, these beads were particularly well seen at several observatories, and were critically studied at Flagstaff. In connection with a new phenomenon detected there, that of a dark core in the shadow the rings threw across the planet's face, an explanation suggested itself to account for both them and it: to wit, that the rings were not really flat, but tores; rings, that is, like an anchor ring, any cross-section of which would be of the nature of an oval flattened on its inner side. The cogency of the explanation consisted in its solution not only of the appearances but of the cause competent to bring those appearances about.

For measurement showed that the knots were permanent in position, which, since the ring revolved, indicated that they extended all round it in spite of their not seeming to do so, and that their distances from Saturn were just what this cause should produce.

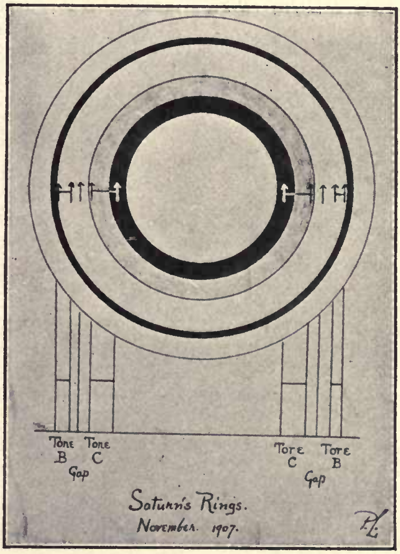
The action observed was a corollary from the important principle of commensurability of orbital period. As we saw in the case of the asteroids, if two bodies be travelling round a third and their respective periods of revolution be commensurate, they will constantly meet one another in such a manner that great perturbation will ensue and the bodies be thrown out of commensurability of period.

What has happened to the asteroids has likewise occurred in Saturn's rings. The disturber in this case has been, not Jupiter, as with them, but one or other of Saturn's own satellites. For when we calculate the problem, we find that Mimas, Enceladus, and Tethys have periods exactly commensurate with the divisions of the rings; in other words, these three inner satellites, whose action because of proximity is the greatest, have fashioned the rings into the three parts we know, called A, the outermost; B, the middle one; and C, the crêpe ring, nearest to the body of the planet. Mimas has been the chief actor, though helped by the two others, while Enceladus has further subdivided ring A by what is known as Encke's division.

Such has been the chief action of the satellites on the rings: it has made them into the system we see. But if we consider the matter, we shall realize that a secondary result must have ensued — when we remember that the particles composing the rings must be very crowded for the rings to show as bright as they do, and also that, though relatively thin, the rings are nevertheless some eighty miles through.

Now it is evident that any disturbance in so closely packed a system of small bodies as that constituting Saturn's rings must result in collisions between the bodies concerned. Particles pulled out or in must come in contact with others pursuing their own paths, and as at each collision some energy is lost by the blow, a general falling in toward the planet results. At the same time, as the blow will not usually be exactly in the plane in which either particle was previously moving, both will be thrown more or less out of the general plane of their fellows, and the ring at that point, even if originally flat, will not remain so. For the ring, though very narrow relatively, has a real thickness, quite sufficient for slantwise collision, if the bodies impinge.

Now the knots or beads on the rings appeared exactly inside the points where the satellites' disturbing action is greatest, or, in other words, in precisely their theoretic place. We can hardly doubt that such, then, was their origin.*

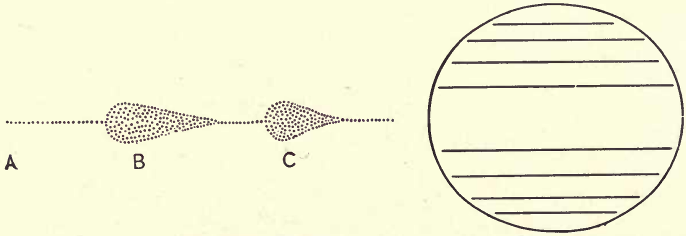


The result must be gradually to force the particles as a rule nearer the planet, until they fall upon its surface, while a few are forced out to where they may coalesce into a satellite, — a result foreseen long ago by Maxwell. It is this process which in the knots we are actually witnessing take place, and which, like the corona about

* Paper by the writer in the *Phil. Mag.*, April, 1908.

the eclipsed Sun, only comes out to view when the obliterating brightness of the main body of the rings is withdrawn by their edgewise presentation.

The reason the out-of-plane particles are most numerous just inside the point of disturbance is not only that there the action throwing them out is most violent, but that all the time a levelling action quite apart from disturbance is all the time tending to reduce them again to one plane, as we shall see further on when we come to the mechanical forces at work. Thus the tore is most pronounced on its outer edge, and falls to a uniform level at its inner boundary. The effect is somewhat as represented in the adjoining cut, in which the vertical scale is greatly magnified: —



THE TORES OF SATURN. Not drawn to scale.

With Saturn ended the bounds of the solar system as known to the civilized world until 1781. On March 13 of that year Sir William Herschel in one of his telescopic voyages through space came upon a strange object which he at once saw was not a star, because of its very perceptible round disk, and which he therefore took for a peculiar kind of comet. Nearly a year rolled by before Lexell showed by calculation of its motion that it was no comet, but undoubtedly a new planet beyond Saturn travelling at almost twice that body's mean distance from the Sun.

By reckoning backward, it was found to have been seen and mapped several times as a star, — no less than twelve times by Lemonnier alone, — and yet its planetary character had slipped through his fingers. It can even be seen with the naked eye as a star of the 6th magnitude, and its course is said to have been watched by savage tribes in Polynesia long before Sir William Herschel discovered it.

Its greenish blue disk indicates that it is about thirty-two thousand miles in diameter, and its mass that its density is about 0.22 of the Earth's or, like Jupiter's, somewhat greater than water. Of its surface we probably see nothing. Indeed, it is very doubtful if it have any surface properly so called, being but a ball of vapors. Its flattening, $\frac{1}{11}$ according to Schiaparelli, which is probably the best determination, agrees with the density given above, indicating its substance to be very light. Belts have faintly been descried traversing its disk after the analogy of Jupiter and Saturn. These would be much better known than they are but for the great tilt of the planet's axis to the ecliptic, so that during a part of its immense annual sweep its poles are pointed nearly at the Earth, and its tropical features, the places where the belts lie, are wholly hidden or greatly foreshortened from our point of view. As the planet's year is eighty-four of our years long, it is only at intervals of forty odd years that the disk is well enough displayed to bring the belts into observable position.

The planet is attended by four satellites, — Ariel, Umbriel, Titania, and Oberon, — a midsummer night's dream to a watcher of the skies. They travel in a plane inclined 98° to the ecliptic, so that their motion is nearly up and down to that plane and even a little backward. Whether their plane is also the equatorial plane of the planet, we do not know for certain. The observations as yet are not conclusive one way or the other. If the two planes should turn out not to coincide, it will open up some new fields in celestial mechanics. The belts have been thought to indicate divergence, but the most recent observations by Perrotin on them minimize this. They suggest, too, a rotation period of about ten hours, which is what we should expect.

Its albedo, or intrinsic brightness, is, according to Müller, 0.73, or almost exactly that of cloud. This tallies with the lack of pronouncement of the belts and is another argument against the reality of the recent diametral measurements, as all Müller's values are got by dividing the amount of light received by the amount of surface sending it. If the diameter were much less than thirty-two thousand miles, the resulting albedo would become impossibly high.

If we know but little about the actual surface of Uranus, we know now a good deal about its atmosphere. And this partly because atmosphere is almost all that it is. The satellites are the only solid thing in the system. If we needed a telltale that the solar system had evolved, the gaseous constitution of its primaries and the condensed state of their attendants would sufficiently inform us. Probably all the major planets are nothing but gas. It has been debated whether Jupiter be almost all vapor with a solid kernel beneath, or vapor entirely. That he grows denser toward the core is doubtless the case, but that he is anywhere other than a gaseous fluid is very unlikely. For if he had really begun to condense, he must have contracted to far within his present dimensions. The same is true of Uranus.

The surprising thing about Uranus is the enormous extent of his atmosphere. The earliest spectroscopists perceived this, but the more spectroscopy advances, the greater and more interesting it proves to be. By pushing inquiry into the red end of the spectrum, hitherto a terra incognita, Dr. Slipher has uncovered a mass of as yet unexplained revelation. Of these remarkable spectrograms we shall speak later. Here it is sufficient to say that so great is the absorption in the red that only the blue and green in anything like their entirety get through; which accounts for the well-known sea-green look of the planet. Furthermore, the spectroscope shows that this atmosphere, or the great bulk of it, must lie above what we see as the contour of the disk. For the spectroscope is as incapable of seeing through opacity as the eye, though it distances the eye in seeing the invisible. It is not what is condensed into cloud, but what is not, of which it reveals the presence. We are thus made aware of a great shell of air enveloping the planet.

In Uranus, then, we see a body in an early amorphous state, before the solid, the liquid, and the gaseous conditions of matter have become differentiate and settled each into distinctive place. Without even an embryo core its substance passes from viscosity to cloud.

Neptune has proved a planet of surprises. Though its orbital revolution is performed direct, its rotation apparently takes place backward, in a plane tilted about 35° to its orbital course. Its satellite certainly travels in this retrograde manner. Then its appearance is unexpectedly bright, while its spectrum shows bands which as yet, for the most part, defy explanation, though they state positively the vast amount of its atmosphere and its very peculiar constitution. But first and not least of its surprises was its discovery, — a set of surprises, in fact. For after owing recognition to one of the most brilliant mathematical triumphs, it turned out not to be the planet expected.

"Neptune is much nearer the Sun than it ought to be," is the authoritative way in which a popular historian puts the intruding planet in its place. For the planet failed to justify theory by not fulfilling Bode's law, which Leverrier and Adams, in pointing out the disturber of Uranus, assumed "as they could do no otherwise." Though not strictly correct, as not only did both geometers do otherwise, but neither did otherwise enough, the quotation may serve to bring Bode's law into court, as it was at the bottom of one of the strangest and most generally misunderstood chapters in celestial mechanics.

Very soon after Uranus was recognized as a planet, approximate ephemerides of its motion resulted in showing that it had several times previously been recorded as a fixed star. Bode himself discovered the first of these records, one by Mayer in 1756, and Bode and others found another made by Flamstead in 1690. These observations enabled an elliptic orbit to be calculated which satisfied them all. Subsequently others were detected. Lemonnier discovered that he had himself not discovered it several times, cataloguing it as a fixed star. Flamstead was spared a like mortification by being dead. For both these observers had recorded it two or more nights running, from which it would seem almost incredible not to have suspected its character from its change of place.

Sixteen of these pre-discovery observations were found (there are now nineteen known), which with those made upon it since gave a series running back a hundred and thirty years, when Alexis Bouvard prepared his tables of the planet, the best up to that time, published in 1821. In doing so, however, he stated that he had been unable to find any orbit which would satisfy both the new and the old observations. He therefore rejected the old as untrustworthy, forgetting that they had been satisfied thirty years before, and based his tables solely on the new, leaving it to posterity, he said, to decide whether the old observations were faulty or whether some unknown influence had acted on the planet. He had hardly made this invidious distinction against the accuracy of the ancient observers when his own tables began to be out and grew seriously more so, so that within eleven years they quite failed to represent the planet.

The discrepancies between theory and observation attracted the attention of the astronomic world, and the idea of another planet began to be in the air. The great Bessel was the first to state definitely his conviction in a popular lecture at Königsberg in 1840, and thereupon encouraged his talented assistant Flemming to begin reductions looking to its locating. Unfortunately, in the midst of his labors Flemming died, and shortly after Bessel himself, who had taken up the matter after Flemming's death.

Somewhat later Arago, then head of the Paris observatory, who had also been impressed with the existence of such a planet, requested one of his assistants, a remarkable young mathematician named Leverrier, to undertake its investigation. Leverrier, who had already evidenced his marked ability in celestial mechanics, proceeded to grapple with the problem in the most thorough manner. He began by looking into the perturbations of Uranus by Jupiter and Saturn. He started with Bouvard's work, with the result of finding it very much the reverse of good. The farther he went, the more errors he found, until he was obliged to cast it aside entirely and recompute these perturbations himself. The catalogue of Bouvard's errors he gave must have been an eye-opener generally, and it speaks for the ability and precision with which Leverrier conducted his investigation that neither Airy, Bessel, nor Adams had detected these errors, with the exception of one term noticed by Bessel and subsequently by Adams.* The result of this recalculation of his was to show the more clearly that the irregularities in the motion of Uranus could not be explained except by the existence of another planet exterior to him. He next set himself to

* Adams, "Explanation of the Motion of Uranus," 1846.

locate this body. Influenced by Bode's law, he began by assuming it to lie at twice Uranus' distance from the Sun, and, expressing the observed discrepancies in longitude in equations, comprising the perturbations and possible errors in the elements of Uranus, proceeded to solve them. He could get no rational solution. He then gave the distance and the extreme observations a certain elasticity, and by this means was able to find a position for the disturber which sufficiently satisfied the conditions of the problem. Leverrier's first memoir on the subject was presented to the French Academy on November 10, 1845, that giving the place of the disturbing planet on June 1, 1846. There is no evidence that the slightest search in consequence was made by anybody, with the possible exception of the Naval Observatory at Washington. On August 31 he presented his third paper, giving an orbit, mass, and more precise place for the unknown. Still no search followed. Taking advantage of the acknowledging of a memoir, Leverrier, in September, wrote to Dr. Galle in Berlin asking him to look for the planet. The letter reached Galle on the 23d, and that very night he found a planet showing a disk just as Leverrier had foretold, and within 55′ of its predicted place.

The planet had scarcely been found when, on October 1, a letter from Sir John Herschel appeared in the *London Athenæum* announcing that a young Cambridge graduate, Mr. J. C. Adams, had been engaged on the same investigation as Leverrier, and with similar results. This was the first public announcement of Mr. Adams' labors. It then appeared that he had started as early as 1843, and had communicated his results to Airy in October, 1845, a year before. Into the sad set of circumstances which prevented the brilliant young mathematician from reaping the fruit of what might have been his discovery, we need not go. It reflected no credit on any one concerned except Adams, who throughout his life maintained a dignified silence. Suffice it to say that Adams had found a place for the unknown within a few degrees of Leverrier's; that he had communicated these results to Airy; that Airy had not considered them significant until Leverrier had published an almost identical place; that then Challis, the head of the Cambridge Observatory, had set to work to search for the planet but so routinely that he had actually mapped it several times without finding that he had done so, when word arrived of its discovery by Galle.

But now came an even more interesting chapter in this whole strange story. Mr. Walker at Washington and Dr. Petersen of Altona independently came to the conclusion from a provisional circular orbit for the newcomer that Lalande had catalogued in the vicinity of its path. They therefore set to work to find out if any Lalande stars were missing. Dr. Petersen compared a chart directly with the heavens to the finding a star absent, which his calculations showed was about where Neptune should have been at the time. Walker found that Lalande could only have swept in the neighborhood of Neptune on the 8th and 10th of May, 1795. By assuming different eccentricities for Neptune's orbit under two hypotheses for the place of its perihelion, he found a star catalogued on the latter date which sufficiently satisfied his computations. He predicted that on searching the sky this star would be found missing. On the next fine evening Professor Hubbard looked for it, and the star was gone. It had been Neptune.*

This discovery enabled elliptic elements to be computed for it, when the surprising fact appeared that it was not moving in anything approaching the orbit either Leverrier or Adams had assigned. Instead of a mean distance of 36 astronomical units or more, the stranger was only at 30. The result so disconcerted Leverrier that he declared that "the small eccentricity which appeared to result from Mr. Walker's computations would be incompatible with the nature of the perturbations of the planet Herschel," as he called Uranus. In other words, he expressly denied that Neptune was his planet. For the newcomer proceeded to follow the path Walker had computed. This

* Proc. Amer. Acad., Vol. I, p. 64.

was strikingly confirmed by Mauvais' discovering that Lalande had observed the star on the 8th of May as well as on the 10th, but because the two places did not agree, he had rejected the first observation, and marked the second as doubtful, thus carefully avoiding a discovery that actually knocked at his door.

Meanwhile Peirce had made a remarkable contribution to the whole subject. In a series of profound papers presented to the American Academy, he went into the matter more generally than either of the discoverers, to the startling conclusion "that the planet Neptune is not the planet to which geometrical analysis had directed the telescope, and that its discovery by Galle must be regarded as a happy accident." * He proved this first by showing that Leverrier's two fundamental propositions, —

1. That the disturber's mean distance must be between 35 and 37.9 astronomical units;

2. That its mean longitude for January 1, 1800, must have been between 243° and 252°, —

were incompatible with Neptune. Either alone might be reconciled with the observations, but not both.

In justification of his assertion that the discovery was a happy accident, he showed that three solutions of the problem Leverrier had set himself were possible, all equally complete and decidedly different from

* Proc. Amer. Acad., Vol. I, p. 65 *et seq.*

each other, the positions of the supposed planet being 120° apart. Had Leverrier and Adams fallen upon either of the other two, Neptune would not have been discovered.*

He next showed that at 35.3 astronomical units, an important change takes place in the character of the perturbations because of the commensurability of period of a planet revolving there with that of Uranus. In consequence of which, a planet inside of this limit might equally account for the observed perturbations with the one outside of it supposed by Leverrier. This Neptune actually did. From not considering wide enough limits, Leverrier had found one solution, Neptune fulfilled the other.† And Bode's law was responsible for this. Had Bode's law not been taken originally as basis for the disturber's distance, those two great geometers, Leverrier and Adams, might have looked inside.

This more general solution, as Peirce was careful to state, does not detract from the honor due either to Leverrier or to Adams. Their masterly calculations, the difficulty of which no one who has not had some experience of the subject can appreciate, remain as an imperishable monument to both, as does also Peirce's to him.

* Proc. Amer. Acad., Vol. I, p. 144.

† Proc. Amer. Acad., Vol. I, p. 332.

CHAPTER V

FORMATION OF PLANETS

IN our first two chapters we saw what sign-posts in the sky there are pointing to the course evolution of a solar system probably follows, and secondly, what evidence there is that our system took this road. We now come to a question not so easy to precise, — the actual details of the journey. It is always difficult to descend from a glittering panoramic survey to particular path-finding. The obstacles loom so much larger on a near approach.

Most men shy at decisions and shun self-committal to any positive course, but when it comes to constructing a cosmogony, few at all qualified hesitate to frame one if the old does not suit. The safety in so doing lies in the fact that nothing in particular happens if it refuses to work. Its absurdity is promptly shown up, it is true, by some one else. For there is almost as good a trade in exposing cosmogonies as in constructing them. But no special opprobrium attaches to failure, because everybody has failed, from Laplace down, or up, as you are pleased to consider it. Besides it is really not so easy to do, as one is tempted to believe before his book is published. Then only does the difficulty dawn, with a speed and clarity inversely proportional to the previous relation of the critic to the author. For the author himself is apt to be blind. With the fatal fondness of a parent for his offspring it is rare for the defects to be so glaringly apparent to their perpetrator. At the worst he considers them venial faults which can be glossed away.

Attacking the subject in this judicial spirit, the reader can hardly expect me to satisfy him with a cosmogony entirely home-made, but at best to pursue a happy middle course between creator and critic, advocating only such portions as happen to be my own, while sternly exposing the mistakes of others.

In undertaking the hazardous climb toward the origin of things two qualities are necessary in the explorer: a quick eye for possibilities and a steady head in testing them. Without the discernment to perceive relations no ascent to first principles is possible; and without the support of quantitative criterion, one is in danger of becoming giddy from one's own imagination. Congruities must first hint at a path; physical laws then determine its feasibility.

An eye for congruities is the first essential. For congruity alone accuses an underlying law. It is the analogic that with logic leads to great generalizations. Certain concords of the sort in the motions of the planets were what suggested to Laplace his system of the world. With the uncommon sense of a mathematician he perceived that such accordances were not necessitated by the law of gravitation, and on the other hand, could not be due to chance. The laws of probability showed millions to one against it. One of these happy harmonies was that all the large planets revolved about the Sun in substantially the same plane; another that they all travelled in the same sense (direction). Had they been unrelated bodies at the start, such agreement in motion was mathematically impossible. Their present consensus implied a common origin for all. In other words, the solar system must have grown to be what it is, not started so.

This basic fact we may consider certain. But from it we would fain go on to find out how it evolved. To do so the same process must be followed. Considering, then, our solar system from this point of view, one cannot but be struck by some further congruities it presents. These are not quite those that inspired Laplace, because of discoveries since, and demand in consequence a theory different from his.

The out about constructing a theory is that fresh facts will come along and knock for admission after the door is shut. They prove irreconcilables because they were not consulted in advance. The consequence is that since Laplace's time new relations have come to light, and some supposed concords have had to be given up; so that were he alive to-day he would himself have formulated some other scheme. Two, however, are still as true: that the planets all revolve in the same plane and in the same sense, and that sense that of the Sun's rotation. But so general a congruity as this points only to an original common moment of momentum and is equally explicable however that motion was brought about. It seems quite compatible with an original shock. To say that it was caused by a disruption is simply to go one step farther back than Laplace. If, then, such a catastrophe did occur as the meteorites aver, we may perhaps draw some interesting inferences about it from the present state of the system. In a very close approach such as we must suppose for the disruption, one within Roches' limit of 2.5 diameters, the stranger, supposing him of equal size, would sweep from one side of the former Sun to the other in about two hours, and the brunt of the disrupting pull occur within that time. That the former Sun was rotating slowly seems established by the time, twenty-eight days, it now takes to go round. In which case the orbits of the masses which were to form the planets would all lie in about the same plane,—the plane of the tramp's approach. If there were exceptions, they should be found in the innermost. For such should partake most largely of the Sun's own original rotation and travel therefore most nearly in its plane. And as a fact Mercury, the Benjamin, does differ from the others by revolving in a plane inclined some 7° to their mean, agreeing in this with the Sun's own rotation, with whose plane it was probably originally coincident (digression from it now being due to secular retrogression of the planets' nodes).[4]

From the relations which advance has left unchanged we pass to those phenomena which seemed to present congruities in Laplace's day, but which have since proved void owing to subsequent detection of exceptions. Time prevents my making the catalogue complete, but the reader shall be shown enough to satisfy him of the problem's complexity and to whet his desire for further research — on the part, preferably, of others.

First comes, then, the rotations of the planets upon their axes, which Laplace supposed to be all in the same

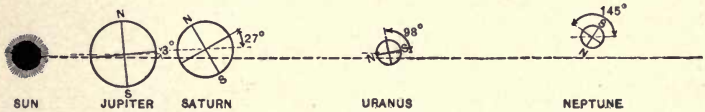
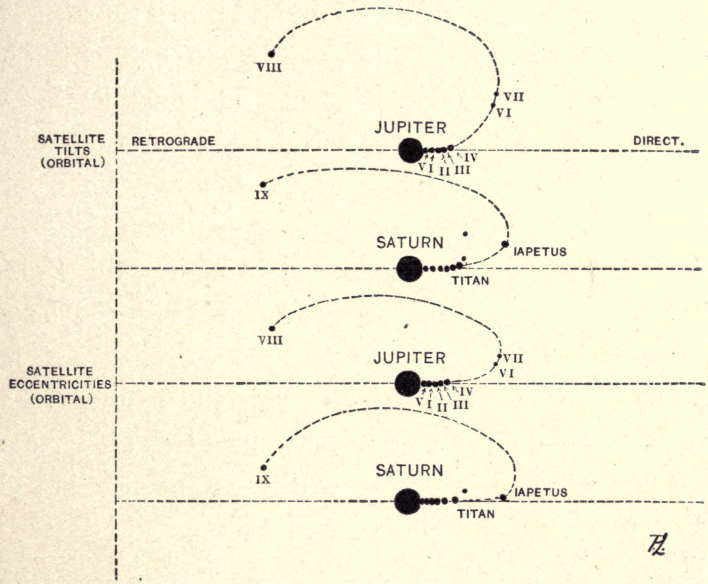


CHART SHOWING INCREASING TILTS OF THE MAJOR PLANETS.

direction, counter to the hands of a clock; for the heavens mark time oppositely from us. All those within and including Saturn, the only ones he knew, turn, indeed, in the same sense that they travel round the Sun. But Uranus departs from that direction by a right angle, wallowing rather than spinning in his orbit; while Neptune goes still farther in idiosyncratic departure and actually turns in the opposite direction. Here, then, Laplace's congruity breaks down, but in its place a little attention will show that a new one has arisen. For Saturn's tilt is 27° and Jupiter's 3°, so that with the major planets there is revealed a systematic righting of the planetary axes from inversion through perpendicularity to directness as one proceeds inward toward the Sun.

Another congruity supposed to exist a century ago was the exemplary agreement of all the satellites to follow in their planetary circuits the pattern set them by their primaries round the Sun. But as man has penetrated farther into space and photographic plates have come to be employed, satellites have been revealed which depart from this orderly arrangement. This is the case with the ninth, the outermost, satellite of Saturn and with the eighth, the outermost, of Jupiter. But, as before, the breaking down of one congruity seems but the establishing of another. It appears that only the most distant satellites are permitted such unconformity of demeanor. For departure from the supposed orthodoxy occurs in both instances where the distance is most, and does not occur in the case of all the other satellites found since Laplace's day, eleven in number, nearer their planets.

A third congruity formerly believed in has suffered a like fate; to wit, that satellites always moved in or near the equatorial plane of their primary. All those first discovered did; the four large ones of Jupiter, the main ones of Saturn, and probably those of Uranus and



Neptune. Even the satellites of Mars conformed. Iapetus alone seemed to make exception, and that by a glossable amount. But this orderliness, too, has been disposed of, only, like the others, to experience a resurrection in a different form.

On examining more precisely the inclinations of these orbits some years ago, an interesting relation between them and the distances of the satellites from their primaries forced itself on my notice. The tilt increased as the distance grew. The only exceptions were very tiny bodies occupying a sort of asteroidal relation to the rest.

A diagram will make this clear. The kernel of it dates from the lectures then delivered before the Massachusetts Institute of Technology in 1901. The interesting thing now about it is that the congruity there pointed out has been conformed to by every satellite discovered since, — the sixth, seventh, and eighth of Jupiter and the ninth and tenth of Saturn. It is evident that we already know enough of the geniture of our system to prophesy something about it and have the prophecy come true.

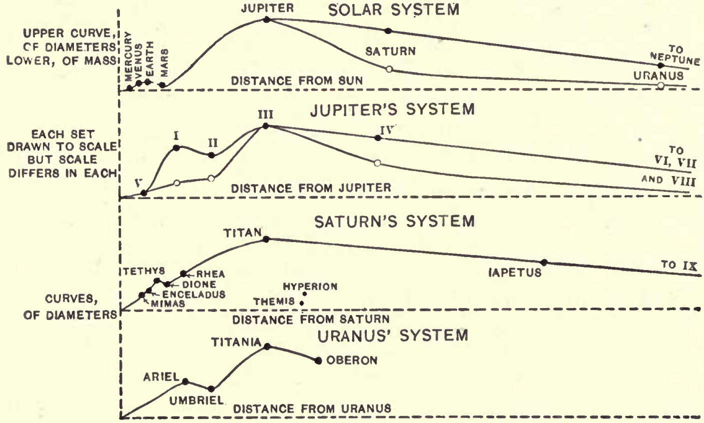
Closely connected with the previous relation is a fourth concordance clearly of mechanical origin, the relation of the orbital eccentricities of the satellites to their distances from their respective planets. The satellites pursue more and more eccentric orbits according as they stand removed from planetary proximity.

A fifth congruity is no less striking. All the satellites of all the planets that we can observe well enough to judge of turn the same face always to their lords. That the Moon does so to the Earth is a fact of everyday knowledge, and the telescope hints that the same respectful regard is paid by Jupiter's and Saturn's retinues to them. What is still more remarkable, Mercury and Venus turn out to observe the like vassal etiquette with reference to the Sun. And it will be noticed that they stand to him the nearest of his court. Here, then, is a law of proximity which points conclusively to some well-established force.

Last is a remarkable congruity which study disclosed to me likewise some years ago, and which has received corroboration in discoveries since. This congruity is the peculiar arrangement of the masses in the solar system.

Consider first the way in which the several planets, as respects size, stand ordered in distance from the sun. Nearest to him is Mercury, the smallest of all the principal ones. Venus and the Earth follow, each larger than the last; then comes Mars, of distinctly less bulk, and so to the asteroids, of almost none. After this the mass rises again to its maximum in Jupiter, and then subsequently falls through Saturn to Uranus and Neptune. Here we mark a more or less regular gradation between mass and position, a curve in which there are two ups and downs, the outer swell being much the larger, though the inner, too, is sufficiently pronounced.

Now turn to Saturn and his family, which is the most numerous of the secondary systems and that having the greatest span. Under Saturn's wing, as it were, is the ring, itself a congeries of tiny satellites. Then comes Mimas, the smallest of the principal ones; then Enceladus, a little larger; then Tethys, the biggest of the three. Next stands Dione, smaller than Tethys. Then the mass increases with Rhea, reaching its culmination in Titan, after which it declines once more. Strangely reproductive this of the curve we marked in



MASSES OF PLANETS AND SATELLITES.

the arrangement of the planets themselves, even to the little inner rise and fall.

Striking as such analogous ordering is, it is not all. For, scanning the Jovian system, we find the main curve here again; Ganymede, the Jupiter or Titan of the system, standing in the same medial position as they. Lastly, taking up Uranus and his family of satellites, the same order is observable there. Titania, the largest, is posted in the centre.

Thus the order in which the little and the big are placed with reference to their controlling orb is the same in the solar system and in that of every one of its satellite families. Method here is unmistakable. Nor is it easy to explain unless the cause in all was like. That the rule in the placing of the planets should be faithfully observed by them in the ordering of their own domestic retinues, is not the least strange feature of the arrangement. It argues a common principle for both. Not less significant is the secondary hump in their distribution, denoting recrudescence farther in of the primary procedure shown without.

One point to be particularly noticed in these latter-day congruities is that they are not simply general concords like the older ones — the fact that the planets move in one plane or in the same sense in that plane — but detailed placings, ordered according to the distances of the planets from the Sun or of the satellites from the planets. They are thus not simply of the combinative but of the permutative order of probabilities, a much higher one; in other words, the chance that they can be due to chance is multiplicately small. Thus just as these analogies are by so much more remarkable, so are they by so much more cogent. They tell us not only of an evolution, but they speak of the very manner of its work. They do not simply generalize, they specify the mode of action. The difficulty is to understand their language. It is a case of celestial hieroglyphics to which we lack the key.

In attempting now to discover how all this came about we notice first that the system could not have originated in the beautifully simple way suggested by Laplace, because of several impossibilities in the path. If rings were shed, as he supposed, from a symmetric contracting mass, they should have resulted in something even more symmetric than we observe to-day. In the next place they could not, it would appear, even if formed, have collected into planets.

Nor could there have been an original "fire-mist" with which as a stock in trade Laplace thriftily endowed his nebula to start with — the necessity for which has been likened to our supposed descent from monkeys; but which in truth is as misty a conception of the facts in the one case as it is a monkeying with them in the other. Darwin's theory distinctly avers that we were *not* descended from monkeys; and Laplace's fire-mist under modern examination evaporates away. It is an interesting outcome of modern analysis that the very fact which suggested the annular genesis of planets to Laplace, the rings of Saturn, should now probably be deemed a striking instance of the reverse. Far from its being an exemplar in the heavens of the pristine state of the solar system, we may now see in it a shining pattern of how the devolution of bodies comes about. For instead of typifying an unfortunate set of particles which untoward circumstance has prevented from coalescing into a single orb, it almost certainly represents the distraught state to which a once more compact congeries of them has been brought by planetary interference. For to just such fate must the stresses in it caused by Saturn have eventually led. Disruption inevitable to such a group the observation of comets demonstrates is daily taking place. When a comet passes round the Sun or near a planet, the partitive pulls of the body tend to dismember it, and the same is *a fortiori* true of matter circulating round a planet as relatively near as the meteoric particles that constitute Saturn's rings. Starting as a congeries, it was pulled out more and more into a ring until it became practically even throughout. And the very action that produced it tends to keep it as surprisingly regular as we note to-day.

No, the planets probably were otherwise generated and may have looked in their earlier stages as the knots in the spiral nebulæ do to-day. But this does not mean that we can detail the process.[5]

Taking now the congruities for guide, we proceed to see what they affirm or negative. Laplace, when he ventured on his exposition of the system of the world, did so "with the mistrust which everything which is not the direct outcome of observation or calculation must inspire." To all who know how even figures can lie this caution will seem well timed. The best we can do to keep our heads steady is to lay firm hold at each step on the great underlying principles of physics. One of these is the conservation of the moment of momentum. This expression embodies one of the grandest generalizations of cosmic mechanics. The very phrase is fittingly sonorous, with something of that religious sublimity which the dear old lady said she found such a consolation in the biblical word Mesopotamia. Indeed the idea is grand for its very simplicity. Momentum means the quantity of motion in a body. It is the speed into the number of particles or the mass. Moment of momentum denotes the rotatory power of it round an axis. Now the curious and interesting thing about this quantity is that it can neither be diminished nor increased. It is an abstraction from which nothing can be abstracted — but results. It is the one unalterable thing in a universe of change. What it was in the beginning in a system, that it forever remains. Because of this unchangeableness we can use it very effectively for purposes of deduction. One of these is in connection with that other great principle of physics, the conservation of energy. By the mutual action of particles on one another, by contraction, by tidal pulls, and so on, some energy of motion is constantly being changed into heat and thus dissipated away. Energy of motion, therefore, is slowly being lost to the system, and the only stable state for the bodies composing it is when their energy of motion has decreased to the minimum consistent with the initial moment of momentum. This principle we shall find very fecund in its application. It means that our whole system is evolving in a way to lessen its energy of motion while keeping its quantity of motion unchanged. The universe always does a thing with the least possible expenditure of force and gets rid of its superfluous energy by parting with it to space. Philosophers may wrangle over its being the best possible of worlds, but it is incontrovertibly mechanically the laziest, which a pessimistic friend of mine says proves it the best.

Now this generalization finds immediate use in explaining certain features of the solar system. In looking over the congruities it will be seen that deviation from the principal plane of the system or departure from a circular orbit is always associated with smallness in size. The insignificant bodies are the erratic ones. Now it has been shown mathematically in several different ways that when small particles collect into a larger mass, the collisions tend to make the resultant orbit of the combination both more circular and more conformant to the general plane than its constituents. But we may see this more forthrightly by means of the general principle enunciated above. For in fact both results are direct outcomes of the conservation of moment of momentum. Given a certain moment of momentum for the system, the total energy of the bodies is least when they all move in one plane. This is evident at once because the components of motion at right angles to the principal plane add nothing to the moment of momentum of the system. It is also least when the bodies all revolve in circles about the centre of gravity. The circle has some interesting properties which almost justify the regard paid to it by the ancients as the only perfect figure. It encloses the maximum area for a given periphery, so that according to the old legends, if one were given as much land as he could enclose with a certain bull's hide, he should, after cutting the hide into strips, arrange these along the circumference of a circle. Now this property of the circle is intimately connected with the fact that a body revolving in a circle has the greatest moment of momentum for the least expenditure of energy. For under the same central force all ellipses of the same longest diameters — major axes these are technically called — are described in the same time, and with the same energy, and of all such, the circle encloses the greatest area, which area measures the moment of momentum.[6]

Given a certain moment of momentum, then the energy is least when the bodies all move in one plane and all travel in circles in that plane. As energy is constantly being dissipated while any alteration among the bodies is going on, to coplanarity and circularity of path all the bodies must tend, if by collision they be aggregated into larger masses. As in the present state of our system the small bodies travel out of the general plane in eccentric ellipses while the big ones travel in it in approximate circles, the facts indicate that the origin of the larger masses was due to development by aggregation out of smaller particles.

The next principle is of a different character. Half a century ago celestial mechanics dealt with bodies chiefly as points. The Earth was treated as a weighted point, and so was the Sun. This was possible because a sphere acts upon outside bodies as if all its mass were collected at its centre, and the Sun and many of the planets are practically spheres. But when it came to nicer questions of their present behavior and especially of their past career, it grew necessary to take their shape into account in their mutual effects. One of the results was the discovery of the great rôle played in evolution by tidal action. Inasmuch as the planets are not perfectly rigid bodies, each is subject to tidal deformation by the other, the outside being pulled more than the centre on one side and less on the other. Bodily tides are thus raised in it analogous to the surface tides we see in the ocean, only vastly greater, and these in turn act as a brake on its rotation.

Now the retrograde motions occurring in the outermost parts of all the systems, principal and subsidiary, only and always there: the retrograde rotations of

Neptune and Uranus, the retrograde revolutions of the ninth satellite of Saturn and of the eighth of Jupiter, point to something fundamental. For when we consider that it is precisely in its outer portions that any forces shaping the development of the system have had less time to produce their effect, we perceive that apparent abnormality now is really survival of the original normal state, only to be found at present in what has not been sufficiently forced to change. It suggests that the pristine motion of the constituents of the scattered agglomerations which went to form the planets was retrograde, and that their present direct rotations and the direct revolutions of most of their satellites have been imposed by some force acting since. Let us inquire if there be a force competent to this end, and what its mode of action.

Let us see how tidal action would work. Tidal force would raise bulges, and these, not being carried round with the planet's rotation except to a certain distance, due to viscosity, must necessarily act as brakes upon the planet's spin. In consequence of the friction they would thus exert, energy of motion must be lost. So long, then, as tidal forces can come into play, the energy of the system is capable of decrease. According to the last principle we considered, the system cannot be in stable equilibrium until this superfluous energy is lost or until tidal forces become inoperative, which cannot be till all the bodies in the system turn the same face to their respective centres of attraction.

To see this more clearly, take the case of a retrograde spin of a planet as compared with a direct one. The energy of the planet's spin is the same in both cases, because energy depends on the square of a quantity; to wit, that of the velocity, and is therefore independent of sign. Not so the moment of momentum. For this depends on the first power of the speed, and if positive in the one case, must be negative in the other. The moment of momentum of the whole system, then, is less in the former case, since the moment of momentum of the retrograde rotation must be subtracted from, that of the direct rotation be added to, that of the rest of the system. For a given initial moment of momentum with which the system was endowed at the start, there is, then, superfluous energy in the first state which can be got rid of through reduction to the second. Nature, according to her principles of least exertion, avails herself of the chance of dispensing with it, and a direct rotation results. Sir Robert Ball first suggested this argument.

Tidal action accomplishes the end. In checking up a body rotating contrary to the general consensus of spin, its first effect is to start to turn the axis over. For the body is in dynamical unstable equilibrium with regard to the rest of the system. The righting would continue, practically to the exclusion of any diminution at first of the spin, until the body had turned over in its plane so that the spin became direct. As the force increases greatly with nearness to the Sun, the effect would be most marked on the nearer, and most so on the biggest, bodies. This would account for the otherwise strange gradation from retrograde to direct in the tilts of the axes of the outer planets, and also for the present tilts of all the inner ones.

Related to the initial retrograde rotations of the planets, and in a sense survivals from an earlier state of things, are two of the latest discoveries of motions in the solar system, the retrograde orbital movements of the ninth satellite of Saturn and the eighth of Jupiter. Considered so anomalous as scarcely at first to be believed, it has been stated that they directly contradict the theory of Laplace. This is true; in the same sense and no more in which they directly contradict the contradictor, one of the latest theories. For neither theory has anything to explain them as the result of law. That they cannot be the sport of indifferent chance seems evidenced by their occupying similar external positions in their respective systems. As the product of a law we must regard them, and to find that law we now turn. Suppose the planet originally to have been rotating backward, or in the direction of the hands of a clock. At this time the satellite, which may never have formed a part of its mass, was travelling backward too, according to what we have said. Then under the friction of the tides raised on the planet by the Sun, the planet proceeded to turn over. It continued to do so until it spun direct. During this process there was no passage through zero of its moment of momentum *considered with regard to itself*, and therefore no difficulty on that score of supposing that it successively generated satellites at all degrees of inclination. That its children are of the nature of adopted waifs, Babinet's criterion (1861) would seem to imply. But it must be remembered that the Sun has been slowing up the planet's rotation now for æons. As it turned over, its tidal bulges tended to carry over with it such satellites as it already had. This effect was much greater on the nearer ones, both because they were nearer and because they were much larger than the outer. So that the nearer kept with the planet, the others lagged proportionately behind. This suggests itself to account for the facts, but the subject involves so much that is uncertain that I submit the hypothesis with the distrust which Laplace has so eminently bespoken. I advance in its favor only the three striking facts: that a steady progression in their tilts of rotation is observable from Neptune to Jupiter and a substantially accordant one from Mars to Mercury; secondly, that the satellites turn their faces to their primaries, as likewise do Mercury and Venus to the Sun; and, thirdly, that the orbits of the satellites of all the planets are themselves tilted in accordance with what it would require.[7]

After the axial spins have been made over to the same sense, the second consequence of tidal action in the case of two bodies revolving about their common centre of gravity is to slow down both spins until first the smaller and then the larger turn the same face to each other and remain thus constant ever after. Now such is precisely the pass to which we observe the satellites of the planets have come. All that we can be sure of now turn the same face always to their primary. The Moon was the first to betray her attitude, because the one we can best note. On scrutiny, however, Jupiter's satellites, so far as we can make out, do the like; and Saturn's, too. And a very proper attitude it is, this regard paid to compelling attraction. Thus one of the congruities we noticed stands accounted for. The satellites could hardly have been at first so observant; time has brought about this unfailing recognition of their lords.

Of the peculiar massing of the bodies in the family of the Sun, and the still stranger copying of it in their own domestic circles, little can as yet be said in interpretation. That the planetary families and their ancestral group should agree is not the least strange part of the affair. It shows that none of them was fortuitous, but that at the formation of all some common principle presided, apportioning the aggregations to their proper place. But it is such fine print of the system's history as at present to preclude discernment.

So much for the details we may deduce of the method of our birth. We perceive unmistakably that our solar system grew to be what it is, and that it developed by agglomeration of its previously shattered fragments into the planets we behold to-day, but exactly how the process progressed we are as yet unable to precise. We are, however, as what I have mentioned and tabled show, every day accumulating data which will enable an eventual determination probably to be reached.

From the fact of agglomeration, the essence of the affair, we turn to the traces it has left upon its several offspring.

Just as the continued existence to-day of meteorites *in statu quo* informs us of a previous body from which our nebula sprang; so a physical characteristic of our own earth at the present time shows it to have evolved from that nebula — even though we cannot make out all the steps. Of its having done so, we are far more sure than of how it did.

That primitive man perceived that somewhere below him was a fiery region which was not an agreeable abode, is plain from his consigning to such Tophet those whose religious tenets did not square with his own. That his conception of it was not strictly scientific is evidenced by his not realizing that to bury his enemies was the way to make them take the first step of the journey thither. Indeed, the vindictive venting of his notions clearly indicates their source as volcanic, rather than bred of a general disapproval of a downward descent either in silicates or sin.

It was not till man began to bore into the Earth for metallic or potable purposes that he brought to light the generic fact that it was everywhere hotter as one went down. And this not only in a very regular, but in a most speedy, manner. The temperature increased in a really surprising way 1° F. for every sixty-five feet of descent. As the rise continued unabated to the limit of his borings, becoming very unpleasant at its end, it was clear that at a depth of thirty-five miles even so refractory a substance as platinum must melt, and practically all the Earth except a thin crust be molten or even gaseous.

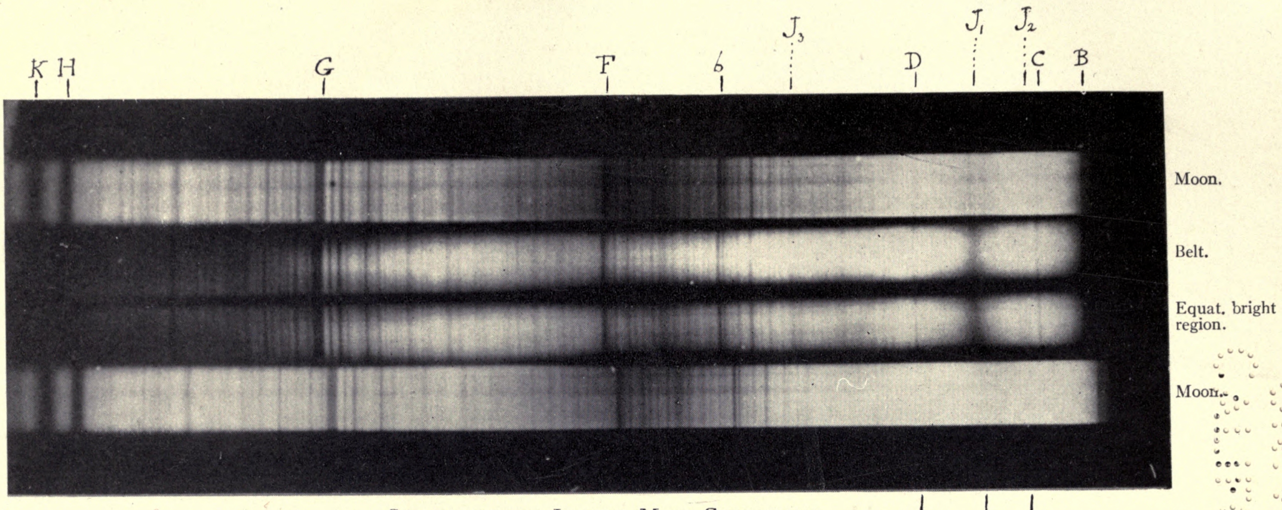
Now heat, like money, is easy to dissipate but hard to acquire, as primitive man was the first to realize. It does not come without cause. Being a mode of motion, other motion must have preceded it from which it sprang. So much the doctrine of the conservation of energy teaches us, a doctrine considered now to have been the great scientific heirloom of the nineteenth century to the twentieth, yet which in its day caused the death of its first discoverer, Mayer, of a broken heart from non-recognition; its second, Helmholtz, was refused publication by the leading Berlin physical magazine of the time. So quick is man to delay his own advance.

The only conceivable motion for thus heating the Earth as a whole was the falling together of its parts. The present heat of the Earth, then, accuses the concourse of particles in the past to its formation, or in other words proves that the Earth was evolved out of material originally more sparcely strewn. It does so not only in a generic but in a most particular manner, for the heat is distributed just where it would be by such a process. It is greater to-day within, increasingly, because when the globe began to cool, the surface necessarily cooled first and established a regular gradient of heat from core to cuticle.

It is possible to test this qualitative inference quantitatively and see if the falling together of the meteorites was equal to the task. Knowing the mechanical equivalent of heat, what we do is to calculate the quantity of motion involved and then evaluate it in heat. As we are unaware of the exact law of density of the Earth, and are ignorant of how much was radiated away in the process, the problem is a little like estimating the fortune of a man when we do not know the stocks in which he has invested, and ignore how much he has spent the while. We only know what he would have been worth had he followed our advice in the matter of investments and lived as frugally as we recommended. For here, too, we are obliged to make certain assumptions. Nevertheless the figure obtained in the case of the planets' stores of heat is so enormous as to leave a most ample margin for dissipation. Had the Earth contracted from a fairly generous expansion to its present state under the probable law of density suggested by Laplace in another connection, the heat developed would have been enough to raise the whole globe to 160,000° F. if of iron, 90,000° F. if of stone. As 10,000° F. would have sufficed for the Earth to have kept up its past, to say nothing of its present, state, we are justified of our deduction.

Nor is the Earth the only body in the system which thus argues itself evolved by the falling together of its present constituents. In the larger planets Jupiter and Saturn we seem to see the heat, far as we are away. For the cherry hue they disclose between their brighter belts proves to come from greater absorption there of the green and blue rays of the spectrum, indicating a greater depth of atmosphere traversed. Thus these parts lie at a lower level, and their ruddy hue is just what they should show were they still glowing with a dull red heat.

Heat is not only the end of the beginning, it is the be-



Spectrogram of Jupiter, Moon Comparison.

Lowell Observatory. V. M. Slipher.

ginning of the end as well. It is both the result of the evolving of definite bodies out of the agglomeration of matter-strewn space, and the cause of the higher evolution of those globes themselves. For the acquisition of heat is the necessary preface to all that follows. Heat is a body's evolutionary capital whose wise expenditure through cooling down makes all further advance to higher products possible. A body too small to have acquired it must remain forever lifeless, as dead as the meteorites themselves that enter our air as mere inert bits of stone or iron.

Curiously enough, heat both must have been and then must have been lost. Like the loss of fortune or of friends sometimes in the ennobling of character, it is through its passing away that its effects are realized. For in cooling down from a once heated condition, that train of events occurs which we most commonly particularize as evolution. So far in our survey the march of advance has been through masses of matter, a molar evolution; from this point on it passes into its minute constituents and becomes a molecular one. The one is the necessary prelude to the other. Up to this great turning-point in the history of each member of a solar system we have been busied with the acquisition of heat, though we may not have been aware of it the while. All the motions we have studied tended to that end. During these three chapters, I, II, V, we have been gradually rising in our point of view until we stand at the temperature pinnacle of the whole process. In the next three we are to descend upon the other side. The slope we have come up was of necessity barren; the one we are to go down brings us to verdure and the haunts of men. Coming from the causes above, we reach at each step effects more and more related to ourselves which those causes will help us to explain.

CHAPTER VI

A PLANET'S HISTORY

Self-sustained Stage

UP to this point in our retrospective survey the long course of evolution has taken one line, that of dynamical separation of the system's parts with subsequent reunitement of them according to the laws of celestial mechanics. Of this action I have submitted the reader my brief: departing in it from common-law practice, in which the cause of action is short and the brief long. And I have, I trust, guarded against his appealing on exceptions.

From this point on we have two kinds of development to follow: the one intrinsic, the chemical; the other incidental, the physical. Not that, in a way, the one is divorcible from the other. For the physical makes possible the chemical by furnishing it the conditions to act. But in another sense, and that which is most thrust upon our notice, the two are independent. Thus oceans and land, hills and valleys, clouds and blue sky, as we know them, — everything, pretty much, which we associate with a world, — are not universal, inevitable, results of planetary evolution, but resultant, individual, characteristics of our particular abode. They are as much our own as the peculiar arithmetic of waiters is theirs, or as used to be the sobriety of the country doctor's horse — his and no other's. Our whole geologic career is essentially earthly. Not that its fundamental laws are not of universal application, but the kaleidoscopic patterns they produce depend on the little idiosyncrasies of the constituents and the mode in which these fall together. Our everyday experiences we should find quite changed, could we alight on Venus or on Mars.

On the other hand, the chemical changes which follow a body's acquisition of heat, setting in the moment that heat has reached its acme and starts to decline, are as universal as the universe itself. They are conditioned, it is true, by the body's size and by the position that body occupied in the primal nebula, but they depend directly upon the degree of heat the body had attained. The larger the planet, the higher the temperature it reached and the fuller its possibilities. Even the planets are born to their estate. Thus the little meteorites live their whole waking life during the few seconds they spend rushing through our air. For then only does change affect their otherwise eternally inert careers. That the time is too short for any important experience is evident on their faces.

Heat is most intimately associated with the very constitution of matter. It is, in fact, merely the motion of its ultimate particles, and plays an essential part in their chemical relations. Just as a certain discreet fervor and sufficient exposure for attraction to take, make for matrimony, so with the little molecules, a suitable degree of warmth and a propitious opportunity similarly conduce to conjunction; too fiery a temperament resulting in a vagabondage preventative of settled partnership and too cold a one in permanent celibacy. You may think the simile a touch too anthropomorphic, but it is a most sober statement of fact. Indeed, it is more than probable that in some dull sense they feel the impulse, though not the need of expressing it in verse. That metals can remember their past states seems to have been demonstrated by Bose, and is certainly in keeping with general principles as we know them to-day. For memory is the partial retention of past changes, rendering those changes more facile of repetition.

A high degree of heat, then, makes chemical union impossible, because the great speeds at which the molecules are rushing past each other prevents any of them being caught. Lack of speed is equally deterrent. Nor is it wholly or even principally, perhaps, a movement of the whole which is here concerned, but a partitive throbbing of the molecule itself. Certain it is that great cold is as prohibitive of chemic combination as great heat. Phosphorus, which evinces such avidity for oxygen at ordinary temperatures as to have got its name from the way it publishes the fact, at very low ones shows a coolness for its affinity amounting to absolute unconcern. Thus only within a certain range of temperature does chemical combination occur. To remain above or below this is to stay forever immortally dead. To get hot enough in the first place, and then subsequently to cool, are therefore essential processes to a body which is to know evolutionary advance.

To pen the history of the solar system and leave out of it all mention of its most transcendentally wonderful result, the chemical evolution attendant upon cooling, would be to play "Hamlet" with Hamlet left out. For the thing which makes the second half of the great cosmic drama so inconceivably grand is the building up of the infinitely little into something far finer than the infinitely great. The mechanical action that first tore a sun apart, and then whirled the fragments into the beautifully symmetric system we behold to-day, is of a grandeur which is at least conceivable; the molecular one that, beginning where the other left off, built up first the diamond and then humanity is one that passes our power to imagine. That out of the aggregation of meteorites should come man, a being able to look back over his own genesis, to be cognizant of it, as it were, from its first beginnings, is almost to prove him immanent in it from the start. Fortunate it is that his powers should seem more limited than his perceptions, and the more so as he goes farther, else he had been but the embodiment of conceit.

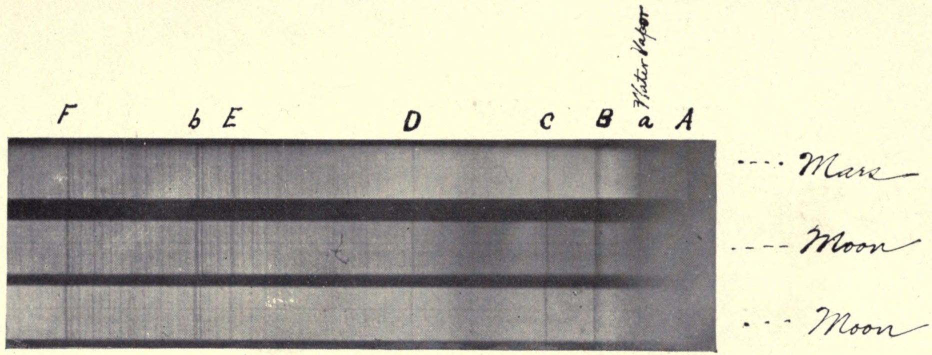
We must sketch, therefore, the steps in this marvellous synthesis; hastily, for I have already spoken of it elsewhere in print and repetitions dull appreciation, — in the appreciative, — though we have the best of precedents for believing that, even in science, to be dull and iterative insures success; the dulness passing for wisdom and the iteration tiring opposition out.

In the Sun all substances are in their elemental state. Though its materials are the same as the Earth's, we should certainly not feel at home there, even if we waived the question of comfort, for we should recognize nothing we know. We talk glibly of elements as if we had personal acquaintance with them, man's innate snobbery cropping out. For to the chemist alone are they observable entities. No one but he has ever beheld calcium or silicon, or magnesium, or manganese, and most of us would certainly not know these everyday elements if we met them on the street. Of all the substances composing the Earth's crust, or the air above, or the water beneath, practically the only elements with which we are personally familiar are iron, copper, and carbon, and these only in minute quantities and in that order of acquisition; which accounts for the stone, iron, and bronze ages of man, ending we may add with the graphite or lead-pencil age of early education.

Yet that elementary substances once existed here we have evidence. We find such in volcanic vents. That the Earth was once as hot on its surface as it now is underneath, we know from the condition of the plutonic rocks where sedimentary strata have not covered them up. Volcanoes and geysers are our only avenues now to that earlier state of things. From these pathways to the past, and only from them, do we find elementary substances produced to-day, — hydrogen, sulphur, chlorine, oxygen, and carbon.* We are thus made aware that once the Earth was simple, too, on the surface as well as deeper down. A side-light, this, to what we knew must have been the case.

From its primordial state, the least complex compounds were evolved first. As the heat lessened, higher and higher combinations became possible. And this is why the more complex molecules are so unstable, the organic ones the most. Since they are not possible at all under much stir of their atomic constituents, it shows that the bond between them must be feeble — and, therefore, easily broken by other causes besides heat. To the instability of the organic molecule is due

* Geikie, "Geology," pages 85, 86, and 131–136.



Lowell Observatory Spectrogram showing water-vapor in the atmosphere of Mars, January 1908.—V. M. Slipher.

its power; and to cooling, the possibility of its expression.

For the steps in the chemical process from Sun to habitable Earth we must look to the spectroscope; not in its older field, the blue end of the spectrum, but in that which is unfolding to our view in Dr. Slipher's ingenious hands, the extension of the observable part of it into the red. For at that end lie the bands due to planetary absorption. Here we have already secured surprising results as to the atmospheres of the various planets. We have not only found positive evidence of water-vapor in the atmosphere of Mars, but we have detected strange envelopes in the major planets which show a constitution different from that of the Sun on the one hand, and of the Earth on the other. That size and position are for much in these peculiarities, I have already shown you; but something, too, is to be laid at the door of age. The major planets are not so advanced in their planetary history as is our Earth; and Dr. Slipher's spectrograms of them disclose what is now going on in that prefatory, childish stage.

These spectrograms are full of possibilities, and it is not too much to say that chemistry may yet be greatly indebted to the stars. Compounds, the strange unknown substances there revealed by their spectral lines, may be cryptic as yet to us. Some of the elements missing in Mendeléeff's table may be there, too. Helium was first found in the Sun; coronium still awaits detection elsewhere. So with these spectral lines of the outer planets. It looks as if chemistry had been a thought too previous in making free for others with what should have been their names, Zenon and Uranium. For we may yet have to speak of Dion and Varunium.

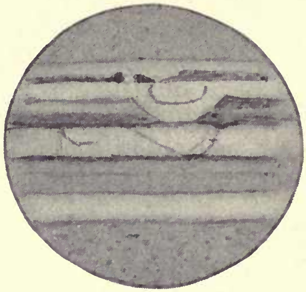
From the chemical aspect of evolution we pass to its physical side; from the indirectly to the directly visible results. Here again, to learn what happened after the sunlike stage, we must turn to the major planets. For the cooling which induced both physical and chemical change has there progressed less far, inasmuch as a large globe takes longer to cool than a small one. To the largest planets, then, we should look for types of the early planetary stages to-day.

Almost as soon as the telescope was directed to Jupiter, among the details it disclosed were the Jovian belts (in the year 1630), dark streaks ruling the planet's disk parallel to its equator. They are of the first objects advertised as visible in small glasses to-day, vying with the craters in the Moon as purchasable wonders of the sky. As the belts were better and better seen, features came out in them which proved more and more interesting. Cassini, in 1692, noticed that the markings travelled round Jupiter and those nearest his equator the quickest. Sir William Herschel thought them due to Jovian trade-winds, the planet's swift rotation making up for deficiency of sun; why, does not appear.

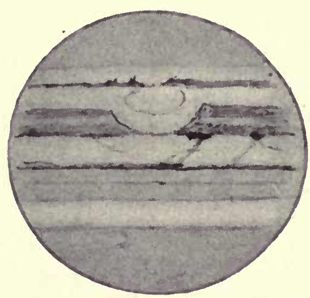
Modern study of the planet shows that the bright longitudinal layers between the dark belts are unquestionably belts of cloud. Their behavior indicates this, and their intrinsic brightness bears it out. For they are of almost exactly that albedo. Whether they are the kind of cloud with which we are familiar, clouds of water-vapor, we are not yet sure. But whatever their constitution, their conduct is quite other than is exhibited by our own.

In the first place, they are of singular permanence for clouds. The fleeting forms we know as such assume in the Jovian air a stability worthy of Jove himself. In their general outlines, they remain the same for years at a time. "Constant as cloud" would be the proper poetic simile there. But while remaining true to themselves, they prove to be in slow, unequal shift with one another. Thus Jupiter's official day differs according to the watch of the particular belt that times it. Spots in different latitudes drift round lazily in appearance, swiftly in fact, those near the equator as a rule the fastest. Nor is there any hard and fast latitudinal law; it is a go-as-they-please race in which one belt passes its neighbor at a rate sometimes of four hundred miles an hour. The mean day is $9^h\ 55^m$ long.

A side-light is cast upon the Jovian state of things by the "great red spot," which has been more or less visible for thirty years, and which takes five minutes longer than the equatorial band to travel round. Its tint bespoke interest in what might be its atmospheric horizon. Yet it betrayed no sign of being either depressed or exalted with regard to the rest of the surface. "In 1891," as Miss Clerke puts it, "an opportunity was offered of determining its altitude relative to a small dark spot on the same parallel, by which, after months of pursuit, it was finally overtaken. An occultation appeared to be the only alternative from a transit; yet neither occurred. The dark spot chose a third. It coasted round the obstacle in its way, and got damaged beyond recognition in the process." It thus astutely refused to testify.

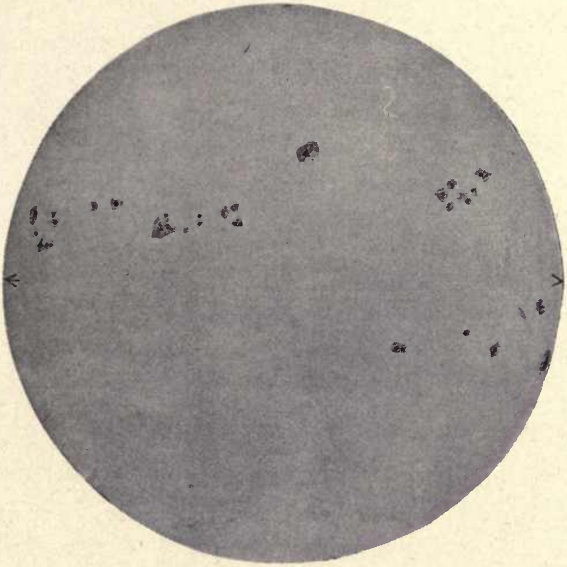


JUPITER AND ITS "GREAT RED SPOT" — A DRAWING BY DR. LOWELL, APRIL 12, $7^h\ 0^m–5^m$, 1907.



JUPITER AND ITS "GREAT RED SPOT" — A DRAWING BY DR. LOWELL, APRIL 12, $7^h\ 28^m–42^m$, 1907.

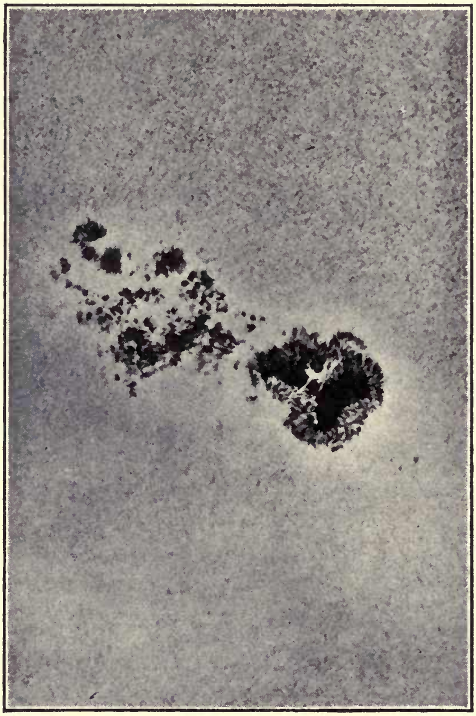
Now, this exclusiveness on the part of the "great red spot" really offers us an insight to its character. Clearly it was no void, but occupied space with more than ordinary persistency. As it was neither above nor below the dark spot and shattered that spot on



SUN SPOTS — AFTER BOND.

approach, which its former surroundings had not done, its force must have been due to motion. This can be explained by its being formed of a vast uprush of heated vapor from the interior. In short, it was a sort of baby elephant of a volcano, or geyser, occurring as befits its youth in fluid, not solid, conditions, but fairly permanent, nevertheless — a bit of kindergarten Jovian geology. This estimate of it is concurred in by Dr.

Slipher's spectrogram of the dark and light belts respectively. For in the spectrum of the dark one we see the distinctive Jovian bands intensified as if the light had traversed a greater depth of Jovian air. Its color, a cherry red, abets the conclusion — that in such places we look down into the fiery, chaotic turmoil so incessantly going on.



PHOTOGRAPH OF A SUN SPOT — AFTER THE LATE M. JANSSEN.

It is of interest to note that we have prototypes of this sort of extraterrestrial cyclone in the Sun. His spots are probably local upsettings of atmospheric equilibrium, using the word atmospheric in the widest possible sense. Just as our storms are the mildest examples of the like expostulation at the impossibility of keeping up a too long continued decorum. Only that with us the Earth is not so much to blame as the Sun; while both Jupiter and the Sun are themselves responsible for their condition.

Thus we have, in the very depth of their negation, warrant from the dark belts of Jupiter that the bright ones are cloud. But also that they are not clouds ordered as ours. The Jovian clouds pay no sort of regard to the Sun. In orbital matters Jupiter obeys the ruler of the system; but he suffers no interference from him in his domestic affairs. His cloud-belts behave as if the Sun did not exist. Day and night cause no difference in them; nor does the Jovian year. They come when they will; last for months, years, decades; and disappear in like manner. They are *sui Jovis*, caused by vertical currents from the heated core and strung out in longitudinal procession by Jupiter's spin. They are self-raised, not sun-raised, condensations of what is vaporized below. Jove is indeed the cloud-compeller his name implies.

Yet Jupiter emits no light, unless the cherry red of his darker belts be considered its last lingering glow. He is thus on the road from Sun to world, and his present appearance informs us that this incubation takes place under cloud.

The like is true of Saturn, in fainter replica, even to the cherry hue. In one way Saturn visibly asserts his independence beyond that possible by Jupiter. For

Jupiter's equator lies almost in the plane of his orbit, and on a hasty view the Sun might be credited with the ordering of the belts, as was indeed long the case. But Saturn's inclination to his orbital plane is 27°; yet his belts fit his figure as neatly as his rings, and never get displaced, no matter how his body be turned.

Uranus and Neptune are in the same self-centred attitude at present as the faint traces of belts on their disk, otherwise of the same albedo as cloud, lead us to conclude. Yet both their densities and their situation give us to believe them further advanced than the giant planets, and still they lie wrapped in cloud.

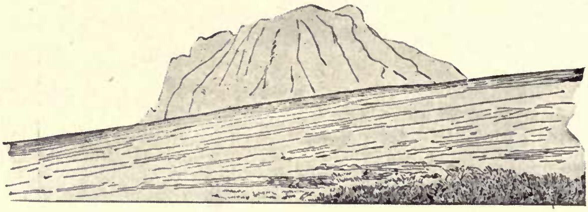
These planets, then, are quite unbeholden to the Sun for all their present internal economies. What goes on under that veil of clouds with which they discreetly hide their doings from the too curious astronomic eye — we can only conjecture. But we discern enough to know that it is no placid uneventfulness. That it will continue, too, we are assured. For whether these clouds are largely water-vapor now, or not, to watery ones they must come as the last of all the wrappers they will eventually put off.

The major planets are the only ones at the present moment in this self-centred and self-sustained stage. Their great size has kept them young. In the smaller terrestrial planets we could not expect to witness any such condition to-day. If they experienced an ebullient youth, they have long since outgrown it. Only by rummaging their past could we find evidence on the point, and this, distance both in time and space bars

THE VOLCANO COLIMA, MEXICO, MARCH 24, 1903 — JOSÉ MARIA ARREOLA, PER FREDERICK STARR.

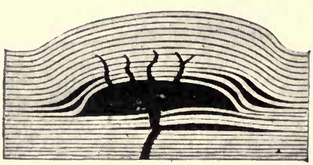
us from doing. There is but one body into whose foretime career we could hope to peer with the slightest prospect of success — our own Earth.

Whether our Earth was ever hot enough at the surface to vaporize those substances which now form the Jovian or Saturnian clouds, we do not know; but that it was once hot enough to vaporize water we are perfectly certain. And this from proof both of what did exist



Jukes Butte, a denuded laccolith, as seen from the northwest — Gilbert.

and of what did not. That the surface temperature was at one time in the thousands of degrees Fahrenheit, the Plutonic magma underlying all the sedimentary rocks of the Earth amply shows. Reversely, the absence of any effect of water until we reach these sedimentary deposits, testifies that during all the earlier stages of the Earth's career water as such was absent, and as water subsequently appeared, it is clear that the conditions did not at first allow it to form. We are sure, therefore, that there was a time when water existed only as steam, and very possibly a period still anterior to that when it did not exist at all, its constituent hydrogen and oxygen not having yet combined. There was certainly an era, then, in the morning of the



Ideal section of a laccolith — Gilbert.

ages, when the Earth wore her cloud-wrapper much as Jupiter his now.

That the seas were not once and yet are to-day, affords proof positive that at some intermediate period they began to be. A very long intermediate one it must have been, too,—all the time it took the Earth to cool from about 2000° C. to 100° C. Not till after the temperature had fallen to the latter figure in the outer regions of the atmosphere could clouds form, and not till it had done so at the solid surface could the steam be deposited as water. Reasoning thus presents us with a picture of our Earth as a vast seething caldron from which steam condensing into cloud was precipitated upon a heated layer of rock, to rise in clouds of steam again. The solid surface had by this time formed, thickening slowly and more or less irregularly, and into its larger dimples the water settled as it grew, deepening them into the great ocean basins of to-day. We see the process with as much certainty and considerably more comfort than if, in the French sense, we had assisted at it. Presence of mind now thus amply makes up for absence of body then.

Passing on evolutionarily we reach more and more tolerable conditions and solid ground in fact, as well as theory. Thus the crust hardened and cooled, while the oceans still remained uncomfortably hot. For water requires much more heat to warm it to a given temperature than rock, about four and a half times as much. It has therefore by so much the more to lose, and is proportionally long in the losing. These hot seas must have produced a small universe of cloud, and as the conditions were the same all over the Earth, we can see easily with the mind's eye that we could not have seen at all with the bodily one, had we occupied the land in those very early days. To be quite shut out from curious sight without, was hardly made up for by not being able to see more than dimly within. Any one who has stood on the edge of a not-extinct crater when the wind was blowing his way, will have as good a realization of the then state of things as he probably cares for.

Now this astronomic drawing of the then Earth, which by its lack of detail allows of no doubt whatever, permits us to offer help in the elucidation of some of their phenomena to our geologic colleagues. We are the more emboldened to do so in that they have themselves appealed to astronomy for diagnosis, and accepted nostrums devised by themselves. It is always better in such cases to call in a regular practitioner. Not that he is necessarily more astute, but that he knows what will not work. It was in the matter of the paleologic climate that they were led to consult astronomy. The singular thing about paleologic times was the combination of much warmth with little light; and the not less singular fact that these conditions were roughly uniform over the whole Earth. From this universality it was clear, as De Lapparent, their chief spokesman, puts it, that nothing local could explain the fact. It was something which demanded a cause common to the globe.

It thus fell properly within the province of astronomy. For if we are to draw any line between the spheres of influence of the two sciences, it would seem to lie where totality ends and provincialism begins. I use this not as a pejorative, but simply to part local color from one universal drab. In the Earth's general attributes, — its size, shape, and weight, — we must have recourse to astronomy to learn the facts. Not less so for those principal causes which have shaped its general career; we surrender it only at the point where everyday interest begins, when those causes that led it through its uninviting youth give way to effects which in the least concern humanity at large.

Between the mere aggregation of matter into planetary bodies, of which nebular hypotheses treat, and the specific transformation of plants and animals upon their surfaces with which organic evolution is concerned, lies a long history of development, which, beginning at the time the body starts to cool, continues till it become, for one cause or another, again an inert mass. In this period is contained its career as a world. Planetology I have ventured to call the brand of astronomy which deals with this evolution of worlds. It treats of what is general and cosmic in that evolution, as geology treats of what is terrestrial and specific in the history of one member of the class, our own Earth. The two do not interfere, as the one faces questions in time and space to which the other remains perforce a stranger. If the picture by the one be fuller of detail, the canvas of the other permits of the wider perspective. Certain events in the history of our Earth can only be explained by astronomy, as geologists have long since recognized. It is these that fall into our present province.

Geologists, however, have applied astronomy according to their own ideas. Either they called in aurists, so to speak, when what they needed was an oculist, or they went to books for their drugs, which they then administered themselves — a somewhat dangerous practice. Thus they began by displacing the Earth's axis in hope of effecting a result; not realizing that this would only shift the trouble, not cure it; in fact, make it rather worse. They next tried what De Lapparent, one of the most brilliant geologists of the age, calls "a variation in the eccentricity of the ecliptic * joined to precession of the equinoxes," — a startling condition unknown to astronomy which does not deal in eccentric planes, whatever such geometric anomalies may be, but by which its coiner evidently means a change in the

* "Abrégé de Geologie," De Lapparent.

eccentricity of the orbit, as the context shows. Its effect on the Earth, as he wisely points out, would be to reduce its extremities to extremes. To get out of his quandary he then embraced a brilliant suggestion of a brother geologist, M. Blandet. M. Blandet conceived the idea, and brought it forth unaided, that all that was necessary was a sun big enough to look down on both poles of the Earth at once. To get this he travelled back to the time when, in Laplace's cosmogony, the Sun filled the whole orbit of Mercury. This conception, which, De Lapparent remarks, "might, at the time of its apparition, have disconcerted spirits accustomed to consider our system as stable," — an apparition which we may add would certainly continue to disconcert them, — he says seems to him quite in harmony with that system's genesis. That it labors under two physical impossibilities, one on the score of the Sun, the other on that of the Earth, and that in this case two negatives do not make an affirmative, need not be repeated here, as the reader will find it set forth at length elsewhere,* together with what I conceive to be the only explanation of paleothermal times which will work astronomically — presently to be mentioned. But before I do so, it is pertinent to record two things that have come to my notice since. One is that in rereading Faye's "Origine du Monde," I came upon a passage in which

* "Mars as the Abode of Life," Macmillan, 1908.

it appears that M. Blandet had actually consulted Faye about his hypothesis, and that Faye had shown him its impossibility on much the same grounds as those above referred to; which, however, did not deter M. Blandet from giving it to the world nor De Lapparent from godfathering the conception.

Faye, meanwhile, developed his theory of the origin of the world, and by it explained the greater heat and lesser light of paleologic times compared with our own, thus: The Earth evolved before the Sun. In paleologic times the Sun was still of great extent, — an ungathered-up residue of nebula that had not yet fallen together enough to concentrate, not a contracting mass from which the planets had been detached, — and was in consequence but feebly luminous and of little heating effect; so that there were no seasons on Earth and no climatic zones. The Earth itself supplied the heat felt uniformly over its whole surface.

This differs from my conception, as the reader will see presently, in one vital point — as to why the Earth was not heated by the Sun. In the first place Faye's sun has no *raison d'être;* and in the second no visible means of existence. If its matter were not already within the orbit of the Earth at the time, there seems no reason why it should ever get there; and if there, why it should have been so loath to condense. We cannot admit, I think, any such juvenility in the Sun at the time

TREE FERN.

the Earth was already so far advanced as geology shows it to have been in paleologic times. For the Earth had already cooled below the boiling-point of water.

To understand the problem from the Earth's point of view, let us review the facts with which geology presents us. The flora of paleologic times, as we see both at their advent in the Devonian and from their superb development in the Carboniferous era, consisted wholly of forms whose descendants now seek the shade.* Tree ferns, sigillaria, equisetæ, and other gloom-seeking plants composed it. That some tree-fern survivals to-day can bear the light does not invalidate the racial tendency. We have plenty of instances in nature of such adaptability to changed conditions. In fact, the dying out and deterioration of most of the order shows that the conditions have changed. And these plants, grown to the dimensions of trees, inhabited equally the tropic, the temperate, and the frigid zones as we know them now. Lastly, no annual rings of growth are to be found on them.† In other words, they grew right on, day in, day out. The climate, then, was as continuous as it was widespread.

On the other hand, astronomy and geology both assert that the seas were warm.‡ From this it follows

* De Lapparent, Dana, Geikie, *passim.*

† De Lapparent.

‡ De Lapparent, Dana, Geikie, *passim.*

that a vastly greater evaporation must have gone on then than now, and that a welkin of cloud must thus inevitably have been formed.

Now put the two facts together, and you have the solution. The climate was warm and equable over the whole globe because a thick cloud envelope shut off the Sun's heat, the heat being wholly supplied from the steamy seas. At the same time, by the same means the light was necessarily so tempered as to produce exactly that half-light the ferns so dearly love. One and the same cause thus answers the double riddle of greater warmth and less light in those old days than is now the case.

And here comes in the second find I spoke of above, in the person of some old trilobites who stepped in unexpectedly in corroboration. It has long been known — though its full significance seems to have escaped notice — that in 1872 M. Barrande made the discovery that many species of trilobites of the Cambrian and lower Silurian, the two lowest, and therefore the oldest, strata of paleozoic times, and distant relative of our horseshoe crabs, were blind. What is yet more significant, the most antediluvian were the least provided with eyes. Thus in the primordial strata, one-fourth of the whole number of species were eyeless, in the next above one-fifth, and in the latest of all one two-hundredth only.* Furthermore, they testify to the difficulty of

* Suess, "The Face of the Earth," p. 213.

seeing, in two distinct ways, some by having no eyes and some colossal ones, strenuous individuals increasing their equipment and the lazy letting it lapse. It seems more than questionable to attribute this blindness to a deep-sea habitat, as Suess does in describing them, for they lived in what geologists agree were shallow seas on the site of Bohemia to-day. Besides, trilobites never had abyssal proclivities; for they are found preserved in littoral deposits, not in deep-sea silt. Muddy water may have had some hand in this, but muddy water itself testifies to great commotion above and torrential rains. So the light in those seas was not what it became later, or would be now. Thus these trilobites were antelucan members of their brotherhood, and this accuses a lack of light in those earlier eras even greater than in Carboniferous times, which is just where it ought to be found if the theory is true.

I trust this conception may prove acceptable to geologists, for it seems imperative from the astronomic side that something of the sort must have occurred. And it is just as well, if not better, to view it thus in the light of the dawn of geologic history as to remain in the dark about it altogether. Nescience is not science — whether hyphenized or apart; for the whole object of science is to synthesize and explain. Its body of learning is but the letter, coördination the spirit, of its law. Nevertheless, the unpardonable impropriety of a new idea, I am aware, is as reprehensible as the atrocious crime of being a young man. Yet the world could not get on without both. Time is a sure reformer and will render the most hardened case of youth senile in the end. So even a new idea may grow respectable at last. And it is really as well to make its acquaintance while it still has vigor in it as to wait till it is old and may be embraced with impunity. Boasted conservatism is troglodytic, and usually proves a self-conferred euphuism for dull. For conservatism proceeds from slowness of apprehension. It may be necessary for certain minds to be in the rear of the procession, but it is of doubtful glory to find distinction in the fact.

Thus the youth of a world, like the babyhood of an individual, is passed screened from immediate contact from without. That this is the only way that life can originate on a planet we cannot say, but that it is a way in which it does occur, our own Earth attests, and that, moreover, it is the way with all planets of sufficient size, the present aspect of the major planets shows. It may well be that with celestial bodies as with earthly species, some swaddle their young, others cast them forth to take their chance, and that those that most protect them rear the higher progeny in the end. What glories in evolution thus await the giant planets when they shall have sufficiently cooled down, we can only dimly imagine. But we can foresee enough to realize that we are not the sum of our solar system's possibilities, and by studying the skies read there a future more wonderful than anything we know.

CHAPTER VII

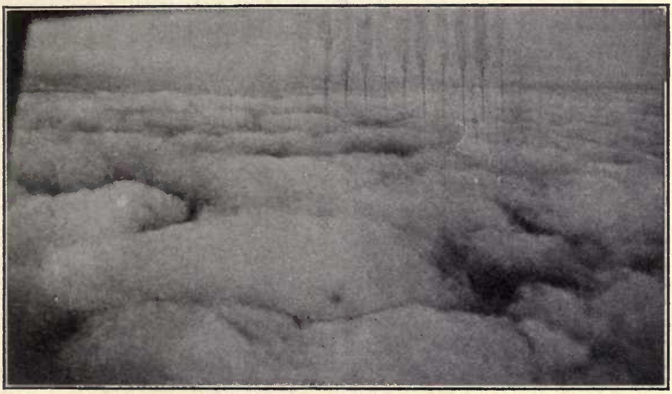
A PLANET'S HISTORY

Sun-sustained Stage

TWO stages have characterized the surface history of the Earth,—stages which may be likened to the career of the chick within and without the egg. In the first of them the Earth lay screened from outside influence under a thick shell of cloud, indifferently exclusive of the cold of space or of the heating beams of the Sun. Motherless, the warmth of its own body brooded over it, keeping its heat from dissipating too speedily into space, and so fostering the life that was quickening upon its surface.

The second stage began when the egg-shell broke and the chick lay exposed to the universe about it, to get its living no longer from its little world within, but from the greater one without. One and the same event ended the old life to make possible the new. So soon as the cloud envelope was pierced, both the Earth's own heat escaped and the Sun's rays were permitted to come in.

It is not surprising that under such changed conditions development itself should have changed, too. In fact, the transformation was marked. That its epochal character has failed to impress itself generally on geologists, is perhaps because they look too closely, missing the march of events in the events themselves,



EARTH AS SEEN FROM ABOVE — PHOTOGRAPHED BY DR. LOWELL AT AN ALTITUDE OF 5500 FEET.

and because, too, of the gradual nature of its processional change. We can recall only De Lapparent as having particularly signalled it; although not only in its cause, but for its effects, it should have delimited two great geologic divisions of time.

Astronomy and geology are each but part of one universal history. The tale each has to tell must prove in keeping with that of the other. If they seem at variance, it behooves us very carefully to scan their respective stories to find the flaw where the apparent incongruity slipped in. Each, too, fittingly supplements the other, and especially must geology look to astronomy for its initial data, since astronomy deals with the beginning of our own Earth.

That study of our Earth in its entirety falls properly within the province of astronomy, is not only deducible from its relationship to the other planets, but demonstrable from the cosmic causes that have been at work upon it, and the inadequacy of anything but cosmic laws to explain them. The ablest geologists to-day are becoming aware of this, — we have one of them at the head of the geology department of the Institute, — while from the curious astronomy at second hand which gets printed in geologic text-books, by eminent men at that, dating from some time before the flood, — of modern ideas,—it seems high time that the connection should be made clear.

For, after all, our Earth too is a heavenly body, in spite of man's doing his best to make it the reverse. It has some right to astronomic regard, even if it is our own mother. At the same time it is quite puerile to consider the universe as bounded by our terrestrial backyard. If man took himself a thought less importantly, he might perceive the humor of so circumscribed a view. Like children we play at being alone in the universe, and then go them one better by believing it too.

I shall, of course, not touch on any matters purely geologic, for fear of committing the very excesses I deplore; mentioning only such points as astronomy has information on, and which, by the sidelights it throws, may help to illuminate the subject.

Thus it certainly is interesting and may to many be a new point of view, that the changes introduced when paleologic times passed into neologic ones were in their fundamental aspects essentially astronomic; which shows how truly astronomic causes are woven into the whole fabric of the Earth. For it was then only, terrestrially speaking, that the year began. The orbital period had existed, of course, from the time the Earth first made the circuit of the Sun. But the year was more a *succès d'estime* on the Sun's part than one of popular appreciation. As the Sun could not be seen and worked no striking effects upon the Earth, the annual round had no recognizable parts, and one revolution lapsed into the next without demarcation. Only with the clearing of the sky did the seasons come in: to register time by stamping its record on the trees. Before that, summer and winter, spring and autumn, were unknown.

Climate, too, made then its first appearance; climate, named after the sunward obliquity of the Earth, and seeming at times to live down to that characterization. Weather there had been before; pejoratively speaking, nothing but weather. For the downpours in paleologic times must have been exceeded in numbers only by their force. One dull perpetual round of rain was the programme for the day, with absolutely no hope of a happy clearance to-morrow. It was the golden age only for weather prophets whose prognostications could hardly go wrong. With climate, however, it was a very different matter. With polyp corals building reefs almost to the pole (81° 50′),* as far north nearly as man has yet by his utmost efforts succeeded in getting, while their fellows were busy at the like industry in the tropics, it is clear that latitude was laughed at and climate even lacked a name.

Another astronomic feature, then for the first time disclosed, was the full significance of the day and the revelation of its cause. While the Earth brooded under perpetual cloud, there could have been but imperfect recognition of day and night. Or perhaps we may put it better by saying that the standard of both was greatly depressed, dull days alternating with nights black as pitch. But the moment the Sun was let in, all this changed, though not in a twinkling. The change came on most gradually. We can see in our mind's eye the first openings in the great welkin permitting the Earth its initial peeps of the world beyond, and how quickly and tantalously they shut in again like a mid-storm morning which dreams of clearing only to find how drowsy it still is. But eventually the clouds parted afresh and farther, and the Earth began to open its eyes to the universe without.

* Dana, "Geology."

The cause of the clearing, of course, was the falling temperature of the seas. Evaporation went on much less fast as the heat of the water lessened. The whole round of aquatic travel from ocean to air, and back to ocean again, proceeded at an ever slackening pace. And here, if it so please geologists, may be found a reconciling of their demands for time to the relative pittance astronomy has been willing to dole them out, a paltry 50 or 100 millions of years, which like all framers of budgets they have declared utterly insufficient. For in early times the forces at work were greater, and by magnifying the means you quicken the process and contract the Earth's earlier eras to reasonable limits.

Upon these various astronomic novelties, the Earth on thus awakening looked for the first time. Such regard altered for good its own internal relations. The wider outlook made impossible the life of the narrower that preceded it. A totally changed set of animals and plants arose, to whom the cosmos bore a different aspect. The Earth ceased to be the self-centred spot it seemed before. As long ago as this had the idea that our globe was the centre of the universe been cosmically exploded. The Earth knew it if man did not.

Its denizens responded. The organisms that already inhabited it proceeded to change their character and crawl out upon the land. For in Devonian times the Earth was the home of fishes. The land was not considered a fit abode by anything but insects, and not over-good by them. But it looked different when the Sun shone. Some maritime dwellers felt tempted to explore, and proceeded in the shape of amphibians to spy

Tracks of Sauropus primævus ($\times \frac{1}{3}$). I. Lea. — Dana, "Manual of Geology."

out the land. They have left very readable accounts of their travels in foot-notes by the way. As one should always inspect the original documents, I will reproduce the foot-notes of one early explorer. It is one of the few copies we have, as the type is worn out. But it tells a pretty full story as it stands. The ripple-marks show that a sea beach it was which the discoverer trod in his bold journey of a few feet from home and friends, and the pits in the sandstone that it was raining at the time of his excursion. No Columbus or Hakluyt could have left a record more precise or more eminently trustworthy. The pilgrims found it so good that their eventual collaterals, the great reptiles, actually took possession of the land and held it for many centuries by right of eminent domain. Yet throughout the time of these bold adventurers, their skies were only clearing, as the pitting of the sandstone eloquently states.

It was not till the chalk cliffs of Dover were being laid down that we have evidence that seasons had fully developed, in the shape of the first deciduous trees.* Cryptogams, cycads, and, finally, conifers had in turn represented the highest attainments of vegetation, and the last of these had already recognized the seasons by a sort of half-hearted hibernation or annual moulting; deeming it wise not to be off with the old leaves before they were on with the new. But finally the most advanced among them decided unreservedly to accept the winter and go to sleep till spring. The larches and ginkgo trees are descendants of the leaders of this coniferous progressive party.

At the same time color came in. We are not accustomed to realize that nature drew the Earth in grays and greens, and touched it up with color afterward. Only the tempered tints of the rocks and the leaden blue of the sea, subdued by the disheartening welkin overhead to a dull drab, enlivened their abode for the oldest inhabitants. But with Tertiary times entered the brilliantly petalled flowers. Beginning with yellow, these rose through a chromatic scale of beauty from white through red to blue.† They decked themselves

* Dana, Geikie, De Lapparent.

† Cf. Grant Allen.

thus gaudily because the Sun was there to see by, as well as eyes to see. For without the Sun those unconscious horticulturists, the insects, could not have exercised their pictorial profession.

To the entering of the Sun upon the scene this wondrous revolution was due; and once entered, it became the dominant factor in the Earth's organic life. We are in the habit of apostrophizing the Sun as the source of all terrestrial existence. It is true enough to-day, and has been so since man entered on the scene. But it was not always thus. There was a time when the Sun played no part in the world's affairs.

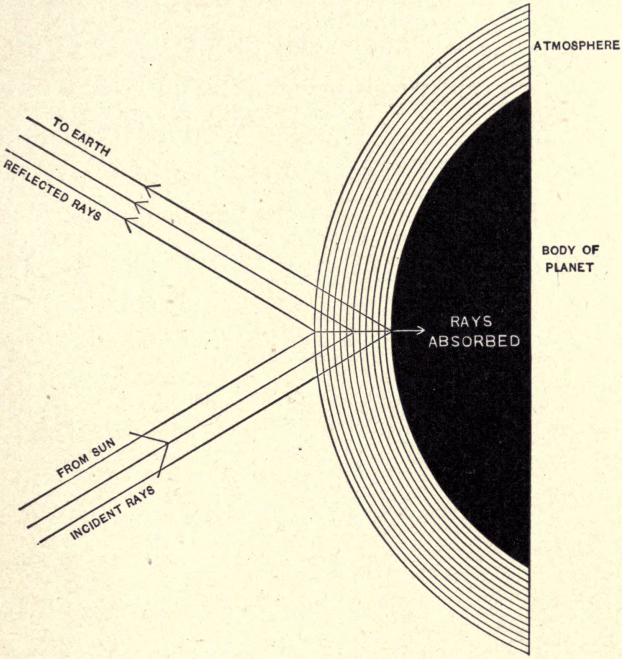
As its heat is now all-important, it becomes an interesting matter to determine the laws governing its amount. That summer is hotter than winter we all know from experience, pleasurable or painful as the case may be. This is due to the fact that the Sun is above the horizon for a greater number of hours in summer and passes more directly overhead. But not so many people are aware that on midsummer day, so far as the Sun is concerned, the north pole should be the hottest place on earth. That Arctic explorers, who have got within speaking acquaintance of it, assure us it is not so, shows that something besides the direct rays of the Sun is involved. Indeed, we learn as much from the extensively advertised thermometers of winter resorts which, judiciously placed, beguile the stranger to sojourn where it is just too cold for comfort. The factor in question is the blanketing character of our air. Now a blanket may keep heat out as well as keep it in. Our air acts in both capacities. It is by no means simply a storer of heat, as many people seem to suppose; it is a heat-stopper as well. What it really is is a temporizer, a buffer to ease the shocks of sudden change like those comfortable, phlegmatic souls who reduce all emotion to a level. For the heating power of the Sun, even at the Earth's distance away, is much greater than appears. Knowledge of this we owe most to Langley, and then to Very, who continued his results to yet a finer determination, the best we have to-day. In consequence we have learnt that the amount of heat we should receive from the Sun, could we get above our air, — the solar constant, as it is called, — would be over three times what it is on the average in our latitude at the surface, and is rising still, so to speak. For as man has gone higher he has found his inferences rising too, and the limit would seem to be not yet. We see then that the air to which we thought ourselves so much indebted, actually begins its kindly offices by shutting off two-thirds of what was coming to us. As it plays, however, something of the same trick to what tries to escape, we are really somewhat beholden to it after all.

But not so much as has been thought. We used to be told that the Moon's temperature even at midday hardly rose above freezing, but Very has found it about 350° F., which even the most chilly of souls might find warm. By the late afternoon, however, he would need his overcoat, and no end of blankets subsequently, for during the long lunar night of fourteen days the temperature must fall appallingly low, to – 300° F. or less.

As the determination of temperature is a vital one, not only to any organic existence, but even to inorganic conditions upon a planet, it behooves us to look carefully into the question of the effective heat received from the Sun. Until recently the only criterion in the case was assumed to be distance from the illuminating source, about as efficient a mode of computation as estimating a Russian army by its official roll. For as we saw in our own case, not all that ought to ever gets to the front, to say nothing of what is lost there. Yet on this worse than guesswork astronomic text-books still assert as a fact that the temperature of other bodies — the Moon and Mars, for example — must be excessively low.

Let us now examine into this most interesting problem. It is intricate, of course, but I think you will find it more comprehensible than you imagine. Indeed, I shall be to blame if you do not. For if one knows his subject, he can always explain it, in untechnical language, technical terms being merely a sort of shorthand for the profession. The physical processes involved can be made clear without difficulty, although their quantitative evaluation is less forthrightly demonstrable. Let me, then, give you an epitome of my investigation of the subject.

Consider a ray of light falling on a surface from the



ADVENTURES OF A HEAT RAY.

Sun. A part of it is reflected; that is, is instantly thrown off again. By this part the body shines and makes its show in the world, but gets no good itself. Another part is absorbed; this alone goes to heat the body. Now if the visible rays were all that emanated from the Sun, it would be strictly true, and a pretty paradox for believers in the efficacy of distance, that what heated the planet was precisely what seemed not to do so. Unfortunately there are also invisible rays, and these, too, are in part reflected and in part absorbed, and their ratio is different from that of the visible ones. To appreciate them, Langley invented the bolometer, in which heat falling on a strip of metal produces a current of electricity registered by a galvanometer. By thus recording the heat received at different parts of the spectrum and at different heights in our atmosphere, he was able to find how much the air cut off. Very has since determined this still more accurately. By thus determining the depletion in the invisible part of the spectrum joined to what astronomy tells us of the loss in the visible part, we have a value for the whole amount. By knowing, then, the immediate brightness of a planet and approximately the amount of atmosphere it owns, we are enabled to judge how much heat it actually receives. This proves to be, in the case of Mars, more than twice as much as distance alone would lead us to infer.

The second question is how much of this it retains. The temperature of a body at any moment is the balance struck between what it receives and what it radiates. If it gets rid of a great deal of its income, it will clearly be less hot than if it is miserly retentive. To find how much it radiates we may take the difference in temperature between sunset and sunrise, since during this interval the Earth receives no heat from the Sun. In the same way the efficacy of different atmospheric blankets may be judged. Thus the Earth parts with nine centigrade degrees' worth of its store on clear nights, and only four degrees' worth on cloudy ones, before morning. This is at sea-level. By going up a high mountain we get another set of depletions, and from this a relative scale for different atmospheric blankets. This is the principle, and we only have to fill out the skeleton of theory with appropriate numbers to find how warm the body is.

In doing so, we light on some interesting facts. Thus clouds reflect 72 per cent of the visible rays, letting through only 28 per cent of them. We feel chilly when a cloud passes over the Sun. On the other hand, slate reflects only 18 per cent of the visible rays, absorbing all the rest. This is why slate gets so much hotter in the Sun than chalk, and why men wear white in the tropics. White, indeed, is the best color to clothe one's self in the year around, except for the cold effect it has on the imagination, for it keeps one's own heat in as well as keeping the Sun's out. The modest, self-obliterating, white winter habit of the polar hares not only enables them to keep still and escape notice, but keeps them warm while they wait.

Astronomically, the effect is equally striking. Mars, for example, owing to being cloudless and of a duller hue, turns out to have a computed mean temperature nearly equal to the Earth's,—a theoretic deduction which the aspect of the planet most obligingly corroborates. It thus enjoys a comparatively genial old age.

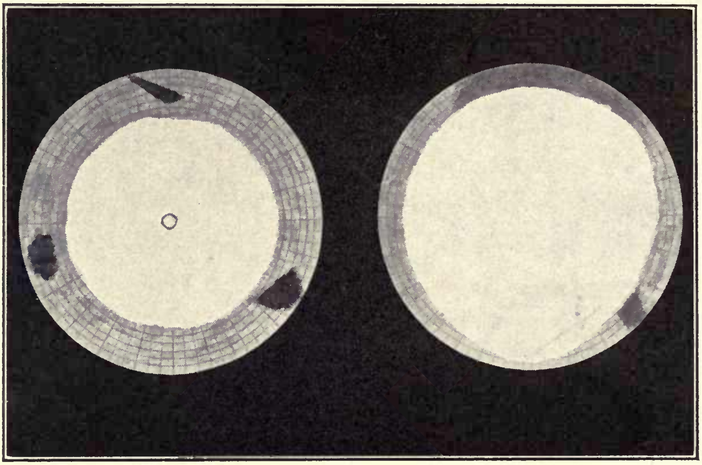
For what is specially instructive in planetary economy is that, on the whole, clear skies add more by what they let in than they subtract by what they let out. If the Earth had no clouds at all, its mean temperature would be higher than it is to-day. Thus as a planet ages a beneficent compensation is brought about, the Sun's heat increasing as its own gives out. Not that the foreign importation, however slight the duty levied on it by the air, ever fully makes up for the loss of the domestic article, but it tempers the refrigeration which inevitably occurs.

The subject of refrigeration leads us to one of the most puzzling and vexed problems of geology: how to account for the great Ice Age of which the manifest sign manuals both in Europe and in America have so intrigued man since he began to read the riddle of the rocks. Upon this, also, planetology throws some light.

If I needed an apology to the geologists for seeming again to trespass on their particular domain, I might refer to the astrocomico expositions put forward to account for the great Ice Age.

We can all remember Croll's "Climate and Time," a book which can hardly be overpraised for its title and which had things worth reading inside, too. It had in consequence no inconsiderable vogue at one time. It undertook to account for glacial epochs on astronomic principles. It called in such grand cosmic conditions and dealt in such imposing periods of time that it fired fancy and almost compelled capitulation by the mere marshalling of its figurative array. Secular change in the eccentricity of the Earth's orbit, combined with progression in the orbital place of the winter's solstice, was supposed to have induced physical changes of climate which accentuated the snowfall in the northern hemisphere and so caused extensive and permanent glaciation there. In other words, long, cold winters followed by short, hot summers in one hemisphere were credited with accumulating a perpetual snow sheet, such as short, warm winters and long, cold summers could not effect.

Now it so happens that these astronomic conditions affecting the Earth several thousand years ago, are in process of action on one of our nearest planetary neighbors at the present time. The orbit of Mars is such that its present eccentricity is greater than what the Earth ever can have had, and the winter solstice of the planet's southern hemisphere falls within 23° of its aphelion point. We have then the conditions for glaciation if these are the astronomic ones supposed, and we should expect a southern polar cap, larger at its maximum and still more so, relatively, at its minimum, than in the opposite hemisphere. Let us now look at the facts, for we have now a knowl-



MARS.

NORTH POLAR CAP.		SOUTH POLAR CAP.	
At maximum	full extent of white	At maximum	white
At minimum	inner circle	At minimum	nothing

edge of the Martian polar caps exceeding in some respects what we know of our own. The accompanying diagrams exhibit the state of things at a glance, the maximum and minimum of each cap being represented in a single picture and the two being placed side by side. It will be observed that the southern cap outdoes its antipodal counterpart at its maximum, showing that the longer, colder winter has its effect in snow or hoar-frost deposition. But, on the other hand, instead of excelling it at its minimum, which it should do to produce permanent glaciation, it so far falls short of its fellow that during the last opposition at which it could be well observed, it disappeared entirely. The short, hot summer, then, far exceeded in melting capacity that of the longer but colder one.

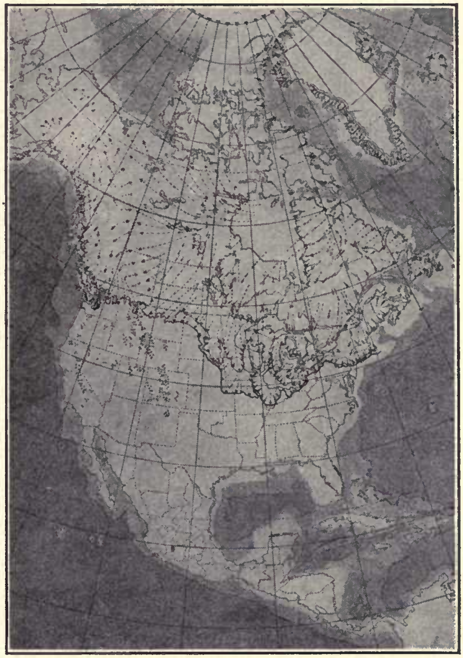
Let us now suppose the precipitation to be increased, the winters and summers remaining both in length and temperature what they were before. The amount of snow which a summer of given length and warmth can dispose of is, roughly speaking, a definite quantity. For it depends to a great extent only on its amount of heat. The summer precipitation may be taken as offsetting itself in the two hemispheres alike. If, then, the snowfall in the winter be for any reason increased daily in both, a time will come when the deposition due the longer winter of the one will exceed what its summer can melt relatively to the other, and a permanent glaciation result in the hemisphere so circumstanced. Increased precipitation, then, not eccentricity of orbit, is the real cause of an Ice Age. And this astronomic deduction we owe not to theoretic conclusions, for which we lack the necessary quantitative data, but wholly to study of our neighbor in space. Had any one informed our geologic colleagues that they must look to the sky for definite information about the cause of an Ice Age, they would probably have been surprised.

With this Martian information, received some years ago, it is pleasing now to see that Earthly knowledge is gradually catching up. For that increased precipitation could account for it, the evidence of pluvial eras in the

GLACIAL MAP OF EURASIA — AFTER JAMES GEIKIE.

equatorial regions, contemporaneous with glacial periods, indicates. But another and probably the chief factor involved was not a generally increased precipitation, potent as that would be, but an increased snow deposit due to temporary elevation of the ground.

For it now appears that there was no glacial *epoch*. Our early ideas inculcated by text-books at school received a rude shock when it appeared that the glacial *epoch* was not, as we had been led to believe, a polar phenomenon at all, but a local affair which on the face of it had nothing to do with the pole. For investigation has disclosed that instead of emanating from the pole southward, it proceeded from certain centres, descending thence in all directions, north as much as south. Thus there was a centre in Norway in 65° N. lat. and another in Scotland in 56° N. In North America there were three — the Labradorian in latitude 54° N., the Kerwatin to the northwest of Hudson's Bay in latitude 62° N., and the Cordilleran along the Pacific coast in latitude 58° N. On the other hand, northern Siberia, the coldest region in the world, was not glaciated. That the ice flowed off these centres proves them to have been higher than the sides. But we have



Map showing the glaciated area of North America — the arrows indicating the direction of ice movement — Chamberlin and Salisbury.

further evidence of their then great height from the fact that dead littoral shells have been dredged from 1333 fathoms in the North Atlantic, and the prolongation under water of the fiords of Norway and of land valleys in North America witness to the same subsidence since.

But evidence refuses to stop here. The Alps were then more glaciated than they are now. So was Kilimanjaro and Ruwenzori on the equator; and finally at the same time more ice and snow existed round about the south pole than is the case to-day. Now this is really going too far even for the most ardent believers in the force of eccentricity. For if the astronomic causes postulated were true, they must have produced just the opposite action at the antipodes, to say nothing of the crux of being equally effective at the equator. The theory lies down like the ass between two burdens. Whichever load it chooses to saddle, it must perforce abandon the other.

So it turns out that the Ice Age was not an Ice Age at all but an untoward elevation of certain spots, and is to be relegated to the same limbo of exaggeration of a local incident into a world-wide cataclysm as the deluge. That some geologists will still cling to their former belief I doubt not; for as the philosophic old lady remarked: "There always have been two factions on every subject. Just as there are the suffragists and anti-suffragists now, so there were slaveholders and the anti-slavery people in my time; and even in the days of the deluge, there were the diluvians who were in favor of a flood and the antediluvians who were opposed to it." A tale which has a peculiarly scientific moral, as in science *anti* and *ante* seem often interchangeable terms.

When I began the course of lectures that resulted in this volume, I labored under the apprehension that an account of cosmic physics might prove dull. It soon threatened to prove too startling. I therefore hasten to reassure the timid by saying that we are outgrowing ice ages and probably deluges. Elevations of the Earth's crust are likely to be less and less pronounced in the future, and meanwhile such as exist are being slowly worn down. Secondly, the Sun is sure to continue of much the same efficiency for many æons to come. And lastly, the essential ingredient of both prodigies, water, is daily becoming more scarce. To this latter point we now turn, and perhaps when it is explained to him the reader may think that he has been rescued from one fate only to fall into the hands of another.

Geology is necessarily limited in its scope to what has happened; planetology is not so circumscribed in its domain. It may indulge in prognostication of the future, and find countenance for its conclusions in the physiognomy of other worlds. Thus one of the things which it foresees is the relative drying up of our abode.

To those whose studies have never led them off this earth, the fact that the oceans are slowly evaporating into space may seem as incredible as would, to one marooned on a desert island, the march of mankind in the meantime. We live on an island in space, but can see something of the islands about us, and our conception of what is coming to our limited habitat can be judged most surely by what we note has happened to others more advanced than ourselves. Just as we look at Jupiter to perceive some likeness of what we once were, the real image of which has travelled by this time far into the depths of space beyond possibility of recall, so must we look to the Moon or Mars if we desire to see some faint adumbration of the pass to which we are likely to come. For from their lack of size they should have preceded us on the road we are bound to travel. Now, both these worlds to-day are water-lacking, in whole or part; the Moon practically absolutely so, Mars so far as any oceans or seas are concerned. We should do wisely then to take note. But we have more definite information than simply their present presentments. For both bear upon their faces marks of having held seas once upon a time. They were once, then, more as we are now. We cannot of course be sure, as we are unable to get near enough to scan their surfaces for signs of erosive action. But so far as we can make out, past seas best explain their appearance.

So sealike, indeed, was their look that the first astronomers to note them took them unhesitatingly for water expanses. Thus the moment the telescope brought the Moon near enough for map making of it we find the dark patches at once designated as seas. The Sea of Serenity, the Sea of Showers, the Bay of Rainbows, speak still of what once was supposed to be the nature of the dark, smooth, lunar surfaces they name. Suggestively, indeed, in an opera glass do they seem to lap the land. The Lake of Dreams foreshadowed what was eventually to be thought of them. With increasing optical approach the substance evaporated, but the form remained. It was speedily evident that there was no water there; yet the semblance of its repository still lurked in those shadows and suggests itself to one scanning their surfaces to-day. If they be not old sea bottoms, they singularly mimic the reality in their smooth, sloping floors and their long, curving lines of beach. Their strange uniformity shows that something protected them from volcanic fury while the rest of the

THE MOON — PHOTOGRAPHED AT THE LOWELL OBSERVATORY.

lunar face was being corrugated. This preservative points to some superincumbent pressure which can have been no other than water. Lava-flows on such a scale seem inadmissible. What these surfaces show and what they do not show alike hint them sea bottoms once upon a time. In the strange chalk-like hue of the lunar landscape they look like plaster of Paris death-masks of the former seas.

A like history fell to the lot of the surface features of Mars. There too, as soon as the telescope revealed them and their permanency of place, the dark patches upon the planet's face were forthrightly taken for seas, and were so called: the Sea of the Sirens and the Great Red Sea. Such they long continued to be deemed. The seas of Mars held water in theory centuries after the idea of the lunar had vanished into air. At last, ruthless science pricked the pretty bubble analogy had pictured. Being so much farther off than the Moon, it was much later that their true character came out. Come out it has, though, within the last few years. Lines — some of the so-called canals — have been detected crossing the seas, lines persistent in place. This has effectually disposed of any water in them. But here again something of semblance is left behind. They are still the darkest portions of the planet, and their tint changes in places with the progress of the planet's year. That their color is that of vegetation, and that its change obeys the seasons, stamp it for vegetation in fact. Thus these regions must be more humid than the rest of Mars. They must, therefore, be lower. That they are thus lower and possess a modicum of water to-day marks them out for the spots where seas would be, were there any seas to be. As we know of a *vera causa* which has for ages been tending to deplete them, extrapolation from what is now going on returns them the water they have lost and rehabilitates their ancient aquatic character. To the far-sight of inference, seas they again become in the morning of the ages long ago when Mars itself was young.

Nor is this the end of the evidence. When we compare quantitatively the areas occupied by the quondam seas on Mars and on the Moon, we find reason to increase our confidence in our deduction. For the smaller body, the Moon, should have had less water relatively, at the time when the seas there were laid down, than the larger, Mars. Because from the moment its mass began to collect, it was in process of parting with its gases, water-vapor among the rest, and, as we shall see more in detail in the next chapter, it had from the start less hold on them than Mars. Its oceans, therefore, should have been less extensive than the Martian ones. This is what the present lunar Mare seem to attest. They are less extended than the dark areas of Mars. A fact which becomes the more evident when we remember that the Moon has long turned the same face to the Earth. Her shape, therefore, has been that of an egg, with the apex pointing toward our world. Here the water would chiefly collect. The greater part of the seas she ever had should be on our side of her surface, the one she presents in perpetuity to our gaze.

It is to the heavens that we must look for our surest information on such a cosmic point, because of the long perspective other bodies give us of our own career. Less conclusive, because dependent upon less time, is any evidence our globe can offer. Yet even from it we may learn something; if nothing else, that it does not contradict the story of the sky. To it, therefore, we return, quickened in apprehension by the sights we have elsewhere seen.

The first thing our sharpened sense causes us to note is the spread of deserts even within historic times. Just as deserts show by their latitudinal girdling of the Earth their direct dependence upon the great system of planetary winds, as meteorologists recognizingly call them, so a study of the fringes of these belts discloses their encroachment upon formerly less arid lands. The southern borders of the Mediterranean reveal this all the way from Carthage to Palestine. The disappearance of their former peoples, leaving these lands but scantily inhabited now, points to this; because other regions, as

India, which still retain a waterful climate, are as populous as ever. Much of this is doubtless due to the overthrow of dynasties and the ensuing lapse of irrigation, but query: Is it all? For we have still more definite information in the drying up of the streams which have left the aqueducts of Carthage without continuation, as much to water on the one hand as to its drinkers on the other. Men may leave because of lack of water, but water does not leave because of dearth of men to drink.

Recent search around the Caspian by Huntington has disclosed the like degeneration due to encroaching desertism there. Indeed, it is no chance coincidence that just where all the great nations thrived in the morning of the historic times should be precisely where populous peoples no longer exist. For neither increasing cold nor increasing heat is responsible for this, seeing that no general change has occurred in either. Nor were they particularly exposed to extermination by northern hordes of barbarians. Egypt as a world power died a natural death, and Babylonia too; but the common people died of thirst, indirect and unconscious and not wholly of their own choosing. Prehistoric records make this conclusion doubly sure, by lengthening the limit of our observation. Both extinct flora and extinct fauna tell the same tale. In the neighborhood of Cairo petrified forests attest that Egypt was not always a wiped slate, while the unearthed animals of the Fayum bear witness to water where no water is to-day.

Anywhere we wander along these girdling belts we find the same story written for us to read. The great

PETRIFIED BRIDGE, THIRD PETRIFIED FOREST, NEAR ADAMANA, ARIZONA — PHOTOGRAPH BY HARVEY.

deserts of New Mexico and Arizona show castellated structures far beyond the means of its present Indian population to inhabit. Yet this retrenchment occurred long before the white man came with his exterminating blight on everything he touched. Nor have we reason to suppose that it arose in consequence of invasion by other alien hordes. Individual communities may thus indeed have perished as the preservation of their domiciles intact leads us to infer, but all did not thus vanish from off the Earth. Here again humanity died or moved away because nature dried the sources of its supply. And here, as elsewhere, we find prehistoric record in the rocks of a once more smiling state of things, strengthening the testimony we deduce from man. The forests, crowning now only the greater heights, are but the shrinking residues of what once clothed the land. The well-named Arid Zone is becoming more so every day.

If from the land evidence of drying up we turn to the marine, we see the same shrinkage at work. It has even been discovered in a lowering of the ocean bed, but as this may so easily be disputed, we turn to one aspect of the situation which cannot so easily be gainsaid, — the bodies of water that have been cut off. That the Dead Sea, the Caspian, the Great Salt Lake, are slowly but surely giving way to land, is patent. If the climate at least were not more arid than before this could not occur; but more than this, if the ocean were not on the whole shrinking, there would be no tendency to leave such arms of itself behind to shrivel up. That the ocean basins are deepening is possible, but we know of one depletion which is not replaced — evaporation into space; and of another bound to come — withdrawal into fissures when the earth shall cease to be too hot.

This gradual withdrawal of the water may seem an unpleasant one to contemplate, but like most things it has its silver lining in the hope it holds out that sometime there shall be no more sea. Those of us who detest the constant going down to the sea in ships hardly more than the occasional going down with them, can take a crumb of comfort in the thought. Unfortunately it partakes of a somewhat far-off realization in our distant descendants, coming a little too late to be of material advantage to ourselves.

But let me not leave the reader wholly disconsolate. For another thought we can take with us in closing our sketch of so much of the Earth's life as brings it well down to to-day, — the thought that it has grown for us a steadily better place to contemplate from the earliest eras to the present time. Indeed, with innate prescience we forbore to appear till the prospect did prove pleasing. Finally, we may palliate prognostication by considering that if its future seem a thought less attractive, we, at least, shall not be there to see.

CHAPTER VIII

DEATH OF A WORLD

EVERYTHING around us on this Earth we see is subject to one inevitable cycle of birth, growth, decay. Nothing that begins but comes at last to end. Not less is this true of the Earth as a whole and of each of its sister planets. Though our own lives are too brief even to mark the slow nearing to that eventual goal, the past history of the Earth written in its rocks and the present aspects of the several planets that circle similarly round the Sun alike assure us of the course of aging as certainly as if time, with all it brings about, passed in one long procession before our very eyes.

Death is a distressing thing to contemplate under any circumstances, and not less so to a philosopher when that of a whole world is concerned. To think that this fair globe with all it has brought forth must lapse in time to nothingness; that the generations of men shall cease to be, their very records obliterated, is something to strike a chill into the heart of the most callous and numb endeavor at its core. That æons must roll away before that final day is to the mind of the far-seeing no consolation for the end. Not only that we shall pass, but that everything to show we ever were shall perish too, seems an extinction too overpowering for words.

But vain regret avails not to change the universe's course. What is concerns us and what will be too. From facing it we cannot turn away. We may alleviate its poignancy by the thought that our interest is after all remote, affecting chiefly descendants we shall never know, and commend to ourselves the altruistic example so nobly set us by doctors of medicine who, on the demise of others at which — and possibly to which — they have themselves assisted, show a fortitude not easily surpassed, a fortitude extending even to their bills. If they can act thus unshaken at sight of their contemporaries, we should not fall behind them in heroism toward posterity.

Having in our last chapter run the gantlet of the geologists, we are in some sort fortified to face death — in a world — in this. The more so that we have some millenniums of respite before the execution of the decree. By the death of a planet we may designate that stage when all change on its surface, save disintegration, ceases. For then all we know as life in its manifold manifestations is at an end. To this it may come by many paths. For a planet, like a man, is exposed to death from a variety of untoward events.

Of these the one least likely to occur is death by accident. This, celestially speaking, is anything which may happen to the solar system from without, and is of the nature of an unforeseen catastrophe. Our Sun might, as we remarked, be run into. For so far as we know at present the stars are moving among themselves without any too careful regard for one another. The swarm may be circling a central Sun as André states, but the individual stars behave more like the random particles of a gas with licensed freedom to collide; whereas we may liken the members of the solar system to molecules in the solid state held to a centre from which they can never greatly depart. Their motions thus afford a sense of security lacking in the universe at large.

Such an accident, a collision actual or virtual with another sun, would probably occur with some dark star; of which we sketched the ultimate results in our first chapter. The immediate ones would be of a most disastrous kind. For prefatory to the new birth would be the dissolution to make such resurrection possible. Destruction might come direct, or indirectly through the Sun. For though the Sun would be the tramp's objective point, we might inadvertently find ourselves in the way. The choice would be purely academic; between being powdered, or deorbited and burnt up.

So remote is this contingency that it need cause us no immediate alarm, as I carefully pointed out. But so strong is the instinct of self-preservation and so pleasurable the sensation of spreading appalling news, that the press of America, and incidentally Europe, took fire, with the result, so I have been written, that by the time the pictured catastrophe reached the Pacific "it had assumed the dimensions of a first magnitude fact."

This is the first way in which our world may come by its death. It is possible, but unlikely. For our Earth, long before that, is morally certain to perish otherwise.

The second mode is one, incident to the very constitution of our solar system. It follows as a direct outcome of that system's mechanical evolution, and may be properly designated, therefore, as due to natural causes. It might be diagnosed as death by paralysis. For such it resembles in human beings, palsy of individual movement afflicting a planet instead of a man.

Tidal friction is the slow undermining cause; a force which is constantly at work in the action of every body in the universe upon every other. As we previously explained, the pull of one mass upon another is inevitably differential. Not only is the second drawn in its entirety toward the first, falling literally as it circles round, but the nearer parts are drawn more than the centre and the centre more than those farthest away. We may liken the result to a stretched rotating rubber ball, with, however, one important difference,—that each layer is more or less free to shear over the others. The bulge, solicited by the rotation to keep up, by the disturber to lag behind, is torn two ways, and the friction acts as a break upon the body's rotation, tending first to turn it over if it be rotating backward and then to slow it down till the body presents the same face in perpetuity to its primary. The tides are the bulge, not simply those superficial ones which we observe in our oceans, and know to be so strong, but substantial ones of the whole body which we must conceive thus as egg-shaped through the action that goes on — the long diameter of the egg pointing somewhat ahead of the line joining its centre to the distorting mass. All the bodies in the solar system are thus really egg-shaped, though the deformation is so slight as to escape detection observationally. The knowledge is an instance of how much more perceptive the brain is than the eye. For we are certain of the fact, and yet to see it with our present means is impossible, and may long remain so.

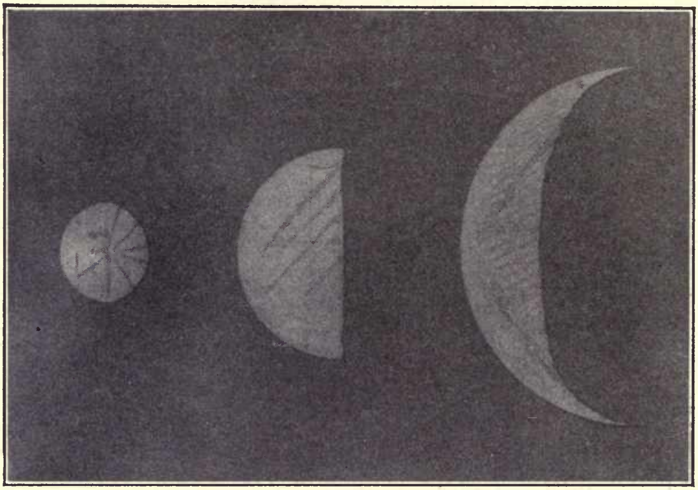
Two concomitant symptoms follow the friction of the tidal ansæ: a shift of the plane in which the rotation takes place, and a loss of speed in the spin itself. The first tends to bring the plane of rotation down to the orbital plane, with rotation and revolution in the same sense. This effect takes place quicker than the other, and in consequence different stages may be noted in the creeping paralysis by which the body is finally overcome. Loss of seasons characterizes the first. For the coincidence of the two planes means invariability in the Sun's declination throughout the year for a given latitude. This reduces all its days to one dead level in which summer and winter, spring and autumn, are always and everywhere the same. There is thus a return at the end of the planet's career to an uneventful condition reminiscent of its start; a senility in planets comparable to second childhood in man.

In large planets this outgrowing of seasons occurs before they have any, while the planet is yet cloud-wrapped. Such planets know nothing of some attributes of youth, like those unfortunate men who never were boys; just as reversely the meteorites are boys that never grew up. For if the planet be large, the action of the tidal forces is proportionately more powerful; while on the other hand the self-aging of the planet is greatly prolonged, and thus it may come about that the former process outstrips the latter to the missing of seasons entirely. This is sure to be the case with Jupiter, as the equator has already got down to within 3° of the orbit, and threatens to be the case with Saturn. These bodies, then, when they shall have put off their swaddling clothes of cloud, will wake to climates without seasons; globes where conditions are always the same on the same belts of latitude, and on which these alter progressively from equator to pole. Variety other than diurnal is thus excluded from their surfaces and from their skies. For the Sun and stars will rise always the same, in punctual obedience only to the slowly shifting year.

The next stage of deprivation is the parting with the day. Although the day disappears, the result is too much day or too little, depending on where you choose to consider yourself upon the afflicted orb. For tidal friction proceeds to lengthen the twenty-four or other hours first to weeks, then months, then years, and at last to infinity; thus bringing the sun to a stock-still on the meridian, to flood one side of the world with perpetual day and plunge the other in eternal night.

Which of these two hemispheres would be the worse abode, is matter of personal predilection; dust or glacier, deserts both. Everlasting unshielded noon would cause a wind circulation from all points of the enlightened periphery to the centre, whence a funnel-shaped current would rise to overflow back into the antipodes, thence to return by the horizon again. As the night side would be several hundred degrees at least colder than the noon one, all the moisture would be evaporated on the sunlit hemisphere, to be carried round and deposited as ice on the other, there to stay. Life would be either toasted or *frappé*. A Sahara backed by polar regions would be the obverse and the reverse of the shield.

The reader may deem the picture a fancy sketch which possibly may not appeal to him. Nevertheless, it not only is possible, but one which has overtaken our nearest of neighbors. To this pass the Mater Amorum, Venus herself, has already been brought. She betrays it by the wrinkles which modern observation has re-



October 15, 1896. February 12, 1897. March 26, 1897.

VENUS — DRAWINGS BY DR. LOWELL SHOWING AGREEMENT AT DIFFERENT DISTANCES.

vealed upon her face. Innocent critics, with a gallantry one would hardly have credited them, — which shows how one may wrong even the humblest of creatures, — have denied the existence of these marks of age, on the chivalrous *a priori* assumption that it could not possibly be true because never seen before. Their negation, in naïve ignorance of the facts, partakes the logic of the gallant captain, who, when asked by a lady to guess her age, replied: "'Pon my word, I haven't the slightest idea," hastily adding, "But you don't look it!" Less commendable than this conventional nescience, but unfortunately more to the point, is the evidence of prying scientific curiosity. Shrewdly divined as much as detected by Schiaparelli, made more certain by the crow's-feet disclosed at Flagstaff, and corroborated by the testimony of the spectroscope there, her isochronism of rotation and revolution lies beyond a doubt. Attraction to her lord has conquered at last her who was the cynosure of all. Venus, in her old age, stares forever at the Sun, and we all know how ill an aging beauty can support a garish light.

Mercury has been brought to a like pass. This was evident even before the facts came out about Venus, for Venus, true to her instincts, shields herself with a veil of air which largely baffles man's too curious gaze. Mercury, on the other hand, offers no objection to observation. When looked for at the proper time, his markings are quite distinct, dark, broken lines suggesting cracks. Schiaparelli, again, was the first to perceive the true state of the case, and his observations were independently confirmed and extended at Flagstaff in 1896. In so doing the latter disclosed a very interesting fact. It was evident that the markings held in general a definite fixed position upon the illuminated part of the disk, showing that the planet kept the same face always to the Sun. But systematic observation, continued day after day for weeks, disclosed a curious shift, which, though slight, was unmistakable. Upon thought the cause suggested itself, and on being subjected to calculation proved equal to such accounting. In this

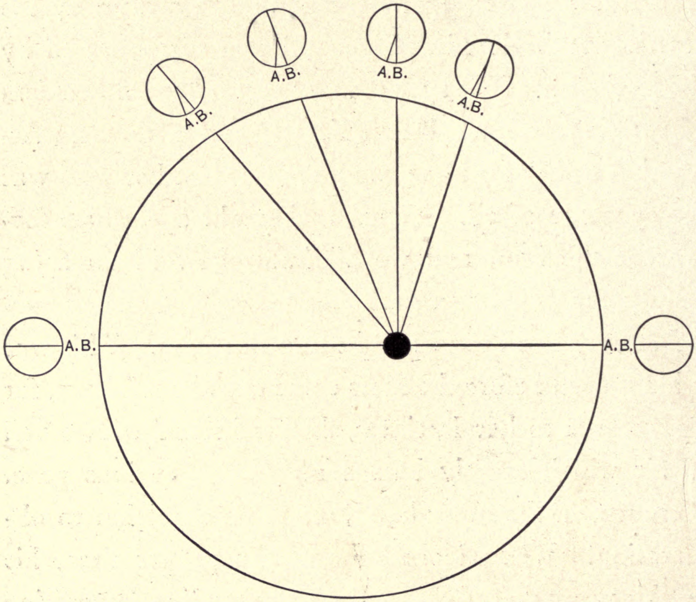
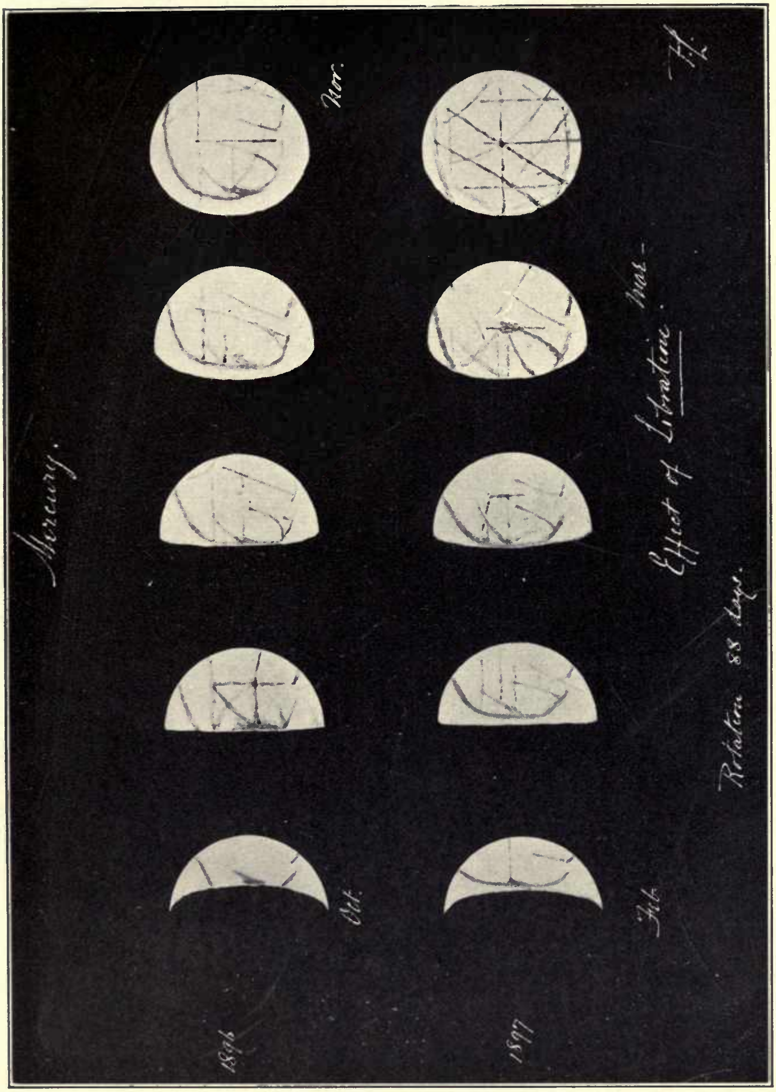


DIAGRAM OF LIBRATION IN LONGITUDE DUE TO ROTATION.

singular systematic sway stood revealed the libration in longitude caused by the eccentricity of the planet's orbit.

Mercury revolves about the Sun in an ellipse more eccentric than that of any other principal planet. At times he is half as far off again from him as he is at others. When near, he travels faster than when far.


Mercury.
Effect of Libration.
Rotation 88 days.
1896
Oct.
Nov.
1897
Feb.
Mar.

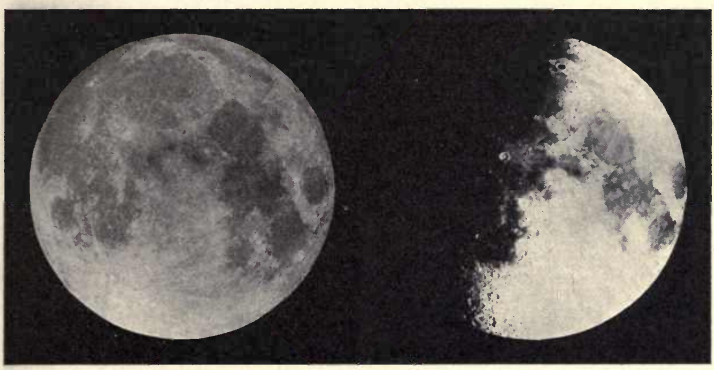
For both reasons, nearness and speed, his angular revolution about the Sun varies greatly from point to point according to where he finds himself in his orbit. His rotation, however, is necessarily uniform. For even the Sun has no power at once to change the enormous moment of momentum of his axial spin. In consequence, at times his angular velocity of revolution gains on his rotation, at other times loses, both coming out together at the end of a complete Mercurial year. The result is a superb rhythmic oscillation, a true mercurial pendulum compensated by celestial laws to perfect isochronism of swing.

The outward sign of this shows in the movement of the markings. To observers in space like ourselves, the planet seems to sway his head as he travels along his orbit. For weeks he turns his face, as shown by the markings on it, more and more over to the left; then turns it back again as far over to the right. It is as if he were looking furtively around as he hastens over his planetary path.

Venus, of course, is equally subject to this law of distraction, but owing to the almost perfect circularity of her orbit she is less visibly affected. In fact, it is not possible to detect her lapse from a fixed regard to the Sun. At most it is no more than a glance out of the corner of her eyes — her slight deviation from perfect rectitude of demeanor. Knowledge of the laws governing such action alone permits us to recognize its occurrence.

Mercury and Venus are the only planets as yet that turn a constant face to their overruling lord. The reason for this appears when one goes into the matter analytically. The tidal force is not the direct pull of the Sun on a particle of the body, but the difference in the pulls upon a particle at the centre and one at the circumference. Being differential, it depends directly upon the radius of the distorted body and inversely upon the third power of its distance away. As the space through which the force acts is proportional to the force itself, the effect is as the squares of the quantities mentioned, or, inversely, as the sixth power of the distance and as the square of the body's radius. The result thus proves greatest on the planets nearest to the Sun, and diminishes rapidly as we pass outward from him. If, then, the solar force had had time enough to produce its effects, it would be first in Mercury and then in Venus that it should be seen. And this is precisely where we observe it.

The Moon presents us a well-known case of such filial regard, resulting in permanent incompetency of action on its own account. It turns always the same face to us, following us about with the mute attention of a dog to its master. Here again the libration may be detected, for no dog but makes excursions on the road. This case differs from those of Mercury and Venus in that the body to which the regard is paid is not also the dispenser of light and warmth. In consequence, though the side of the Moon with which we are presented remains always



MOON—FULL AND HALF, PHOTOGRAPHED AT THE LOWELL OBSERVATORY.

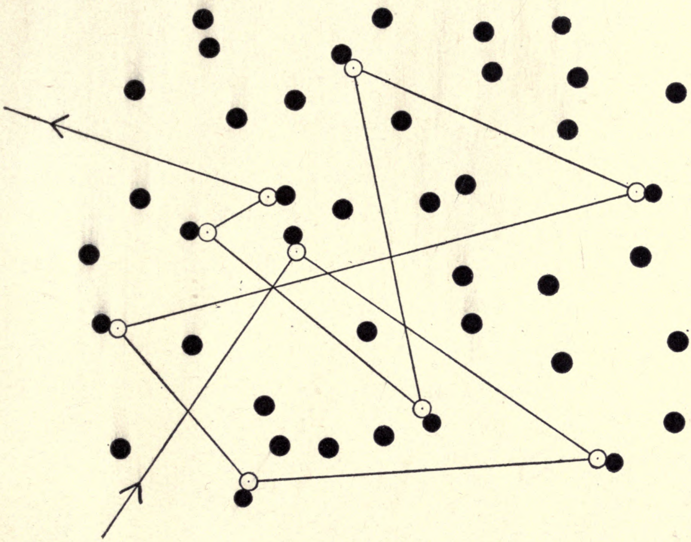
the same, we do not always see it; the light creeping over it with the progress of the lunation, from new to full. On this account the worst that happens to our Moon in its old age is that its day becomes its month.

Our Moon is not peculiar in having its day and its month the same. On the contrary, it is now the rule with satellites thus to protract their days. So far as we can observe, all the large satellites of Jupiter turn the same face to him; those of Saturn pay him a like regard; while about those of Uranus and Neptune we are too far off to tell. Their direct respect for their primary, with only secondary recognition of the Sun, keeps them from the full consequences of their fatal yielding to attraction. It is bad enough to have the day half a month long, but worse to have one that never ends, or, still worse, perpetual night.

In our diagnosis of the cause of death in planets, we now pass from paralysis to heart failure. For so we may speak of the next affection which ends in their taking off, since it is due to want of circulation and lack of breath. It comes of a planet's losing first its oceans and then its air.

To understand how this distressing condition comes about, we must consider one of the interesting scientific legacies of the nineteenth century to the twentieth: the kinetic theory of gases.

The kinetic theory of gases supposes them to be made up of minute particles all alike, which are perfectly elastic and are travelling hither and thither at great speeds in practically straight lines. In consequence, these are forever colliding among themselves, giving and taking velocities with bewildering rapidity, resulting in a state of confusion calculated to drive a computer mad. Somebody has likened a quiet bit of air to a boiler full of furious bees madly bent on getting out. The simile flatters the bees. To follow the vicissitudes of any one molecule in this hurly-burly would be out of the question; still more, it would seem, that of all of them at once. Yet no less Herculean a task confronts us. To find out about their motions, we are therefore driven to what is called the statistical method of inquiry, — which is simply a branch of the doctrine of probabilities. It is the method by which we learn how many people are going to catch cold in Boston next

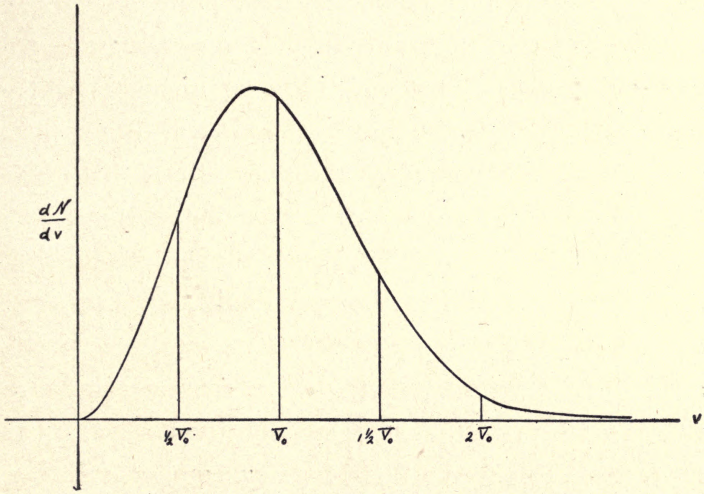


ILLUSTRATING MOLECULAR MOTION IN A GAS (BLACK MOLECULES HERE CONSIDERED AT REST).

week when we know nothing about the people, or about colds, or about catching them. At first sight it might seem as if we could never discover anything in this hopelessly ignorant way, and as if we had almost better call in a doctor. But in the multitude of colds — not of counsellors — lies wisdom. So in other things not hygienic. As you cannot possibly divine, for instance, what each boy in town is going to do during the year, nor what is his make of mind, how can you say whether he will accidentally discharge a firearm and shoot his playmate or not! And yet if you take all the boys of Boston, you can predict to a nicety how many will thus let off a gun and "not know that it was loaded."

In this only genuine method of prophecy, complete ignorance of all the actual facts, we are able without knowing anything whatever about each of the molecules to predicate a good deal about them all. To begin with, the pressure a gas exerts upon the sides of a vessel containing it must be the bombardment the sides receive from the little molecules; and the heating due this rain of blows, or the temperature to which the vessel is raised, must measure their energy of translation. On this supposition it is found that the laws of Avogadro and of Boyle are perfectly accounted for, besides many more properties of gases which the theory explains, and as nothing yet has been encountered seriously contradicting it, we may consider it as almost as surely correct as the theory of gravitation. To three great geniuses of the last century we owe this remarkable discovery — Clausius, Clerk Maxwell, and Boltzmann.

By determining the density of a gas at a given temperature and under a given pressure, we can find by the statistical method the average speed of its molecules. It depends on the most probable distribution of their energy. For hydrogen at the temperature of melting ice, and under atmospheric pressure, this speed proves to be a little over a mile a second — a speed, curiously enough, which is to that of light almost exactly as centimetres to miles. But some of the molecules are going



DISTRIBUTION OF MOLECULAR VELOCITIES IN A GAS.

at speeds much above the mean; fewer and fewer as the speed gets higher. Just how many there are for any assigned speed, we can calculate by the same ingenious application of unknown quantities.

These speeds have been found for a temperature of freezing, and as the speed varies as the square root of the absolute temperature, we might suppose that when an adventurous or lucky molecule arrived at practically the limit of the atmosphere, where the cold is intense, it would become numbly sluggish. But let us consider this. When we enclose a gas in a cooler vessel, the molecules bombard the sides more than they are bombarded back. In consequence, they lose energy; as we say, are cooled. But in free air if a molecule be fortunate enough to elude its neighbors, there is nothing to take away its motion but the ether through radiation, and this is a very slow process. Thus the escaping fugitive must arrive at the confines of the air with the speed it had at its last encounter. We reach, then, this result: In space there is no such thing as temperature; temperature being simply the aggregate effect of molecular temperament. The reason we should consider it uncommonly cold up there is that fewer molecules would strike us. Quantity, therefore, in our estimation replaces quality, — a possible substitution which also accounts for some reputations, literary or otherwise. The only forces which could affect this lonely molecule would be the heating by the Sun, the repellent force of light, and gravity.

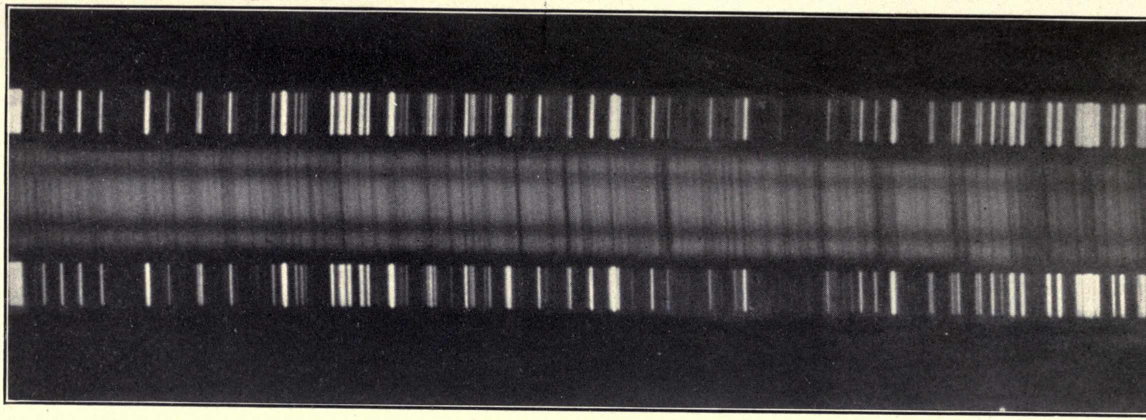
Now the speed which gravity on the Earth can control is 6.9 miles a second. It can impart this to a body falling freely to it from infinite space, and can therefore annul it on the way up, and no more. If, then, any of the molecules reach the outer boundary of the air going at more than this speed, they will pass beyond the Earth's power to restrain. They will become little rovers in space on their own account, and dart off on interstellar travels of their own. This extension of the kinetic theory and of the consequent voyages of the molecules is due to Dr. Johnstone Stoney, who has since, humorously enough, tried to stop the very balls he set rolling. First thoughts are usually the best, after all.

As among the molecules some are already travelling at speeds in excess of this critical velocity, molecules must constantly be attaining to this emancipation, and thus be leaving the Earth for good. In consequence there is a steady drain upon its gaseous covering. Furthermore, as we know from comets' tails, the repellent power of the light-waves, what we may call the levity of light, much exceeds upon such volatile vagrants the heat excitement or even the gravity of the Sun, so that we arrive at this interesting conclusion—their escape is best effected under cover of the night.

Again, the heavier the gas, the less its molecular speed at a given temperature, because its kinetic energy which measures that temperature is one-half the molecule's mass into the square of its speed. Thus their ponderosity prevents as many of them from following their more agile cousins of a different constitution. So that the lighter gases are sooner gone. Water-vapor leaves before oxygen. Nor is there any escape from this escape of the gases. It may take excessively long, but go they must until a solitary individual who happens to have had the wrong end of the last collision is alone left hopelessly behind.

Another factor also is concerned. The smaller the planet, the lower the utmost velocity it can control, and the quicker, therefore, it must lose its atmosphere. For a greater number of molecules must at every instant reach the releasing speed. Thus those bodies that are little shall, perforce, have less to cover themselves withal.

Now this inevitable depletion of their atmospheric envelopes, the aspects of the various planets strikingly attest. They do so in most exemplary fashion, according to law. The larger, the major planets, as we have already remarked, have a perfect plethora of atmosphere, more than we at least know what to do with in the way of cataloguing yet. The medium-sized, like our own Earth, have a very comfortable amount; Mars, an uncomfortable one, as we consider, and the smallest none at all. All the smaller bodies of our system are thus painfully deprived so far as we can discover. We are certain of it in the case of our Moon and Mercury, the only ones we can see well enough to be sure. In further evidence it has been shown at the Yerkes and at Flagstaff that no perceptible effect of air betrays itself in the spectroscopic imprint of the rings of Saturn, those tiny satellites of his, and very recently a spectrogram of Ganymede, Jupiter's third moon, made at Flagstaff for



Spectrogram of Saturn — Photographed by Dr. V. M. Slipher, Lowell Observatory, October 11, 1904. Exposure 4^h on "27" gilt edge plate. Long camera placed beneath the slit. Titanium comparison spectrum. Enlargement by Mr. C. O. Lampland.

the purpose by Mr. E. C. Slipher has proved equally void of atmospheric hint.

With the loss of water and of air, all possibility of development departs. Not only must every organism die, but even the inorganic can no longer change its state. In the extinction thus not only of inhabitants but of the habitat that made them possible, occurs a curious inversion of the order we are familiar with in the life-history of organisms. In planets it is the grandchildren that die first, then the children, and lastly their surviving parent. And this is not accidental, but inevitably consequent upon their respective origins. For the off-spring, as we may spell it with a hyphen, of any cosmic mass is of necessity smaller than that from which it issued. Being smaller, it must age quicker. In the natural order of events, then, its end must be reached first.

Such has been the course taken, or still taking, by the bodies of our solar family. The latest generation has already succumbed to this ebbing of vitality with time. Every one of the satellites of the planets — those of Neptune, Uranus, Saturn, Jupiter, and our own Moon — is practically dead; born so the smaller which never were alive. Our own Moon carries its decrepitude on its face. To all intents and purposes its life is past; and that it had at one time a very fiery existence, the great lunar craters amply testify. It is now, for all its flooding with radiance our winter nights, the lifeless statue of its former self.

The same inevitable end, in default of others, is now overtaking the planetary group. Its approach is stamped on the face of Mars. There we see a world dying of exhaustion. The signs of it are legible in the markings we descry. How long before its work is done, we ignore. But that it is a matter of time only, our study of the laws of the inexorable lead us to conclude. Mars has been spared the fate of Mercury and Venus to perish by this other form of planetary death.

Last in our enumeration of the causes by which the end of a world may be brought about, because the last to occur in order of time, is the extinction of the Sun itself. Certain to come and conclude the solar system's history as the abode of life, if all the others should by any chance fail to precede it, it fittingly forms the climax, grand in its very quietude, of all that went before.

By the same physical laws that caused our Earth once to be hot, the Sun shines to-day. Only its greater size has given it a life and a brilliancy denied to smaller orbs. The falling together of the scattered particles of which it is composed, caused, and still is causing, the dazzling splendor it emits. And so long as it remains gaseous, its temperature must increase, in spite of its lavish expenditure of heat, as Homer Lane discovered forty years ago.

But the Sun's store of heat, immense as it is to-day, and continued as it is bound to be for untold æons by means of contraction of its globe upon itself, and possibly by other causes, must some day give out. From its present gaseous condition it must gradually but eventually contract to a solid one, and this in turn radiate all its heat into space. Slowly its lustre must dim as it becomes incapable of replenishing its supply of motive power by further shrinkage in size. Fitfully, probably, like Mira Ceti to-day, it will show temporary bursts of splendor as if striving to regain the brightness it had lost, only to sink after each effort into more and more impotent senility. At last some day must come, if we may talk of days at all when the great event occurs when all days shall be blotted out, that the last flicker shall grow extinct in the orb that for so long has made the hearth of the whole system. For, presciently enough, the Latin word *focus* means hearth, and the body which includes within it the focus about which all the planets revolve also constitutes the hearth from which they all are lighted and warmed.

When this ultimate moment arrives and the last spark of solar energy goes out, the Sun will have reverted once more to what it was when the cataclysm of the foretime stranger awoke it into activity. It will again be the dark body it was when our peering into the past first descries it down the far vista of unrecorded time. Ghostlike it will travel through space, unknown, unheralded, till another collision shall cause it to take a place again among the bright company of heaven. Thus, in our account of the career of a solar system, we began by seeing with the mind's eye a dark body travelling incognito in space, and a dark body we find ourselves again contemplating at the end.

In this kaleidoscopic biograph of the solar system's life, each picture dissolves into its successor by the falling together of its parts to fresh adjustments of stability, as in that instrument of pleasure which so witched our childish wonder in early youth. Just as when a combination had proved so pretty, once gone, to our sorrow no turning of the handle could ever bring it back, so in the march of worlds no retrace is possible of steps that once are past. Inexorable permutations lead from one state to the next, till the last of all be reached.

Yet, unlike our childhood's toy, reasoning can conjure up beside the present picture far vistas of what preceded it and of what is yet to come. Hidden from thought only by the distraction of the day, as the universe to sight lies hid by the day's overpowering glare, both come out on its withdrawal till we wonder we never gazed before. Our own surroundings shut out the glories that lie beyond. Our veil of atmosphere cloaks them from our view. But wait, as an astronomer, till the Sun sinks behind the hills and his gorgeous gold of parting fades to amber amid the tender tapestry of trees. The very air takes on a meaning which the flood of day had swamped. Seen itself, no longer imperfectly seen through, it wakes to semi-sentient existence, a spirit come to life aloft to shield us from the too immediate vacancy of space. The perfumes of the soil, the trees, the flowers, steal out to it, as the twilight glow itself exhales to heaven. In the hushed quiet of the gloaming Earth holds her breath, prescient of a revelation to come.

Then as the half-light deepens, the universe appears. One by one the company of heaven stand forth to human sight. Venus first in all her glory brightens amid the dying splendor of the west, growing in lustre as her setting fades. From mid-heaven the Moon lets fall a sheen of silvery light, the ghostly mantle of her ghostlike self, over the silent Earth. Eastward Jupiter, like some great lantern of the system's central sweep, swings upward from the twilight bow to take possession of the night. Beyond lies Saturn, or Uranus perchance dim with distance, measuring still greater span. All in order in their several place the noble cortège of the Sun is exposed to view, seen now by the courtesy of his withdrawal, backgrounded against the immensity of space. Great worlds, these separate attendants, and yet as nothings in the void where stare the silent stars, huge suns themselves with retinues unseen, so vast the distances 'twixt us and them.

No less a revelation awaits the opening of the shutters of the mind. If night discloses glimpses of the great beyond, knowledge invests it with a meaning unfolding and extending as acquaintance grows. Sight is human; insight seems divine. To know those points of light for other worlds themselves, worlds the telescope approaches as the years advance, while study reconstructs their past and visions forth their future, is to be made free of the heritage of heaven. Time opens to us as space expands. We stand upon the Earth, but in the sky, a vital portion not only of our globe, but of all of which it, too, forms part. To feel it is to enter upon another life; and if to realization of its beauty, its grandeur, and its sublimity of thought these chapters of its history have proved in any wise the portal, they have not been penned in vain.

NOTES

NOTES

I

Meteor Orbits

If the space of the solar system be equally filled with meteors throughout, or if they diminish as one goes out from the Sun according to any rational law, their average speed of encounter with the Earth would be nearly parabolic.

If they were travelling in orbits like those of the short-period comets, that is with their aphelia at Jupiter's orbit and their perihelia at or within the Earth's, their major axes would lie between 6.2 and 5.2. If we suppose their perihelion distances to be equally distributed according to distance, we have for the mean a major axis of 5.7. Their velocity, then, at the point where they cross the Earth's track would be given by

$$v^2 = \mu\left(\frac{2}{1} - \frac{1}{2.85}\right),$$

in which $\mu = 18.5^2$ in miles per second

$= 342.25,$

whence $v = 23.76$ in miles per second.

Suppose them to be approaching the Earth indifferently from all directions.

At sunset the zenith faces the Earth's quit; at sunrise the Earth's goal. Let θ be the real angle of the meteor's approach reckoned from the Earth's quit; θ_1 the apparent angle due to compounding the meteor's velocity-direction with that of the Earth. Then those approaching it at any angle θ less than that which makes $\theta_1 = 90°$ will be visible at sunset; those at a greater angle, at sunrise. The angle θ_1 is given by the relation,

$$\cos \theta_1 = +\frac{a}{x},$$

in which a is the Earth's velocity, x the meteor's, and θ_1 is reckoned from the Earth's quit.

The portion of the celestial dome covered at sunset is, therefore,

$$\int_0^{\theta_1}\int_0^{360°} \sin\theta \cdot d\theta \cdot d\phi,$$

where ϕ is the azimuth,

that at sunrise, $$\int_{\theta_1}^{180°}\int_0^{360°} \sin\theta \cdot d\theta \cdot d\phi.$$

If the meteors have direct motion only, θ can never exceed 90°, and the limits become,

for sunset, $$\int_0^{\theta_1}\int_0^{360°} \sin\theta \cdot d\theta \cdot d\phi,$$

and for sunrise, $$\int_{\theta_1}^{90°}\int_0^{360°} \sin\theta \cdot d\theta \cdot d\phi.$$

The mean inclination at sunset is

$$\frac{\int_0^{\theta_1}\int_0^{360°} \theta_1 \cdot \sin\theta \cdot d\theta \cdot d\phi}{\int_0^{\theta_1}\int_0^{360°} \sin\theta \cdot d\theta \cdot d\phi},$$

in which θ_1 must be expressed in terms of θ, etc.

From this it appears that the relative number of bodies, travelling in all directions and at parabolic speed, which the Earth would encounter at sunrise and sunset respectively would be:—

sunrise	5.8
sunset	1.0

and with the speed of the short-period comets,

sunrise	8.0
sunset	1.0

If, however, the bodies were all moving in the same sense as the Earth, *i.e.* direct, the ratios would be:—

	Parabolic Speed	Speed of Short Period Comets	Speed of Actual Short-Period Comets about Jupiter
Sunrise	2.4	3.5	3.3
Sunset	1.0	1.0	1.0

As the actual number encountered is between 2 and 3 to 1, we see that the greater part must be travelling in the same sense as the Earth, since they come indifferently at all altitudes from the plane of her orbit.

2

Densities of the Planets

The densities of the principal planets, so far as we can determine them at present, the density of water being unity, are:—

Mercury . . .	3.65	Jupiter	1.33
Venus	5.36	Saturn	0.72
Earth	5.53	Uranus	1.22
Moon	3.32	Neptune . . .	1.11
Mars	3.93		—— mean 1.09
	—— mean 4.36	Sun	1.38

The second decimal place is not to be considered as anything but an indication.

3

Variation in Spectroscopic Shift

In the case of a body reflecting light, the shift differs from that for a body emitting it. If the planet be on the further side of the Sun, the approaching rim advances both toward the Sun and toward the Earth, thus doubling the shift. The receding rim recedes in like manner. At elongation the rims approach or recede with regard to the Earth, but not the Sun, and the shift is single as for emission. At inferior conjunction rotational approach to the Earth implies rotational recession from the Sun, and the two effects cancel.

4

On the Planets' Orbital Tilts

The tilts of the plane of rotation of the Sun and of the orbits of the several planets to the dynamical plane of the system tabulated are:—

Sun	7°	Asteroids	various
Mercury	6° 14′	Jupiter	20′
Venus	2° 4′	Saturn	56′
Earth	1° 41′	Uranus	1° 2′
Mars	1° 38′	Neptune	43′

where, in the determination of that plane, the latest values of the masses of the planets and the rotations of the Sun, Jupiter, and Saturn have been taken into account.

These tilts suggest something, doubtless, but it is by no means clear what it is they suggest. They are just as compatible with a giving off from a slowly condensing nebula as with an origin by shock. The greater inclinations of Mercury and Venus may be due to their late birth from the central mass without the necessity of a cataclysm, the rotation of that central mass out of the general plane being caused by the consensus of the motions of the particles from which it was formed. The accordance of the larger planetary masses with the dynamical plane of the system would necessarily result from their great aggregations. So that this, too, is quite possible without shock.

5

Planets and their Satellite Systems

If we compute the speeds of satellites about their primaries in the solar system and compare them with the velocities in their orbits of the planets themselves, a striking parallelism stands displayed between the several systems. This is shown in the following table of them:

	Mean Speed, Miles a Second		Parabolic Speed at Orbit	Ratio Speed Sat. about Primary to Planet's Speed in Orbit
	of Primary in Orbit V	of Satellite about Primary v	Miles a second	
Jupiter . .	8.1		11.5	
Sat. 1		10.7		1.32
2		8.5		1.05
3		6.7		0.83
4		5.1		0.63
Saturn . .	6.0		8.5	
1		9.0		1.50
2		7.9		1.31
3		8.2		1.36
4		6.3		1.05
5		5.3		0.89
6		3.5		0.59
8		2.0		0.34
Uranus . .	4.2		5.9	
1		3.5		0.82
2		2.9		0.70
3		2.3		0.54
4		2.0		0.47
Neptune . .	3.4		4.8	
1		2.7		0.81

The relations here disclosed are too systematic to be the result of chance.

The orbits of all these satellites have no perceptible eccentricity independent of perturbation except Iapetus, of which the eccentricity is about .03.

In view of the various cosmogonies which have been advanced for the genesis of the solar system it is interesting to note what these speeds imply as to the effect upon the satellites of the impact of particles circulating in the interplanetary spaces at the time the system evolved. To simplify the question we shall suppose — which is sufficiently near the truth — that the planets move in circles, the interplanetary particles in orbits of any eccentricity.

Taking the Sun's mass as unity, the distance R of any given planet from the Sun also as unity, let the planet's mass be represented by M and the radius of its satellite's orbit, supposed circular, as r. We have for the space velocity of the satellite on the sunward side of the planet, calling that of the planet in its orbit V and that of the satellite in its orbit round the planet v,

$$V - v = \sqrt{\frac{1}{R}} - \sqrt{\frac{M}{r}}.$$

For a particle, the semi-major axis of whose orbit is a_1 and which shall encounter the satellite,

the velocity is $\quad v_1 = \left(\frac{2}{R - r} - \frac{1}{a_1}\right)^{\frac{1}{2}}.$

That no effect shall be produced by the impact of these two bodies, their velocities must be equal, or

$$\sqrt{\frac{1}{R}} - \sqrt{\frac{M}{r}} = \sqrt{\frac{2}{R - r} - \frac{1}{a_1}}.$$

As $R - r = a_1(1 + e)$ for the point of impact if the particle be wholly within the orbit of the planet and e the eccentricity of its orbit, we find $e = 2\sqrt{\frac{MR}{r}} - \frac{RM}{r}$ approx.

for the case of no action, the other terms being insensible for the satellites in the table, since in all $r < \frac{R}{400}\cdot$

Supposing, now, the particles within the orbit of the planet to be equally distributed according to their major axes, then as the velocity of any one of them, taking $R - r = R$ approx. as unity, is

$$v_1 = \left(\frac{2}{1} - \frac{1}{a_1}\right)^{\frac{1}{2}},$$

the mean velocity of all of those which may encounter the satellite is, at the point of collision,

$$\frac{\int_{\frac{1}{2}}^{1} \frac{(2a_1 - 1)^{\frac{1}{2}}}{a_1^{\frac{1}{2}}} da_1}{\int_{\frac{1}{2}}^{1} da_1}$$

$$= 2\left[(2a_1^2 - a_1)^{\frac{1}{2}} - \frac{1}{\sqrt{2}} \log \{(2a_1 - 1)^{\frac{1}{2}} + \sqrt{2a_1}\}\right]_{\frac{1}{2}}^{1}$$

$$= 0.754;$$

that is, just over three-quarters of the planet's speed in its orbit.

If we suppose the particles to be equally distributed in space, we shall have more with a given major axis in proportion to that axis, and our integral will become

$$\frac{\int_{\frac{1}{2}}^{1} (2a_1 - 1)^{\frac{1}{2}} a_1^{\frac{1}{2}} da_1}{\int_{\frac{1}{2}}^{1} a_1 da_1}$$

$$= \frac{8}{3}\left[\frac{4a_1 - 1}{8}(2a_1^2 - a_1)^{\frac{1}{2}} - \frac{1}{16\sqrt{2}} \log \left[(2a_1^2 - a_1)^{\frac{1}{2}} + \sqrt{2}\cdot a_1 - \frac{1}{2\sqrt{2}}\right]\right]_{\frac{1}{2}}^{1}$$

$= 0.792$ of the planet's orbital speed.

The speed v, then, at which a satellite must be moving round the planet to have the same velocity as the average particle within the planet's orbit, is

$$V - v_1 = v.$$

This velocity is, for the several planets: —

	Distribution of Particles as their Major Axes	Distribution of Particles Equal in Space
	Miles a second	Miles a second
Jupiter	2.0	1.6
Saturn	1.5	1.2
Uranus	1.0	0.9
Neptune	0.8	0.7

If the satellite be moving in its orbit less fast than this, its space-speed will exceed that of the average particle; it will strike the particle at its own rear and be accelerated by the collision. If faster, the particle will strike it in front and retard it in its motion round its primary.

From the table it appears that all the large satellites of all the planets have an orbital speed round their primaries exceeding those in either column. In consequence, all of them must have been retarded during their formation by the impact of interplanetary particles and forced nearer their primaries than would otherwise have been the case; and this whether the particles were distributed more densely toward the Sun, as $\frac{1}{a_1}$, or were equally strewn throughout.

For interplanetary particles whose orbits lie without the particular planet's path the mean speed is the parabolic at the planet's distance, given in the third column of the table. This is the case on either supposition of distribution. The orbital speed of the satellite which shall not be affected by collisions with them is, for the several planets:—

	Miles a Second
Jupiter	3.4
Saturn	2.5
Uranus	1.7
Neptune	1.4

All the satellites but Iapetus have orbital speeds exceeding this, and consequently are retarded also by these particles.

For particles crossing the orbit (2) the mean velocity would be practically parabolic, 1.4, even if the distribution were as $\frac{1}{r'}$, r' being the distance from the Sun. The effect would depend upon the angle of approach and in the mean give a greater velocity for the particle than for the satellite within the orbit, a less one without; retarding the satellite in both cases. Thus the total effect of all the particles encountering the large satellites is to retard them and to tend to make them hug their primary.

For retrograde satellites the velocities of impact with inside and outside particles moving direct are respectively:

	Inside	Outside
Jupiter	$2.0 + v$	$v + 3.4$
Saturn	$1.5 + v$	$v + 2.5$
Uranus	$1.0 + v$	$v + 1.7$
Neptune	$0.8 + v$	$v + 1.4$

In both cases the impact tends to check the satellite.

Comparing with these the velocities of impact for direct satellites in a direct plenum:—

	Inside	Outside
Jupiter	$2.0 - v$	$3.4 - v$
Saturn	$1.5 - v$	$2.5 - v$
Uranus	$1.0 - v$	$1.7 - v$
Neptune	$0.8 - v$	$1.4 - v$

the signs being taken positive when the motion is direct, we see that retrograde satellites would be more arrested than direct ones with the same orbital speed round the primary.

In a plenum of direct moving particles, then, the force tending to stop the satellite and bring it down upon the planet is greater for retrograde satellites than for direct ones.

If, therefore, the positions of the satellites have been controlled by the impact of interplanetary particles, the retrograde satellites should be found nearer their planets than the direct ones.

6

On the Induced Circularity of Orbits through Collision

Since the moment of momentum is the velocity into the perpendicular upon its direction, in the time dt it is:—

$$vpdt = hdt = r^2 d\theta.$$

The whole moment of momentum from perihelion to perihelion is therefore:—

$$\int_0^{360^\circ} r^2 d\theta = \frac{a^2 \cdot (1 - e^2)^2}{1 - e^2} \left[\frac{-e \sin\theta}{1 + e\cos\theta} + \frac{2}{(1 - e^2)^{\frac{1}{2}}} \tan^{-1}\left(\sqrt{\frac{1 - e}{1 + e}} \cdot \tan\frac{\theta}{2} \right) \right]_0^{360^\circ}$$

$$= 2\pi a^2 \cdot (1 - e^2)^{\frac{1}{2}},$$

which is twice the area of the ellipse.

The energy in the ellipse during an interval dt is

$$\frac{1}{2} mv^2 dt = \frac{1}{2} m\mu\left(\frac{2}{r} - \frac{1}{a}\right)dt,$$

from the well-known equation for the velocity in a focal conic. The integral of this for the whole ellipse is

$$\int_0^T \frac{1}{2} mv^2 dt = \int_0^{360^\circ} \frac{1}{2}\frac{m\mu}{h}\left(2r - \frac{r^2}{a}\right)d\theta$$

$$= m\mu^{\frac{1}{2}}\pi a^{\frac{1}{2}}.$$

Since

$$\int r d\theta = \int \frac{a \cdot 1 - e^2}{1 + e\cos\theta} d\theta = \frac{2a \cdot 1 - e^2}{(1 - e^2)^{\frac{1}{2}}} \tan^{-1}\left(\sqrt{\frac{1 - e}{1 + e}} \tan\frac{\theta}{2}\right)$$

and $\int r^2 d\theta$ is given above.

By collision a part of this energy is lost, being converted into heat. The major axis, a, is, therefore, shortened. But from the expression $2\pi a^2 \cdot (1 - e^2)^{\frac{1}{2}}$ for the moment of momentum we see that this is greatest when e is least. If, therefore, a is diminished, e must also be diminished, or the moment of momentum would be lessened, which is impossible.

7

Capture of Satellites

See has recently shown (*Astr. Nach.* No. 4341–42) that a particle moving through a resisting medium under the attraction of two bodies revolving round one another in circles may eventually be captured by one of them though originally under the domination of both. The argument consists in introducing the effect of a resisting medium upon the motion in the space permitted by Jacobi's integral, following Darwin's examination of this space. In the actual case of nature the effect is much more complicated, and at present is not capable of exact solution for masses other than indefinitely small, even supposing circular orbits for the chief bodies. It may, however, explain the curious relation shown in the arrangement of the direct and retrograde movement of satellites.

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