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THE SOLAR SYSTEM—SOME UNSOLVED PROBLEMS[1]

ABOUT forty years ago I attended several of the famous noon-hour lectures in Tremont Street Temple, Boston, by Dr. Joseph Cook. I should not be able now to quote anything Dr. Cook said, but I do recall distinctly that whatever his subject he did not at once begin to speak upon it, but gave first what he called a "prelude" upon some specially timely topic. With this distinguished precedent in mind, I venture to preface my address upon the unsolved problems relating to the solar system, by a plea for instruction in astronomy in our secondary schools.

This is a question to which I have given thought for many years, but the decision to speak about it to you to-night was formed as the result of a visit to the Lick Observatory in April by the senior class of one of our state teachers' colleges. I had the opportunity, in the course of the evening, to talk with several groups of these young people, who will, within a few months, be among the teachers to whom we entrust the education of our children.

Frankly, their ignorance of the most obvious of celestial phenomena and of the most elementary facts relating to the sun, the moon and the stars was appalling. Doubtless they all knew that the sun rises in the east, but I question whether they knew that this is also true of the new moon! Certainly, they did not know that the sun and the moon differ in size nor that the moon does not, like the sun, originate its light. They did not know the difference between a planet and a star, nor did they know even the most conspicuous of the stars and constellations. Orion and the Pleiades, Sirius and Arcturus meant nothing to them, so far as I could ascertain. I told them of the *teacher* to whom I once showed Jupiter, and who, after a single glance at the glorious disk, exclaimed "Is this a star? I thought all stars had five points!" and they looked at me with blank faces. Perhaps they, too, thought that Jupiter was a star and that all stars had five points!

If this were true of the students in only one institution it would be bad enough, but there would be no occasion for bringing the matter to your attention. Unfortunately, I fear that is true of a large proportion of the students in all our schools. It is entirely possible for a student to pass from the kindergarten

[1] Address of the retiring president of the Pacific Division, American Association for the Advancement of Science, delivered at Mills College, June 16, 1926.

to a university degree and remain as ignorant of these matters as the young people with whom I talked, and I fear that great numbers of them are in just that condition. I think it no exaggeration to say that the North American Indians in the days of Columbus knew more about the apparent motions of the sun, moon and planets, about the configurations of the stars, and the relation of their appearance in the night sky to the seasons of the year, than does the average university graduate to-day.

I am not concerned about the practical benefits of a knowledge of astronomy. I am not pleading that the technicalities of astronomy be taught to all our children. It is not necessary that they should be able to take a time observation, compute a comet orbit, observe the sun's altitude or find their way across country at night by the aid of the stars. Nor do I care to do more than mention the fact that it would seem hard to find better material for training the child's powers of observation than is afforded by the varying motions of the sun, the moon and the planets and the heliacal rising of the stars.

I do plead that every child has a right to be introduced to the stars as ever-present friends; to be taught the simple relations of the earth to the sun and moon and planets and stars; to have his imagination stimulated and his mental horizon widened by some conception of the vastness and the wonders of the greater universe.

Literature, from Job and Homer to Tennyson and Browning, abounds in allusions to the stars. What significance can they have to the teachers in training with whom I talked?

"What the Stars Predict," "Nannette's Horoscope," and similar puerilities are featured in our daily papers. Why not, when a large percentage of our people practically live in the Pre-Copernican age, so far as knowledge of the universe is concerned!

To free us from superstitions and the childishness of mind, of which a recent essayist complains; to give us a proper realization of relative human values; to teach us humility through knowledge of the insignificance of our puny earth among the worlds of space; and to help us to know exaltation through awareness that our earth and we ourselves are organic parts of this great universe; all this is the mission of astronomy. Is it not right to demand that every child in our schools be granted the opportunity to gain at least a little knowledge of this universe, "a universe," in the words of Justice Holmes, "not measured by our fears, a universe that has thought and more than thought inside of it!"

From the beginning of the present century astronomers have been giving their attention chiefly to the study of distinctively stellar problems; the number, distance and distribution of the stars, the motions of the stars, their organization into systems, the physical nature of stars and nebulae and their origin and evolution. In illustration of this tendency I may cite the fact that out of twenty-three papers to be presented at the meetings of the Astronomical Society of the Pacific to-morrow and Friday, only five relate to the solar system, and four of these have to deal with the sun. We are pressing our researches ever farther into space, and in recent years it is precisely the most distant known objects, the globular clusters and the spiral nebulae, that have contributed most strikingly to our knowledge. This is as it should be and is but the natural consequence of the development of spectroscopy and photography, the construction of giant telescopes, the development of ever more effective accessory equipment, and the great advance in knowledge of the fundamental properties of matter which have characterized this period. The additions that have been made to our knowledge of the greater universe within the lifetime of our own generation immeasurably exceed all that was known of it a hundred years ago.

The emphasis thus placed upon stellar research may lead the uninitiated to conclude that we have little or nothing more to learn about the motions or physical conditions of the bodies in our immediate solar system, and to correct that conclusion is one reason for my choice of subject. I am also of opinion that it is well, from time to time, to call attention to what we do *not* know, for I share in the view once expressed by the noted pathologist, Dr. Theobald Smith, that "to induce men to fill the gaps of our knowledge seems quite as important as the pioneering for entirely new vistas or outlooks."

Our knowledge of the general organization of the solar system may be said to be fairly complete. Nevertheless, wherever we turn, to sun, moon, planets or comets, we encounter unsolved and ofttimes apparently unsolvable problems. There are unexplained anomalies in the motions of the moon and of the planets; astronomical opinion is far from being unanimous as to the nature and origin of the surface markings on the moon, on Mars or on Jupiter; we know something about the rings of Saturn, but we do not know why Saturn and Saturn only has such rings; the origin and the mutual relations of the many hundreds of minor planets and of the even more numerous comets of long and short period are still open to question; we have some knowledge of *what* a sunspot is, but we do not know *why* it is; we can calculate the enormous amount of radiant energy emitted by the sun, in the thousand million years or more of its life history, and many recent brilliant investigations have convinced us that this store of energy is inherent. In

Eddington's words, it "is, with insignificant exception, energy of constitution of the atoms and electrons, that is to say, subatomic energy"; but as to the mechanism of its release and in particular, of the *constancy* of its release, we are still completely in the dark. We are convinced that the present form of our planetary system is the result of an orderly process of evolution, but we can give no account of its origin unless we assume the near approach of another star under conditions that amount almost to a special dispensation.

My enumeration is by no means exhaustive, but it lists some of the more obvious and important of the unsolved problems relating to our solar system and will serve to indicate how many are the gaps that still exist in our knowledge. Let us look more closely at some of these problems.

Celestial mechanics is justly regarded as one of the most exact of all the sciences. Its aim is to trace to the last detail the consequences of the law of gravitation as applied to the interaction of the various bodies in the solar system and to predict the future motions of these bodies. A dramatic illustration of the accuracy already attained was provided by the return of Halley's Comet in 1909, after its long journey out beyond the orbit of Neptune, in the course of which it had been invisible for nearly seventy-five years. The form of its orbit and the perturbations in its motion due to the attraction of the other bodies in the solar system were so accurately calculated that when the comet was found upon a photograph taken on September 11, 1909, its actual position upon the plate and the point predicted by the ephemeris for that date were separated by less than the breadth of a pinhead!

Nevertheless, there are unexplained anomalies in the motion of the moon and of the planets. The "Tables of the Motion of the Moon," published in 1919, by Professor E. W. Brown, of Yale University, are by far the most accurate so far constructed. The theory has been extended to include every known force that acts upon the moon, even in the slightest degree, and the equation expressing the moon's position at any date includes nearly one thousand five hundred terms, and yet Professor Brown writes in his preface:

> While many efforts have been made in the past to represent the motion of the Moon by gravitational theory alone, it is now admitted that this can not be done completely . . . There are oscillating differences (between observation and theory) which do not correspond to any theoretical gravitational terms, and they are large enough to exclude the possibility of being due to errors either in the theory or in the observations.

Following Newcomb, Brown has represented the principal portion of these by a purely empirical term, a term, that is, for which no explanation has as yet been accepted, with a period of about 270 years. Even then, puzzling oscillations of shorter periods and smaller amplitudes remain and, to quote again:

> All that can be done is to make an estimate of their magnitude from the observations of the past few years whenever it is desirable to predict the position of the Moon with high accuracy, as in the case of an eclipse of the Sun, and alter the values obtained from the Tables accordingly.

It is hardly necessary to say that astronomers are not willing to let the question rest here, even if, for practical purposes of observation, it is now possible at any time to secure a sufficiently accurate predicted position of the moon. We want an *explanation* of these differences which are not accounted for by known gravitational forces. The Einstein theory of relativity does not help us at all. In fact, this theory successfully accounts for but one of the outstanding anomalies in planetary motions—the advance in the perihelion of Mercury, and there are astronomers who are not yet convinced that it is necessary to invoke its aid in this instance.

Many years ago Newcomb pointed out that, "making abstraction of possible limitations imposed by the laws of motion, the observed fluctuations in the moon's mean motion may be equally due to actual changes in that motion or to changes in the earth's rotation, leading to errors in our measurements of time." At that time astronomers in general were not prepared to admit the possibility of variations in rate of rotation of the earth, and the hypothesis was not very seriously considered. Later attempts to account for the observed irregularities have, however, brought forward evidence which has placed Newcomb's suggestion in a more favorable light and within the past two months two quite different papers have appeared which argue strongly for its correctness. Dr. Innes, of the Union Observatory, South Africa, discusses the available observations of the transits of Mercury, and from them concludes that "the earth's rotation changes abruptly by an amount which is about ± 1 second a year"—and that "this change may continue until the total reaches about ± 30 seconds." "In compensation" for having to accept such an unwelcome conclusion, he adds, "this irregularity in one motion will more or less reconcile the motions of the moon, the satellites of Jupiter, the inner planets, and the sun."

Professor Brown, in his paper presented at the April meeting of the National Academy of Sciences, proceeding along different lines, also concludes that after all errors of observation are taken into account the remaining deviations in the moon's motion give good evidence in support of Newcomb's hypothesis.

He points out that the only reasonable explanation of such a variation in the earth's rotation time is one that assumes variations in the external radius of the earth, of from five inches to twelve feet, according to the depth of the source from which the changes originate, and considers the geophysical evidences of such oscillations. These are not wanting, and it is not at all impossible that they may be sufficient to produce the required effects. Further investigations along these lines and further observations of occultations of stars by the moon and of transits of Mercury are, however, required, before we can say that the problem is solved.

The moon, our satellite, is our nearest neighbor in space. Its mean distance is less than 240,000 miles, and even when it is farthest from the earth, light from it comes to us in less than one and a half seconds. It can be kept under almost continuous observation from every observatory in the world, and, moreover, it has no atmosphere and hence no clouds, and no dust storms to obscure our view of its surface. Every detail stands out sharply, and we can make accurate measures of positions and dimensions.

And yet astronomers are by no means in full accord in their views of the conditions upon the moon. The majority, I suppose, believe it to be an absolutely lifeless globe, upon which no change has been or is likely to be observed, however careful the survey and however powerful the telescope used. But there are not a few trained observers of great experience who are convinced that changes do take place, and that, particularly in or near certain of the craters, some of these changes are best explained by assuming the growth and decay of low forms of vegetation in the period of the lunar day. The water required to support such vegetation they assume to escape from the crater fissures. While I share the view of the majority on this question, I regard it desirable to settle it conclusively, if that is possible.

A similar statement may be made about the origin of the larger and smaller craters that pit the lunar surface. With the majority of astronomers, I hold that these have been produced by internal explosive forces, analogous to those to which we owe our volcanic eruptions. It must be admitted that it is difficult to account for all the observed details upon this theory, but it would seem to be still more difficult to account for them upon the only rival theory so far advanced with any plausibility, namely, that they are the consequences of a tremendous meteoric bombardment suffered in the early life of the moon. The latter theory, however, has strong adherents and the whole matter presents an interesting problem that may perhaps be solved conclusively by the new methods of investigation that are now available.

No one, so far as I know, has been able to suggest an explanation that is at all satisfactory for the bright streaks that radiate from several of the great craters like Tycho and Copernicus. They cast no shadows under any phase of illumination and hence can be neither elevations nor depressions on the surface, and they run without reference to topography, crossing craters, peaks and level areas alike.

Even the shape of the moon is not beyond question. Is it spherical, or is it ovoid, with the longer axis directed toward the earth, as might perhaps be expected to follow from the tidal interaction of the two bodies? It would seem possible to settle this point by a properly planned photographic investigation.

If the moon, which is so near us, and which offers us such continuous opportunity for observation, still presents so many unsolved problems, it is hardly reasonable to expect that our knowledge of our planetary neighbors should be complete, or even satisfactory. We do indeed know their mean distances from the sun, their masses, diameters and mean densities and some other statistical facts, within very narrow limits; beyond that, it is fair to say that we know comparatively little about them.

Our knowledge is most complete in the case of Mars. We know that it resembles the earth in having a solid crust, an atmosphere containing some water vapor, a succession of day and night almost precisely identical with our own and a succession of annual seasons that differ from our own chiefly in that each Martian season is nearly twice as long as the corresponding terrestrial one. Beyond this we know little. A definite advance was made at the opposition in 1924 in our knowledge of the temperature of the planet's surface, but much additional work is required before we can feel assurance on this point. Seasonal color changes have also been established beyond question, but whether the plausible conjecture that these are due to growth and decay of vegetation is the best explanation is still not beyond dispute. While all observers agree that the amount of water on the planet's surface is very limited, observations made in 1924 throw some doubt upon the conclusion generally accepted before that time that the Martian atmosphere is not only rare, but very limited. As to the nature of the famous system of canals, or by whatever other name we designate the markings on the planet's surface, the views of astronomers are as divergent to-day as they were a generation ago. Views as to the habitability of the planet vary with the opinions held on these disputed points. Some advance in knowledge may be expected from the observations to be made at the approaching opposition of Mars. Photographic studies, in light of different wave lengths, checked by comparative photographs of other objects, should lead to a better determination of the quality and extent of the planet's atmosphere, and radiometric measures should yield more accurate values of the temperature.

In my college course in descriptive astronomy, I learned that Jupiter and Saturn were bodies more closely resembling the sun than the earth in physical conditions; that is, that they were wholly gaseous, and still intensely hot; these conclusions resting chiefly upon their known low mean densities. Now, radiometric observations indicate that their surface temperatures, at least, are extremely low, so low as to make improbable any heat supply aside from solar radiation. That reopens the whole question as to the physical condition of these planets, and as to the nature of the complicated and ever-varying system of markings which produce the appearance of the characteristic and beautiful belts. The variation in the rotation periods of these planets with the latitude, like the similar variation in the rotation period of the sun, raises another question for which we have no positive answer.

Moon and planets shine only by reflected sunlight and their spectra should therefore be identical with the spectrum of the sun, except as the light is affected by passing through the atmosphere of the planet or of the moon. The spectra of the moon, of Mercury and of Venus, in point of fact, show no atmospheric absorption effects. It is doubtful whether or not such effect is visible in the spectrum of Mars. A few astronomers consider that it shows evidence of the presence of water vapor in the Martian atmosphere, but the majority regard this evidence as of very little weight.

The case is different for the four outer planets. The spectra of Jupiter, Saturn, Uranus and Neptune are characterized by broad absorption bands in the less refrangible or red end of the spectrum. Doubtless these bands will tell us much of the nature of the atmosphere—or outer layers of these planets, if we regard them as gaseous throughout—when we have learned to interpret them. The message has been written and has been delivered to us, but so far we have been able to read but a very small fragment of it.

And why has Saturn, and Saturn only, that beautiful ring system? It has been known since the time of Clerk Maxwell that the rings consist of an innumerable assemblage of fragmentary bodies; and the spectrographic measures by Keeler proved beyond question that these bodies in each successive zone of the rings are revolving about the planet in a period appropriate to a satellite at that distance from its center. But while we know their nature and can measure their breadth and thickness, no one has, so far as I am aware, ever suggested even a plausible hypothesis for the existence of the rings. They seem to be absolutely unique; the only system in the least resembling them being the ring of asteroids or minor planets between Mars and Jupiter, and the resemblance here is remote indeed. The asteroid belt contains more than a thousand known, and probably thousands of unknown tiny bodies. These are quite numerous at certain average distances and are few, or lacking, at certain intermediate distances, giving the effect of vacant lanes vaguely analogous to Cassini's Division between the two bright rings of Saturn. The minor planets resemble the Saturnian Ring System also in the fact that no one has yet advanced any adequate theory for their existence and particularly for their existence in the general region where, since Kepler's time, it seemed reasonable to expect to find another planet.

It was this expectation and the cooperative search for such a planet, based upon the relation between the mean distances from the sun of the known planets which has been formulated in what is known as Bode's Law, that led to the discovery of the first few minor planets. It led also to the hypothesis, when the number of known objects had increased, that these bodies were the remnants of a shattered planet. The hypothesis is now quite untenable, but we have no really satisfactory substitute.

The care of the known minor planets, their observation and especially the computation of their "perturbations" constitute a practical problem of the first magnitude. They number, as has been said, more than one thousand, in fact, more nearly one thousand one hundred, and additional discoveries are being made yearly. Their orbits are in many instances considerably more eccentric than those of the planets, the inclinations of their orbit planes show a far greater range, and in their orbital motions about the sun they are all greatly affected by the disturbing attractions of their planet neighbors, particularly Jupiter. These perturbations, in some instances, change the orbit so radically that when the minor planet is again observed it may be mistaken for a new body.

Work of great value in the way of computation of perturbations and the preparation of tables of a number of the more interesting asteroids has been done at several different institutions in our own country and abroad. But the task of carrying out the necessary observations and computations for all these bodies far exceeds the powers of any single institution. A well-planned cooperative program of research is needed, and it is to be hoped that the efforts now being made to effect this, under the auspices of the appropriate committee of the International Astronomical Union, may be successful.

The relations of the minor planets to other bodies in the solar system raise some interesting questions. For years it appeared that they all revolved about the sun between Mars and Jupiter. More recently a number have been discovered whose aphelia lie beyond the orbit of Jupiter, and a smaller number which at perihelion come well within the orbit of Mars, and approach the earth more nearly than any body except the moon and an occasional comet. In passing, it may be noted that these latter planets are admirably adapted for precise determinations of the solar parallax, and the best known member of the group, Eros, was in fact extensively observed for that purpose at the favorable opposition of 1900. Another very favorable opposition occurs in the winter of 1930–1931, and plans are already maturing for a similar campaign at that time.

It is not at all improbable that other small bodies may be found which differ in no particular from the known minor planets, except that the outer ends or aphelia of their orbits lie farther from the sun, as far out as the orbit of Saturn, or even farther. The question then arises, may not an occasional wanderer of this kind be "captured" by Jupiter or by Saturn and be forced thereafter to revolve as a satellite about one or the other planet? In point of fact, when the eighth satellite of Jupiter was discovered at Greenwich, it was uncertain, at first, whether it was a satellite or a minor planet. This satellite and the ninth, discovered at the Lick Observatory, describe their orbits in what is known as the "retrograde" direction, whereas the other seven satellites, like almost all the other satellites and planets in the solar system, move in direct orbits. This does not necessarily preclude the capture theory of their origin. Greater stability is obtained by retrograde than by direct motion at the great distance of these satellites from their primary and that may permit those forced into retrograde motion at time of capture to survive, while others are recaptured by the sun. This is speculation, of course.

There is another group of objects which revolve about the sun in quite eccentric orbits whose aphelia lie near the orbit of Jupiter, while their perihelia lie within the orbit of Mars, or even of the earth. This group is known as the Jupiter family of comets. These comets are all apparently small bodies, consisting of a more or less sharply defined nucleus, surrounded by a nebulous envelope or coma. The tail, which is the most prominent feature of a comet as usually depicted, is entirely lacking, and in some instances the nucleus is so sharp and the coma so faint that the object is hardly distinguishable from an asteroid. If no other comets were known there can be little question but that we should class these objects with the asteroids, noting the nebular appearance as an individual peculiarity to be accounted for, just as we now note the variability in brightness of certain of the asteroids, and it is not impossible that there is a real relationship between the two groups of objects.

The general opinion, however, is that these comets originally revolved in orbits of much longer period and much greater eccentricity and that they were drawn into their present orbits by the powerful perturbing action of the planet Jupiter. In similar manner it is suggested that Halley's Comet owes its present orbit to the attraction of the planets, chiefly Neptune.

We know that comets exist in the outer regions of the sun's domain in very great numbers. The orbits they describe, while far distant from the sun, are very elongated ellipses of such dimensions that their revolution periods must in general be reckoned in thousands of years. They are only visible to us for a short time during which they are near their perihelion points and then they seem to describe arcs of the open curves, known as parabolas or hyperbolas. This, and the fact that their orbit planes are inclined at all possible angles, led to the theory that such comets, which include nearly all the brilliant ones that have been observed, are visitors to our system from external space. In his address on "What we know of Comets" delivered to the Pacific Division at the San Diego meeting ten years ago, Dr. Campbell summarized the researches of various astronomers which have established the fact that these apparent parabolic or hyperbolic orbits are due to planetary perturbations and that before they came under these disturbing influences all these comets were travelling in elliptic orbits. The evidence is conclusive that the "parabolic" comets as well as the short period comets originated in the solar system.

Dr. Campbell lends the weight of his personal opinion to the view that not only the long period "parabolic" comets but also comets like the one that bears Halley's name and those of the Jupiter family consist of fragments from the outer portions of the primal nebula or stream of matter out of which our planetary system developed, though he adds that this view is to a certain extent speculative. This would imply that the periodic comets owe their present orbits to relatively close encounters with one or more of the major planets. Dr. Crommelin, the well-known English authority, has recently questioned the validity of the latter conclusion, largely on statistical grounds. To effect the radical change in orbit demanded to bring it into the Jupiter family, a comet, according to his calculations, would have to pass Jupiter at a distance less than that of its fourth satellite and only one comet in five hundred thousand would pass the planet within this distance. On the average, he concludes, it would require two hundred thousand years for Jupiter to capture a comet, and, at this rate, it would be difficult indeed to account for the more than forty members of the family. A fact of importance in this connection is that these short-period comets are apparently also relatively short-lived, and one or two have been lost completely within quite recent times. Their substance is wasted away or scattered all along their orbit by the disintegrating influence of the sun. The earth periodically encounters swarms of meteors, the Perseids, for example, and in some instances, at least, it is practically certain that these meteors are the fragmentary remains of comets.

Whatever may be the truth in the matter, it is evident that we have still quite as much to learn about these minor members of the solar system as about the planets themselves.

Most important of all, however, are the unsolved problems relating to the sun itself, partly because it is but a slight exaggeration to say that the sun *is* the solar system, since it contains within itself 99 6/7 per cent. of the mass of the system; partly because what happens upon the sun must always be of paramount interest to us dwellers upon the earth, since our very lives depend upon the energy it radiates. From the astronomer's viewpoint there is the additional reason that the sun is a typical star which is believed to have passed the meridian of its course and to be now on the dwarf or descending branch of its evolutionary curve. A complete solution of solar problems is equivalent to the solution of one of the two major problems of astronomy, the problem of stellar evolution. That is why observatories have been and are being established in different parts of the world equipped with apparatus designed to study every detail of the solar surface and to measure with greatest accuracy the intensity of the solar radiation. That is why it is worth while to spend time and labor and money on expeditions to distant parts of the earth to observe total eclipses of the sun, which provide our only opportunity to study the outer atmosphere of the sun, the corona. That is why, to refer to just one detail, we are so eager to know all about sunspots. Why do they appear at all; why does their number vary periodically; why in each cycle do they appear first in moderately high latitudes, 30° to 40° (but never at or near the poles), and then in increasing numbers in lower latitudes, leaving, however, a nearly free zone of about 10° on either side of the equator; and why is the polarity of the magnetic sunspot fields reversed in the alternate eleven-year cycles? We have made remarkable advances in our knowledge of all solar phenomena in the last few decades, through the researches at such observatories as those on Mount Wilson and at Meudon, Paris, to name but two of many, but our answers to the questions I have enumerated and to many others must still be regarded as more or less plausible speculations.

This is particularly true of the two most fundamental problems of all: what is the source of the sun's heat, and what is the nature of the mechanism by which it is generated at just the rate required to keep its radiation practically constant through hundreds of millions of years?

Consider the magnitude of the problem. According to Abbot and Fowle the solar constant is 1.93 calories. That means that every acre of the earth's surface which is exposed to the vertical rays of the sun is constantly receiving energy at the rate of four thousand horse power. But as seen from the sun, the earth's disk would cover only one two billionth part of the surface of the celestial sphere. Therefore, if we make the natural and plausible assumption that the sun is radiating light and heat with substantially equal intensity in all directions, the heat radiated into space by the sun must be two billion times that intercepted by our earth. In other words, the sun must be continuously radiating energy at the rate of approximately a million million million million (10^{24}) horse power.

No geologist is prepared to accept a figure short of two hundred to two hundred and fifty millions of years for the age of the earth; the majority demand an age at least three times as great; and geological evidence strongly supports the contention that throughout this enormous stretch of time the radiation received from the sun has not varied in any marked degree. Even the glacial epochs may be accounted for, not by variations of the sun's output of heat, but by changes in the conditions governing its transmission to the earth's surface; possibly by the passage of our solar system through one or more of the great gaseous nebulae which are known to abound in that part of the stellar system away from which we are now travelling.

Cosmogonists are as insistent as geologists in their claims for the great age of the sun and of the stars. Jeans says that "the figure of 10^9 (*i.e.*, a thousand million) years is the absolute minimum that can be considered" for the age of the sun, and Eddington, "certainly we can not abate our demands below 10^9 years." The actual figure, both believe, is vastly greater.

What is true of the sun must be true also of every one of the stars in our system, with due regard to individual differences in mass and in temperature, and to estimate the number of the stars at one thousand five hundred million is to be very conservative. Quite recently I have seen the number seriously set down as ten billion. We can write the figures which represent the total energy radiated into space by all these millions of stars continuously through a thousand or ten thousand million years, but who can comprehend their significence?

What is the source of all this energy? One statement about it, at least, may be made with confidence; it must lie deep within the sun (or star) itself; for, as Eddington remarks, supplies of energy from without, from whatever source, would simply affect the surface temperature and increase for the time being the intensity of the radiation emitted. They would not prolong the life of the sun at all. That is why the Helmholtz-Kelvin contraction hypothesis was at first received so favorably. This theory assumes that the gravitational energy released by the sun's gradual contraction suffices to balance the heat radiation, and it can, in fact, be shown that the sun's present radiation would be accounted for by a shrinkage in diameter too small to be measurable in a period of less than five thousand years. There is no question but that gravitational contraction does operate to generate heat in the sun, but, on the most favorable assumption, if this were the only source of solar energy, the sun's past life would be limited to about forty-six million years. The hypothesis is thus hopelessly inadequate. Nor does the suggestion of radioactive forces, though they too must contribute, give much help, for at best they can add but a few million years to the sun's life.

The one adequate source seems to be found in the very constitution of matter itself under the conditions of temperature and pressure prevailing in the deep interior of the sun or of a star. Under modern theories, which have been discussed in detail in the symposium this afternoon,[2] a rapidly moving electron has greater mass than one at rest, "since more force is required to deflect it from its path or to produce a specified acceleration." It follows that any body which receives energy increases its mass and one which radiates energy loses mass. The sun, on this basis, by its radiation is losing mass at the enormous rate of four million tons a second or more than one hundred and twenty million million tons a year. Even at this prodigious rate it would lose but one tenth of one per cent. of its mass in fifteen thousand million years. The theory thus solves, as Jeans says, "with a comfortable margin to spare the age-long problem of the source of the energy of stellar radiation."

But it does not by any means relieve us of our difficulties, for we have still to account for the mechanism of the release of energy, or the conversion of matter, in our usual definition of the term, into energy, and for its release at just the rate required to maintain the constant radiation from sun and stars. So far all attempts to solve this problem have raised more difficulties than they have cleared away, and Eddington, whose name is intimately associated with such progress as has been made in its investigation, is forced to conclude his most recent series of lectures on "the source of stellar energy" with the paragraph:

> I should have liked to close this course by leading up to some great climax. But perhaps it is more in accordance with the conditions of scientific progress that it should fizzle out, ending with a glimpse of the obscurity which marks the frontiers of present knowledge. I do not apologize for the lameness of my conclusion, for it is not a conclusion. I wish I could feel confident that it is even a beginning.

Eddington's words are not words of discouragement. Rather, they are a stimulus to more strenuous efforts. There is so much still to be learned, there are so many problems still to be solved. We need more data, data secured by the execution of carefully planned programs of observation and experiment. Data relating to stars and nebulae, but also data relating to the moon, the planets, the asteroids and the comets of our own solar system. They all hold secrets, secrets which can be unveiled, and in Professor Whitehead's words, "it is this instinctive conviction vividly poised before the imagination, which is the motive power of research."

ROBERT G. AITKEN

LICK OBSERVATORY

[2] June 16, 1926.

SCIENTIFIC EVENTS

RECENT RESEARCHES AT THE NATIONAL PHYSICAL LABORATORY OF GREAT BRITAIN

A LARGE number of visitors were given an opportunity of seeing something of the work of the National Physical Laboratory at Teddington on the occasion of the annual inspection by the general board. According to the London *Times,* the exhibits—nearly 200 were enumerated in the program—were for the most part selected to illustrate the more recent researches undertaken by the laboratory and the methods and apparatus employed in carrying them out.

Perhaps from the point of view of mere size the equipment of the aerodynamics department and of the ship-model experiment tank is the most imposing of all. In the former the whirling arm, one of the older pieces of apparatus, has been reconstructed and is to be used for experiments on aeroplane and airship models to determine the effect of a steady rotation in yaw upon the aerodynamic forces and moments. The shed in which it is housed has been made