WITH THE CAMBRIDGE ECLIPSE EXPEDITION

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THE Royal Chinese astronomers, Hsi and Ho, met a sad fate at the first eclipse recorded in history. On October 22nd, 2137 B. C., these officials became very drunk at the hour of the expected event. As a result, they were quite unable to perform their customary duties of shooting arrows at the monster which was devouring the sun. They were promptly beheaded by order of the Emperor. It is hardly necessary to add that their punishment has served as an awful warning to all astronomers from that day to this.

The most recent eclipse took place on August 31st, A. D. 1932. It was noteworthy because the path of totality passed through a thickly populated district of Quebec and New England at a convenient time of the year. Consequently this rare spectacle aroused intense public interest. More scientific expeditions were sent out than on any previous occasion and, it is safe to say, more scientists were prepared to study this eclipse than will undertake similar work again for many years to come.

In an age accustomed to mechanical inventions most things become a commonplace. An eclipse of the sun still excites the interest of the most blasé and occasions many questions which do not ordinarily arise in the minds of men. How does it come about? How can astronomers calculate it so accurately long in advance? Why do scientists take so much trouble to observe an eclipse, and what do they hope to discover? What is done in the weeks of preparation at camp? What happens in the few precious seconds of totality?

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An eclipse of the sun takes place, of course, when the moon comes between the earth and the sun. The earth moves around the sun in a plane called the ecliptic. If the moon moved around the earth in the same plane we should have an eclipse with each new moon. The moon's orbit, however, lies in a plane inclined at a small angle to the ecliptic, and only twice in a revolution around the earth will it lie in the ecliptic plane; still less frequently, of course, will it be in line with the sun. Earth and moon rotate with different periods, the year and the month. A time comes when both are in line with the sun. Then an eclipse of the sun or the moon can take place, depending on whether the moon or the earth is nearer the sun.

A further condition is to be noted. The moon is much smaller than the sun, but being much nearer the earth is just about able to cover the sun completely, giving a total eclipse. It is not always able to do so, however, owing to the varying distances from earth to sun and from earth to moon. These distances can vary somewhat since the orbits of both earth and moon are not circles, but approximate ellipses. If the eclipse occurs when the moon is closest to the earth (perigee) and the sun is furthest from the earth (aphelion), the moon's disc can comfortably cover the sun, and the sun will be eclipsed for the maximum possible time. When, however, the moon is furthest from the earth (apogee) and the sun nearest (perihelion), the moon cannot completely cover the sun, and an "annular" eclipse results, a narrow ring of the sun remaining uncovered. A simple experiment with a coin (representing the moon) placed between a frosted electric light bulb (the sun) and the eye (an observer on the earth) will easily show the various possibilities.

It is very fortunate that the size of the moon is sufficient to produce a total eclipse. If the diameter of the moon were only 140 miles smaller, this would be impossible even under the most favourable conditions. This closeness of fit will explain why an eclipse lasts such a short time. The maximum possible duration is about seven and a half minutes. For the same reason, totality is confined to a narrow region of the earth, about 160 miles at most. The observer need be only slightly off the line of centres of sun and moon to be prevented from seeing the eclipse as total. It is little wonder, then, that on the average this phenomenon will be visible in any one locality only once every 360 years. On the average, there are about 66 total and 88 annular eclipses in a century. Of those which are total, only a fraction will be in accessible regions or of sufficient duration to justify expeditions.

Until quite recently tables of forthcoming eclipses showed that the next occurring in an easily accessible part of North America would be on August 21st, 2107. Within the last few months a new one has been "discovered" which will on July 20th, 1963, cover about the same region as the 1932 eclipse.

The rough calculations for such an occurrence are relatively simple, and can be worked out with the aid of the Nautical Almanac. Accurate computation of times and places on the earth represents one of the highest branches of spherical astronomy. It is dependent on the tables of the moon's motion. To this department of knowledge the great contributors have been Hansen, Simon Newcomb, and E. W. Brown. At present, by international co-operation, the computing of eclipses is in the hands of the "American Ephemeris" which aims at an accuracy of one quarter of a mile in position and two seconds in time.

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Most people have seen partial eclipses of the sun, but comparatively few have seen a total eclipse. It must be emphasized that, spectacularly, there is a vast difference between the two. The brightness of the sun is so great that if only a small fraction is left uncovered, there is still sufficient light to mask the effects visible at totality. The total light visible from the fully eclipsed sun is about half that of the full moon and one millionth that of the noon-day sun. Hence at an eclipse which is 90% total, there is still one hundred thousand times as much light as at totality. Only totality discloses the real features of what we want to observe.

A total eclipse begins when the disappearing crescent of the sun suddenly breaks up into the so-called Baily's beads, caused by the last rays of the sun shining through the valleys of the moon. A quick glance at the landscape would show the shadow of the moon rushing towards the observer at a speed of several thousands miles an hour. The next instant the sun is completely covered. Scattered irregularly around the edges of the moon's disc may be seen the red prominences due to eruptions of hot gases, flung high enough above the sun's surface to be visible beyond the moon's edge.

The most striking feature of an eclipse is the corona shining forth as "the matchless glory of the heavens." It is a ring of pearly white light extending far out beyond the black disc of the moon. At some points streamers may extend out beyond the ring to a distance of ten million miles, twelve times the sun's diameter. Beyond the corona many stars are visible. For a few seconds this spectacle persists; but, all too soon for the astronomer, Baily's beads break out on the other side of the moon, and an instant later the thin crescent of the new-born sun illuminates the landscape while the moon's shadow rushes away as quickly as it came.

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To the scientist a total eclipse offers the opportunity of studying many features of the sun which are normally concealed by the intense light from its central portion. The time available for observation is pitifully small. There is no time to repeat an observation, and a mistake once made cannot be rectified. The most assiduous of astronomers could not expect in his whole life time to enjoy as much as one hour of totality. He must travel to the ends of the earth, and work under very unfavourable conditions in the field at great expense. To cap it all, the months of preparation may go for nothing because of the untimely appearance of a cloud.

What then is the justification for all this trouble and expense? Even to those who value only results of immediate and obvious practical importance, adequate reasons can be given. The very existence of life is dependent upon the sun. No opportunity of gaining further information about it should be missed by the utilitarian. The prediction of the weather, the growth of crops, the safety of navigation, and the quality of radio broadcasting may all benefit by increased knowledge of the nature of the sun.

But the search after knowledge for its own sake brings rich rewards. The nation which has ceased to be curious has resigned its place in civilization. Scientists who came from many lands to study the latest eclipse were carrying on a long tradition, the breaking of which would be almost unthinkable. One might obtain a very good idea of the progress of science by comparing the programmes of successive eclipse expeditions in the last hundred years. New theories and improved experimental facilities have both led to an ever widening range of questions to be asked of nature at the favourable moments of a total eclipse.

The aims of such scientific study should not be difficult of comprehension by the layman. Our sun is a rather typical star. Out of the multitude of stars it is the only one near enough to us to permit a study of its separate parts. What physical astronomers aim at is a thorough knowledge of the constitution of the stars. Information is desired, not only as to their size, weight, and luminosity, but also as to their chemical constitution, pressure, temperature and electrical condition at various depths. It is an enlightening commentary on modern scientific methods that the scientist who starts to investigate a star soon finds himself discussing an atom. Observations on the sun, experimental work in the physical laboratory, and deductions from atomic and other physical theories combine to make astrophysics one of the most fascinating fields of modern research.

In the sun's atmosphere is found a range of temperatures and pressures far greater than any attainable on the earth. The sun really forms a super-laboratory, not inaccessible to observation.

It is about 865,000 miles in diameter, over a hundred times that of the earth, and is probably a completely gaseous sphere. In its interior the temperature is probably millions of degrees and the pressure millions of atmospheres. The atoms of the elements under these extreme conditions may well be quite different from those of the same elements as we know them on the earth. Surrounding this interior is a relatively thin gaseous shell, called the photosphere, which is opaque to the radiation from the interior. From the photosphere comes most of the light we receive from the sun. The temperature of the outside of the photosphere is about 6,000° C and the pressure one thousandth of an atmosphere. Outside of this again is the chromosphere, a layer of hot gases at the sun's surface. It is really the sun's atmosphere. It has no definite outer boundary, but has been observed to extend out for nearly 10,000 miles beyond the photosphere. There its pressure may be only the billionth part of an atmosphere, and its temperature of the order of 5,000°C.

By far the most important instrument in the study of the constitution of the sun is the spectroscope. When a beam of light is passed through a prism or reflected from a closely ruled reflecting surface, called a grating, it is spread out into a spectrum of all the colours from red to violet. The spectrum may be followed far beyond the visible region into the infra-red and ultra-violet by suitable photographic plates. Different sources of light give different tvpes of spectra which are generally classified as continuous, line, and absorption spectra. Continuous spectra come from all bodies at very high temperatures and show no structure, but rather a continuous gradation from one colour to the next. Line spectra are quite different, giving discrete, narrow, bright lines of various colours. They are characteristic of the element emitting the light, and are invaluable for its identification. The position of the line in the spectrum is denoted by its wave-length. This can be measured with extraordinary accuracy, equal indeed to the accuracy with which the standard metre or yard itself may be determined.

The spectrum of ordinary sunlight is different from either of these types. It is continuous, and superimposed on it are a great number of dark lines, called the Fraunhofer lines. It is, in fact, a typical absorption spectrum. The true explanation of this spectrum was due to Kirchhoff and from its discovery, in 1859, there began the modern science of astrophysics.

The element sodium emits a line spectrum containing a very bright pair of lines in the yellow, familiar to everyone who has ever used a spectroscope as the "D" lines. Dark lines, of exactly the same wave lengths, had been found by Fraunhofer in the solar spectrum. Kirchhoff allowed light from a hot source, giving a continuous spectrum, to pass through a cooler flame containing sodium before reaching the spectroscope, and found that the continuous spectrum was broken by two dark "D" lines. The "D" light from the continuous spectrum had been absorbed by the cooler sodium flame, which itself would have given out the bright "D" lines if viewed alone. The explanation of the dark lines in the solar spectrum was now clear. The continuous spectrum from the hot photosphere must pass through the cooler gases of the chromosphere before reaching the earth. An absorption spectrum results whose lines permit the identification of elements in the surface of the sun. At the present time about 60 of the 90 known elements have been found in the sun. It is not to be concluded, however, that the other 30 elements are absent. It may be that the spectra emitted by these elements under solar conditions of temperature and pressure are so far in the ultra-violet regions as to be absorbed by the earth's upper atmosphere and never reach the spectroscope.

Professor Young of Princeton predicted that the chromosphere itself should give a bright line spectrum if it could be examined alone. He verified this at the eclipse of 1870 by observing the sun's edge at the instant before totality when the photosphere is covered but the chromosphere is still showing. Since that time the observation of this "flash spectrum" has occupied a prominent place in all eclipse programmes. Two "flash spectra" may be obtained, one at the beginning and one at the end of totality. The obtaining of these spectra forms one of the most difficult practical problems in the whole of astronomy. Exposures must be so accurately timed that computed times cannot be relied upon. The timing must be made by personal judgment in the nerve-racking moments of a total eclipse. An error of a tenth of a second may ruin the results. It is little wonder, then, that out of more than a hundred attempts not more than half a dozen have given first-class results.

These few precious photographs have probably yielded more valuable information than any other eclipse work. They show a bright line spectrum, whose wave-lengths in general agree exactly with those of the dark lines of the ordinary solar spectrum. The intensities of these lines are very different, however, and therein lies their importance. Many strong lines in the solar spectrum become weak in the flash spectrum, and many bright lines of the latter are faint or missing in the former. The element helium, now used for inflating airships, was first discovered in the sun's chromosphere, though no lines due to it are to be found in the ordinary dark line spectrum of the sun.

The atom of an element, calcium for instance, forms a miniature solar system of exceedingly small dimensions. At the centre is the heavy nucleus, charged with 20 positive units of electricity, and around this there rotate 20 electrons each of unit negative electrical charge. This is the ordinary neutral calcium atom of chemistry which gives its own peculiar line spectrum. Under special conditions, e. g. temperature and pressure, it may lose one of its outer electrons and become "ionized calcium", an exceedingly unstable atom giving out quite a different kind of line spectrum. Now by ingenious arrangements of apparatus, the flash spectrum of the chromosphere may be made to disclose what is happening at different heights. It is found that the character of the sun's atmosphere changes profoundly as one goes further out. The spectra of neutral atoms change into spectra of ionized atoms, some elements disappear, while other elements, particularly calcium, become prominent. It is at first sight difficult to see why calcium lines should be stronger than those of hydrogen, the lightest of the elements, which would be expected to predominate in the highest part of the sun's atmosphere.

The difficulty was solved in a very satisfactory manner by an Indian physicist, Megh Nad Saha. He assumed that the change of neutral calcium into ionized calcium could be treated as an ordinary chemical reaction, whose dependence on temperature and pressure is well known. The temperatures involved in the sun are much higher and the pressures much lower than any obtained in the laboratory. Nevertheless it was found that the results predicted by his theory admirably fitted the conclusions drawn from the flash spectrum when certain temperatures and pressures were assumed in the chromosphere. It is felt with some confidence that we now know the temperature and pressure at various levels in the sun's atmosphere, as well as its composition and the electrical state of its atoms.

With this striking confirmation in the chromosphere, it has become possible with some confidence to extend Saba's theory to the stars. The stars may be classified in a definite order, dependent mainly upon the appearance of their spectra. Saha's theory made it clear why the sequence in star types really represented an evolutionary process going on in the universe. The conditions of appearance and disappearance of spectral lines, due to ionization, are now calculable, and it has thus been possible to assign temperatures to stars of different types which are in substantial agreement with those derived from other lines of research. Not all of the difficulties have been cleared away, but there has been a great step forward.

Returning to the flash spectrum, one must acknowledge that, notwithstanding great successes, much work yet remains to be done. Great improvements have been made in the last year in photographic plates sensitive far down in the infra-red region of the spectrum. The application of these plates to the flash spectrum should yield much valuable information in a hitherto unexplored spectral region.

In regard to the corona, one has to confess that this is still an unsolved mystery. It gives a spectrum that is partly continuous, which indicates that much of its light is sunlight, scattered by some kind of particles found high above the sun. In addition, it gives a spectrum of a few lines only, none of which have been found to belong to any known element. These lines have been given the name "coronium". It is not now believed that they belong to some hitherto undiscovered element, for various sorts of research indicate that there is no room for a new element. Rather, it is thought that they are due to some known element under conditions of temperature and pressure unobtainable in the laboratory. The search for the explanation of these lines is possible only at eclipses. At the latest eclipse, the most modern and powerful of a type of instruments called an interferometer was made ready to study not the whole coronium spectrum, but a single line of it, in order to get at the truth piecemeal.

Space will permit mention of only two more of these problems. One is the testing of the Einstein theory of gravitation. This theory, brought out in 1916, took the world by storm at a time when men's minds were glad to turn away from the war. Of the three crucial tests applied to it, two had to do directly with the sun. One of these was the bending of the light from a star as it passed close to the sun, and the only time at which this could be measured was at an eclipse. The British were the only people who were ready for the 1919 eclipse, which offered a very favourable field of stars near the sun on which to measure the deflections. Results were strongly in favour of the Einstein theory. In the light of these experiments it was possible at an eclipse in Australia three years later to decide, without reasonable doubt, in favour of the Einstein theory. This year but little attempt was made to repeat the measurements, partly because the starfield was unsuitable, partly because scientists were so convinced of the Einstein deflection that they felt their time could more profitably be spent for other purposes.

A new field of investigation in 1932 was a study of the "radio eclipse." It is known that there are one or two layers, high up in the earth's atmosphere, which are electrically conducting. They are usually called Heaviside layers, after the brilliant and eccentric Englishman, Oliver Heaviside. The atoms of the rarified air are conducting because they are ionized, i.e., have lost electrons. Without these layers, wireless waves would not bend around the earth, but would spread out into space, making long distance broadcasting well-nigh impossible. The ionization is not due to temperature, since the earth's atmosphere is quite cool. It is due to something coming from the sun, as is clear from the difference between day and night reception of radio signals. The question is, what is that something?

It may be rays of ultra-violet light which ionize the air on being absorbed by the earth's upper atmosphere. Or it may be a stream of material particles of atomic size, perhaps neutral corpuscles, shot out by the sun. The corpuscles would travel with a much lower speed, perhaps less than a hundredth of the speed of light. Hence an eclipse offers the possibilities of deciding between these two hypotheses by finding the time and place at which the Heaviside layers are weakened, through the cutting off of the ionizing agent by the moon. The surprising result of calculations is that the "corpuscular eclipse" should occur several hours earlier and much further to the eastward than the "optical eclipse." Fortunately, the experiments are independent of clouds since the Heaviside layers are high above them. The results will be awaited with great interest.

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It remains to describe the activities at an eclipse camp in preparation for the 100 seconds of totality at the 1932 event. This was really an eclipse *de luxe* for the astronomers. It occurred in the temperate zone, at a pleasant season of the year and a convenient time in the afternoon, in a settled country with supplies and skilled labour close at hand. One can easily appreciate the contrast with some recent eclipses occurring in the Eastern tropics, where high humidity and the lack of such essentials as ice for photographic development were coupled with untrained native Labour speaking an unknown tongue.

There were at least 30 well equipped expeditions strung along the path of totality, about 8 of which were in Canada. The camp at Magog, Quebec, was noteworthy for including what was probably the largest single expedition ever sent to study an eclipse. This was sent out by the Solar Physics Observatory of Cambridge University, with Professor F. J. M. Stratton as leader. Just beside it was stationed a party from the University of Virginia under the direction of Professor S. A. Mitchell, the Canadian-born astronomer who has the distinction of having seen more coronas than any other man who has ever lived. In addition there was a party from McGill, and several well equipped English amateur astronomers. Altogether, there must have been at least 60 scientists gathered at Magog manning various instruments.

Their instruments were housed in a number of army tents pitched on a hill overlooking the beautiful lake Memphramagog. The exact site was on the rough between two fairways of the golf course of the Hermitage Country Club. It must be recorded that the skill of the members of that club was not so great as to avoid the landing of an occasional golf ball among the tents. Vital parts of the instruments were well protected, however, and no harm was done. Another hazard of the camp was an abundance of skunks. The English visitors were making their first acquaintance with these animals, and often expressed the hope that they would not become terrified by the appearance of the eclipse.

All the privileges of the Hermitage Club were extended to the visitors, and the efforts of members and officials to assist in every way possible were much appreciated. A number of the younger men, chiefly college students, volunteered their services, and put in many days of hard manual labour with great willingness.

Visitors to the camp usually expected to see a number of large telescopes, with scientists busily peering through them. As a matter of fact, all observations were made by photography, and there was not a telescope in the camp. Some idea of the type of work attempted may be had from the fact that out of twenty large instruments only one was a camera for photographing the eclipse. All the rest were spectroscopes in one form or another! They were usually arranged horizontally, and were fed by a coeliostat, which is essentially a mirror moved by clockwork to furnish a steady beam of sunlight.

The eclipse astronomer is evidently a great borrower. Professor Mitchell boasted that though this was his ninth eclipse, neither he nor his university had ever owned a piece of eclipse equipment. Professor Stratton's party had brought along apparatus from London, Oxford, Dublin, and Aberdeen, as well as from Cambridge. Dalhousie also made a small contribution. One was struck by the history of some of the equipment, which had travelled much about the world to various eclipses. Among the most interesting pieces was a very perfect large mirror of speculum metal which had been made by William Herschel, probably a hundred years ago. He had evidently made it for his own amusement, and then soldered it up in a tin. Quite recently someone looked through

Herschel's old house in the hope that something of his might turn up, and this mirror was found among others behind some stairs. In 1932 it was still doing duty in as perfect condition as when it left the hands of one of the greatest astronomers who ever lived.

The English equipment came out in 68 large packing cases, weighing some 6 tons. Months of preparation were necessary in testing the apparatus in England and in carefully packing it for shipment. Each case contained many pieces of equipment. Had a single one been mislaid in packing, the whole of a large piece of apparatus would have been rendered useless. No sooner had some of the apparatus been unpacked and set up in Magog than a tornado came along and levelled the tents. Fortunately, no serious damage ensued. There was much photographic work to be done, and three large dark rooms were improvised in the cellars of the club house. Many concrete pillars were set up to furnish solid foundations for the instruments. At night photographs had to be taken for focussing and alignment. To one accustomed to the convenient facilities of a laboratory, work under field conditions was somewhat strange. Behind it all was always the thought that everything must be ready by a certain day and hour; the experiment could not wait for the convenience of the operator.

In the last few days many rehearsals were carried out so that everyone might carry on his appointed tasks smoothly to a fraction of a second. The whole complicated process was to be started by one man, who was supposed to watch the sun through binoculars and signal the exact beginning and the exact end of totality. From the first signal, another counted off the seconds from a metronome. Each observer moved his plates and opened his shutters at prearranged times. The whole proceeding was like the working of a well trained battery of artillery.

Success or failure depended entirelv on the weather. The morning of August 31st was clear, but towards noon high clouds filled the sky. A few minutes before totality, the sun shone wanly through the clouds, only to disappear again. The signals were given at the computed time, and the whole programme was carried out in the hope that the sun might shine through the clouds at some moment of totality. Even this hope, alas, was unfulfilled, and no appreciable results were obtained.

There was nothing to do but grin and bear the disappointment. Even with the clouds, the spectacle was awe-inspiring. No sound was to be heard save the calling of the seconds and the click of the shutters as a dark shadow rushed down over the lake. A bright patch of sky was visible on either horizon, while the nearby landscape was dimly visible in an unfamiliar light. For a minute and a half this lasted, then the darkness seemed to rush away as at the lifting of a gigantic curtain. It was an experience never to be forgotten.

Afterwards press reports began to come in. It appeared that the eclipse had been clearly visible in Canada only at the point where the path of totality crossed the St. Lawrence river. The only astronomers who saw it were a party of amateurs with no effective equipment. It was also clearly seen by an excursion of bridge players on a steamer from Montreal. According to the press, they made many pseudo-scientific observations, assisted by professors of a certain university. Similar weather conditions prevailed in most of the United States. It was later learned that one or two parties, notably the Lick and the Harvard expeditions, had apparently been successful, while the Greenwich party at Parent, Que., got some photographs through thin clouds. It is greatly to be hoped that good results have been obtained by them.

On the rough of the golf course at Magog there will be left standing one of the concrete pillars used by the expedition. On it will be fixed a brass plate, so that the errant golfer may read the date and the names of those who on that spot played a strange game with the sun and lost, but who were not sorry they had tried.