SCIENCE

Vol. 77 | Friday, April 21, 1933 | No. 1999

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SCIENCE: A Weekly Journal devoted to the Advancement of Science, edited by J. McKeen Cattell and published every Friday by

THE SCIENCE PRESS

New York City: Grand Central Terminal

Lancaster, Pa. Garrison, N. Y.

Annual Subscription, $6.00 Single Copies, 15 Cts.

SCIENCE is the official organ of the American Association for the Advancement of Science. Information regarding membership in the Association may be secured from the office of the permanent secretary, in the Smithsonian Institution Building, Washington, D. C.

SOLAR ECLIPSE PROBLEMS[1]

By Dr. J. H. MOORE

ASTRONOMER IN THE LICK OBSERVATORY

A total solar eclipse affords an opportunity to study the faint outer portions of the sun, invisible under ordinary conditions. Several serious attempts have been made to observe the solar corona without an eclipse, and although partial success has recently attended certain observations of this character we still are confined to the fleeting moments of totality for a study of its detailed structure. Moreover, at the time of a solar eclipse we are able to investigate most efficiently the spectrum of the chromosphere, and from such studies to obtain important information, not only concerning the distribution of the elements within the sun's atmosphere, but also of the physical conditions that obtain there. These two fields of research in solar physics may be regarded as preeminent among those associated with a total eclipse of the sun, and it is to certain of the problems related to the constitution of the chromosphere and the corona that I wish to direct your attention, stressing the observational more than the theoretical aspect.

[1] Address of the retiring vice-president and chairman of Section D—Astronomy, American Association for the Advancement of Science, Atlantic City, December, 1932.

The Chromosphere

Immediately preceding and following totality when the glaring photosphere is hidden behind the moon's limb, the outer portion of the solar atmosphere appears as a narrow brilliant scarlet-colored crescent. To this envelope of the sun, Lockyer gave the name of chromosphere. Its spectrum was first observed at the eclipse of 1870 by Young, who found it to consist of bright lines on a dark background, which flash out as the photosphere is hidden, and remain for a few seconds, until covered by the advancing moon. This "flash spectrum" was regarded by Young as a reversal of the Fraunhofer lines whose origin was ascribed to the "reversing layer," a shell of comparatively shallow depth, as shown by the brief duration of the flash.

Although numerous attempts were made to observe the spectrum of the chromosphere visually at succeeding eclipses, it was not until 1893 that the first photographs of the flash spectrum were secured by Fowler in West Africa and by Shackleton in Brazil. These observers employed prismatic cameras, a type of instrument admirably adapted to this particular problem, since the chromospheric crescent is so narrow that the slit of the spectrograph may be dispensed with. The spectrum recorded on the photographic plate consists of monochromatic images of the crescent in the different wave-lengths emitted by the chromosphere. Spectrographs of this form have generally been used in photographing the spectrum of the chromosphere at subsequent eclipses. Prism systems, of one, two or three prisms, or plane gratings, have been employed with camera lenses of various focal lengths, depending upon the region to be studied and the dispersion desired. Some observers have obtained beautiful flash spectra with the concave grating spectrograph in its slitless form. Photographs made in quick succession with an instrument of this type will record the changing spectrum at the sun's limb, Fraunhofer, flash and prominence spectra.

At the moment when the last vestige of the photosphere has disappeared the dark lines of the ordinary solar spectrum are replaced by the bright lines of the chromosphere, the lengths of the arcs being obviously an indication of the heights to which the various emissions can be traced. The majority of the lines are found at low levels and disappear at heights of only a few hundred kilometers, while a few, like those of helium, hydrogen and ionized calcium, ascend to heights of from 7,500 to 14,000 km.

While the procedure of recording the chromospheric spectrum, outlined above, appears to be quite simple, in practise it encounters certain difficulties. Aside from those common to most eclipse observations of adjusting and operating apparatus under trying conditions, there is the serious one of making the exposure at the proper time to obtain the fainter lines, which are visible for only about a second. This difficulty is obviated by the method devised by Campbell, in which the changing spectrum in a short central section of the crescent is recorded on a moving plate. The procedure consists in placing immediately in front of the plate a narrow slit parallel to the length of the spectrum, so that only a very short section of the crescent falls upon the sensitive film. The plate is then moved at a uniform rate behind the slit in a direction perpendicular to its length. By starting the exposure 25 or 30 seconds before second or third contact and continuing it for as many seconds after, a continuous record is obtained of the changing spectrum at the sun's limb from the Fraunhofer to the emission lines. The method was successfully employed by Campbell at the eclipses of 1898, 1900, 1905 and 1908. One of the chief difficulties he encountered with it was in obtaining a uniform motion of the photographic plate with the mechanical devices then available. Trouble from this source has been overcome at recent eclipses by driving the plate carriage by an electric motor of constant speed.

Spectrograms taken on the moving plate furnish a continuous record of the changes that take place in the spectral lines at only one point on the sun's limb as different levels of the solar atmosphere are covered or uncovered by the moon. On such photographs we note again the great heights shown by the lines of ionized calcium, hydrogen, helium, ionized strontium, the intermediate heights given by the lines of other atoms, generally in the ionized state, and the great number of the lines in the lower levels given for the most part by neutral atoms. One is impressed with the fact that while the spectrum of the chromosphere appears to be a reversal of the Fraunhofer spectrum, there are marked differences between the intensities of corresponding lines in the two spectra. The most pronounced dissimilarities are found in the enhanced lines or those that are given by ionized atoms, such lines being especially prominent in the chromosphere. Certain radiations appear in the flash spectrum that are not represented in the solar spectrum, while to some strong Fraunhofer lines there correspond only weak lines in the spectrum of the chromosphere. Most of these peculiarities that were once so puzzling, are now explained in a beautiful manner by the theory of ionization, first stated by Saha and developed in further detail by the contributions of Milne, Russell, R. H. Fowler, Eddington, and others.

Since the intensity of a spectral line depends upon the number of atoms acting in a given time to produce it, the relative number of atoms that are in the neutral and ionized states becomes a question of considerable importance in the interpretation of spectra. On the assumption that the general laws of thermodynamics apply equally well to electrons and molecules, Saha was able to calculate the degree of ionization that takes place in gases under different conditions of temperature and pressure. It was found that ionization is favored by increase in temperature or decrease in density of the gas, and that for different elements at the same temperature and pressure the degree of ionization is less for the one of greater ionization potential.

At the higher levels in the chromosphere the density must be much less than in those near its base, consequently the ionization is increased in spite of the somewhat lower temperature. The extension of the enhanced lines to heights greater than those of the neutral atom and the strength of these lines in the flash spectrum is thus seen to be the result of decreased density within the chromosphere. The familiar lines of calcium furnish an interesting illustration of the point in question. The ultimate line of the neutral atom, g, or λ 4227, extends to a height of about 5,000 kilometers, while the H and K lines given by the ionized atom are visible to a height of 14,000 kilometers. Above 5,000 kilometers practically all the calcium atoms are ionized, leaving none to emit the lines of the neutral atoms, while the lines of the ionized atom appear as far up as the level where the chromosphere thins out entirely. Similar differences are found between the enhanced lines and those of the neutral atoms of strontium, scandium, titanium and other elements.

One might expect that the relative heights of the lines would correspond to the atomic weights of the elements, the greater heights being associated with elements of lower atomic weights. Calcium, however, with an atomic weight nearly twice that of sodium, can be traced to a greater height than either hydrogen or helium. This puzzling fact may be explained as the selective effect of radiation pressure. Above 1,500 km the sodium atoms are completely ionized, and the lines of ionized sodium lie in the far ultraviolet, where they are not observable. Ionized calcium, on the other hand, has strong ultimate lines in the visible region and so ascends to great heights.

Not only do the lines of greatest intesity, in general, reach the highest levels, but it is found that for any element the lines of greatest intensity and extending to the greatest heights in the chromosphere arise from multiplets of the lowest excitation potential. An interesting example of the relation of intensity and excitation potential is shown by the two pairs of Fe lines given by the neutral atom at λλ 3887.0 and 3886.3, and λλ 3878.0 and 3878.6. Though of comparable intensity in the sun, the second line of each pair is stronger in the flash, and arises from the lowest energy level in the atom, while the first ones come from the next higher level, with an excitation potential greater by only one volt.

This qualitative study of flash spectra has called attention to the fact that the heights to which the individual lines can be traced depends largely upon their intensities, which in turn are functions of abundance, atomic weight, ionization potential, excitation potential, etc.

A quantitative investigation of such spectrograms involves the determination of the wave-lengths, intensities and heights of the various spectral lines and is obviously a work of considerable magnitude. Studies of this character have been made by several investigators. Two of these have been published within the last two years, the one by S. A. Mitchell and the other by D. H. Menzel. Since they are the most extensive and thorough investigations of the flash spectrum that have been made, they merit our special attention at this time.

Mitchell's discussion is based largely upon his flash spectra obtained at the eclipses of 1905, 1925 and 1930, and includes the region from λ 3066 to λ 7065. His spectra were taken on a stationary plate, with a concave-grating spectrograph used in its slitless form. Menzel's results were derived from the Lick spectrograms taken without slit, the dispersion being given by prisms of flint or ultra-violet glass. These were supplemented by data obtained from spectra secured at the 1905 eclipse on fixed plates. The region of spectrum investigated by him was from λ 3229 to λ 5328.

Intensities of the chromospheric lines were estimated on the Rowland scale and for these the two observers are in satisfactory agreement. Their values for the relative heights of the high and low level lines, however, exhibit marked disagreement. Several explanations for this have been offered. The heights of the chromospheric vapors are derived from the angular length of the cusps on the stationary plate, while on the moving plate these heights are measured from a zero level somewhat arbitrarily chosen as the point where the continuous background seems to fade out. Moreover, these heights would be expected to be different, since they depend in part upon the speed of the spectrograph and of the photographic plate used. Differences arising from the choice of zero level, or from the speed of the recording apparatus, should not affect materially the relative heights of high and low level lines. The presence of a valley or mountain on the moon at the point of contact or near the ends of the cusps may readily give erroneous values of relative heights determined on the stationary plate, while lack of uniformity in the motion of the moving plate will produce similar errors. In order to check the uniformity in motion of the plate the second-breaks of a chronometer have been recorded on spectrograms secured by the method of the moving plate at recent eclipses. This is not the place to discuss the relative merits of the two methods of observing the flash spectrum; each has its own advantages and disadvantages. The record obtained by the one method offers a valuable check upon that of the other, and both were used by the Lick Observatory expedition at the eclipse of last August, as well as in 1905.

From the preceding discussion it will be evident that great caution should be exercised in drawing conclusions concerning apparent variations in the depth of the chromosphere from observations made at different eclipses. Both Mitchell and Menzel have found evidence of such changes in chromospheric structure. On Mitchell's spectrograms of the 1905 and 1925 eclipses, taken with the same instrument, the lines of intermediate level are noticeably higher in 1925 than 1905, although no systematic difference is shown for the high level lines. Menzel's heights for the 1908 eclipse are uniformly lower than those derived from the 1905 plate. After careful consideration of all possible contributory factors, he is led to the conclusion that his observations indicate a real difference of height in the chromosphere at the two dates. In each case the greater heights were obtained at the time of greater solar activity, which is in harmony with what we should be led to expect from our present views of the structure of the chromosphere. More data, however, are needed before a variation of the character suggested can be considered as established.

Data of intensities and heights determined from flash spectra enable us to derive the distribution of the atoms at different levels, or the density gradient in the chromosphere. There are two independent methods by which this may be accomplished: (1) from the line intensities measured at different levels; (2) from the relation of the theoretical intensities of the members of multiplets to the heights of the corresponding lines. Menzel determined the relative intensities at six different levels in the chromospheric spectrum from microphotometer measures of the 1905 spectrogram. Laboring under the severe handicap of not having the characteristics of his plate defined by standard squares, he was forced to check his material from the interagreement of the data for different lines. The method of employing intensities at different heights along the spectral line, although apparently the most direct one for determining the density distribution, is complicated by the fact that the energy at a given level is the integrated light of this and the higher levels. It also becomes necessary to correct the observed intensity for the effect of self-reversal.

Both Mitchell and Menzel have used the second method of deriving the density gradient in the chromosphere up to a height of 2,500 km. The intensities of the members of a multiplet may be computed from the formulae relating the transition probabilities to the energy emitted by the different lines. It is then possible to derive a simple expression for the number of atoms per unit volume that are involved in the emission of a line of given intensity. From a knowledge of the heights to which the different lines of the multiplet extend in the chromosphere and the relative number of atoms concerned in the production of the lines, the relative concentration of the atoms at different levels may readily be obtained. In Menzel's discussion, all elements were grouped together, while Mitchell discussed the elements separately. Their results are in good agreement and show that the density gradient for the lower chromosphere is much less than would be expected in an isothermal atmosphere. It corresponds closely to that which would be given by an atmosphere of hydrogen in gravitational equilibrium, while at higher levels the chromosphere is even more distended. It is of interest to note in this connection that Menzel found the electron pressure at the base of the chromosphere to be about 10^{-7} atmospheres or about 500 times smaller than Russell's value for the pressure at the base of the reversing layer.

One of the most important fields of spectroscopic investigation is the determination of the energy emitted by a spectral line or the absolute intensity of the line. The problem on the experimental side is an extremely difficult one. Some progress, however, has been made by Unsöld and others for the strong resonance lines in the solar spectrum. Pannekoek and Minneart have attempted a similar investigation for the lines of the flash spectrum, utilizing for this purpose their high dispersion spectrograms secured at the eclipse of 1927. After calibration of the spectra through comparison with standard sources and elimination of the effects of instrumental and atmospheric absorption they were able to determine the absolute surface intensity of the chromosphere. The observed intensities for lines in well-known multiplets were compared with their theoretical intensities and found to increase more slowly than the latter. They interpret this as indicating an appreciable amount of self-absorption in the chromospheric layer when viewed tangentially. The density gradient for hydrogen deduced by them shows characteristics similar to those noted above.

The intensity of a spectral line, whether emission or absorption, is a function of the abundance of the element producing it. For an assembly of atoms in thermodynamic equilibrium the relation may be easily derived. Russell has, after making allowance for departure from thermodynamic equilibrium, utilized this relation in a most skilful investigation of the abundance of the various elements in the solar atmosphere, on the basis of the lines in the Fraunhofer spectrum. Since the intensities in the solar spectrum are estimated on an arbitrary scale, that of Rowland, it is necessary to reduce these to the scale based on theoretical intensities, before they can be used for determining the relative number of atoms engaged in the production of different lines. The calibration of Rowland's scale was obtained by comparison of the estimated and theoretical intensities of multiplets. Following Russell's procedure, both Mitchell and

Menzel have determined the abundance of the various elements in the chromosphere. The results show that for all the elements investigated, there appears to be little difference, except for hydrogen, between the relative abundance derived from Fraunhofer and flash spectra. Hydrogen seems to be considerably more abundant in the chromosphere than in the reversing layer.

By plotting the ratio of the number of atoms giving rise to multiplets in the reversing layer and chromosphere against the excitation potential of these lines Menzel finds evidence that the number of highly excited atoms in the chromosphere is greater than that predicted by the Boltzmann law. This excess, which increases with the excitation potential, is closely allied with the effect found by Russell and Adams from stellar spectra and generally known as the deviation of stellar atmospheres from thermodynamic equilibrium. In the chromosphere, however, it seems to be greatly intensified.

Determination of the temperature gradient in the chromosphere from the intensities and heights of the flash lines meets with certain difficulties, chiefly for the reason that the procedure of referring the observed intensities to the theoretical ones automatically corrects for possible temperature gradient. The observations afford some evidence that the mean temperature of the chromosphere is about 1,000 degrees lower than that of the reversing layer, and that the temperature gradient is low.

It appears then that the observed chromosphere lies above the layers that contribute the major portion of the absorption in the wings of the Fraunhofer lines, and that the chromospheric absorption accounts only for the central dark cores of some of the strongest lines. To this extent alone is the chromosphere the seat of Fraunhofer absorption.

The need for more observations of the flash spectrum is apparent. Spectrograms should be secured with both stationary and moving plates with as high dispersion as feasible and should be provided with photometric standards to permit of accurate calibration. The region of the infra-red is still a virgin field. The study of prominence spectra is also an important and closely related field of investigation which has been cultivated but slightly. A further investigation of the relation of the structure of the chromosphere to the cycle of solar activity is worthy of attention. Advantage should be taken of the excellent opportunity for securing spectrograms of the flash at a partial eclipse.

On the theoretical side important contributions to the problem of the structure of the chromosphere have been made by a number of investigators in an attempt to explain the small density gradient and the great heights to which the chromosphere extends. Milne has developel a beautiful theory of the equilibrium of an atmosphere of ionized calcium atoms supported by radiation pressure. It accounts for the high levels at which ionized calcium is found, and certain other phenomena of the chromosphere, but does not give the observed density gradient or emission of sufficient intensity. Moreover a chromosphere of the quiescent type postulated by the theory does not exist. McCrea and Rosseland have called attention to the effect of turbulence in the sun's atmosphere as an efficient aid in the support of the chromosphere. Pannekoek has shown that the electrons in an atmosphere, owing to their small atomic weight, would rise to great heights if they were not kept down by the attraction of the positively charged ions. This attraction, on the other hand, aids in keeping the ionized atoms at high levels. Menzel has made a careful discussion of the various theories and concludes that an extension of McCrea's theory to include the effects of self-reversal and Pannekoek's and Stewart's theories of electrostatic levitation gives a fair representation of the observed density gradient in the chromosphere and of the general featurs of the flash spectrum.

THE CORONA

From the brief review of the present status of certain problems relating to the structure of the chromosphere, it will be seen that real progress has been made toward a solution of at least a few of them. The situation with reference to the problems of the corona is less encouraging. Important facts concerning it have been established, but they are more or less isolated and in general their relations to each other are unknown. The paucity of results obtained thus far is due, primarily, to the unique condition that the opportunities for observing the corona are few and the time available for its study, at any one eclipse, is at best of but a few minutes' duration. Fortunate indeed would be the observer who could obtain an hour of totality with clear skies, in his entire lifetime.

Photography of the corona has comprised a part of the work of most expeditions that have observed total eclipses of the past fifty years. One of the most extensive series of coronal photographs is that obtained by eclipse expeditions of the Lick Observatory. These photographs were secured with cameras of various focal lengths, but since 1892 the more important observations of this character have been made with a form of photographic telescope designed by J. M. Schaeberle and used by him at that time in Chile. In this instrument the lens, of 5 inches aperture, remains stationary and the diurnal travel of the sun is allowed for by moving the photographic plate in the focal plane of the lens. The photographs secured with it have generally been of excellent quality and reveal the intricate detail of structure, as well as the faint outer portions of the corona. The obvious advantages of large scale photographs of the corona have led other observers to employ cameras of even greater focal lengths.

At the eclipse of August 31, 1932, the responsibility for this part of the Lick Observatory program was undertaken by W. H. Wright. After careful consideration of the most advantageous form of instrument for coronal photography, he abandoned the 40-foot camera of the Schaeberle type for two photographic telescopes of 5 inches aperture and 15 feet focal length, rigidly mounted on a polar axis. The lenses are of excellent quality and are estimated to have about five times the speed of the 40-foot camera. This arrangement proved to be a very fortunate one at an eclipse where clouds were present, since it was possible to secure a greater number of photographs and to obtain a few of exceptionally long effective exposures. The superior quality of Wright's photographs fully supports the wisdom of his choice of instruments. When enlarged to the scale of those taken with the 40-foot camera they are equal, if not superior, in the excellence of their definition and in the delineation of coronal detail.

Photographs of the corona secured in this manner, although subject to the limitations of a composite picture of structural detail at different positions along the line of sight, afford a basis for study of the general form and structure of the corona.

It has long been known that the shape of the corona near the time of maximum in the sun-spot cycle is different from that near minimum sun-spots. The type of corona associated with sun-spot maximum is approximately circular in form, while that near minimum is roughly rectangular with the polar brushes and wing-like extensions at lower latitudes in which the sun-spots and prominences are found. Ludendorff has devised a simple method of representing more precisely the form of the corona through the ellipticity of lines of equal intensity drawn on coronal photographs. Studies made by him in this way, of the coronas from thirteen eclipses secured at different phases in the sun-spot cycle, reveal a closer relation between the coronal shape and the actual number of spots visible for a few days preceding and following the date, than with the phase in the solar cycle. From a study of the coronas observed since 1860, Lockyer has found a close correlation between the shape of the corona and the position of the prominences, the maximum type occurring when prominences are near the polar region.

Examination of the individual details in the corona has revealed a connection in some cases between the long streamers and prominences visible at the limb. The structure of the inner corona is affected to a marked extent in the neighborhood of prominences. On the other hand, in only a few instances has it been possible to trace a direct connection between disturbed areas in the corona and large spots, or groups of spots, visible near the sun's limb. "Arches," "hoods" or "striated cones" are marked features of the inner and middle corona and are especially conspicuous near sun-spot maximum. In most instances, they are found to be erected over a large prominence and their forms suggest that the coronal materials are being driven outward from the prominence. That such is the case was found by Miller, who compared large scale photographs of the corona in 1918, taken at three separate stations, those of the Lick, Lowell and Sproul expeditions. Measures were made on three arches surrounding three conspicuous prominences. These gave fairly accordant results and indicated that in the twenty-six minutes that elapsed between the times of the Lick and Sproul photographs the arches had receded from the sun, with an average speed of about ten miles per second. Other attempts to detect motion of the coronal details on direct photographs taken at one station or by comparing those from widely separated stations have yielded little more than the result that, for the most part, the motion is small.

Progress in acquiring information about the spectrum of the corona has been painfully slow. The reasons are not far to seek. The coronal spectrum is very weak and the opportunities for observing it are few. The inner corona, up to about ten minutes of arc from the sun's limb, gives a continuous spectrum upon which are superimposed a number of bright lines extending to distances of from 5′ to 10′ from the sun. With the possible exception of the strong red line at λ 6374, none of these have been observed in laboratory spectra or in those of the stars or nebulae. About 42 coronal emission lines in the region λ 3164 to λ 6800 have been reported by various observers but in the case of half of these it is extremely doubtful whether they are of coronal origin. The strongest lines are the well known one in the green, λ 5303, and the ultra-violet line, λ 3888. Next in intensity are λλ 6374, 3601, 4231, etc. The wave-lengths of but a few are known to a tenth of an angstrom, those of λ 5303 and λ 6374 being the most accurately determined.

Although the slit spectrograph is superior to the slitless form for wave-length determinations, spectrograms obtained with the latter instrument yield information of the greatest value concerning the distribution of intensities in the coronal emissions. The radiation in a single line is found to have very different intensities in different parts of the inner corona. The coronal ring exhibited by λ 5303, for example, is very faint in the polar regions and even at lower latitudes shows a marked variation in intensity. At the eclipse of 1918, this radiation was strengthened near the bases of the prominences and had its greatest intensity near the eruptive prominence at the southwest limb of the sun. Similar effects are to be seen in the green coronal ring obtained at the eclipse of last August, its greatest strength being shown near the two prominences on the west limb, while it was extremely faint over the whole east limb. On the same spectrogram the coronal ring in λ 6374 shows a more uniform distribution than λ 5303, although it, too, is weak in the polar regions and of greatest strength near the prominence on the southwest limb. In other details the distribution in the two radiations shows great dissimilarity. This difference, noted also by other observers, indicates that the two radiations can not take their origin in the the same atom in the same state of ionization.

Studies of the distribution of the intensities exhibited by the different coronal radiations enable us to group together lines of like behavior and should prove an important aid in the identification of the atom, or atoms, responsible for these emissions. Some of the stronger coronal lines have been so grouped by several observers, but there is a manifest disagreement in their opinions in this matter. At present, there seems to be reliable evidence that λ 3601 and λ 4086 belong together and that λ 5303 and λ 3388 form a pair, but the data for the others are not sufficient to permit their classification.

The great variation in intensity of the emission in different parts of the corona obviously limits the value of line intensities derived from spectra secured with a slit spectrograph and also accounts to a large extent for the failure to observe certain lines at one eclipse, which were obtained in good strength at another. To this cause may be ascribed some of the observed variation in the green line shown by comparing slit spectrograms of different eclipses, although there seems to be some evidence that this line is stronger near sun-spot maximum than near the minimum in the cycle. One of the most fruitful fields of coronal spectroscopy is undoubtedly that of the investigation of the forms, intensities and structural details in the coronal rings obtained with slitless spectrographs of fairly high dispersion.

Several observers have attempted to study the green line with an interferometer of the Fabry and Perot type, but without success. At the eclipse of last August, Shane made use of a slit spectrograph provided with an etalon of 2.5 mm separation and obtained very weak interference fringes in the green line. The observation is of importance not only because it explains the failure of previous attempts in which higher orders of interference were used, but also because it gives definite indication as to the width of the line. This, Shane estimates to be of the order of one third of an angstrom. The observed width of the line is probably due to the effect of turbulence in the inner corona.

A number of suggestions have been made as to the atom giving the coronal emissions. Pannekoek once suggested that they were due to doubly ionized calcium. Freeman, from coincidences in wave-length, attributed them to argon, while Rosenthal attempted to identify them with radiations of the helium atom in a special state. None of these identifications are entitled to any weight. Recently Hopfield has called attention to an unclassified line in the spectrum of oxygen, having wave-length 6374.29 A. and in close agreement with that of the red coronal line 6374.28 A. de Bruin has calculated three additional lines in the spectrum of neutral oxygen which he identifies with λ 5303, λ 6704 and λ 6775, but here again the identification appears to be open to serious criticism, so that the great mystery of the coronal lines still remains unsolved.

Many attempts have been made to study the corona without an eclipse, but until recently all have ended in failure. One of the most important advances in the investigation of the inner corona made in recent years is that due to Bernard Lyot, who, in full sunlight, obtained the red and green lines with his spectrograph and determined their wave-lengths. Moreover, with a spectroheliograph he photographed the inner corona in light of these two radiations. It is well known that the great obstacle standing in the way of observations of this character is that of the light scattered by the atmosphere and by the image-forming lens. By working at the observatory of Pic du Midi at an altitude of 2,870 meters, he reduced to a minimum the scattering of light by particles suspended in the air. A carefully ground simple lens was used to obtain the image, the light scattered by it being excluded through use of properly arranged diaphragms. Only by careful attention to the elimination of every possible source of scattered light in his instrument was success finally attained. The possibilities offered by this method to astronomers at mountain observatories for studies of coronal radiation, without the necessity of waiting for a total eclipse, are certainly alluring.

The spectrum of the corona beyond 8′ to 10′ from the sun's limb exhibits the Fraunhofer lines of the solar spectrum. The relative intensities of the coronal lines seem to be quite similar to those of the sun's spectrum. They have, however, a hazy appearance which is doubtless due to the fact that they record light scattered by different portions of the corona in the line of sight. That the Fraunhofer spectrum of the corona is caused by the scattering of sunlight by coronal material in a finely divided state is substantiated by the fact that the light of the corona is polarized. Measures by R. K. Young of the photographs obtained with polarigraphs by Lick observers show that the polarization is radial and that the percentage of polarized light increases rapidly from the sun's limb, reaching a maximum of 37 per cent. at a distance of 5′, and then diminishes slowly as the distance from the limb increases.

On the spectrograms secured in 1922, I measured the positions of the Fraunhofer lines in the coronal spectrum at points east and west of the sun and found that these were displaced toward the red with reference to the ordinary solar lines. The displacements, interpreted as a Doppler-effect, indicate radial motion of the coronal particles at points 20′ east and west of the sun's limb of about 12 or 15 miles per second, a speed of the same order as that found by Miller. These results are subject to considerable uncertainty on account of the character of the spectra measured. For this reason an attempt was made to repeat the observations at the eclipse of last August, with spectrographs especially designed for this particular problem. Unfortunately, the value of the spectrograms secured is somewhat impaired by the effect of scattered light from the clouds covering the sun during totality. Preliminary measures of these plates indicate the presence of small displacements in the Fraunhofer lines of the corona east and west of the sun, corresponding to a velocity of recession of about ten miles per second. At present we have no reliable information concerning the rotation of the corona.

Our knowledge of the total light of the corona and the distribution of its intensity with distance from the sun is still in an unsatisfactory state. The most reliable information we have at present, concerning the total brightness of the corona is to the effect that it is about 0.50 that of the full moon, although it probably varies with the cycle of solar activity. Observations of this character are beset with numerous difficulties but those made by recent investigators give evidence that many of them have been overcome. A most thorough investigation of the distribution of coronal intensity with distance from the sun was made by Bergstrand, who brought to this problem many years of experience in the methods of photographic photometry. He found that the intensity of coronal light in the photographic region varies inversely as the square of the distance from the sun's surface. Other observers have derived the law of variation to be according to the fourth, sixth, seventh and eighth powers.

Of coronal theories there is a sufficient number to permit of choice according to the particular phase of coronal studies in which one happens to be interested. Mechanical, electric, magnetic and other theories have been suggested, but in the present state of our knowledge with respect to the phenomena of the corona, it would not be profitable to give serious consideration to any of them. A corona composed of electrons and ions will account for many of the phenomena, especially those associated with its radiation. While there is much to commend the theory, it too meets with its share of difficulties.

The problems of the structure of the chromosphere and the corona are many and the solutions for a number of them are still to be given. Most encouraging progress has been made in unraveling the structure of the chromosphere, largely through the aid of the recent developments in our ideas of the behavior of the atom under different conditions and the manner in which it radiates energy. Regarding the corona our knowledge is in a less advanced state, but the time is not far distant, in my opinion, when many of its complex phenomena will receive a satisfactory interpretation.

OBITUARY

ACHILLES DE KHOTINSKY

On March 28, 1933, occurred the death, in Pentwater, Michigan, of Captain Achilles de Khotinsky, who, through his genius in invention, design and construction, leaves a permanent impression on physics and chemistry in America. Captain de Khotinsky was born on January 6, 1850, in St. Petersburg, Russia. Having completed the course in the Imperial Naval Academy, he spent the next 13 years in the Russian navy, in which he attained the rank of captain. It was during this period, in 1878, that he first saw America, while on commission to supervise the construction of three battle cruisers for the imperial navy. In the late seventies he obtained European patents on incandescent lamps which he manufactured on a large scale in Russia, Germany, Austria, England, France and Holland. He also held a basic French patent on the pasted storage battery plate. While in England, he developed the widely used de Khotinsky cement, known to every research physicist as indispensable in investigations involving vacuum technique.