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SCIENCE

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MSS. intended for publication and books, etc., intended for review should be sent to Professor J. McKeen Cattell, Garrison-on-Hudson, N. Y.

THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

RECENT PROGRESS IN SPECTROSCOPY[1]

We should pause a moment to pay a tribute of respect to the eminent physicists who have died during the past year. Among these may be named John Oren Reed, of the University of Michigan; Arthur W. Wright, one of the pioneers in physical research in this country; Cleveland Abbe, the father of the Weather Bureau; Sylvanus Thompson, the many-sided scholar; Ernst Mach, the philosophic thinker, and Pierre Duhem, the mathematical physicist. We honor these men for their achievements, but we need not grieve that they have left us, for their full day's work was done; but sorrow we must over the needless and untimely end of many young men who had given promise of brilliant careers, and countless others, whose names we shall never know, whose potential genius has been sacrificed to the Moloch which is the mongrel offspring of the union of a brutish feudalism with the vampire of commercial exploitation. While we may form some conception of the loss of life and property in the great war, no one can ever guess the extent of the irreparable loss to humanity caused by the destruction of embryo scholars and statesmen, artists and scientists. It is the irony of fate that so many scientists have been the victims of the conditions arising from ignorance, superstition, greed and devotion to outworn traditions

[1] Address of the vice-president and chairman of Section B—Physics—of the American Association for the Advancement of Science, New York meeting, December, 1916.

which science has ever sought to remedy; and yet there are many who hold science in some measure responsible for the terrible destructiveness of this war. Fire is man's friend, but it may become a terrible scourge when uncontrolled; and so the beneficent discoveries of science may be perverted to evil ends. We must remember, however, that death-dealing devices based on scientific discoveries may be the defense of the rights and liberties of peoples as well as the instruments of those who would devastate the world for their own advantage. There have always been those who have exploited the discoveries of science for their own selfish ends, but who can point to one of these exploiters who was himself a scientist? When we are told that the ends of science are material, let us think of Faraday, who never had time for money-making; when we are told that the aims of science are selfish, let us think of the men engaged in medical research who have sacrificed themselves to discover how others might be saved. Such men are typical of the ideals of science. Yet it is true that we are sometimes too much absorbed in our individual work, although our aims may be unselfish. With the lesson before us of the great cataclysm in Europe, we must not only recognize our greater responsibility in carrying forward scientific investigation, but we must likewise seek to arouse in our people a fuller realization of the relations of this work to their own happiness and prosperity. Conditions and habits of thought similar to those which have brought disaster upon Europe are not entirely absent from our own country, and will have similar results if not remedied in time. Certain social, economic and political ills which are held to be inevitable to imperfect humanity by minds which move in the grooves of tradition or of legalistic logic may be found capable of improvement if treated by scientific methods, which seek the truth regardless of the harm it may do to ancient superstitions, prejudices and privileges. We must look to those who think scientifically, even though they may not call themselves scientists, to replace our haphazard ways in agriculture, business, manufacture, law and politics, our criminal wastefulness and careless extravagance, by more efficient methods, not only to the end of increasing national prosperity, but still more to the end of promoting intellectual development, universal justice and happiness, unselfish and enlightened patriotism, and exalted ideals of life and conduct. Fortunately there seems to be a growing tendency to recognize the service which science may render to society. For the first time in our history, our government has sought advice from scientific men, and those who have been called upon are giving their services fully and loyally, with no thought of pay or political preferment.

It seems not altogether irrelevant to preface my remarks with this protest against some current criticism of science; but now I turn to the specific subject of my address.

Ten years ago the subject of Professor Crew's vice-presidential address was "Facts and Theories in Spectroscopy." Since that time some notable discoveries have been made and some remarkable theories have challenged attention. It is my purpose to review a few of the more important experimental results and to discuss the relations of some of them to theories brought before you in two recent vice-presidential addresses on "Atomic Theories of Radiation" and "The Theory of the Nucleus Atom." Inasmuch as it will be necessary to refer to them, I will restate the salient features of the theories which have attracted the most attention.

Planck derived an expression for the

spectral energy distribution of black-body radiation from the assumption that the radiation was emitted and absorbed by electric oscillators in definite quanta, each equal to the frequency of the oscillator multiplied by a universal constant, h, the wirkungsquantum. Later he modified this theory so far as absorption is concerned. Einstein and others went further in assuming that these quanta preserve their identity in their propagation through space, thus reviving a form of corpuscular theory. This extreme view has been generally abandoned, but it has been found impossible to explain away the wirkungsquantum h. It appears in too many relations to be the result of chance. The work of Millikan in particular proves the exact validity of Einstein's relation $Ve = h(\nu - \nu_0)$ in the photoelectric effect, in which Ve is the measure of the emission energy of the electrons, ν the frequency of the incident light, and ν_0 the minimum frequency which will cause emission of electrons. A similar relation appears to hold good in many cases of X-ray and light spectra. It seems probable that this constant depends upon atomic structure only, and affects radiation through space only in so far as emission and absorption are determined by atomic structure.

The theory of the nucleus atom is likewise of fundamental importance in spectroscopy. The work of Rutherford and others leaves no escape from the conclusion that the nucleus of the atom is a concentrated group of positive charges and electrons, with an excess of positive elementary charges approximately equal to half the atomic weight, while the same number of electrons circulate about the nucleus in rings. The spectroscopist must try to fit his theories to these probable facts, but he is met at the outset with apparently insuperable difficulties in accounting for the stability of such atoms and for the manifold complexity of spectra according to accepted electrodynamical laws. Bohr cut the Gordian knot by supposing that the classic laws apply only to conditions of stability, when no energy is radiated, and that radiation attends the transition of an electron from one state of stability to another, the frequency being determined by the relation that h multiplied by the frequency is equal to the difference between the energies of the system in the two stable states. In the case of hydrogen, to which he assigns one radiating electron and one nucleus charge, it is difficult to account for the existence of so many stable states, for the failure to radiate while subject to uniform radial acceleration, and for monochromatic radiation while passing between two positions of stability. Nevertheless Bohr derived an expression like that of Rydberg which locates accurately not only the Balmer series, but also an infra-red and an ultra-violet series predicted by Ritz and found by Paschen and by Lyman, respectively. His attempt to apply the same method to helium led to results which are still in dispute, and which will be referred to later.

In reviewing recent progress we may begin with that field in which this country has taken a leading part—that of astrophysics. This domain belongs as much to the physicist as to the astronomer. The heavenly bodies are laboratories on a vast scale, in which nature has provided conditions of temperature, pressure and electrical state which we may never hope to rival on the earth. The spectroscope gives us data from which it may be possible to form some idea of these conditions by comparison with our feeble laboratory imitations of celestial phenomena, and conversely, the latter may aid in the interpretation of terrestrial phenomena.

One of the most fruitful astronomical applications of the spectroscope is to the determination of velocities in the line of sight, by the Doppler-Fizeau principle. A large mass of such data has been collected, from which some important generalizations have been derived. For example, Campbell has determined the velocity and direction of motion of the solar system through space, and has found a remarkable and as yet unexplained relation between the velocities of stars and their apparent age, the redder and presumably older stars and a class of nebulæ having in general the greater velocities. It likewise appears that two immense star streams are crossing each other in the Milky Way. Many spectroscopic binaries have been discovered and their orbits determined, and recently there have been found remarkable displacements and rotations in nebulæ which may throw some light on the nature and destiny of these bodies. The spectroscope has enabled astronomers to undertake the ambitious task of tracing the course of stellar evolution.

The most ingenious and fruitful device for studying the sun is the spectroheliograph, invented by Hale in 1892. With this instrument photographs of the distribution of a given constituent of the solar atmosphere may be obtained by restricting the light falling on the photographic plate to the wave-length of one of the characteristic lines of the element. The configuration of the hydrogen clouds in the neighborhood of sunspots led Hale to suspect vortical motions in such regions. In 1908 the study of a number of plates, which showed that hydrogen flocculi were actually drawn into these spots from great distances, proved without question that sunspots are cyclonic areas of enormous extent. Thus the long-disputed question as to the nature of sunspots was answered, but this was not all. Vapors which emit or absorb line spectra are ionized, and as the more mobile electrons would diffuse more rapidly to higher levels than the positive ions, Hale inferred that the immense whirls of electrified vapors in the neighborhood of the spots must cause a radial magnetic field. If such fields are sufficiently intense, the longitudinal Zeeman effect should be produced. As a matter of fact, the spectrum of light from the spots is characteristically different from that of the surrounding photosphere, one of these peculiarities being the doubling of many lines. As Hale anticipated, an examination of the state of polarization of such lines showed them to be circularly polarized, and the direction indicated that the whirling vapor was negatively electrified. Hale likewise sought for the more minute effects which might be expected from the rotation of the solar atmosphere as a whole. A study of the breadth of spectral lines at different latitudes and the detection of traces of circular polarization at their edges showed that the sun possesses a magnetic field with polarity corresponding to that of the earth, but of much greater intensity. Although the atmospheric conditions on the earth are very different from those on the sun, it is possible that these investigations may assist us in solving the baffling problem of the earth's magnetism.

One of the most impressive facts revealed by the spectroscope is the substantial identity of constitution of the heavenly bodies. Everywhere we find evidence of the existence of such elements as hydrogen, sodium, calcium and iron. But we also find an infinitude of differences in the appearance of the lines, which we must attribute to differences of temperature, vapor density, pressure and electrical condition. It is suggestive to find that the spectrum of some stars resembles that of the arc, of others that of the spark. We may hope by comparing the spectra of these bodies with those produced in our laboratories under varied conditions to reach some conclusions regarding their physical state. The Mount Wilson physical laboratory is doing much valuable work of this kind.

In the spectra of the solar corona and of nebulæ and nebulous stars certain lines are found which do not belong to known elements. This need not indicate any fundamental differences between the life history of such bodies and that of the older stars. Twenty-five years ago Lockyer's views regarding the dissociation of elements in the stars were treated with levity by most physicists and astronomers. To-day such notions are held to be quite rational. The more elementary forms of matter would naturally be of small atomic weight, and hence would diffuse to higher levels than the heavier elements, and might ultimately escape into space. If it were not for the fact that it is held captive in chemical combinations, we should know nothing of hydrogen. Helium first revealed itself to us through its solar lines, and would still be otherwise unknown to us were it not for its continuous production in radioactive processes. The elements giving the spectra of the corona and of the nebulæ are presumably of small atomic weight, and are possibly the units out of which more complex known elements are built, in later stages of development; or they may be, conversely, the results of the disintegration of such elements. It is not impossible that in the future we may detect traces of these elements on the earth or manufacture them by some powerful disintegrative process. Meanwhile deductions from known relations between frequencies of the spectral lines, their breadth, and the atomic weight of the elements may give us some clue to their atomic weights. Nicholson has succeeded in constructing hypothetical atoms with given nuclear charges and electron ring systems which give with remarkable accuracy the positions of the lines of the corona and nebulæ. Rayleigh showed from kinetic theory and Michelson proved experimentally that at low pressures the width of lines may be entirely due to Doppler displacements, which vary directly as the square root of the absolute temperature and inversely as the square root of the atomic weight. Buisson and Fabry have verified this law and applied it to the study of nebulæ. The width of certain lines, determined from the limit of interference, indicates that the temperature of the Orion nebula is about 15,000 degrees, and that two groups of lines are due to atoms of weights 2.72 and between 1 and 2 respectively. This is a remarkable confirmation of Nicholson's previous conclusion that the emission centers are of atomic weights 2.95 and 1.31.

During the past ten years the boundaries of the known spectrum have been greatly extended in both directions. The difficulties of investigation in the infra-red are very great, but by the methods of reststrahlen and of focal isolation Rubens, working in succession with Nichols, Wood and von Baeyer, has isolated and measured certain regions of great wave-length. The longest wave-length measured is about .3 mm., while the shortest Hertzian waves so far obtained are 2 mm. long. The study of line radiation in this region is even more difficult, but Paschen and his pupil, the American Randall, have succeeded in measuring many lines extending to about 90,000 Ångström units.

In the ultra-violet Lyman has extended the region first made known to us by Schumann to a wave-length of about 600 Ångström units. Beyond this point it is difficult to go, on account of absorption, lack of sensitiveness of the photographic plate, and small reflecting power of speculum metal. Gratings ruled on silicon and photoelectric detectors may enable us to bridge the gap between these waves and the much shorter ones which may be examined with the aid of nature's diffraction gratings, crystals, which have made the study of X-ray spectra possible.

Of all the discoveries of recent years, that of the wave nature of the X-rays and of a practical method of examining their spectra is the most remarkable and the most important, for it has revealed to us the most fundamental radiations of the elements and has given us a glimpse into the very heart of the atom. In quick succession Laue and his pupils demonstrated the diffraction effects produced by crystals, the Braggs showed how reflection might be employed to isolate waves of different lengths by a principle similar to that producing colors of thin plates, but of far greater resolving power by reason of the greater number of effective reflecting surfaces, and Moseley photographed many characteristic spectra by an extraordinarily simple method. He found that the principal lines in the spectra of a large number of elements were connected by a remarkably simple relation, namely that the square roots of the frequencies are proportional to the ordinal numbers, which increase by one in passing from one number of a periodic group to the next. When there are anomalies between the atomic weight and the place of an element in a group, this anomaly disappears when the atomic number rather than the atomic weight is considered. This work has been extended by others, notably by Siegbahn and Friman, to include nearly all the known elements between sodium and uranium, inclusive, with the result that all the atomic numbers between hydrogen and uranium are accounted for, with the exception of six gaps. As interpreted by Bohr's theory, the ordinal number which determines the frequency is the excess number of positive elementary charges in the nucleus, and these results are, therefore, in complete harmony with the theory of the nuclear atom developed by Rutherford, van den Broek, Soddy and others. The comparison of the X-ray spectrum of lead obtained by Siegbahn with the gamma-ray spectrum of radium B obtained by Rutherford and Andrade shows the identity of ten of the principal lines. This strikingly confirms the accepted theory of isotopes, or elements of different atomic weights, which are chemically and spectroscopically alike because they have the same resultant nuclear charge.

The positions of the principal lines are consistent with Bohr's general formula, but perhaps this relationship is purely formal. But whether or not this theory applies, apparently we can not dispense with the wirkungsquantum. In addition to the characteristic X-radiation of an element, there is a continuous spectrum, with a sharply defined boundary on the side of shorter wave-lengths. The investigations of Duane, Hull and D. L. Webster have shown that this boundary is accurately defined by Einstein's relation $Ve = h\nu$ for fields up to 110,000 volts. Such a simple law does not hold for the characteristic radiations; but Webster has shown that they do not appear until the voltage somewhat exceeds that demanded by the Einstein relation. The longest X-waves so far discovered by Siegbahn are about 12 Ångström units in length, so that there is not a very great gap between them and the shortest waves discovered by Lyman. The investigation of this region is difficult, but undoubtedly means will be found to attain success. Much also remains to be done in the study of details of X-ray spectra, which contain many weak lines, and possibly bands, which have not so far been carefully examined.

During the past ten years great advance has been made in our knowledge of spectral series. Rydberg, Ritz, Paschen, Fowler and others have shown that a generalized form of the Balmer equation, with Rydberg's universal constant and a few special constants, is capable of wide application. Different combinations of a few constants have been found to give a number of related series, and many new lines so predicted have been found. The common limit and other numerical relationships between different series of the same element indicates that the different emission centers have some dynamic coupling and Rydberg's universal constant indicates a structural element common to all substances. According to Bohr, this quantity is a function of the electronic and atomic mass, the elementary electrical charge, and the wirkungsquantum h, and should slightly increase with increasing atomic weight. As it is commonly assumed that it is an absolute constant, careful measurements may furnish a test of the validity of Bohr's theory.

The relationships of frequency to atomic number found by Moseley recalls that Ramage, Watts, Runge and Precht and Hicks have found linear relationships between the squares of the atomic weights and the frequencies or frequency differences of homologous lines in the spectra of elements of the same group. Ives and Stuhlmann have shown that in some cases the results are improved by substituting atomic numbers for atomic weights, but the relationship is evidently not so simple as in the case of X-ray spectra.

The discovery of the Zeeman effect and the explanation of its simpler forms by Lorentz was the first step toward a rational spectroscopic theory. The later discovered complexities and anomalies, while they may defy mathematical analysis, do not lessen our confidence in the theory, for they are what we might expect as a result of complicated atomic structure. The same intellectual satisfaction does not attend the discovery of the analogous effect of an electric field, because the simplest cases are so complex that they can not be adequately explained by any theory yet proposed. The possibility of such an effect had long been the subject of speculation, but Stark was the first to realize and attain the necessary conditions for its occurrence. Lo Surdo also discovered it in the neighborhood of the cathode in capillary tubes. As in the case of the Zeeman effect, the phenomena are different when viewed transversely and parallel to the field. In each case the lines are split into a number of components, the number being different for different lines, even for those belonging to the same series. In the transverse effect the components are plane-polarized in hydrogen and helium, the stronger central lines vibrating at right angles to the field, and the stronger outer components vibrating parallel to the field. A remarkable relation is found for the series lines of hydrogen, helium and lithium. For each the number of principal normal components appears to be equal to the ordinal number of the line in the series. Higher dispersion shows that in the case of hydrogen each component is double. If this rule holds good throughout the series, the last known line, the twenty-eighth, would have 56 such components, an equal number polarized at right angles to these, and a number of weaker components of both kinds—truly a formidably complicated system. In general the longitudinal components appear to be unpolarized, although Miss Howell has found some anomalies with lithium and calcium. In some cases the components are unsymmetrical both in position and in intensity. Of all the other elements investigated, mercury alone shows a slight broadening. It might be expected that the great nuclear charges of heavy atoms would diminish the effect of an external field. The inverse absorption effect has so far not been observed.

Long before the Stark effect was observed Voigt showed that such results might be expected from quasi-elastic forces in the atom and the stresses produced by the field. Schwarzschild has attempted to explain it by the ordinary laws of electrodynamics, and Warburg, Gehrcke, Garbasso and Bohr by Bohr's theory. Each attempt was successful in some respects, but each failed to account fully for all the components, their displacements and their state of polarization, and all the theories assign the same number of components to each line of a series, whereas one of the most significant features is the progressive difference in number of components, displacements and relative intensities in passing from one line to another. Stark not only rejects them all, but is led by his study of the phenomenon to finally abandon the quantum and light-cell theories, because he considers that he has proved that the greatest possible energy which an electron can acquire in its orbit falls far short of one energy quantum. Moreover, he argues that it seems impossible to explain the phenomenon in terms of Bohr's one electron. He concludes that a number of electrons must take part in the emission of a single line, each having the same frequency under ordinary conditions or in a magnetic field, but different frequencies when displaced unsymmetrically in an electric field. It is difficult, however, to understand why hydrogen has only one detachable electron if Stark's view is correct.

It has already been mentioned that at low pressures the width of lines may be ascribed entirely to the Doppler effect. The great broadening at higher pressures has never been explained, but it has been assumed that damping, collisions and rotations all play a part. Stark suggests that it may be largely due to atomic electric fields, which may exercise a large influence when the atoms are crowded together. It seems significant that the broadening increases with the ordinal number of a line in a series, is often unsymmetrical, and diminishes with increasing atomic weight in most cases, quite in harmony with the effects of an electric field. Nicholson and Merton have found that the broadening of hydrogen lines is in quantitative agreement with Stark's suggestion.

With changes in vapor density, pressure, temperature or the mode of excitation lines belonging to one series may weaken or disappear, other lines may be strengthened, and new lines may appear. We must assume that different groups of lines are due to different emission centers. These differences must depend upon the size of the particles, or upon the number and arrangement of electrons. Any theory must take account of the molecular or atomic state or the electrical charge of the emission centers. In some cases we have rather definite information on these points.

A number of elements emit band spectra under some conditions, line spectra under others. One conclusion which seems to be well established is that band spectra are emitted by molecules, line spectra by atoms. Universally we find that compounds give band spectra, never line spectra. If a compound is dissociated by the discharge the line spectrum of one or both constituents appears. Elements give band spectra with feeble excitation, line spectra when the discharge is so intense as to cause dissociation. It seems reasonable to infer that the band spectra of elements is likewise associated with the molecular condition. In the case of monatomic elements which give both band and line spectra electrical conditions must determine the nature of the radiation.

Radiation is an electromagnetic process, and must be determined by the electrical state of the radiator. A molecule may be neutral or for a moment charged by the loss or gain of an electron. This type of ionization must actually occur, as indicated by the conduction of electricity through the vapor of a compound which shows no evidence of chemical dissociation. What causes the light emission? It may accompany the loss or gain of an electron by a neutral molecule, in which case the emission center would be charged. It may be due to the shock of elastic collision with an electron or ion, or to the reunion of an electron with a positively charged molecule, in which cases the emission center would be neutral. Luminous vapors emitting band spectra usually appear to be neutral at the instant of emission, so that it seems probable that band emission is due either to elastic shock or to the recovery of a lost electron. It is to be remarked that as a rule band spectra are not subject to the Zeeman, Stark or Humphreys-Mohler effect; in the exceptional cases it is probable that those subject to one of these effects are subject to all. It would be of interest to examine these cases with reference to the nature of the molecular charge.

Luminous vapors emitting line spectra appear, in many cases at least, to be positively charged. A sodium flame is attracted to the negative plate of a condenser. A metallic salt introduced near the cathode of a spark discharge colors the spark only in that neighborhood; if introduced near the anode, the color flashes entirely across the spark. The most promising method of verifying such conclusions appears to be by the study of canal or positive rays. Sir Joseph Thomson, from a study of the deflections produced by magnetic and electric fields, found that, with very few exceptions, no molecules of either elements or compounds carry a negative charge, while those with positive charges are common. No molecule acquires more than one positive charge. The atoms of but few elements are found with a negative charge, but all may acquire positive charges and many may be multiply charged. For example, krypton may have as many as five and mercury eight positive charges. Hydrogen never has more than one charge, which accords with Bohr's view that it has but one detachable electron.

Stark has reached similar conclusions from a study of the spectra of canal rays. In many cases the motion in the line of sight gives a Doppler effect. There is an undisplaced line due to the stationary gas and a displaced line due to the canal rays. A distinct separation between the displaced and stationary lines shows that the canal rays can not radiate until their kinetic energy reaches a threshold value, which Stark first interpreted in favor of the quantum theory, but which he now believes to represent the energy necessary for ionization. There may be two or even three displaced lines, with separations consistent with the view that the luminous centers are doubly or triply charged. The radiation is evidently due to collisions, for a reduction of pressure in the canal ray chamber causes a reduction of luminosity. In general, all series lines are subject to the Doppler effect. Fulcher has shown that nitrogen canal rays give the negative pole band spectrum, with displacements, but no other bands have been found to give this effect. The series lines of hydrogen show displacements, but they are not observed in the many-line spectrum except to a slight extent in a few cases. Stark concludes that the series lines are emitted by positive atom ions, and the lines of the secondary spectrum by neutral atoms. He thus associates the compound spectrum with band spectra, which he supposes to be due to neutral systems. It may be remarked that Fabry and Buisson have concluded from measurements of the width of lines that both spectra are due to emission centers of atomic size. From a study of the displaced components of many elements, electronegative as well as electropositive, Stark concluded that in all cases line spectra are emitted by positively charged atoms. Aluminum atom ions may have one, two or three charges, which appear in succession as the voltage is increased. The same is true of argon. The red spectrum is apparently due to singly charged ions, the blue or spark spectrum to multiple charges. Mercury may have as many as four charges, each giving rise to a characteristic group of lines, all those due to multiple charges being spark lines. From an examination of many such cases Stark concludes that in general arc lines or those of the positive column are due to singly charged ions, sharp spark lines to double charges, and diffuse spark lines to triple charges. There are some apparent exceptions to this classification, but in the main the evidence seems to support his views, which are also consistent with the results obtained by Reichenheim from the study of anode rays. For the first time we are thus enabled to assign a common cause for spark lines produced under apparently very different conditions. They are found in the spectra of disruptive discharges, of the negative glow in vacuum tubes; in the intermittent or oscillating arc when rapid changes in potential occur, although the maximum potential may be small; near the poles of the arc, where the anode and cathode potential gradients are steep; in the electric furnace when the temperature is high; in high temperature stars, and, as found by Hemsalech and de Watteville, even in the green cone of the Bunsen flame, where chemical action is energetic. In all these cases we might expect multiple ionization to be favored.

Similar conclusions regarding the charges of emission centers may be derived from observations by Stark, Child, Strutt and others on the luminous vapors from an arc between charged condenser plates. The carriers of the line spectra are swept out of the field, while the luminous vapors giving band spectra are unaffected; or, if the lines of several series are present, their intensities are modified in different degrees by the electric field. Studies of the oscillatory spark by Schuster and Hemsalech, Schenck, Milner, Royds and others indicate that the spark lines do not persist as long as arc lines. If the emission centers of the former are multiply charged this is what we might expect.

Investigations on the mechanism of the spark give results which at first sight seem opposed to Stark's theory. All observers agree that the luminous vapors appear to be projected from the cathode, with different velocities for different lines, and the tacit assumption seems to have been made that they are negatively charged. That metallic vapors are projected from the cathode is evident from the fact of cathode disintegration, and probably the particles are initially negatively charged. We know very little concerning this phenomenon, but two things are almost certain—that only a small fraction of the metallic particles take part in the luminosity, and that these particles are not negatively charged while radiating. The large velocities indicated by the curvature of the streamers viewed in a rotating mirror do not give rise to a corresponding Doppler effect, and it seems highly probable that Hull and Royds are correct in their surmise that what happens is really the propagation of a condition of luminosity through vapor which continuously fills the gap after the first discharge. Electrons initially projected with a high velocity, which diminishes as the field intensity drops to zero, and producing multiply charged ions in the beginning and singly charged ions toward the end of their course, would apparently account for all the observed effects.

While the experimental evidence seems to favor the idea that lines are emitted by positively charged centers, there is no *a priori* reason why neutral or even negative ions should not emit line spectra. It is quite possible that the canal ray lines which Stark attributes to singly charged ions may be emitted at the instant of neutralization; but we can not escape the conclusion that spark lines at least are emitted by positive ions unless we accept the improbable view that a multiple charge may be instantaneously entirely neutralized. Lenard inferred from the distribution of emission centers in the arc that the lines of the principal series are emitted by neutral atoms, those of subordinate series and spark lines by multiply charged atoms. Wien and others have suggested that line spectra may be emitted by molecules, but this seems improbable. On the other hand, we must admit the possibility of negatively charged centers which would probably exist only under exceptional conditions. Nicholson has, with success, assumed the existence of positive, neutral, and negative centers in accounting for the spectrum of the corona.

The fundamental importance of reaching definite conclusions as to the magnitude of the electric charge of emission centers is evident when we remember that any theory must take this into account. Bohr's theory rests upon the assumption that series lines are emitted by electrons previously detached as they return to equilibrium positions determined by the resultant charge of the system. In the case of hydrogen, if there be but one detachable electron, the radiating system must be neutral. If it can be shown without question that the emission centers of the Balmer series are positively charged, some modification of the theory seems necessary. Furthermore, if the centers are thus deprived of the one detachable electron, we must accept Stark's view that the series emission is due to electrons which can not be detached. Fulcher has pointed out the necessity for a similar conclusion with respect to helium. Some of its lines are attributed to doubly charged atoms; but these are identical with alpha particles, the nuclei of the atoms, from which the radiation must be emitted.

Beyond the probable fact that band spectra are usually emitted by neutral systems, there is little evidence upon which we may rest a theory. Emission may accompany the neutralization of a positively charged molecule by an electron or may be the result of internal vibrations due to collisions, without complete ionization. Stark believes that the band emission is due to the detachable valency electrons, although the coupling between them and more firmly bound electrons may cause the latter to take part.

Evidence supporting Stark's views is to be found in absorption spectra. Hydrogen shows no absorption until it is ionized by a current. The cold vapors of the alkali metals and of mercury show line absorption, but their susceptibility to the photoelectric effect indicates how ionization may be the prelude to absorption. All the corresponding emission lines appear to be due to singly charged emission centers. Absorption of the lines due to multiple charges does not take place until the vapor is highly ionized by electric discharges or high temperature. Substances which show band absorption under ordinary conditions, such as iodine, do not appear to be ionized when either emitting or absorbing. Both processes appear to be due to neutral systems. In such cases emission must be due to internal disturbances, without ionization. The bands of some substances, such as nitrogen, are not found in absorption under any conditions, and the conditions of their occurrence indicate that the emission bands are due to the recombination of a detached electron with a positive molecule. The negative pole bands appear under the same conditions as spark lines, and it seems not improbable that they are due to the neutralization of a doubly charged molecule.

The spectral differences attending different stages of ionization are well illustrated by some recent experiments. Franck and Hertz found that mercury vapor is ionized by a field of 4.9 volts, and then emits the one ultra-violet line 2537. The Einstein relation $Ve = h\nu$ is fulfilled. McLennon and Henderson verified this conclusion, and also found that with a field of about 12 volts a second stage of ionization occurs, attended by the emission of the many-lined spectrum attributed by Stark to multiple charges. McLennon finds that zinc, cadmium and magnesium also give single line spectra which probably conform with Einstein's equation, which we should not expect to apply in a simple form to the many-line spectrum.

It appears from such experiments that there is a threshold value of kinetic energy which must be imparted to an emission center before it can radiate, which represents the work of ionization and is equal to a light quantum. Franck holds that this energy may be devoted either to ionization or to emission, but that both can not simultaneously occur. Stark believes that the two are coincident, the emission accompanying the rearrangement of electrons in the atom after one has been ejected. This suggests an explanation of quantum emission involving no departure from accepted electromagnetic theory.

The spectra of hydrogen and of helium are of particular interest because their atoms are of the simplest type and because it is possible that they are the basic units of which all elements are composed. The Pickering series in stellar spectra was attributed to hydrogen because of its numerical relationships with the Balmer series. The study of series relations led Rydberg to predict the occurrence of a principal series for hydrogen beginning at wave-length 4686, and this line was subsequently found in nebular and stellar spectra. After many attempts to reproduce these spectra in the laboratory, Fowler succeeded in 1812, by passing a powerful disruptive discharge through a mixture of hydrogen and helium. Produced only under such conditions, these must be classed as spark lines; and if Stark's views are correct and if they are really due to hydrogen, that element must have more than one detachable electron.

In applying his theory to the helium spectrum, and assuming one electron returning to a helium atom from which two electrons have been detached, Bohr obtained a formula which gives lines corresponding in position to those of the Pickering and Rydberg series, and also another series almost coincident with the Balmer hydrogen series. This remarkable conclusion was strengthened by Stark's discovery of 4686 in a helium tube which gave no lines of the ordinary hydrogen spectrum. He concluded from the canal-ray displacements that the emission centers were doubly charged. Evans also found the first members of all the series assigned to helium by Bohr, including that corresponding to the Balmer series, in a tube containing no hydrogen. The experimental evidence thus favors Bohr's theory, but we must remember the remarkable way in which the presence of one element may intensify or suppress the spectrum of another. For example, Lyman found that the ultraviolet series attributed without question to hydrogen is greatly intensified by the presence of helium. It may be added that Merton has concluded, from a study of the width of 4686, that it is due to an atom smaller than that of helium.

Some light may be thrown on this problem by observations such as those made by Wright and others on the distribution of materials in nebulæ, as indicated by the length of the nebular lines. Wright finds that usually 4686 is confined to the nucleus; helium lines extend further, and those of nebulum and hydrogen still further. These results favor the view that the elements distribute themselves according to their atomic weights and that 4686 is due to an atom at least as heavy as that of helium. But this is not conclusive, because a high temperature line of hydrogen might be found only in the hot nucleus, if we grant the possibility of a higher degree of ionization for hydrogen.

Fundamental questions which are of importance to physicists and astronomers alike are involved in this problem, but it is evidently an elusive one. Curiously enough, as Fowler has proved by comparison with other spectra, general series relations would permit us to assign the disputed series to hydrogen or to helium impartially, and it seems possible that both elements may give the same spectrum under appropriate conditions. Bohr has also concluded, from the formula derived from the assumption of the return of an electron to a lithium atom which has lost three electrons, that lithium would emit lines close to the Balmer series. Bohr has not yet succeeded in applying his method to the case where an electron returns to a singly charged helium or lithium atom, and hence has not been able to account for the known helium lines, which are assigned by Stark to singly charged atoms. Nor has he taken account of atomic magnetic fields, which, as Humphreys, Allen and others have shown, may exercise an appreciable influence.

One of the most fascinating fields of research is that of fluorescence and resonance spectra, in which much work has recently been done, particularly by Wood. He has found that white light will excite the complete band and line resonance spectrum of sodium or iodine, but that a single exciting line will cause the emission of a line of the same length and also of a number of lines approximately equally spaced which may not always coincide in position with one of the absorption lines. Thus the vapor is caused to emit forced vibration, giving a spectrum not its own. As Wood has suggested, this method enables us to strike one key of the complex vibrating system of the atom, instead of the whole keyboard at once. Time does not permit a detailed account of this remarkable work, but it is evident that it may render great service in the study of the mechanism of the atom. Nor is there time to even mention any of the results obtained in the field of absorption spectra.

After reviewing the work of the past decade, we may feel encouraged by the progress that has been made both in the perfecting and application of spectroscopic methods of research and in the discovery of new phenomena. Some of these discoveries have led to fundamental revisions of our notions of atomic structure. The Rutherford atom has definitely displaced that of Thomson. In some respects this has seemed to make the problem more difficult, but it has at least defined it more precisely. Many attempts have been made to represent an atomic structure which would satisfy the necessary mathematical conditions, most of them so impossible as to be absurd or so speculative that they suggest no experimental tests of their validity. The great merit of Bohr's hypothesis is that it does lend itself to such tests, and it is for that reason that I have paid special attention to the methods of experimental attack which seem to give the most concrete results in this connection. Hesitant as we may be to accept in all its details a theory which asks us to abandon laws upon which we have pinned our faith, this theory, and the quantum theory as well, may be the flashes of genius which reveal incompletely the outlines of the truth toward which we struggle along a dimly lighted path. Fuller knowledge may resolve some of our difficulties and reconcile apparent contradictions. Ptolemy's theory of epicycles would appear wholly irrational to one acquainted with Newton's laws but ignorant of Kepler's conclusions, yet it correctly described the facts as Ptolemy saw them. Some day the Kepler and the Newton of the atom may appear, but their task will not be an easy one. If the astronomer is baffled by the problem of three bodies which he can see, how can we expect to define the exact laws determining the motions of the invisible hosts of electrons and positive charges in an atomic system? How can we hope to correctly picture the mechanism which emits radiations of almost infinite complexity, or account for the additional complications called forth by external forces? We may be almost tempted to accept the pessimistic view expressed by Planck in his Columbia lectures, that nothing in the world entitles us to believe that it will ever be possible to represent completely through physical formulæ the inner structure of the atom. And Kayser has said:

> A true theory must assume a complete knowledge of electrical and optical processes, and therefore is an Utopia.

But even if we never reach the goal, who can set a limit to our approach to it? We may never set foot upon the promised land, but some day we may perceive its shadowy outlines dimly from afar.

University of California E. P. Lewis

WILLIAM RANE LAZENBY

William Rane Lazenby, professor of forestry in Ohio State University, died at Columbus on September 14 of pneumonia. In the passing of Professor Lazenby there is removed from us one who has devoted his life with marked success to the advancement of agriculture and agricultural education.

He was born on a farm at Belona, Yates County, N. Y., December 5, 1850; he entered Cornell University in the fall of 1870, and graduated with his class in 1874. During this period, he not only kept up his studies, but also supported himself by labor, first, on the university farm and campus, and later, in the botanical department. This at times was an extremely difficult thing to do, as the compensation for such labor was small and the time that he could spare for this work was limited. At times he was greatly discouraged; but the steadfastness of purpose, which was a prominent characteristic of his entire career, kept him at his self-imposed task. In spite of the handicap of the necessity of self-support he was so successful in his studies that he won the Ezra Cornell prize in agriculture, and on graduation he was made a member of the teaching staff of the university.

His first appointment was as instructor in horticulture; later he was promoted to an assistant professorship in horticulture, which position he held till he was called to the Ohio State University. As he was the first member of the Cornell faculty whose duties were limited to horticulture, he may be regarded as the founder of the horticultural department of this institution.

He was called to the Ohio State University as professor of botany and horticulture in 1881, which position he held till 1892, when his title was changed to professor of horticulture and forestry; since 1910 his field has been restricted to forestry.

Professor Lazenby had published much on the subjects that he taught. He spent many of his summer vacations in studying horticulture and forestry in Europe. He was a fellow of the American Association for the Advancement of Science, a founder and past president of the Ohio Academy of Science and a life