SCIENCE

FRIDAY, APRIL 6, 1917

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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.

RADIATION AND ATOMIC STRUCTURE[1]

WHILE the study of the physical and chemical properties of matter has produced our present atomic theory and furnished most of the information which is available about the way in which the myriad molecular structures are built up out of their atomic constituents, it has been chiefly the facts of radiation which have provided reliable information about the inner structure of the atom itself. Indeed, during all the years in which the dogma of the indestructible and indivisible atom was upon the stage, it was the complexity of the spectra even of simple gases which kept the physicist in the path of truth and caused him continually to insist that the atom could not be an ultimate thing, but rather that it must have a structure, and a very intricate one at that—as intricate, in Rowland's phrase, as a grand piano.

Yet the evidence of spectroscopy, though tremendously suggestive in the series relationships brought to light between the frequencies of the different lines of a given substance, was, after all, most disappointing, in that it remained wholly uninterpreted in terms of any mechanical model. No vibrating system was known which could produce frequencies related in the manner corresponding to the frequencies found even in the simplest of series, viz., the Balmer series of hydrogen. The discovery and study in the late nineties of corpuscular radiations of the alpha and beta type, with the changes in chemical properties accompanying them, merely

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[1] Address of the president of the American Physical Society, New York, December, 1916.

served to confirm the century-old evidence of the spectroscope as to the fact of the complexity of the atom, and to educate the public into a readiness to accept it, without at first adding much information as to its nature. These studies did reveal, however, two types of bodies, the alpha and beta particles, as atomic constituents, though they said nothing at first as to their number, their arrangement, or their condition within the atom.

It was the study by Barkla of a radiation problem, namely the problem of the secondary X-radiations scattered by atoms, which furnished the first important evidence as to the number of electronic constituents within an atom. He found that the number of electrons which can act as scattering centers for X-rays is about half the atomic weight.[2] This conclusion was brilliantly confirmed by the simultaneous study in the Manchester laboratory of the scattering of the alpha rays in passing through matter,[3] and out of the converging evidence of these two types of research there emerged with considerable definiteness the Rutherford nucleus atom, consisting of a central, positively charged body of extraordinarily minute dimensions, its diameter being not over a ten thousandth of the diameter of the atom, surrounded in the outer regions of the latter by a number of negative electrons equal to about half the atomic weight. In this statement the "diameter of the nucleus" means the diameter of that portion of the atom which is found by experiment to be impenetrable to the alpha rays, while the diameter of the atom means the average distance of approach of the centers of two atoms in thermal encounters.

But it was again the study of a radiation problem which had to be called upon to furnish unquestionable information as to the exact value of this number, and at the same time to provide the most convincing evidence that we have of the general correctness of the conception of the nucleus atom.

In a research[4] which is destined to rank as one of the dozen most brilliant in conception, skilful in execution, and illuminating in results in the history of science, a young man but twenty-six years old threw open the windows through which we can now glimpse the subatomic world with a definiteness and certainty never even dreamed of before. Had the European war had no other result than the snuffing out of this young life, that alone would make it one of the most hideous and most irreparable crimes in history.

For the proof that there exist but 92 elements, from the lightest known one, hydrogen to the heaviest known one, uranium, and that these are built up one from the other by the successive addition of one and the same electrical element to the nucleus, this proof comes alone from Moseley's discovery (checked and extended as it has been by de Broglie clear up to uranium) that the square roots of the characteristic X-ray frequencies of the elements progress by almost exactly equal steps from the lightest observable one to the heaviest. Moseley proved this in a general way for both the alpha and the beta emission lines of the hardest characteristic X-ray of the elements, the so-called K rays, and also for the alpha and beta lines of the next softest series, the L series. De Broglie[5] and Hull[6] have recently shown that Moseley's law holds for the frequencies above which the different elements absorb the general radiation of tungsten. This critical frequency

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[2] Barkla, *Phil. Mag.*, 21, 648, May, 1911.

[3] Rutherford, *Phil. Mag.*, 21, 669, May, 1911.

[4] Moseley, *Phil. Mag.*, 26, 1024, Dec., 1913, and 27, 703, 1914.

[5] de Broglie, *Compte Rendu*, 165, 87, 352, 1917.

[6] Hull, *Proc. Nat. Acad. of Sciences*, 2, 265, 1916.

coincides for each element, nearly, if not exactly, with the highest emission frequency characteristic of that element. De Broglie has measured accurately these critical absorption frequencies for all the heavy elements clear up to thorium, thus extending the K series from N = 60, where he found it, to N = 90—a notable advance. It is to be noted, however, that in going up from bromine, atomic number 35, to uranium, atomic number 92, the length of the step does change by a few per cent.

Now it is these radiating and absorbing properties of atoms and these alone which justify a series of atomic numbers differing from and more fundamental than the series of atomic weights. Our present series of atomic numbers is simply this Moseley series of steps based on square root frequencies. It is true that a series of atomic numbers coinciding with the series of atomic weights was suggested earlier, indeed 100 years earlier, by Prout, and by many others since then, and it is true, too, that changes in the chemical properties of radioactive substances accompanying the loss of alpha and beta particles led van den Broek,[7] just before Moseley's work appeared, to suggest that position in the periodic table might be a more fundamental property than atomic weight, but since this position is in some instances uncertain, and since the number of elements was wholly unknown, no definite numbers were or could be assigned to all the elements until Moseley's discovery was made, and the only evidence which we now have as to just how many elements there are between hydrogen and uranium, and as to just where each one belongs, is the evidence of the X-ray spectra. It is true that between helium, atomic number 2 and sodium, atomic number 11, we have no evidence other than the order of atomic weights, the progression of chemical properties and the number of known elements in this region to guide us in completing the table, but since in the region of low atomic weights the progression in the Moseley table is always in agreement with the progression in the periodic table there can be little doubt about the correct number of each element even in this region which is as yet inaccessible to X-ray measurements. Moseley's name must then be set over against one of the most epoch making of the world's great discoveries. And I wish to call attention to some important conclusions as to atomic structure which are rendered extremely probable by it.

The first is this: If we may assume that the ordinary law of inverse squares holds for the forces exerted by the atomic nucleus on negative electrons near it—and this time-honored law, so amply verified in celestial regions, has been fully verified for subatomic regions as well by the work done at the University of Manchester on the scattering of alpha rays—then the Moseley law that the square roots of the highest frequencies obtainable from different atoms are proportional to the nuclear charge[8] means, without any quantum theory, that the distances from the nucleus of each type of atom to the orbit of the inmost electron is inversely proportional to the charge on the nucleus, *i. e.*, to the atomic number. To see this it is only necessary to apply the Newtonian law connecting central force eE, orbital frequency n and radius a, namely,

$$\frac{eE_1}{a^2} = (2\pi n)^2 ma, \quad \text{or} \quad \frac{n_1^2}{n_2^2} = \frac{E_1}{E_2}\frac{a_2^3}{a_1^3} \qquad (1)$$

and then to set as the statement of Moseley's experiment

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[7] Van den Broek, *Phys. Zeit.*, XIV., 32, 1913.

[8] This is the proper statement of the Moseley law, as he himself *interpreted* his experimental results. He knew and was careful to state, that there is not an *exact* linear relation between the atomic numbers and the square roots of the frequencies, but the lack of exactness of equation (2) both as

$$\sqrt{\frac{n_1}{n_2}}=\frac{E_1}{E_2}, \qquad (2)$$

when there results at once from (1) and (2)

$$\frac{E_1}{E_2}=\frac{a_2}{a_1}. \qquad (3)$$

It may be objected that in the setting up of these relations I have made two assumptions, the one that the electrons rotate in circular orbits, and the other that the observed highest frequencies are proportional to the highest orbital frequencies. The first assumption is justified (*a*) by the fact that the recognized and tested principles of physics give us no other known way of providing a stable system, (*b*) by the experimental facts of light (Zeeman effect) and (*c*) by the phenomena of magnetism, especially the recent ones brought to light by Einstein and de Haas,[9] and by Barnett,[10] which well-nigh demonstrate the existence of permanent and therefore non-radiating electronic orbits. The exact circular form for the orbit is a secondary matter upon which, as will appear later, it is not necessary to insist. The second assumption, that the frequencies of the corresponding emission lines in the spectrum of the various atoms are proportional to the orbital frequencies, is from *a priori* considerations probable and from certain theoretical considerations to be presented later, necessary.

A second conclusion may be drawn from Moseley's discovery that the L lines progress in frequency from element to element just as do the K lines, the frequency being in each case between 1/7 and 1/8 as great. It is that, if there is a first or inmost electronic orbit, there must also be a second one in all elements the radius of which is given by (1) to be about 8⅔ or 4 times as great as that of the first.

Guided then by the newly discovered facts of X-radiations and the unquestioned laws of force between electric charges, we get our first information as to the probable positions and conditions of some at least of the negative electrons within the atom.

Again, having found the highest natural frequency which can come from any element, viz., that from uranium, it is of extraordinary interest to inquire where, according to Moseley's law (2), the highest frequency line of the K series would fall for the lightest known element, hydrogen, whose nucleus should consist of but a single positive electron. This is obtained, as shown in (2), by dividing the observed highest frequency of any element by the square of the atomic number. The shortest wave-length given out by tungsten, atomic number 74, and the only heavy element whose X-ray constants have been accurately determined, is $.167 \times 10^{-8}$ cm. according to Hull's measurements. This gives for the shortest wave-length which could be produced by hydrogen $.167 \times 10^{-8} \times 74^2 = 91.4$ $\mu\mu$. This is as close as could be expected, in view of the uncertainties in the measurements and the further fact that Moseley's steps are not quite exact, to the head of the ultra-violet series of hydrogen lines recently discovered by Lyman and located exactly at 91.2 $\mu\mu$. There is every reason to believe, too, from the form of Balmer's series, of which this is the convergence wave-length, that this wave-length corresponds to the highest frequency of which the hydrogen atom is capable. *It is practically certain, then, that this Lyman ultra-violet series of hydrogen lines is nothing but the K X-ray series of hydrogen.* Similarly, it is equally certain that the L X-ray series of hydrogen is the ordinary Balmer series in the visible region, the head of which is at 365 $\mu\mu$. In

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to straightness and as to intercept may well be attributed to secondary causes. (See below.)

[9] *Verh. d. Phys. Ges.*, XVII., p. 152, 1913.

[10] *Phys. Rev.*, 6, 239, 1915.

other words, hydrogen's ordinary radiations are its X-rays and nothing more. There is also an M series for hydrogen discovered by Paschem in the ultra-red. This in itself makes it probable that there are series for all the elements of longer wavelength than the L series, and that the complicated optical series observed with metallic arcs are parts of these longer wavelength series. As a matter of fact an M series has been found for six of the elements of high atomic weight. Thus the Moseley experiments have gone a long way toward solving the mystery of spectral lines. They reveal to us clearly and quite certainly the whole series of elements from hydrogen to uranium, all producing spectra of remarkable similarity, at least so far as the K and L radiations are concerned, but scattered regularly through the whole frequency region, from the ultra-violet, where the K lines for hydrogen are found, clear up to frequencies $(92)^2$ or 8,464 times as high. There can scarcely be a doubt that this whole field will soon be open to our exploration. How brilliantly, then, have these recent studies justified the predictions of the spectroscopists that the key to atomic structure lay in the study of spectral lines. The prophets little dreamed, however, that the study of spectral lines meant the study of X-rays. But now, through this study, a subatomic world stands revealed to us in simpler form than one could have imagined. For the atoms are now seen to be, in their inner portions at least, remarkably similar structures, with central nuclei which are exact multiples of the positive electron, surrounded in each case by electronic orbits which have certainly, so far as the inner ones are concerned, practically the same relations in all the elements, the radii of all these orbits being inversely proportional to the central charge or atomic number.

So far nothing has been said about a quantum theory or a Bohr atom. The results have followed from the known properties of assumed circular electronic orbits combined with Moseley's experimental law, as he interpreted it, and supplemented by the single additional assumption that the observed frequencies are proportional to the orbital frequencies. If they suggest, however, that the experimental facts do not necessitate the quantum theory for their complete interpretation, the consideration of the energy relations involved—these have been entirely ignored thus far—reveals at once the futility of that hope, or of that fear, according to the nature of your predilections with regard to the theory of quanta. *For the experimental facts and the law of circular electronic orbits have limited the electrons to orbits of particular radii.* But the energy principle does not permit them to be so limited without a sudden or explosive loss of energy whenever the orbit is obliged to change. Suppose, for example, that a cathode ray strikes the atom and knocks out any electron from a particular orbit. When this or some other electron returns from infinity to this orbit, it must in this act adjust its energy to the only value which is consistent with this orbit and its characteristic frequency. Hence in the act of readjustment it must radiate a definite quantity of energy. Or again, suppose that the nucleus loses a beta ray through the radioactive process. Every electronic orbit must then adjust itself to the new value demanded by Moseley's law. But this it can not do if its energy is conserved. The only way to permit it to do so is to let it radiate a definite amount of energy in the act of adjustment. This suggests that each emission of a beta ray by a radioactive substance must be accompanied by a whole series of characteristic gamma rays corresponding to each changed orbit. The emission of an alpha particle, on the other hand, would require an absorption rather than an emission of energy, since its egress diminishes rather than increases the nuclear charge. Perhaps this is why beta rays are always accompanied by gamma rays, while alpha rays are not so accompanied. This is, however, a speculation which does not immediately concern us here. The important conclusion, for the purposes of our present subject, is that Moseley's facts and unquestionable mechanics combined with our two assumptions of circular orbits and radiation frequencies proportional in different atoms to corresponding orbital frequencies, lead inevitably to the explosive emission of energy in definite quantities accompanying orbital readjustments. And there is nothing particularly disturbing or radical about this conclusion either, for we have no basis for knowing anything about how an electron inside an atom emits its radiation. The act of orbital readjustment would be expected to send out ether waves. The only difficulty lies in the conception of stable, non-radiating orbits between which the change occurs, and whether or not we can see how such orbits can exist, the experimental evidence that they do so exist is now very strong, and it is to further evidence for their existence, since that is the main point to be established if this theory of atomic structures is to prevail, that I now wish to direct your attention.

I have already mentioned some facts of magnetism and of light which support the orbital point of view. But the strongest evidence is found in the extraordinary success of the Bohr atom, which was devised before any of these Moseley relationships, which have forced us to the essential elements of the Bohr theory,[11] had been brought to light. Bohr, however, was guided solely by the known character of the line spectra of hydrogen and helium, together with the rapidly growing conviction, now dissented from, so far as I know, by no prominent theoretical physicist, that the act of emitting electromagnetic radiation by an electronic constituent of an atom must, under some circumstances, though not necessarily under all, be an explosive process. To show what is the character of this evidence, let us consider first what are the essential elements in the Bohr theory, and, second, what have been the accomplishments of that theory. Bohr's experimental starting point is the Balmer series in hydrogen, the frequencies in which are exactly given by

$$\nu = N\left(\frac{1}{{n_1}^2} = \frac{1}{{n_2}^2}\right) \tag{4}$$

n_1 having always, for the lines in the visible region, the value 2, and n_2 taking in succession the values 3, 4, 5, etc. As previously noted, Paschen had already brought to light a series in the infra-red in which n_1 was 3 and n_2 took the successive values 4, 5, 6, etc. Lyman's discovery, subsequent to the birth of the Bohr atom, of an ultra-violet series of hydrogen lines in which $n_1 = 1$ and n_2 takes the values 2, 3, 4, etc., is not to be regarded as a success of the Bohr atom, but merely as a proof of the power of the series relationships to predict the location of new spectral lines. To obtain an atomic model which will predict these series relationships for the simplest possible case of one single electron revolving around a positive nucleus, Bohr assumed:

A, a series of non-radiating orbits governed by equation (1). This is the assumption of circular orbits governed by the laws which are known to hold inside as well as outside the atom.

B, radiation taking place only when an electron jumps from one to another of these orbits the amount radiated and its frequency being determined by $h = A_1 - A_2$,

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[11] N. Bohr, *Phil. Mag.*, 26, 1 and 476 and 857, 1913. Also 29, 332, 1915, also 30, 394, 1915.

h being Planck's constant and A_1 and A_2 the energies in the two stationary states.

This assumption gives no physical picture of the way in which the radiation takes place. *It merely specifies the energy relations which must be satisfied.* The principle of conservation of energy obviously requires that the energy radiated be $A_1 - A_2$. Also this radiation must be assigned some frequency ν and Bohr placed it proportional to the energy because of the Planck evidence that ether waves originating in an atom carry away from the atom an energy which is proportional to ν.

C, the various possible circular orbits, for the case of a single electron rotating around a single positive nucleus, to be determined by $T = \frac{1}{2}\tau hn$, in which τ is a whole number, n is the orbital frequency, and T is the kinetic energy of rotation. This condition was imposed by the experimentally determined relationship of the frequencies represented by the Balmer series.

It will be seen that if circular electronic orbits exist at all, no one of these assumptions is in any way arbitrary. Each one of them is merely the statement of the existing *experimental* situation. The results derived from them must be correct if the original assumption of electronic orbits is sound. Now it is not at all surprising that *A, B,* and *C* predict the sequence of frequencies found in the hydrogen series. They have been made on purpose to do it, *except for the numerical values of the constants involved.* It was this sequence which determined the form given to *C*. The evidence for the soundness of the conception of non-radiating orbits is to be looked for then, first *in the success of the constants* and second *in the physical significance, if any, which attaches to assumption C.* If the constants come out right within the limits of experimental error, then the theory of non-radiating electronic orbits has been given the most critical imaginable of tests, especially if these constants are accurately determinable.

What are the facts? The constant of the Balmer series in hydrogen is known with the great precision attained in all wavelength determinations and has the value 3.290×10^{15}. From *A, B* and *C* it is given by the simplest algebra as

$$N = \frac{2\pi^2 e^2 E^2 m}{h^3}. \qquad (5)$$

I have recently redetermined e[12] with an estimated accuracy of one part in 1,000 and obtained again the value $4{,}774 \times 10^{-10}$, which I published in 1913. I have also determined "h" photoelectrically[13] with an error in the case of sodium of no more than $\frac{1}{2}$ per cent., the value for sodium being 6.56×10^{-27}. The value found by Webster[14] by the method discovered by Duane and Hunt is 6.53×10^{-27}. Taking the mean of these two results, viz., $6{,}545 \times 10^{-27}$ as the most probable value, we get with the aid of Bucherer's value of e/m which is probably correct to one tenth per cent. $N = 3{,}294 \times 10^{15}$, *which agrees within a tenth per cent. with the observed value.* This agreement constitutes most extraordinary justification of the theory of non-radiating electronic orbits. It demonstrates that the behavior of the negative electron in the hydrogen atom is at least correctly described by the *equation* of a circular orbit. If this equation can be obtained from some other physical condition than that of an actual orbit it is obviously incumbent upon those who so hold to show what that condition is. Until this is done it is justifiable to suppose that the equation of an orbit means an actual orbit.

Again, the radii of the stable orbits for hydrogen are given easily from Bohr's assumptions as

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[12] R. A. Millikan, *Proc. Nat. Acad.*, April, 1917.

[13] R. A. Millikan, *Phys. Rev.*, VII., 362, 1916.

[14] *Phys. Rev.*, Dec., 1916.

$$a = \frac{\tau^2 h^2}{4\pi^2 m e^4}.$$

In other words, since τ is a whole number, the radii of these orbits bear the ratios 1, 4, 9, 16, 25. If normal hydrogen is assumed to be that in which the electron is on the inmost orbit, $2a$ the diameter of the normal hydrogen atom, comes out 1.1×10^{-8}. The best determination for the diameter of the hydrogen molecule yields 2.2×10^{-8}, in extraordinarily close agreement with the prediction from Bohr's theory. Further, the fact that normal hydrogen does not absorb at all the Balmer series lines which it emits is beautifully explained by the foregoing theory, since according to it normal hydrogen has no electrons in the orbits corresponding to the lines of the Balmer series. Again, the fact that hydrogen emits its characteristic radiations only when it is ionized favors the theory that the process of emission is a process of settling down to a normal condition through a series of possible intermediate states, and is therefore in line with the view that a change in orbit is necessary to the act of radiation. Similarly, the fact that in the stars there are 33 lines in the Balmer series, while in the laboratory we never get more than 12 is easily explicable from the Bohr theory, but no other theory has offered even a suggestion of an explanation. But while these qualitative successes of the Bohr atom are significant, it is the foregoing numerical agreements which constitute the most compelling evidence in favor of the single arbitrary assumption contained in Bohr's theory, viz., the assumption of non-radiating electronic orbits.

Another triumph of the theory is that the assumption *C*, devised to fit a purely empirical situation, viz., the observed relations between the frequencies of the Balmer series, is found to have a very simple and illuminating physical meaning, viz., the atomicity of angular momentum. Such relationships do not in general drop out of empirical formulas. When they do we usually see in them real interpretations of the formulas—not merely coincidences.

Again the success of a theory is often tested as much by its adaptability to the explanation of deviations from the behavior predicted by its most elementary form as by the exactness of the fit between calculated and observed results. The theory of electronic orbits has had remarkable successes of this sort. Thus it predicts, as can be seen from 4, 5 and 3, the relationship which we assumed, viz., that for corresponding lines (like values of n_1 and n_2 in 4) the orbital frequencies n are proportional to the observed frequencies ν and similarly it predicts the Moseley law (2). But this latter relation, which is the only one of the two which can be directly tested, was found inexact, and it should be inexact when there is more than one electron in the atom, as is the case save for H atoms and for the He atoms which have lost one negative charge, and that because of the way in which the electrons influence one another's fields. It will probably be found to break down completely for very light atoms like that of lithium. The more powerful the nucleus, however, and the closer to it the inner orbit the smaller should this effect be. Now precisely this result is observed. The Moseley law (2) holds most accurately when tested for hydrogen and the elements of highest atomic number and much less accurately when tested for hydrogen and aluminum or magnesium. Similarly the ratio between the frequencies of the α and β lines of the K series approaches closer to the theoretical value (that for hydrogen) the higher the atomic number of the element.

Again, it is now well known that the α, β, γ lines in the characteristic X-ray spectrum are not single lines as required by the simple theory. Accordingly Sommerfeld[15] extended Bohr equations in the endeavor to account for this structure on the basis of ellipticity in some of the orbits, and Paschen[16] by measurements on the structure of the complex helium lines has obtained so extraordinary checks upon this theory that *e/m* comes out from his measments to within a tenth per cent. of the accepted value.

A further prediction made by the theory and discovered as soon as looked for was the relation between the lines of two succeeding series of this sort:

$$\nu_{K_\beta} - \nu_{K\alpha} = \nu_{L_\alpha}.$$

This should hold accurately from the energy relations between the orbits whether there be one or many electrons in the atoms. I have been able to find no case of its failure, though the data upon which it may be tested is now considerable. I have also recently pointed out[17] that it is equivalent to the well-known Rydberg-Schuster law,[18] which holds quite generally among optical series. Finally, the ionizing potential of hydrogen is given by Bohr's equation as 13.54 volts while experiment yields 11.5 volts. This discrepancy in no way prejudices the theory, but rather lends it support, for the computed value is for the *hydrogen atom* while the observed value relates to the hydrogen *molecule,* which in view of the repulsions of its two negative electrons might be expected to be ionized more easily than the hydrogen atom. Similarly the computed value for helium which has lost one negative is 52.4 volts, but the helium molecule is found experimentally to be ionized at a much lower potential, viz., 20.5 volts. That Bohr computed this latter value at 27 instead of 20.5 volts is not at all serious, since he had to make very particular assumptions to get this result.

If then the test of truth in a physical theory is large success both in the prediction of new relationships and in correctly and exactly accounting for old ones, the theory of non-radiating orbits is one of the best established truths of modern physics. For the present at least it is truth, and no other theory of atomic structure need be considered until it has shown itself able to approach it in fertility. I know of no competitor which is as yet even in sight. I am well aware that the facts of organic chemistry seem to demand that the valence electrons be grouped in certain definite equilibrium positions about the periphery of the atom, and that at first sight this demand appears difficult to reconcile with the theory of electronic orbits. As yet, however, there is no necessary clash. Hydrogen and helium present no difficulties, since the former has but one valency, and the latter none. It is to these atoms alone that the unmodified Bohr theory applies, for it treats only the case of a single negative electron rotating about a positive nucleus. That the K radiations of the heavy elements are so accurately predictable from those of hydrogen indicates indeed that close to the nucleus of these elements there lie electrons to which the Bohr theory fairly accurately applies, but the radiations give us no information about the conditions or behaviors of the external electrons which have to do with the phenomena of valency and we have investigated but little the radiating properties of the atoms which possess but few electrons. A further study of the behavior with respect to X-rays of the elements from lithium, atomic number 3, to sodium, atomic number 11, may be expected to throw new light on this problem.

It has been objected too that the Bohr theory is not a radiation theory because it gives us no picture of the mechanism of the

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[15] *Annalen der Physik.,* 51, 1, 1916.

[16] *Annalen der Physik.,* Oct., 1916.

[17] *Phys. Rev.,* May, 1917, presented before American Physical Society, December 1, 1916.

[18] Baly, "Spectroscopy," p. 488.

production of the frequency ν. This is true, and therein lies its strength, just as the strength of the first and second laws of thermodynamics lies in the fact that they are true irrespective of a mechanism. The Bohr theory is a theory of atomic structure; it is not a theory of radiation, for it merely states what energy relations must exist when radiation, whatever its mechanism, takes place. As a theory of atomic structure, however, it is thus far a tremendous success. The radiation problem is still the most illusive and the most fascinating problem of modern physics. I hope to discuss it at a later time.

R. A. Millikan

Ryerson Laboratory,
University of Chicago

GEORGE CHRISTIAN HOFFMANN

George Christian Hoffmann, formerly assistant director, chemist, and mineralogist of the Geological Survey of Canada, died in Ottawa, March 8, 1917. He was born June 7, 1837, in London, England, and studied at the Royal School of Mines under Sir Henry de la Bèche, under Hoffman, Percy, Smyth, Stokes, Ramsay, Huxley and Willis. He spent several years as chemist in research laboratories of England, and later 1861, wrought in Natal, South Africa, in the Mauritius, later again in Australia. In 1872 he joined the technical staff of the Geological Survey of Canada, Montreal, under Dr. Alfred R. C. Selwyn. Dr. Hoffmann was a fellow of the Institute of Chemistry of Great Britain, a fellow of the Royal Society of Canada and of many other distinguished bodies. He is the author of many numerous reports published by the Geological Survey of Canada and the Department of Mines. While in Australia he devoted considerable time in the phyto-chemical laboratory attached to the Melbourne Botanic Garden in Victoria; inquiries into the tanning properties of the barks of native trees; investigation into the amount of potash in various indigenous trees, besides experiments in reference to various acids, tar and other products. Besides the above enquiry into the suitability for paper-making of various fibrous substances were carried on by Dr. Hoffmann. The essential oils of certain trees, dyeing properties and coloring matter of others and researches on tea, opium and various economic products were carried out in conjunction with Baron Ferdinand Mueller, the distinguished Australian botanist. His bibliography contains valuable reports and papers of analyses and determinations of Canadian ores, minerals and economic products characterizing the rock formations of Canada and elsewhere, including rare and new species.

H. M. Ami

British Embassy,
Washington, D. C.

SCIENTIFIC EVENTS

LECTURES ON SANITARY SCIENCE AT RUTGERS COLLEGE

In connection with the recently established course in sanitary science, Rutgers College has inaugurated a series of public lectures. The list follows:

November 27. Professor Jacques Loeb, of the department of experimental biology of the Rockefeller Institute, New York City, ''Regeneration.''

February 5. Dr. J. G. Needham, professor of entomology, Cornell University, ''Action.''

February 28. Dr. G. M. Potter, of the Bureau of Animal Industry, Washington, D. C., ''Abortion Diseases of Cattle.''

March 7. Professor A. E. Taylor, Ph.D., University of Pennsylvania, ''Agricultural Production in Germany under Blockade.''

March 8. Mr. Allen Hazen, C.E., New York City, ''Purification of Water Supplies.''

March 14. Dr. K. F. Kellerman, associate chief of the Bureau of Plant Industry, Washington, D. C., ''Relation of Algæ to Public Water Supplies.''

March 19. Dr. J. F. Anderson, director of Squibb's Laboratory, New Brunswick, N. J., ''Anaphylaxis.''

March 21. Dr. Theobald Smith, director of the department of animal pathology of the Rockefeller Institute, Princeton, N. J., ''Research in Animal Diseases with Reference to Agriculture and the Industries.''

March 22. Dr. Theobald Smith, director of the department of animal pathology of the Rockefeller