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MODERN VIEWS ON THE CONSTITUTION OF THE ATOM

AT a meeting of the Royal Society of Canada held at Montreal, May, 1914, the writer gave by request a summary of recent work and ideas on the nature of the atom. The object was to concentrate, as clearly as possible, but not exhaustively, the results and opinions scattered through many different publications. Few men have time or opportunity to collect and analyze for themselves the large output bearing on this fascinating subject.

1. It may be well to call attention to the general bearing of the situation. Biologists are divided into three camps, vitalists, mechanists, and those who sit on the boundary fence. The mechanists believe that all phenomena relating to life are attributed to the action of physical and chemical processes only. The vitalists believe that life involves something beyond and behind these. Now those who investigate natural philosophy, or physics, are endeavoring with some fair initial success, to explain all physical and chemical processes in terms of positive electrons, negative electrons, and of the effects produced by these in the ether, or space devoid of matter.

If both the mechanists are right, and also the physicists, then such phenomena as heredity and memory and intelligence, and our ideas of morality and religion, and all sorts of complicated affairs are explainable in terms of positive and negative electrons and ether. All of these speculations are really outside the domain of science, at least at present.

2. It has been remarked by Poincaré that each fresh discovery in physics adds

a new load on the atom. The conditions which the atoms have to explain may indeed be written down, but to do so is merely to make a complete index for all books on physics and chemistry in the widest sense.

3. In the early days of the kinetic theory of gases, now well established in its broad outlines, it was sufficient to regard the atom as a perfectly elastic sphere, and it is about a generation ago[1] that leading savants were triumphantly determining the effective radius as about 10^{-8} cm. (a convenient shorthand for the hundred millionth of a centimeter).

The discovery of electrons as the cathode rays of an electric discharge in an exhausted tube, and as the beta rays of radium, opened up new regions.[2] It appears that negative electricity consists of electrons with their accompanying but unexplained effects in the ether. Electrons in motion produce magnetic fields. Their effective mass is about one eighteen hundredth part of that of a hydrogen atom, and their effective radius one hundred thousandth. The greatest known speed of electrons nearly approaches that of light.

The Zeeman effect, or separation of a single line in the spectrum by suitable magnetic fields, into two or more lines proved conclusively that the vibrations of negative electrons in the atom are the cause of the disturbances in the ether which we know as light.

4. The first scheme of an electronic atom, propounded by Sir Joseph Thomson, was a sphere of positive electricity, of undefined character within which revolved concentric rings of electrons in the same plane. There necessarily followed the simplicity of circular motion under a force to the center, proportional to the distance between the electron and the center of the atom.

5. Previous to this Lord Rayleigh had called attention to a serious anomaly. In a train of waves of a periodic character, the electric intensity E varies as the sine of nt, where t is the time and $2\pi/n$ is the period. As the equations involve the second differential of E, it appears inevitable that the square of n should appear in the law for spectral series. As a matter of fact there appears not the square of n, but n itself. It is desirable to be more explicit. If parallel light from a luminous source passes through a slit and a prism, together with suitable lenses, then the eye or photographic plate can detect a number of bright lines forming the spectral images of the slit for different colors, provided that the light is from luminous mercury vapor or hydrogen, or some such source. Many of these lines have been found to belong to one or more series crowding together towards the violet end. Balmer and Rydberg have found that the general type of formula for their frequency n is

$$n = N_0\left(\frac{1}{a^2} - \frac{1}{b^2}\right),$$

where N_0 is a universal constant called Rydberg's number, the same in value for *all* electrons of *all* atoms; and a and b are whole numbers or integers. We shall refer later to the importance of Rydberg's constant and of this magnificent generalization.

The trouble to which Rayleigh referred was first faced by Ritz in a startling manner. He imagined that there were inside the atom, placed end to end, a number of small magnets with an electron constrained to move in a circular path around the line of magnets. With this hypothesis he was

[1] Young proved this in 1805, but his work was forgotten, until Rayleigh called attention to it in 1890 (*Phil. Mag.*, XXX., 474).

[2] It is remarkable how little the general public has shared in this advance. In Montreal there were eleven thousand people witnessing a wrestling match while few availed themselves of an invitation to meetings and discussions of the Royal Society.

able to account correctly for the above law for series of lines in the spectrum.

We may appreciate Poincaré's criticism—

On a quelque peine à accepter cette conception, qui a je ne sais quoi d'artificiel.

Inasmuch as physicists endeavor to explain magnetism in terms of revolving electrons, there is a lack of simplicity, and there is an inconsistency, in introducing elemental magnets inside the atom. Nevertheless, it must be admitted that Weiss has found remarkable evidence for the conception of *magnetons* or elemental unit magnets, producing intra-molecular fields reaching to millions of Gauss units, far transcending any produced by our most powerful electromagnets, and difficult to explain by revolving electrons.

Again to quote Poincaré—

Qu' est-ce maintenant qu'un magnéton? Est-ce quelque chose de simple? Non, si l'on ne veut pas renoncer à l'hypothèse des courants particulaires d'Ampère; un magnèton est alors un tourbillon d'électrons, et voila notre atome qui complique de plus en plus.

Perhaps the hypothesis of Bohr, explained later, may overcome the difficulty, but for some time to come the more prudent will suspend judgment on the magneton.

Recently there has been nothing short of a revolution in physics. In certain domains, the leading workers and thinkers have deliberately abandoned the classical dynamics and electro-dynamics, and made suppositions which are in direct opposition to these. This startling change may perhaps be justified by the fact that the famous laws and equations were based on large scale experiments, so that they do not necessarily apply to conditions within the atom. Those who put forward and make use of the new hypotheses, men like Planck and Lorentz, Poincaré and Jeans and others, appear to do so with reluctance, like a retiring army forced from one position to another. Others, like Rayleigh and Larmer, appear to regard the whole movement with misgivings, and some endeavor, like Walker and Callendar, to find a way out. There is a young school who go joyfully forward, selecting and suggesting somewhat wild hypotheses, and yet attaining an unexpected measure of success by their apparently reckless methods.

The main phenomena to which the new mechanics have been applied are the radiation within an enclosure, and the distribution of energy therein; the high speed of electrons ejected from matter by ultraviolet light, or by Röntgen rays, or by the gamma or penetrating rays from radioactive substances, or as I suggest that we call them, from *radiants;* the atomic heat of elements, so admirably handled by Debye; the residual energy at low temperatures; and the constitution of the atom.

Space prevents us from considering more than the last of these.

The first step towards the new method was taken by Planck when he saw the necessity of explaining why the energy of short wave radiation is some hundred millionth part of that demanded by classical dynamics. He made the supposition that energy is not indefinitely divisible, but he did not assume that it was atomic. He actually imagined that energy was emitted from oscillators in exact multiples of hn, where n is the frequency of the oscillation and h is a universal constant (Planck's) with a value 6.5×10^{-27} erg second. The magnitude of the energy quantum is thus proportional to the frequency.

This quantum hypothesis has spread like fire during a drought. It pervades the scientific journals. No physicist has pretended to explain or understand it, for, as Jeans says, the lucky guess has not yet been made. Nevertheless, it appears that "h" has truth underlying it, and that it has come to stay, for the applications of the quantum hypothesis have already achieved a great and unexpected measure of success. In the meantime it is necessary to proceed with caution, checking every theory by experiment, for there is no other criterion to guide the investigator, whether to hold to the old or try the new.

7. The first steps towards the idea of the modern or Rutherfordian atom rest on an experimental basis, and are not, therefore, open to suspicion.

Rutherford and Geiger found that when the alpha particles from a radiant, such as radium or polonium, met a thin gold leaf, the bulk of the alpha particles passed through with slight deflection, but about one in eight thousand bounced back, or returned towards the side of their source. Both large and small deviations of the alpha particles in passing through matter were satisfactorily explained by ordinary or Newtonian dynamics, with the law of repulsion inversely as the square of the distance between similar electric charges. One charged particle was the alpha particle with a positive charge twice as large, numerically, as that of an electron. The other charged particle was the *nucleus* of the atom of gold, and the magnitude of this charge was about $\frac{1}{2}A$ where A is the atomic weight of gold. This view was subjected to a searching series of experimental tests and emerged triumphant.

8. About this time C. T. R. Wilson skilfully obtained photographs of the mist-ladened, charged air molecules, marking the track of a recent alpha particle, in an expansion chamber. Some of these photographs showed where a collision had occurred between the alpha particle and one of the heavier molecules of air. It immediately occurred to Sir Ernest Rutherford that a collision between an alpha particle and a lighter atom, such as hydrogen, would result in the nucleus of the latter being projected beyond the known range of the alpha particle. The point was put to the test by Marsden, and a complete justification of Rutherford's nucleus resulted. The hydrogen nuclei were found to produce scintillations on a zinc sulphide screen at a range about *four times as great* as that of the alpha particles. Some mathematical investigations by G. C. Darwin indicated that the alpha particle or nucleus of helium, and the hydrogen nucleus must have approached so close that their centers were but 1.7×10^{-13} cm. apart. This affords further evidence of the extreme minuteness of the nucleus compared with the size of an atom (10^{-8} cm.).

9. It may be well to recall at this point an interesting result of Barkla, obtained some years earlier, who showed from the scattering of Röntgen rays that the number of electrons in the atom must be about $\frac{1}{2}A$, where A is the atomic weight. In the case of an uncharged atom, the positive charge on the nucleus must evidently balance the negative charges on the electrons revolving in orbits around that nucleus.

Thus we can form a clear mental picture of the general character of the atom. It is a miniature solar system. The sun is replaced by the positively charged nucleus. The planets, perhaps confined to one or more definite orbits or rings, are replaced by negative electrons revolving rapidly around the nucleus. The gravitational force is replaced by the electrical attraction between the positive nucleus and negative electrons.

10. A brilliant young Dane, Bohr, has gone a step farther and suggested the structure of an atom capable of explaining the series of spectral lines. His work is remarkable as leading to excellent numerical verification. He assumes the Rutherfordian nucleus of electronic charge about half the

atomic weight; he assumes that for every revolving electron in every atom the angular momentum is constant. To be concise, he supposes that for each electron mass $\times$ velocity $\times$ radius $=$ Planck's constant $/2\pi$.

He further supposes that in a steady stationary orbit even a single electron does not radiate away energy. *This is entirely contrary to classical electrodynamics.* Furthermore he imagines that in passing from one state of stationary orbit to the next possible, there is homogeneous radiation of amount hn, where n is the frequency. This is of course Planck's assumption, and it is certainly unexplained, and probably not in accord with Hamilton's equations as deduced from Newton's laws. Nevertheless, any day we may learn why energy is emitted *per saltum,* and this mystery will vanish.

Now if you permit these somewhat arbitrary assumptions to Bohr, he can and does deduce, at least for the lighter atoms such as hydrogen and helium, the Rydberg formula for the spectral series. He finds:

$$n=\frac{2\pi^2me^4}{h^3}\left(\frac{1}{a^2}-\frac{1}{b^2}\right),$$

where n is the frequency; m, e, mass and charge of an electron; h is Planck's constant; a, b, are integers. The quantity before the bracket should equal the Rydberg number N_0, of observed value 3.29×10^{15}. Bohr's calculated value is 3.26×10^{15}, showing a most satisfactory agreement.

Bohr endeavors to account for the manner in which two hydrogen atoms form a molecule. Each atom has a nucleus of positive charge and a simple electron revolving around it. Their charges are equal and opposite. The nuclei of two such atoms repel each other. The revolving electrons of two atoms close together, if rotating in the same direction, constitute two parallel currents of electricity, and these attract one another and arrive in the same plane. It is easy to make a model on a whirling table with the nuclei on an upright rod, the electrons revolving like the governor balls of an engine. Bohr has gone further, and conceived a similar model of a water molecule with the two nuclei of hydrogen and one nucleus of oxygen in a straight line, with 10 electrons revolving in their zones around them. No doubt these suggestive schemes are somewhat speculative, but it is refreshing to find a first approximation to a dynamical scheme replacing the old unsatisfactory electrostatic atoms, which probably did not approximate to the truth. Some of the formidable organic molecules must have a complexity which it may take generations of physicists to unravel.

11. One of the triumphs of mathematical physics was the forecast of Laue that crystal bodies have their atoms so distributed that Röntgen rays must be diffracted by these atoms in the same manner that closely ruled crossed lines diffract visible light. This forecast and its rapid verification, enable the two Braggs, father and son, to measure with accuracy the wave-lengths of Röntgen rays. While the waves of visible light are of the order 10^{-5} cm., those of Röntgen rays are of the order 10^{-8} cm., about one thousandth of the former. The electromagnetic theory recognizes no intrinsic difference between the great waves of wireless telegraphy, several kilometers in length (10^6 cm.), short electric waves, long heat waves, visible light (10^{-5} cm.), ultraviolet waves, and Röntgen rays (10^{-8} cm.).

The method of reflecting Röntgen rays from a rock-salt or another crystal has been applied by Moseley with marked success to the determination of the nucleus charges of the atoms of most of the elements. He bombarded the elements one after the other, by electrons as cathode rays, reflected the resulting Röntgen rays from a crystal and measured the wave-lengths of one or other of the principal (K or L, hard or soft) radiations.

In this manner he found

$$n = A(N - B)^2,$$

where n is the frequency of vibration, N the nucleus electronic charge, necessarily a whole number, and A and B are determined constants. In this manner he has found the *atomic numbers* N of all the known elements from aluminium 13 to gold 79. There appear to be but two or three elements not yet found by the chemists. These experimental results bear out well a view first propounded by van den Broek, that each element has an atomic number, an integer representing its place in the periodic table (H 1, He 2, Li 3, Be 4, Bo 5, C 6, and so forth). The atomic weight is not an exact integer, nor of such fundamental character as the atomic number. There will be further reference to this point later.

12. Rutherford has extended Moseley's method and results to the crystal reflection of the gamma rays from a radiant (Ra B), and determined the wave-lengths of many lines, in particular of the two strongest. He has bombarded lead with Ra B rays and found the wave-lengths of the radiation stimulated in the lead. He found that

Radiant	Rays	Atomic Number	Atomic Weight About
Uranium 1	α	92	238.5
Uranium X 1	β	90	234.5
Uranium X 2	β	91	234.5
Uranium 2	α	92	234.5
Ionium	α	90	230.5
Radium	α	88	226.5
Radium Em.	α	86	222.5
Radium *A*	α	84	218.5
Radium *B*	β	82	214.5
Radium *C*	α, β	83	214.5
Radium *D*	β	82	210.5
Radium *E*	β	83	210.5
Radium *F*	α	84	210.5
Lead	....	82	206.5 (207.1)

Radium B and lead gave the same spectrum, indicating that they have the same atomic number, 82. Hence he deduced the atomic numbers of all the radiants in the uranium-radium family. His results are worth repeating.

13. All of these results are in harmony with the wonderful advances in radiochemistry due to Soddy, Fajans, Von Hevesy and others. It has been found that when a radiant emits an alpha particle or helium nucleus, the chemical properties of the newly formed radiant differ from the old. A fresh element is formed, a different valency results, and the new radiant, relative to the old, is *two* columns to the *left* in the periodic table. The atomic number has decreased 2, and the atomic weight about 4. But when a radiant ejects a *beta* particle or electron, again there is a new radiant with different valency and chemical properties, but there is a move of *one* column to the *right* in the periodic table; a gain of one in the atomic number and no change in the atomic weight.

A brief example of the whole scheme applicable to all radiants is given below:

Column			
IV.	V.	VI.	At. Wts.
Ur X 1 → 90, β	Ur X 2 → 91, β	Ur 2 92, α	234.5
		Ur 1 92, α	238.5

In the case of these radiants Ur 1 ejects an α particle and gives rise to Ur X 1. The latter and Ur X 2, respectively, emit a β particle.

It should be added that the short-lived product Ur X 2 or "brevium" was discovered by this theory, after it had been formulated from the known behavior of other radiants.

It will be seen that Uranium 1 and 2 are in the same column and have the same atomic *number*, but that their atomic *weights* differ by 4. Such substances have chemical properties so identical that they are called inseparables, or non-separables, or isotopes, for they occupy the *same* place in the periodic table. Thus the old trouble of finding places in the periodic table for the thirty or forty radiant elements has suddenly vanished. They may be superposed even when their atomic *weights* differ, if their atomic *numbers* are the same. The nuclear charges of isotopes must be identical, but the distribution of electrons may be different. Other examples of inseparables are:

Lead, radium B, Radium D, all 82.

Thorium and radiothorium.

Radium and mesothorium.

If these views are distasteful to chemists let them discover some means of the separation of the known isotopes.

It must be further noted that the results of radiochemistry appear to require the presence of negative electrons in the nucleus itself. The expulsion of a β particle, or one negative electron, from the nucleus is equivalent to the gain of one positive electron, and involves a unit increase in the atomic number.

14. The last advance is the most important and far-reaching. There has been long search for the positive electron, and in vain; yet it seems likely that it has been under our eyes all the time. Since the hydrogen atom never loses more than a single electron, is it not possible, suggests Rutherford, that the nucleus of the hydrogen atom may be the positive electron?

The electro-magnetic mass of an electron is $\frac{2}{3}\frac{a}{e^2}$ where e is the charge and a the radius. If the mass of the hydrogen nucleus is wholly electro-magnetic, then its radius must be smaller than that of the electron (negative) as 1:1800, for that is the ratio of their masses, while their charges are equal and opposite. Hence we have

	Mass	Diameter
Atom	1	10^{-8} cm.
Negative electron	1/1800	10^{-13}
Positive electron	1	10^{-16}

Rutherford cautiously remarks that there is no experimental evidence against such a supposition.

Those who wish to follow the matter deeper must refer to many articles in the *Philosophical Magazine*,[3] several letters to *Nature*, Soddy's "Chemistry of the Radio-elements," part II., and Perrin's "Les Atomes." The chief writers have been Rutherford, W. H. Bragg, W. L. Bragg, G. C. Darwin, Moseley, Broek, Bohr, Russell, Fajans, Soddy, Hevesy, Nicholson and Mardsen.

Much has yet to be done, and much to be revised, but that the first great forward strides have been taken in the right direction there can be little doubt.

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STATISTICS OF CROPS

DEGREE OF ACCURACY OF THE REPORTS OF THE BUREAU OF STATISTICS OF THE UNITED STATES DEPARTMENT OF AGRICULTURE

IN the March 28, 1913, number of SCIENCE, Dr. C. G. Hopkins gives a discussion of this topic under the title of "Facts and Fiction about Crops." The Department of Agriculture is accused of "condemnable inflation of crop statistics." The writer does not believe that such a conclusion would be reached if the reports were more carefully studied.

He shows the percentage of error to be very great when the Bureau of Statistics estimates of corn in the southern states are compared with the census report. If the error is due to wilful deception, we should expect to find the