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THE PHYSICIST'S PRESENT CONCEPTION OF AN ATOM[1]

ALL scientists agree upon an atom which has a very minute positively charged nucleus surrounded in its outer regions by a number of negative electrons just sufficient to neutralize the free positive charge upon the nucleus.

We all agree that the number of these positive charges upon the nucleus varies from one, in the case of hydrogen, by unit steps up to 92 in the case of uranium, and hence that the number of negatives held in the outer regions also varies from one to 92.

We all agree that the chemical properties of all atoms, and most of the physical properties, too, mass being the chief exception, are determined simply by the number of these electrons; primarily by the number of them which are found in the outermost shell and which we call the valence electrons.

We all agree, too, that the nucleus is extraordinarily minute, so that if all the dimensions of an atom were magnified ten billion times—a magnification which would make a bird shot swell to the size of the earth and would make the diameter of the atom about a meter—the nucleus, on this huge scale of magnification, would not be more than a tenth of a millimeter in diameter—that is, not larger than a mere pin point.

We all agree, too, that in the case of uranium there are packed into that infinitesimal nucleus 238 positive and 146 negative electrons, the exact number of positives being determined simply by the atomic weight, while the number of negatives which bind the positives is the atomic weight minus the atomic number. This obviously means that both positive and negative electrons are so infinitesimally small that for practical purposes we may ignore their dimensions altogether and think of them as mere point charges.

We all agree that so far as physical science has now gone there have appeared but these two fundamental entities, namely, positive and negative electrons[2] which seem to be the building stones of the

[1] An address delivered before the sixty-seventh convention of the American Chemical Society, Washington, D. C., April 22, 1924.

[2] It is highly to be desired that this historically correct, etymologically most suitable, and authoritatively recognized nomenclature (See Rutherford's B.A. address 1923, Nernst's Physical Chemistry, last edition etc., etc.) be retained. When used without a prefix, or qualifying

universe; that these two entities are electrical charges of exactly the same magnitude, but of opposite sign, and that the *mass* or *inertia* associated with the former is 1,845 times that associated with the latter, so that practically the whole mass of the atom is concentrated in the positive electrons within its nucleus.

We all agree that when any of the electrons in the outer regions of the atom are stimulated to radiate, they do so by virtue of falling from a level of higher potential energy to one of lower, *i.e.,* from a level more remote from the nucleus to one nearer to it.

And we all agree that the frequency of the emitted radiations is proportional to the energy loss in the process of changing from the one level to the other. Indeed, one of the most stimulating advances which physicists have made in the past five years consists in the complete demonstration of this Planck-Einstein-Bohr law of radiation. Very recent experiments go even so far as to indicate that this law holds not only for the radiations emitted by the changes in energy levels of the electrons *outside* the nucleus, but also for the radiations which originate in the nucleus itself—the so-called gamma-rays which accompany changes within the nuclei of radioactive atoms.

These results upon which we all agree are proof enough of the amazing advances which have taken place, mostly within the past ten years, in our ability to peer inside the atom and to see what kind of entities exist there and what they are doing when they are in the act of radiating.

The only place where we have differences of opinion, or better, in which there are uncertainties, is in the matter of how the electrons spend their leisure time—the portions of their lives in which they are not radiating.

The chemist has in general been content with what I will call the "loafer" electron theory. He has imagined these electrons sitting around on dry goods boxes at every corner ready to shake hands with, or hold on to, similar electrons in other atoms. The physicist, on the other hand, has preferred to think of them as leading more active lives, playing ring-around-the-rosy, crack-the-whip and other interesting games. In other words, he has pictured them as rotating with enormous speeds *in orbits,* and as occasionally flying out of these orbits for one reason or another.

adjective, the word electron may signify both the generic thing, the unit electrical charge (this it does, in fact, signify both historically and derivatively) and at the same time the negative member of the species, in precisely the way in which the word man is used without a prefix to designate both the genus homo and also the male of the species. There is no gain in convenience by the use of the word proton and a distinct loss logically, etymologically and historically.

Now the arguments for the "loafer electron" theory, as I have called it, are two in number. The first is that such activity as the physicist postulates would soon wear away all the energy possessed by the electrons—that is, they would tire themselves out and quit their play.

There is no answer to this argument. They would indeed tire themselves out, provided the classical *electro-magnetic laws are universally applicable*—even in the hearts of atoms. And the physicist's only answer to this argument is, "God did not make electrons that way. Why assume that the electromagnetic laws are universally valid when this is the first chance we have had to test them out in the region of the infinitely small?"

The second argument which has been advanced for the "loafer electron" theory is the existence of localized valences in chemistry. Now, that these localized valences exist is admitted on all hands; but it is simply due to a misunderstanding that this argument was ever used against the orbit theory. *For no physicist—and I wish to emphasize this fact—has ever advanced the theory that the electrons all rotate in coplanar orbits.* Localized valences are just as compatible with the orbit theory when the orbits are properly distributed in space as with the stationary electron conception. All this I pointed out in 1916,[3] trying thereby to clear the misconception which existed in the minds of chemists as to the way in which physicists were thinking.

Let me pass now to the arguments in favor of the orbit theory. They are all of them definite *quantitative* arguments in which purely theoretical considerations lead to exact numerical predictions which can be subjected to the test of experiment.

The first was the exact prediction with the aid of orbit equations of the so-called Rydberg spectroscopic constant which is in agreement, with an accuracy of one part in five hundred, with the directly measured value.

The second quantitative argument comes from the prediction of a difference between the positions in two spectral lines, one due to helium, the other to hydrogen, which two lines should theoretically be one and the same line, if it were not for the fact that the helium nucleus is four times as massive as the hydrogen nucleus.

To make clear the difference which this causes let me ask you to reflect that when an electron revolves around the nucleus of an atom of hydrogen, the real thing that happens is that the two bodies revolve about their common center of gravity, but, since the nucleus is 2,000 times heavier than the electron, this center is exceedingly close to the hydrogen nucleus.

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

If now the hydrogen nucleus is replaced by the nucleus of the helium atom, which is four times as heavy as that of hydrogen, the common center of gravity is still closer to the nucleus so that the helium nucleus describes a much smaller circle than does the hydrogen nucleus. This situation is responsible for a certain slight but accurately predictable difference in the energies of the two orbits which should cause the lines produced by electron jumps to these two different orbits to be slightly displaced from one another. This displacement is actually found between the corresponding hydrogen and helium lines, and the ratio of the mass of the electron to the mass of the hydrogen atom computed from this displacement agrees with other determinations of this ratio to within a small fraction of a per cent.

The third amazing quantitative success of the orbit theory came when Sommerfeld showed that the Bohr orbit-theory ought to demand two different hydrogen orbits corresponding to the second quantum state, one a circle and one an ellipse. And by applying the relativity theory to the change in mass of the electron with its change in speed, as it moves through the different portions of its orbit, he showed that these two orbits should have slightly different energies, and consequently that both the hydrogen and the helium lines should be doublets.

Now not only is this found to be the fact, but *the measured separation of these two doublet lines agrees precisely with the predicted value,* so that this again constitutes an extraordinary bit of quantitative evidence for the validity of the orbit conceptions underlying the computation.

The fourth quantitative argument was introduced by Epstein when he applied his amazing grasp of orbit theory to the exceedingly difficult problem of computing the perturbations in electron orbits and hence the change in energy of each due to exciting hydrogen and helium atoms to radiate in an electrostatic field. He thus predicted the whole complex character of what we call the Stark effect, showing just how many new lines were to be expected and where each one should fall, and then the spectroscope yielded, in practically every detail, precisely the result which the Epstein theory had foretold.

The fifth quantitative success of the orbit theory is one which Mr. I. S. Bowen and myself at the California Institute have just brought to light. Through creating what we call "hot sparks" in extreme vacuum, we have succeeded in stripping in succession, one, two, three, four, five and six of the valence, or outer, electrons from the atoms studied. In going from lithium through beryllium, boron and carbon to nitrogen, we have thus been able to play with stripped atoms of all these substances. Now the stripped atoms constitute structures which are all exactly alike, save that the fields in which the single electron which is left is describing its orbit increase in the ratios one, two, three, four, five, as we go from stripped lithium to stripped nitrogen. *Now we have applied the relativity doublet formula which, as indicated above, Sommerfeld had developed for the simple nucleus-electron system found in hydrogen and ionized helium, and have found that it not only predicts everywhere the observed doublet separation of the spectra produced by all these stripped atoms, but that it enables us to compute the effect which the two electrons close to the nucleus of all these atoms have in screening the outer rotating electron from this nucleus.*

At a sufficient distance from the nucleus these two electrons ought to neutralize exactly two of the free positive charges on the nucleus, *provided, and only provided, the forces emanating from these electrons fall off with the inverse square of the distance.* Our relativity doublet formula, with this assumption and without the introduction of any arbitrary constants whatsoever, enabled us to predict what the screening effect due to those two electrons ought to be. *And now our experiments on doublet-separations reveal that* that screening is exactly two, which checks with what we knew beforehand, from radioactive and chemical data, that it must be. In other words, we have another method, based definitely upon the theory of the change of the mass of the electron with speed in the different portions of its orbit, which enables us with certainty to look inside the atom and find how many electrons are in the inmost shell, and the answer comes out two.

Again, when we examine the spectrum due to the stripped atoms of the group of atoms from sodium to sulfur—one electron having been knocked off from sodium, two from magnesium, three from aluminium, four from silicon, five from phosphorus, and six from sulfur—we should find in every case that the number of screening electrons in the two inmost shells, when tested for sufficiently remote orbits, comes out two plus eight, *i.e.,* ten. *And it does come out in every case precisely* as predicted. *This constitutes unambiguous proof that the electrons themselves do possess Coulomb fields (fields falling off with the inverse square of the distance),* a result entirely incompatible with the loafer-electron theory. The physicist has thus piled Ossa on Pelion in his *quantitative* proof of the existence of these electron orbits.

These new results are, however, incompatible with the precise shapes of orbits with which the physicists have been working in the field of optics during the last five years. They necessitate either the abandonment of the relativity cause for the separation of our measured spectroscopic-doublets or else they require us to cease to play with a nucleus about which the

electron orbits are largely symmetrical. In other words, if we retain the relativity explanation of the spectroscopic-doublet formula, we are obliged to suppose that two orbits which have the same shape but different orientations with respect to the nucleus may exhibit widely different screening constants—which is only another way of saying that these orbits may possess widely different energies.

To this extent, then, I am able to help out the chemist in his attack upon the electronic orbits of the physicists. I am able to enable him to say with a good deal of certainty that these orbits can not be of precisely the type which we physicists have been playing with so assiduously for the past five years. If we retain the explanation which has heretofore been given to the relativity doublet formula, an explanation which requires entirely different shapes for the two orbits corresponding to these doublets, then we must begin to work with an atom which is very much less symmetrical with respect to the differently oriented orbits than we have hitherto been imagining.

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REMARKS ON THE SCIENTIFIC ATTITUDE[1]

IF all our farmers were acquainted with the discoveries made by agricultural experts and were willing to adopt methods recommended by these experts the agriculture of this country and of the world would be far in advance of what it is. If all people were acquainted with the laws of health and hygiene and with the knowledge of these subjects possessed by our best investigators in preventive medicine and were willing to follow expert advice the average life would be greatly prolonged. Social progress is made possible through the activities of the few who are far in advance of the masses. The masses, at least in the more civilized countries, accept the material benefits conferred through the activities of the few. There is little hesitancy in adopting the telephone, the radio and the automobile. But in the realm of spiritual things, society lags. There is mental inertia, just as there is physical inertia. How reluctant have been the masses to accept the theory of evolution! The reason for this difference between the masses and the advanced thinkers must be sought in the mental attitude. Let us, then, examine the mental qualities of the scientist, who is an advanced thinker in physical progress, with the assurance that much the same qualities must be possessed by leaders of thought in all branches of social progress.

The scientist searches for truth. He seeks to establish facts. He combines facts, works out their relation, modifies existing theories or systems to accord with increased knowledge. The ideal mental condition of the scientist is known as the scientific attitude. It is open-mindedness in the sense that new ideas are received on their merits and are not discounted in advance by prejudice and preconceived notions.

All here in my audience know what is meant by this term, the scientific attitude. Probably none of us possess this attitude in its ideal completeness. It is a state of perfection toward which we strive but probably never quite reach. The reasons for this imperfect attainment lie in our phylogenetic history.

Man as a social animal is controlled very profoundly by inherited tendencies—instinct it is called among the lower animals. Society also is controlled by inherited tendencies, that is, tradition and custom. In accord with these influences man has tended to be conservative and society has tended to be static. As a unit of society man is and always has been influenced by the mental attitude of the mass, which is that what is, is right. The constructive leader in progress is an individual who is mentally what the horticulturist would call a sport, he must diverge sharply from the average. In so far as he wishes to develop or modify social, political, economic or religious customs or beliefs he comes in contact with the static condition of the masses who think and act in accord with inherited tendencies.

Again, what is the usual ontogenetic history of the individual? From the moment that a child is born it is subjected to the will of others. With few exceptions it is taught to think as do its parents, to obey authority. In school the same kind of influence continues. A good boy is one who obeys his teacher, one who respects authority. In society the youth is taught to look up to his elders, to his superiors, to his boss. Parental discipline, school discipline, organization discipline, on the average and in the main tend to stifle independent thought. In this I am not intending to decry parental authority or school discipline, but to point out that the usual environment in which we grow up does not tend to develop the scientific attitude.

In attaining a condition of open-mindedness we are overcoming our inherited tendencies and the effects of our childhood and our present-day environment, and very few of us are able to do this completely.

There is conservatism in science as in other branches of human knowledge. An accepted theory in chemistry, geology or biology becomes in a sense a tradition, and facts tending to disprove such a theory are not infrequently viewed with a hostile eye by its supporters.

[1] From the address of the retiring president of the Biological Society of Washington. There were three parts: (a) Remarks on the scientific attitude; (b) botanizing in Ecuador; (c) how to help the Biological Society.