RECENT PROGRESS IN THE STUDY OF THE STRUCTURE OF THE NUCLEUS

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Sir Ernest Rutherford first demonstrated by means of the bombardment of atoms by α particles that nearly all of the atomic mass is concentrated in the nucleus. The work of Lewis, Langmuir, Kossel, Bohr, and many others has demonstrated that *chemical* union is effected by means of extra-nuclear electrons in outer or valence orbits. But it should not for this reason be concluded that the chemist has no concern with the nucleus, that on account of its minuteness or inaccessibility that it has a structure of interest only to physicists and mathematicians. It is the nucleus which determines the atomic number and hence the ultimate identity of each atom, it determines the existence of isotopes, and all of the radioactive properties. Finally whatever chances there be of transmuting or of disrupting the atom must depend on our ability to reach the nucleus and to bring about changes in its structure.

Owing to the *infinitessimal* size of the nucleus which even for the heaviest atoms has a radius of the order $3 - 6 \times 10^{-12}$ *cm.* or a volume of the order 10^{-35} *cm.*^{3} and to the large number of structural units that must be contained in it, which for the uranium nucleus is *238* protons and *146* nuclear electrons, it was at first difficult to conceive of its having anything but a closely packed structure. One of the early popular conceptions was that of bricks representing the protons and helium nuclei held together by electrons interspaced like mortar. Indeed a structure suggested by Rutherford (1) for the close packing of helium nuclei in layers with one electron at the center of each cube formed by 8 adjacent helium nuclei gave the correct atomic number for various elements from titanium (22) to platinum (78).

We have, however, numerous indications that a closely packed static structure is not capable of interpreting even the data that we already possess regarding the properties of the nucleus. The fact that rays and high velocity particles are emitted from the nucleus indicates that it is partly at least a dynamic, not a static, system. Just as the multiplicity of the spectroscopic lines had predicted long before we had any definite ideas about electronic structure of the atom that it must have a fairly complicated structure which we now know as the orbital electronic structure, so do the α, β, and γ radiations from the nucleus predict a complex structure. And just as the application of quantum principles to orbital electrons has elucidated the structure and the mechanism of their behavior, so also it appears that quantum principles will be the surest guide in solving the structure of the nucleus, and in interpreting its radioactive instability.

Just as in spectroscopy, the multiplicity of lines was early an embarrassment but later furnished the essential proof of the quantum theory of atomic structure, so we have an accumulation of physical and chemical data awaiting interpretation through a complete theory of the nucleus. On the one hand we have the occurrence or lack of isotopes for each atomic species. Moreover, the occurrence of isobares proves that fundamental differences exist which can only be attributed to structure. The work of Aston has furnished an abundance of data, the precision of which he has recently raised to a degree capable of standing very severe interpretative tests.

Among the ordinary atoms we have then a structure to be interpreted by the distribution of protons and electrons in the nucleus to make up any given atom or isotopes of it. In the radioactive atoms we have also a wealth of experimental evidence. First we know that it is only the heaviest atoms, with the extreme exceptions of potassium and rubidium, which possess radioactive properties. We know also with considerable accuracy the life periods of the various radioactive elements, the type and energy of the radiations emitted by each one and the relation of life period to energy, such as the Geiger-Nuttall relation for range of α particles to the life period of these emitters. Furthermore, we know that the only atomic particles spontaneously emitted from the nucleus of the radioactive atoms are α particles (helium nuclei) and that the only particles which have hitherto been ejected from the light atoms by α ray bombardment are protons. (But since there is such a wide difference in mass between the radioactive elements and the light ones which can be disrupted by α particles, no present conclusion about the general predominance of protons or helium nuclei in certain regions of all nuclei would be justified.)

The idea of quantized states in the nucleus arises from the marked equality of energy possessed by α particles of the same variety, that is by those from the same element. The α particles of polonium have been shown by Irene Curie to have remarkably uniform initial velocity while the same has been demonstrated by Briggs for the much swifter α particles from Ra C′. If the particles were in each case before their emission moving in or about the nucleus with equally uniform velocity, then evidently we have indications of definite and probably of quantized orbits. γ rays from a given atom also exhibit a high degree of homogeneity of wave length. But β particles, on the other hand, are emitted from the same element with velocities varying continuously through a wide range.

It was previously thought that this variation in the speed of β particles could be explained by assuming their emission at speeds corresponding to voltages all the way from 40,000 to 1,050,000 volts to be due to partial expenditure of the initial energy of the swifter β rays before they emerge from the atom. Ellis and Wooster (2) have, however, recently measured the heat evolved in the disintegration of RaE and found it equal to about 350,000 electron-volts, which corresponds to the *average* energy of β ray emission not to the maximum 1,000,000 volts. Therefore they conclude by analogy that the initial β rays from all atoms are truly heterogeneous and that they originate in a part of the atom where they are in random rather than in quantized motion.

Rutherford (3) has recently brought the knowledge of α ray emission to bear on a theory of nuclear structure. His result is that the α particle before emission is a neutral particle revolving in quantized orbits about the nucleus. Its electrons are not in the normal helium orbit but held very close to the nucleus of the satellite. The force holding the neutral atom in its orbit is the attraction due to the distortion or polarization by the central nuclear field. When the α particle is expelled it leaves its two electrons behind, carrying away a double charge as is known from the atomic number of the resulting atom which is lower by two units than that of the parent atom. The two electrons left behind move in closer to the central nucleus from which they are probably emitted later as β particles. Frl. Meitner earlier suggested the neutral α satellite on account of the frequent succession of one α ray by two β ray emissions.

Rutherford (2) developed an equation for the quantized emission of α particles and assigned by trial a quantum number (using half quantum numbers also) to each radioactive element. He evaluated the three universal constants involved in the equation from a standard atomic number 84. The calculated energies of the different sets of α particles agree with observation within a fraction of 1 per cent. The quantum numbers fall in the range 14 to 30, corresponding to distances from the center between 1.9×10^{-12} and 4.5×10^{-12} cm. Probably satellites can exist for atomic numbers as low as 15 but become frequent for atomic numbers about 30, and since we can associate isotopes with the possibility of additional neutral satellites which do not alter the atomic numbers, it is interesting that isotopes become numerous for atomic numbers about 29. The α ray evidence applies only to satellites of mass 4. Unfortunately as Rutherford points out there are no similar data from which estimation may be made in regard to the possibility of adding satellites of mass 2, which are known to play as important rôle in the structure of isotopes and which Harkins has found to be involved in the structure of all atoms.

From the foregoing considerations we can draw the following present picture of the nucleus: a very small compact central portion with a net positive charge, surrounded by a region of electrons in random motion, and finally outer neutral helium satellites revolving in quantized orbits from which they may be ejected from the heavier atoms as α particles of definite energy and speed.

Although the scheme of Rutherford is based wholly on electrostatic forces, it has also been suggested that the nucleus is held together by magnetic forces or a combination of electric and magnetic forces. D. Enskog (4) last year put forth a theory taking into account both forces, by means of which he calculates very accurately not only the energies of the α particles but of the β particles as well.

Many attempts have been made to disrupt or change the nucleus. The only success has been had with α particles, which have been shown to change the nucleus by knocking out a proton and by adding the helium nucleus to the nucleus of the bombarded atom. These results will doubtless contribute to the ultimate solution of atomic structure.

Attempts using less energetic agents have not been successful. Soddy first pointed out that to lower the atomic number of an atom by *one*, it would only be necessary to shoot an electron into the nucleus thus neutralizing one unit of positive charge. Various claims of transmutation have not been substantiated. It is evident that the means that have been employed to change the nucleus either by means of high speed electrons or of high temperature have not been sufficiently energetic. The goal appears by no means an impossible one, and from the reports of high voltage electrons soon to be employed there is a prospect of its attainment in the not distant future.

REFERENCES

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