

## THE DILEMMA OF THE HELIUM ATOM.

BY JOHN H. VAN VLECK.

THE study of helium, the simplest atom except hydrogen, should be a key to a generalized Bohr theory of atomic structure. However, no satisfactory model of normal helium has yet been devised, for the models of Bohr, Langmuir, Franck and Reiche, and Landé all give the wrong ionization potentials if the non-radiating orbits are determined by the Sommerfeld quantum conditions.

It therefore seemed desirable to compute the ionization potential of a model suggested by E. C. Kemble,<sup>1</sup> in which the two electrons, I. and II., move in three dimensions with an axial symmetry, so as to have the cylindrical co-ordinates

$$\text{I. } r, z, \varphi, \quad \text{II. } r, z, \varphi + \pi.$$

After the dynamical solution was obtained as a power series in a parameter, the constants of integration were determined so as to give the action integral the value demanded by the Sommerfeld quantum conditions, assuming one of the coördinates to be used was the cyclic coördinate  $\varphi$  (giving the system a total angular momentum  $\hbar/2\pi$ ), while the other coördinates were unrestricted, provided they have the period of  $r$  and  $z$ . The computed ionization potential (74.9 volts) does not agree with the experimental value (79.3 volts), the discrepancy being of the same order as in the Bohr model, which gives an ionizing potential of 82.7 volts.

Since all the simple, symmetrical models of helium, such as are required by its extreme chemical stability, seem to yield impossible ionization potentials, some radical modification of the conventional quantum theory of atomic structure appears necessary. Two such possible modifications are:

1. Reformulation of the quantum conditions. Two very interesting such suggestions have been made by Langmuir.<sup>2</sup> One of these, that the maximum angular momentum of a single electron should equal  $\hbar/2\pi$ , leads to a correct ionizing potential for his semi-circular dynamical model of helium, but appears contradictory to the fact that in the hydrogen atom and in the theory of rotational specific heats the total angular momentum of the entire system, rather than of a single electron, is  $\hbar/2\pi$ . Also one would expect this modified quantum condition to be equally applicable to Langmuir's semi-circular hydrogen molecule, almost identical with his helium atom, but computations by the writer indicate that in this case the maximum angular momentum of an electron is not  $\hbar/2\pi$ , but  $.956(\hbar/2\pi)$ .

Langmuir's other suggestion, that of a static atom in which the electron is subjected, in addition to the Coulomb force, to a force which it would experience if it were an electrical doublet of strength  $1/2em(n\hbar/2\pi)^2$  does not appear to be consistent with the Rutherford scattering experiments, or with the dynamical orbits found in band spectrum theory. Also complicated modifications to the

<sup>1</sup> Phil. Mag., Vol. XLII., p. 132 (July, 1921).

<sup>2</sup> PHYSICAL REVIEW, Vol. XVII., p. 349; Vol. XVIII., p. 104.

force would be necessary to account for the Sommerfeld fine-structure or even the shift between the lines of the Balmer hydrogen series and those of the Pickering helium series.

2. Modification of the law of force between negative electrons. The experimental evidence of Rutherford establishes the validity of the inverse square law only between negative electrons and positive nuclei, while Compton concludes that the spiral tracks of beta particles indicate that the field of an electron does not have a spherical symmetry.<sup>1</sup>

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#### MOMENT OF MOMENTUM OF MAGNETIC ELECTRONS.

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ACCORDING to the usual electron theory ferromagnetism is due to the circulation of electrons along paths of considerable length and must therefore be accompanied by mechanical angular momentum equal per unit volume to

$$\Gamma = k \frac{m}{e} I, \quad (1)$$

where  $I$  = intensity of magnetization,  $m/e$  = ratio of electronic mass and charge in electromagnetic units and  $k$  has the value 2. This equation is confirmed as to sign by E. Beck,<sup>2</sup> but he finds  $k = 1$  for both iron and nickel. Barnett's results on magnetization by rotation likewise agree as to sign but indicate for  $k$  a value decidedly smaller than 2.

A smaller value of  $k$  is readily obtained in the theory if we abandon the circulation of electrons as wholes and ascribe ferromagnetism to a rotation of the electron about its own axis.

For instance, suppose a Lorentz electron (uniformly charged sphere) to be set in slow uniform rotation. The resulting external magnetic field is the same as that of a doublet at the center of moment  $M = \frac{1}{3}a^2e\omega$ , where  $a$  = electronic radius and  $\omega$  = angular speed; hence the density of electromagnetic momentum at any point outside is  $g = EH_\theta/4\pi c = eM \sin \theta/4\pi r^5$ , where  $r$  = distance from center and  $\theta$  = angle from axis of rotation. Multiplying by  $r \sin \theta$  and integrating throughout the space exterior to the electron one finds as the total angular momentum about the axis of rotation  $\Gamma = 2eM/3a$ . But the mass is, in our units,  $2e^2/3a$ . Hence  $\Gamma = mM/e$  and  $k = 1$ .

For the ring electron, according to D. L. Webster's theory  $k = 2$ . But this result is bound up with the essentially speculative foundation of his theory and it seems certain that electrons of the ring type can be made to give other values to  $k$  than 2.

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<sup>1</sup> Phil. Mag., Vol. XLI., p. 279, Feb., 1921.

<sup>2</sup> Ann. der Phys., 60, p. 109, 1919.