Letters to the Editor.

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The Motion of the Spinning Electron.

IN a letter published in NATURE of February 20, p. 264, Messrs. Uhlenbeck and Goudsmit have shown how great difficulties which atomic theory had met in the attempt to explain spectral structure and Zeeman effects, can be avoided by using the idea of the spinning electron. Although their theory is in complete qualitative agreement with observation, it involved an apparent quantitative discrepancy. The value of the precession of the spin axis in an external magnetic field required to account for Zeeman effects seemed to lead to doublet separations twice those which are observed. This discrepancy, however, disappears when the kinematical problem concerned is examined more closely from the point of view of the theory of relativity.

As usual, letters in heavy type will denote vectors. The anomalous Zeeman effect seems to require that the spin axis of the electron precesses about an external magnetic field **H** with angular velocity

$$\frac{e}{mc}\mathbf{H}, \quad . \quad . \quad . \quad . \quad . \quad (A)$$

where c is the velocity of light and $-e$, m are the electronic charge and mass. Suppose such a spinning electron moves with velocity **v** through electric field **E**. At first sight it would seem that, being subject to magnetic field

$$\mathbf{H} = \frac{1}{c}[\mathbf{E} \times \mathbf{v}],$$

the spin axis will precess about the instantaneous normal to the orbital plane with angular velocity

$$\frac{e}{mc^2}[\mathbf{E} \times \mathbf{v}]. \quad . \quad . \quad . \quad . \quad . \quad (B)$$

As the mean value of this expression is just twice the angular velocity with which the perihelion of the orbit rotates on account of the variation of mass of the electron, this would lead to twice the observed doublet separation.

There is, however, an error in the above reasoning; the precession of the spin axis so calculated is its precession in a system of co-ordinates (2) in which the centre of the electron is momentarily at rest. System (2) is obtained from system (1), in which the electron is moving and the nucleus at rest, by a Lorentz transformation with velocity **v**. If the acceleration of the electron is **f**, and system (3) is obtained from system (1) by a Lorentz transformation with velocity $\mathbf{v} + \mathbf{f}dt$, then the precession which an observer at rest with respect to the nucleus would observe, and which should be summed to give the secular precession, is that precession which would turn the direction of the spin axis at time t in (2) into its direction at time $t + dt$ in (3) if both directions were regarded as directions in (1). To a first approximation system (3) is obtained from system (2) by a Lorentz transformation with velocity $\mathbf{f}dt$ together with a rotation $(1/2c^2)[\mathbf{v} \times \mathbf{f}]dt$. Thus the observed rate of precession will be, to a first approximation,

$$\frac{e}{mc^2}[\mathbf{E} \times \mathbf{v}] - \frac{1}{2c^2}[\mathbf{v} \times \mathbf{f}].$$

To a first approximation

$$\mathbf{f} = -\frac{e}{m}\mathbf{E},$$

so the rate of precession is

$$\frac{e}{2mc^2}[\mathbf{E} \times \mathbf{v}], \quad . \quad . \quad . \quad . \quad . \quad (C)$$

just half the expression (B).

The interpretation of the fine structure of the hydrogen lines proposed by Messrs. Uhlenbeck and Goudsmit now no longer involves any discrepancy. In fact, as Dr. Pauli and Dr. Heisenberg have kindly communicated in letters to Prof. Bohr, it seems possible to treat the doublet separation as well as the anomalous Zeeman effect rigorously on the basis of the new quantum mechanics. The result seems to be full agreement with experiment when the calculation is based on formulæ (A) and (C).

I hope in a later paper to develop the above kinematical argument in greater detail.

In conclusion, I wish to express my appreciation of the encouragement and help of Prof. Bohr and Dr. Kramers.

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Copenhagen, February 20.

Genes and Linkage Groups in Genetics.

Now that Prof. MacBride has delivered himself of his final reply to Prof. Huxley on the subject of linkage and genes, I should like to offer a few comments on a point from which further confusion might easily arise in the future. It concerns the use of the word 'linkage.' This term was originally proposed by Prof. Morgan, and the first evidence of its appearance in print that I have been able to find is in the title of a paper published in the *Biological Bulletin* for August 1912 by T. H. Morgan and Clara S. Lynch on "The linkage of two factors in Drosophila that are not sex-linked." In the previous year Mr. Bateson and I had shown that what we had hitherto termed 'coupling' and 'repulsion' were in reality phases of the same phenomenon, and we subsequently adopted Morgan's term as a convenient one for the phenomenon as a whole. In this matter the United States and Europe saw eye to eye, and henceforward the term 'linkage' in this definite and precise sense has been in use by geneticists all the world over.

Before a case of association between characters in the hereditary process can be assigned to the category of linkage, it must be shown (1) that each character, followed separately, shows normal segregation in the Mendelian sense, and (2) that the relative distribution of the characters in a given generation differs in orderly fashion according as their gametic representatives entered the parental zygote together or apart. Only when these conditions are observed are we entitled to speak of a case as exhibiting the phenomenon of linkage.

Here it seems to me that Prof. MacBride becomes definitely misleading. In his letter of March 6, p. 340, he cites as a case of linkage the effects produced in the developing vertebrate embryo by alterations in amniotic pressure. No doubt such alterations produce simultaneous and definite effects in various organs. Such a statement, coming from such an authority on matters embryological, I do not dream of questioning. But when Prof. MacBride cites this as an example of linkage, I assert that he has no right to do so until he, or some one else, has proved that it fulfils the conditions necessary to bring it under the heading of this phenomenon. Until this has been done, the case, interesting as it may be in other