LETTERS TO THE EDITOR

Prompt publication of brief reports of important discoveries in physics may be secured by addressing them to this department. Closing dates for this department are, for the first issue of the month, the twenty-eighth of the preceding month; for the second issue, the thirteenth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

On the Theory of Electrons and Protons

In a recent paper,[1] Dirac has suggested that the reason why the transitions of an electron to states of negative energy, which are predicted by his theory of the electron, do not in fact occur is that nearly all of the states of negative energy are already occupied. Dirac has further shown that the unoccupied states of negative energy have many of the properties of protons; that, for instance, they may be represented by wave functions which would be taken to correspond to a particle of positive charge and positive mass. He has further shown that the mass associated with these gaps is not necessarily the same as that of the electron, and he has suggested the assumption that the gaps are protons. In order to account for the fact that the divergence of the electric field is not, in spite of the infinite electron density, everywhere infinite, Dirac further assumes that only the departures from the normal state in which all negative states are filled are to be counted in computing the charge density for Maxwell's fourth equation

$$\operatorname{div} E = -4\pi\rho. \qquad (1)$$

Finally, Dirac is able to account for the validity of the Thomson formula for the scattering of soft light by a free electron, in spite of the fact that the derivation of this formula on his theory of the electron—a derivation which makes explicit use of the transitions to states of negative energy which are now forbidden, is invalid. According to Dirac, the scattering takes place by a double electron jump, in which a negative[2] electron jumps up to some state of positive energy, and the original positive electron falls down into the gap left.

There are several grave difficulties which arise when one tries to maintain the suggestion that the protons are the gaps of negative energy, and that there are no distinctive particles of positive charge. In the first place, we can easily see that Dirac's theory requires an infinite density of positive electricity; and since we should expect the de Broglie waves of this charge to be quantized, we should expect some corpuscular properties for the positive charges. The reason why the theory requires an infinite positive charge is this: If the explanation of the scattering of an electron is to be tenable, a negative electron must interact with the electromagnetic field in the way predicted by Dirac's theory of the electron; for otherwise the scheme proposed would not give the Thomson formula. But this means that there must be a term involving the current and charge vector of the negative electrons in the total energy momentum tensor for matter and radiation. Thus by (1), the divergence of the electric field will be everywhere infinite unless there is an infinite density of positive electricity to compensate the negative electrons.

A further difficulty appears when we try to compute the scattering of soft light by a proton. This difficulty is not unconnected with the difference in mass between the electron and proton, and makes it seem improbable that this difference can be explained on the basis suggested by Dirac. For the scattering process must in this case be regarded as a double jump of a single electron, in which a negative electron jumps to some state of positive energy, and then falls back into the hole that is the original proton. Now it is easy to see that the probability of this

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[1] P. Dirac, Roy. Soc. Proc. **A126**, 360 (1930).

[2] By a negative electron we mean an electron of negative energy.

scattering is determined by precisely the same matrix components as those which give the electron scattering, and that the present theory gives equal scattering coefficients for electron and proton. Of course, the interaction between electrons is omitted in this computation; but the difficulty is this, that such interaction would affect electron scattering and proton scattering in precisely the same way; whereas the Thomson formula requires the latter to be smaller by a factor proportional to the square of the ratio of the masses.

Finally, there is a numerical discrepancy to be noted. According to Dirac's suggestions, the filling of the proton gaps in the distribution of negative electrons should correspond to the annihilation of an electron and a proton, and should thus, under all normal conditions, be a very rare occurrence. Now if we consider for definiteness a free electron in an enclosure in which there are n_p free protons per unit volume, we may readily compute the rate at which the electron should, by the Dirac radiation theory, fall into one of the corresponding gaps. The conservation laws require that at least two quanta be emitted in this process; and it is sufficient to consider jumps in which no more than two quanta are emitted. The details of the calculation will be published elsewhere; if we neglect the interaction of the electron with the negative electrons we obtain for the mean life time of the electron:

$$T = Gm^2c^3e^{-4}/n_p \tag{2}$$

where G is a numerical constant of the order of unity, e the charge, and m the mass of the electron. Now again it is difficult to see what large errors could be involved in the computation, since the matrix components which give (2) are of precisely the same type as those which give correctly the Thomson formula and the optical transition probabilities of the electron; and (2) gives a mean life time for ordinary matter of the order of 10^{-10} seconds.

Thus we should hardly expect any states of negative energy to remain empty. If we return to the assumption of two independent elementary particles, of opposite charge and dissimilar mass, we can resolve all the difficulties raised in this note, and retain the hypothesis that the reason why no transitions to states of negative energy occur, either for electrons or protons, is that all such states are filled. In this way, we may accept Dirac's reconciliation of the absence of these transitions with the validity of the scattering formulae.

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The Collision Diameter of the Hydrogen Atom

Harteck measured the viscosity of monatomic hydrogen and calculated the collision radius to be $r_H = 1.3 \times 10^{-8}$ cm (r_0 of the first Bohr orbit is 0.53×10^{-8} cm). We have measured the decrease of intensity of a fine beam of monatomic hydrogen in passing through 3.0 cm of mercury vapor at 0.000185 mm Hg and find the decrease of intensity to be 23 percent. If the collisions are supposed to be between elastic spheres the sum of their radii is 6.2×10^{-8} or assuming $r_{Hg} = 1.8 \times 10^{-8}$, the radius of hydrogen atom is 4.4×10^{-8}. This is larger than would be assumed even on wave mechanics unless there is very considerable resonance interaction between mercury and hydrogen.

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Excited Radicals in Chemical Compounds

The letter of Mr. D. H. Andrews in your number of December 15th makes the important point it is possible to assign definite frequencies to vibrating groups in the molecule, and that these frequencies are constant, to a first approximation, from molecule to molecule e.g. the value of the vibration frequency of C–H in any molecule will be of the order of 3000 cm^{-1}, altering only slightly with change of environment. Although some of Mr. Andrews' values are open to question, there is a weight of evidence, both from the Raman effect and from infra-red spectra, for the essential correctness of his statement;