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 twentieth of the preceding month; for the second issue, the fifth of the month. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents.

Negative Protons and Nuclear Structure

In connection with the discovery of positive electrons, predicted by Dirac's theory, it is interesting to discuss the possibility of the existence of negative protons.

It was pointed out by Bohr[1] that the properties of a proton must be rather different from those of an electron because the protonic-radius (obtained from the collision experiments) is not small compared with h/Mc which is the condition of applicability of Dirac's theory to a particle.

It follows from this that the magnetic moment of a proton need not necessarily be smaller than that of an electron in the ratio of their masses (in fact Stern has found that protonic momenta is 2.5 times larger than was expected) and also that there need be no annihilation when positive and negative protons are brought together. Therefore we accept that a negative and a positive proton are symmetrical with respect to a neutron and the transformation of a negative proton into a neutron (or the reverse process) may take place with emission of an electron (negative or positive).

It appears also that the existence of negative protons is not entirely without experimental support. It is shown by Williams in an accompanying note that the observed ionization by the high energy particles of cosmic rays indicates a protonic mass for these particles, in which case those of them which are observed to have a magnetic deflection corresponding to a negative charge must be interpreted as negative protons.

In this note we shall discuss the consequences which the introduction of negative protons would have for the theory of nuclear structure. The first question which arises is that of the interaction-forces between negative protons and the other particles in the nucleus (neutrons and positive protons). According to Heisenberg[2] one must accept rather strong exchange-forces between a neutron and a proton and much smaller exchange-forces between two particles of the same kind such as two neutrons or two positive protons. On the basis of symmetry between the negative and positive protons we must expect that the interaction between a negative proton and neutrons as well as between two negative protons is just the same as in the case of positive protons. The interaction between a negative and a positive proton one is more problematic. It seems reasonable, however, to accept here rather strong exchange-forces of the same order of magnitude as those between a proton and a neutron, because in both cases the exchange takes place between two different particles. The question whether these exchange-forces are attractive or repulsive can be settled if we turn our attention to the general conditions of nuclear stability.

In Heisenberg's model (built up from neutrons and positive protons) the relative numbers of particles which correspond to the most stable state (maximum binding-energy) is governed by two opposing conditions: (1) the binding-energy due to the exchange-forces between neutrons and protons is a maximum when they are present in equal numbers: $N_n = N_p^+ = N/2$; (2) the negative binding-energy due to the Coulombian repulsion between protons is a minimum when there are no protons present: $N_n = N$; $N_p^+ = 0$. As the optimum-state obtained from these two conditions we shall have $N_n > N_p^+$, the ratio N_n/N_p^+ increasing with atomic number. If we now introduce negative protons and suppose that the exchange-forces between protons of opposite charge are attractive (or even zero in which case we still have the attractive Coulombian forces) it is easy to see that the maximum binding-energy will correspond to $N_n = \frac{1}{2}N$; $N_p^+ = N_p^- = N/4$ that is to a zero total charge. As that is not the case for real nuclei we must accept that *the exchange-forces between negative and positive protons have a repulsive character* and are strong enough to prevent the formation of a great number of protons with opposite charge in the nucleus. However, a small number of negative protons may be present in (positively charged) nuclei in which case the atomic number Z and atomic weight A will be expressed in terms of N_n, N_p^+, N_p^- by the formulae: $A = N_n + N_p^+ + N_p^-$ and $Z = N_p^+ - N_p^-$.

The introduction of negative protons will change Heisenberg's calculations of the total binding-energy of nuclei and the stability-limits for α- and β-decay. One can easily see in which direction this latter change will take place. If, according to Heisenberg, a certain nucleus, described by definite values of N_n and N_p^+, is stable, it will, from the new point of view, have a tendency to transform some of its positive protons into negative protons (with the emission of positive electrons). The stable state will now correspond to an unaltered number

[1] N. Bohr, Report to the Solvay Congress, 1933.

[2] W. Heisenberg, Report to the Solvay Congress, 1933.

of neutrons, but a smaller number of positive protons and a certain number of negative ones. This will shift the stability-limits (in the plot $(A-Z)/Z$ against Z) somewhat upwards. Remembering that Heisenberg's stability-limits lie actually rather too low, it seems that the introduction of negative protons may make the agreement between the theory and experiment much better.

Another consequence of the introduction of negative protons is *the possibility of the existence of isomeric nuclei*, that is, nuclei with the same charge and mass but different internal structure. The difference between two such nuclei will be that one of them has a pair of oppositely charged protons while the other, instead of that, two neutrons. Although such isomeric nuclei may possess rather different energies and spins, the transformation of one of them into the other will be very improbable as it involves the simultaneous transformation of two particles.

As a matter of fact we really have some indications of the existence of such isomeric nuclei. It seems at present rather certain that the radioactive element UZ, found by Hahn is the isomer of UX_2 according to the scheme of Fig. 1. From the observed energies of the emitted β-rays and from the considerations based on the application of the exclusion-principle for β-decay[3] we conclude that the intermediate nuclei UX_2 and UZ have different energies (energy-difference 1×10^6 v) and also different spins. This difference cannot be regarded as a simple excitation, because in that case there would be nothing to prevent UX_2 (which is the one with the greater energy) from

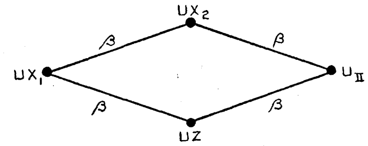

FIG. 1.

transforming very rapidly ($\sim10^{-13}$ sec.) into UZ with the emission of a γ-ray. Actually UX_2 has a life of about one minute and then transforms into U_{II}. The above-mentioned idea of isomeric nuclei may, however, offer the explanation of the stability of UX_2 as regards its transformation into UZ. According to these lines of reasoning one must suppose that the disintegration $UX_1\rightarrow UX_2+\beta^-$ is due to the transformation of a nuclear neutron into a positive proton and electron, while the disintegration $UX_1\rightarrow UZ+\beta^-$ is due to the splitting of a negative proton into a neutron and electron (or the other way round).

It may be also remarked that the introduction of isomers may be of help for the removal of existing contradictions in the estimation of neutronic mass from different nuclear reactions.

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April 1, 1934.

[3] G. Gamow, Proc. Roy. Soc. (in print).

Nature of the High Energy Particles of Penetrating Radiation and Status of Ionization and Radiation Formulae

(I) In this note it is desired in the first place to draw attention to some evidence for supposing that the high energy particles observed in Wilson-cloud photographs of penetrating radiation, have protonic mass. This evidence lies in the indications of a rather low value for the specific ionization by these particles. The most definite data in this respect are due to Kunze,[1] who observed the primary ionization produced by particles with $H\rho\sim6\times10^6$. For this $H\rho$ the theoretical ionization by protons is very near the minimum value for particles with a single electronic charge, whilst that by electrons is about 70 percent greater.[2] Kunze's observations give a value practically equal to the minimum value. The results therefore indicate that these high energy particles are protons rather than electrons.[3] Remembering that the particles of lower $H\rho$, $\leq10^6$, are nearly all electrons (from the investigations of Anderson, and Blackett and Occhialini) this would lead us to classify the ionizing particles of penetrating radiation into, (1) protons of high energy, and therefore possibly constituting the primary particles of penetrating radiation, (2) electrons of lower energy and of secondary origin.

Kunze's results require us to go even further than the assumption of protonic mass for the particles observed by him, because some of them have magnetic deflections corresponding to a negative charge. This would mean that *negative protons* exist, constituting, together with ordinary protons, the more energetic ionizing particles of penetrating radiation.

In view of these deductions it is desirable that more observations be made on the ionization and magnetic deflection of these high energy particles; also on the minimum ionization, I_m, which, from existing observations on ordinary β-particles, we have here taken to be 20 primary ions per cm in normal air. A disquieting feature of the

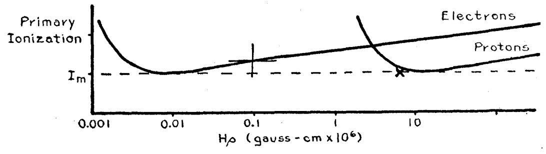

FIG. 1. +, observations requiring electronic mass; ×, observations requiring protonic mass.

[1] Kunze, Zeits. f. Physik **83**, 1 (1933).

[2] In their discussions of the ionization, Anderson, and Blackett and Occhialini, use formulae for the total energy loss. The energy loss is, however, not an exact measure of the specific ionization, and in the region of $H\rho$ considered here it gives an ionization for protons appreciably too high in comparison with electrons.

[3] A similar conclusion has been previously arrived at by the writer, using the same argument, but basing it on Skobelzyn's measurements of the total ionization (Phys. Rev. **42**, 881 (1932)).