Letters to the Editor

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NOTES ON POINTS IN SOME OF THIS WEEK'S LETTERS APPEAR ON P. 439.

CORRESPONDENTS ARE INVITED TO ATTACH SIMILAR SUMMARIES TO THEIR COMMUNICATIONS.

Loss of Energy by Fast Particles in Nuclear Collisions

THE energy lost by a moving particle in traversing matter as the result of exciting or disintegrating atomic nuclei depends on the law of force between it and the particles constituting the nucleus, and also in general on the state of motion and of binding of the nuclear particles. However, if the incident particle is fast and the forces are of short range, the average energy loss in nuclear collisions may be shown to be independent of the latter factors, and is the same as it would be if all the nuclear particles were free and isolated. The general reason for this may be seen as follows.

Let us consider a nuclear encounter in which the incident particle, velocity βc, approaches the nucleus within a distance r. The 'time of collision', τ, is then of the order of $r/\xi\beta c$, where $\xi = (1-\beta^2)^{-1/2}$. Strictly speaking, terms of the order of $\lambda/2\pi\beta c$, and $\alpha/\beta c$, where λ is the de Broglie wave-length, and α represents nuclear dimensions, should be added in order to avoid contradictions with the uncertainty principle and to allow for the size of the nucleus. However, these terms make no significant addition and may be left out here. The 'natural period', T, of a nuclear particle is of the order of δ/u, where u denotes its average velocity in the nucleus and δ represents the dimensions of the region to which it is confined (the nuclear cell in Bohr's model, for example). Now if $\tau \gg T$ the conditions are adiabatic, and the energy loss is greatly suppressed by the binding forces. However, if $\tau \ll T$ we have the condition of 'sudden impulse', and the average energy loss is the same as it would be if the nuclear particles were free. The transition from the one condition to the other takes place for a value, ρ, of r given by $\tau \sim T$, namely, $\rho = \xi\beta(c/u)\delta$. For the nuclear particles we may take $u/c \sim 1/5$, and for fast incident particles, such as those in cosmic rays, $\beta = 1$, $\xi \gg 1$. Thus $\rho \gg \delta$. Now δ is at least of the order of the range of nuclear forces, σ. Therefore $\rho \gg \sigma$. This means that, as r increases, the interaction with the nuclear particles ceases altogether long before adiabatic conditions set in, that is, before binding forces have any effect on the average energy loss. Inside the range of the interacting forces the conditions are those of a sudden impulse, and the average energy loss is accordingly the same as for a free particle.

This result can also be proved by applying Born's theory of collisions in an analogous manner to its application by Bethe[1] to the excitation and ionization of atoms. The result, however, holds under more general conditions than those which have to be satisfied to justify Born's approximation. The application of the above arguments to the excitation and ionization of atoms leads, under the conditions of Born's approximation, to Bethe's formula for 'stopping power', and to Bohr's classical formula under the alternative conditions. Of course, in the atomic problem the interaction, which is Coulombian, is to be classed as long range, and the binding forces play an essential part in limiting the energy loss.

Assuming the mutual potential energy of a cosmic ray particle and a nuclear particle to be $Ve^{-b/r}$ (and using Born's approximation), the average energy lost by fast particles per centimetre in nuclear collisions, according to the above result, is

$$dT/dx = (4\pi/3)NWV^2b^2/Mv^2,$$

where N is the number of nuclei per c.c., W the number of protons and neutrons in the nucleus, M the mass of a proton (or neutron), and v the velocity of the incident particle, which we may take as the velocity c of light. With $V \sim 40$ M.v., and $b \sim 1\cdot0 \times 10^{-13}$ cm., this formula gives an energy loss about one twentieth of that suffered in the usual collisions with the atomic electrons.

The results given here differ from those obtained by Heisenberg[2] in a recent treatment of the problem, though the numerical values are not of a different order of magnitude. Heisenberg calculates the energy loss assuming the nuclear particles to be free, and then assumes that the effect of the nuclear binding forces is to cut out all those collisions which give an energy transfer less than the smallest excitation energy. This procedure is in fact identical with that adopted in a theory of stopping-power given by Henderson[3] before the advent of the new quantum mechanics, and it gives results correct in order of magnitude only. The energy loss calculated by Heisenberg is also greatly increased by his allowance for the initial motion of the nuclear particles in the nucleus. According to my results, this motion does not contribute at all to the average energy loss, though it affects its distribution. The reason for this is that if a free particle with initial momentum p_0 receives in a collision momentum p, at an angle θ with p_0, the energy it acquires is proportional to $p^2 + 2pp_0 \cos\theta$, which on the average is equal to p^2 and is independent of p_0.

A more detailed discussion of the points mentioned in this note will be given elsewhere.

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[1] *Ann. der Phys.*, **5**, 325 (1930).

[2] Leipzig, Akad. der Wissen., **89**, 369 (1937); *Naturwiss.*, **25**, 749 (1937).

[3] *Phil. Mag.*, **46**, 680 (1922).

Anomaly in the Apparent Absorption of Slow Neutrons by Iodine and Boron

IN the course of some experiments on the absorption in boron of the slow neutrons (excluding those of thermal energy) which activate an iodine detector, a rather peculiar phenomenon has been noticed.

It has been found that the absorption coefficient of these neutrons in boron remains apparently constant, even when some 85 per cent of the original intensity has been absorbed. If, however, some 50 per cent is absorbed in an iodine filter, the boron absorption coefficient of the residual neutrons has decreased to a very marked extent. This last effect

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