Change and Exchange of Rest Mass of Elementary Particles During Collisions

In a recent letter I suggested[1] that the possibility of a change of rest mass of elementary particles caused by collisions should be investigated. In general the distribution of energy and of momentum among the various particles which are involved in a collision will be complicated if a change of rest mass is taken into account. In two limiting cases, however, the results may be stated in a simple manner. These two cases are (A) an *exchange* of the rest masses between two elementary particles, and (B) a *change* of the rest mass of one individual particle which passes, for instance, through the field of a nucleus.

We denote with $\mathrm{E}=mc^2/(1-\beta^2)^{\frac{1}{2}}$ the total energy of the particle before the collision. Its kinetic energy is $T=\mathrm{E}-mc^2$. After the collision $\mathrm{E}'=m'c^2/(1-\beta'^2)^{\frac{1}{2}}$ and $T'=\mathrm{E}'-m'c^2$. The limiting case (A) is characterized by $\mathrm{E}'\neq\mathrm{E}$ and $T'=T$, whereas, for the limiting case (B) $\mathrm{E}'=\mathrm{E}$ and $T'\neq T$.

Case (A)

As was suggested in an earlier paper[2] an *exchange of identity* between two elementary particles may take place during a collision, involving for example the exchange of the rest masses m and m' as well as the exchange of the charges e and e'. If the collision takes place next to a heavy third mass whose presence takes care of the change in momentum, the kinetic energy T' of the outgoing particle m' may substantially be equal to the kinetic energy T of the incoming particle m. If the moving particle is analyzed in a uniform magnetic field H the radius ρ of its path will be such that before the collision

$$(H\rho)=(T^2+2mc^2T)^{\frac{1}{2}}/e$$

and after the collision

$$(H\rho)'=(T'^2+2m'c\,T')^{\frac{1}{2}}/e'=(T^2+2m'c^2T)^{\frac{1}{2}}/e'$$

so that $(H\rho)'\gtrless(H\rho)$ for $m'\gtrless m$ if we take $e'=e$.

Case (B)

An elementary particle, such as an electron, may collide with a nucleus and change its rest mass from m to m', so that $\mathrm{E}'=\mathrm{E}=T+mc^2=T'+m'c^2$. In this case

$$(H\rho)=(T^2+2mc^2T)^{\frac{1}{2}}/e$$

and $$(H\rho)'=[T^2+2mc^2T+(m^2-m'^2)c^4]^{\frac{1}{2}}/e$$

so that $(H\rho)'\gtrless(H\rho)$ for $m'\lessgtr m$, respectively.

The change of rest mass therefore produces opposite effects in the cases (A) and (B).

Processes of the type (A) may be expected to take place in nuclear fields where neutrons, protons and possibly electrons of different mass and charge can exchange their identities. The possibility of observing processes of the type (B) however depends on the probability of the transition of an elementary particle from one state of mass and charge into another.

A number of phenomena related to the passage of energetic particles through matter come to mind if the existence of the processes suggested in the preceding is conceded. In particular the apparent changes of energy of fast cosmic-ray particles during their passage through various types of matter may be only partly real and partly caused by a change of the rest mass m or of the charge e. The occurrence of hard and soft showers described by W. Bothe[3] may here find an explanation.

Although the effects on the energy of a change of the charge e in the process (B) cannot be formulated at the present, this possibility also must be carefully examined in view of the fact that the existence of such processes would throw much needed light on the problem of the nature of electric charges and on the problem of the unification of the electromagnetic and the gravitational fields. Some peculiar cloud chamber tracks were pointed out previously which may be due to collisions in which both the rest mass and the charge of elementary particles such as electrons have suffered a change.[1, 2]

F. Zwicky

California Institute of Technology,
Pasadena, California,
March 13, 1938.

[1] F. Zwicky, Phys. Rev. **53**, 315 (1938).
[2] F. Zwicky, Phys. Rev. **43**, 1031 (1933).
[3] W. Bothe, *Kernphysik*, (Ed. E. Bretscher) (J. Springer, Berlin, 1936), p. 122.

Isomers of Radioindium

In a survey of radioactivity produced by high energy neutron bombardment two long periods, 4 hr. and 2 mo., were found in the indium chemical separation.[1] Lawson and Cork subsequently made a detailed study of the radioactivity induced in indium by various methods of excitation and were able to assign reasonably these two periods, more accurately measured 4.1 hr. and 50 days, as well as the five other periods to definite indium isotopes.[2] They found that the 4.1-hr. period appeared weakly with both deuteron and slow neutron bombardments but strongly with fast neutron bombardment. The 50-day period was obtained only with fast neutrons. Both periods were tentatively assigned to In^{114}.

Recently Mitchell reported that the 50-day period is produced also by slow neutrons but that the 4.1-hr. period is not.[3] The activation of the latter would be expected if the periods were isomeric. He suggested that with slow neutrons the formation of the 4.1-hr. period may be impossible due to energy considerations or forbidden because of some selection rule.

The data obtained during the survey of radioactivity[1] produced by fast neutrons have been used to calculate the branching ratios for the radioactive indium periods here involved. From three specimens bombarded 1, 2 and 4 hours respectively with fast neutrons an average branching ratio for the 50-day to the 4.1-hr. period is about 22. The individual values varied considerably being 25.5, 27.3 and 12.2. The ratio of the abundances of the stable isotopes In^{115} to In^{113} is 21.2. From two observations the ratio for the

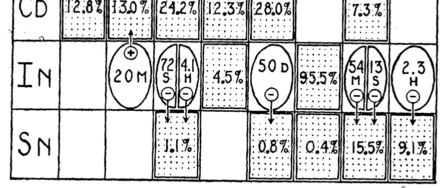

FIG. 1. Stable and radioactive isotopes of indium.