Cloud Chamber Evidence Against the Existence of Heavy Beta-Particles

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By studying collisions of Ra E beta-particles with electrons, photographed in the cloud chamber by Champion, it is shown that Jauncey's hypothesis of heavy beta-particles definitely disagrees with experiment.

RECENTLY the suggestion has often been made that beta-rays are not identical with electrons. Jauncey[1] has put forward a definite, and at first sight attractive hypothesis, to the effect that there is no neutrino; that the change in internal energy of a nucleus emitting beta-rays is always the same; and that the rest mass of every beta-particle is such that it carries away the same total energy. He reported to an informal discussion group at the December, 1937 meeting of the American Physical Society that he repeated the Bucherer experiment with Ra E beta-particles, obtaining results which appeared to support his hypothesis. Previously, Zahn and Spees[2] considered the possibility that for momenta below the upper limit of the beta-ray spectrum "some of the total energy is 'concealed' in a form other than kinetic," and described the results of a much improved modification of the Bucherer experiment. Their observations on Ra E showed a peak corresponding to the mass of the Lorentz electron within ten percent, on the side corresponding to greater mass. There were also small side peaks which will probably be explained as a consequence of the finite resolving power of the apparatus. The present writers accept the conclusion of Zahn and Spees, that their result definitely disproves the existence of the type of heavy electron described above.

Since, on the other hand, their principal result is not in perfect agreement with that to be expected on the basis of electrons of ordinary mass, the possibility still remains that beta-particles differ from ordinary electrons in some less drastic way, and it is of great interest to consider other available evidence from this point of view. On the occasion of the informal discussion mentioned above, one of us suggested reexamination of the cloud chamber experiments of Champion[3] on the conservation of momentum and energy in collisions of Ra E beta-particles with electrons. Champion obtained 30,000 beta-ray tracks and made a detailed study of 15 forked tracks of excellent quality. He discussed them by means of the usual relativistic relations. He believed that his velocity measurements were good to two percent, and his angular measurements to the order of one degree. His conclusion was that the conservation laws are verified, within the limits of his experimental errors, in 14 out of 15 cases. The other collision was definitely non-coplanar, and probably was a radiative collision. Even in this case, the deviation from the conservation laws was slight, so that the emitted quantum must have had small energy. We omit this collision from further consideration.

Suppose the quantities measured are the momenta of the particles and the angles between their paths. If the conservation laws are satisfied when the particles concerned are treated as ordinary electrons, then obviously the momentum relations are still satisfied on the assumption that one of the particles has a rest mass different from that of an electron; but by direct examination of the conservation equations we can see that the conservation of energy is violated by this assumption. We shall not give the simple algebraic proof, because it serves our purpose better to reexamine Champion's data numerically, showing that they definitely disagree with a prediction based on the type of heavy electron discussed by Jauncey.

Consider a collision in which a particle of rest mass Rm_0 collides with an electron of rest mass m_0. For a particle of velocity v, we write $\beta = v/c$,

[1] Jauncey, Phys. Rev. **52**, 1256 (1937); **53**, 106 (1938).
[2] Zahn and Spees, Phys. Rev. **52**, 524 (1937).
[3] Champion, Proc. Roy. Soc. **136**, 630 (1932).

and $\gamma=(1-\beta^2)^{-\frac{1}{2}}$. The relation

$$\beta\gamma=(\gamma^2-1)^{\frac{1}{2}} \tag{1}$$

will be used frequently. The β's and γ's existing before and after the collision are unprimed and primed, respectively, and the subscripts 1 and 2 are attached to quantities describing the incident particle and the electron, respectively.

Champion gives in his paper the fork-angle Ψ, shown in Fig. 1, one of the θ's, and the value of β for the incident particle, derived by measuring $H\rho$.[4] Since β was calculated on the assumption that the incident particle is an ordinary electron, we can recalculate $H\rho$ from it. Of course, when the collision partners are interpreted as ordinary electrons, the experimental values of the angles and of $H\rho$ do not *exactly* fulfill the requirements of the conservation laws; but if we assume that the incident particle is not an ordinary electron, and that the conservation laws *are* exactly satisfied, we can determine the value of R for each collision. The corresponding γ_1 can then be computed. $R\gamma_1$ is the energy of the incident particle in terms of the unit m_0c^2, and we can compare the computed value of $R\gamma_1$ with a value obtained from the heavy electron hypothesis.

Before doing this, we give a simple argument which indicates the order of magnitude of $R\gamma_1$ and makes it probable that the heavy electron hypothesis is incorrect. Let β_e denote the value of v/c for the incoming particle, as given by Champion on the assumption that it is an electron. Then $H\rho e=m_0c\beta_e\gamma_e$. If, however, we interpret this particle as a heavy electron, we have $H\rho e=Rm_0c\beta_1\gamma_1$ so that

$$R\beta_1\gamma_1=\beta_e\gamma_e. \tag{2}$$

Since Champion's collisions nearly satisfy the conservation laws on the assumption of ordinary electrons, it is certain that R will usually be close to unity, and β_1 close to β_e, so we have

$$R\gamma_1\sim\gamma_e. \tag{3}$$

On the heavy electron hypothesis, the beta-raying nucleus always loses the same internal

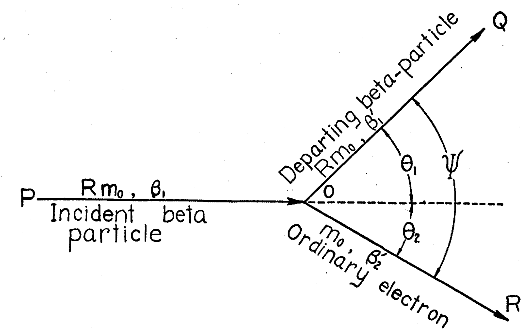

FIG. 1.

energy Q, and if one neglects the very small recoil energy,

$$Q=Rm_0c^2\gamma_1. \tag{4}$$

Let γ_m be the maximum value of γ_1, belonging to a beta-particle at the upper end of the velocity spectrum, for which $Q=m_0c^2\gamma_m$. Then

$$R\gamma_1=\gamma_m, \tag{5}$$

which is to be compared with (3). For radium E, $\gamma_m=3.44\pm0.06$,[5] while Champion's γ_e's are generally less than 2, and run from 1.75 to 2.72.

This is a large discrepancy, and further work might appear unnecessary. Nevertheless, since (3) is only an approximation, we have preferred to compute $R\gamma_1$ on the assumption that the conservation laws are exactly satisfied. The necessary relations are as follows:

Taking momentum components perpendicular to the line OQ in Fig. 1 we have

$$R\beta_1\gamma_1\sin\theta_1=\beta_2'\gamma_2'\sin\Psi \tag{6}$$

and Braunbek[6] has shown that

$$\gamma_2'=\frac{(R\gamma_1+1)^2+(R^2\gamma_1^2-1)\cos^2\theta_2}{(R\gamma_1+1)^2-(R^2\gamma_1^2-1)\cos^2\theta_2}. \tag{7}$$

In Eqs. (2), (6) and (7), the unknowns are R, γ_1, and γ_2'. Solving, we obtain

$$\gamma_2'^2=1+(\beta_e^2\gamma_e^2\sin^2\theta_1/\sin^2\Psi);$$

$$R^2=\left[\left(\frac{\gamma_2'+1}{\gamma_2'-1}\right)^{\frac{1}{2}}\beta_e\gamma_e\cos\theta_2-1\right]^2-\beta_e^2\gamma_e^2; \tag{8}$$

$$\gamma_1^2=1+(\gamma_e^2-1)/R^2.$$

[4] The $H\rho$'s are not available for the arms of the fork, a circumstance which complicates the comparison with theory. Champion states that in a few cases they could be measured with the accuracy necessary to give useful information; in these cases the results agreed, within the experimental errors, with values calculated from β_1, θ_1, and Ψ.

[5] O'Conor, Phys. Rev. **52**, 303 (1937).

[6] Braunbek, Zeits. f. Physik **96**, 600 (1935).

In working out R and γ_1, it must be remembered that we do not know which of the final particles is to be taken as the "heavy" one. Therefore we have carried out the computations for both of the possible cases. First, the final particle whose track makes the smaller angle with the track of the incident one is assumed to have mass Rm_0; then the reverse assumption is made. The results from 14 collisions are as follows:

	Case 1	Case 2
Range of $R\gamma_1$:	1.65 to 2.74	1.73 to 2.74.

Value of $R\gamma_1$ required by Jauncey's hypothesis: 3.44 ± 0.06.

Indeed, the values of $R\gamma_1$ for ten of the collisions lie below 55 percent of γ_m. These results establish the validity of (3) and constitute conclusive evidence against Jauncey's proposal. This conclusion has no bearing on the possibility that the heavy particles reported in cosmic-ray experiments are electrons of exceptional rest mass; it deals only with nuclear beta-rays of Ra E.

In conclusion, it is of some interest to reconsider the extent to which Champion's data support the conservation laws, when the collision partners are treated as ordinary electrons. Study of the computed R values, which should be unity if there were no experimental errors, is not useful, for R is sensitive to experimental errors. (The values of R range from 0.62 to 1.07, and from 0.93 to 1.06, in the two cases mentioned above, the corresponding mean values being 0.923 and 0.994.) Using the customary relativistic mass formula, Champion computed values of Ψ from the observed values of θ_1 and of $H\rho$ for the incident particle, and compared these Ψ-values with the observed ones. The angle Ψ is rather insensitive to experimental errors, so it seems more instructive to proceed as follows. In the absence of $H\rho$ values for the tracks of the departing particles, we obtain the energy of the incident particle in units m_0c^2 from its $H\rho$ and call it $\gamma_1(H\rho)$. Another value of this energy, $\gamma_1(\theta)$, is obtained from the angles θ_1 and θ_2 alone by using the relation

$$2\cot\theta_1\cot\theta_2=\gamma_1+1. \tag{9}$$

Let $\Delta\gamma_1=\gamma_1(\theta)-\gamma_1(H\rho)$, and let us form the fractional error $\Delta\gamma_1/\gamma_1$, where in the denominator we employ the average of $\gamma_1(\theta)$ and $\gamma_1(H\rho)$. This quantity ranges from -0.106 to $+0.040$, and individual values tell us little, but the mean value of $\Delta\gamma_1/\gamma_1$ is -0.0207 ± 0.007. This is an easily understood index of the extent to which the conservation relations are satisfied by Champion's data, when the Lorentz formulas are employed.[7]

Note added in proof: Dr. Champion used his collision 11 in an attempt to discriminate between the Lorentz formula and the Abraham formula. From the data at his disposal he could calculate Ψ on the basis of both theories. It appeared that the value calculated from the Abraham formula was in definite disagreement with the observed angle. We could not check his result and in private communication he states that there was an error in the arithmetic. He requests that we give his revised results. On the Lorentz theory $\Psi=75.2°$ and on the Abraham theory 76°, while the experimental value is $75.2\pm0.5°$. The limits of error are such that this collision does not discriminate between the two theories.

[7] Unfortunately certain compensations which occur in applying the Lorentz and Abraham formulas to Champion's data prevent us from using the data to discriminate between the two theories. This difficulty would not exist if one had $H\rho$ measurements for all three branches of a forked track.