$\gamma = (1-\beta^2)^{-\frac{1}{2}}$. On Jauncey's theory,

$$R\gamma = \gamma_m,$$

where γ_m corresponds to the upper limit of the spectrum; its value is 3.44 ± 0.06 for Ra E.[4] Assuming strict conservation of energy and momentum, and also that the incident particle has a mass Rm_0, we have calculated values of $R\gamma$ from Champion's data. $R\gamma$ represents the energy of the incident beta-particle, in units m_0c^2. $R\gamma$ ranges from 1.65 to 2.74, most of the values being below 2. Their mean is less than 2, while Jauncey's theory predicts the constant value of 3.44 for this product. These results constitute a definite disproof of the hypothesis of heavy beta-particles, supplementing the evidence given by Zahn and Spees.

Our conclusion has no bearing on the possibility that the heavy particles reported in cosmic-ray experiments are electrons of exceptional rest mass. Results which are valid in the region of one million electron volts should be extrapolated to the domain of one billion electron volts.

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January 12, 1938.

ARTHUR RUARK
CREIGHTON C. JONES

[1] Jauncey, Phys. Rev. **53**, 106 (1938).
[2] Zahn and Spees, Phys. Rev. **52**, 524 (1937).
[3] Champion, Proc. Roy. Soc. **136**, 630 (1932).
[4] O'Conor, Phys. Rev. **52**, 303 (1937).

Heavy Beta-Rays—More Theory and Experimental Evidence

Positives of the fifth and eighth films taken with the apparatus described in my third letter[1] are shown in Fig. 1. The line A is due to alpha-rays and the line C to ordinary beta-rays. According to my view the band B is due at least partly to heavy beta-rays. The data for the photographs are:

Film	H	V	β	s	p
5B	318	3372	0.338	1.02	3.37
8B	125	1296	0.328	.47	2.80
8C	125	1296	0.328	1.40	1.07

By reversing both fields I found that the alpha-line was shifted by an amount $H \times 1.0 \times 10^{-4}$. Correction has been made for this in determining s. The value of $p = 1.07$ for the C line of film 8 shows that the apparatus records ordinary electrons and removes all doubt as to the electric field in the selector. The theoretical value of p for the heavy electrons from Ra E for $\beta = 0.328$ is 2.89 in excellent agreement with the experimental value. Film 8 was not covered with aluminum, while film 5 and films 1, 2, 3 of my third letter[1] were covered with $\frac{1}{2}$ mil of aluminum. The absorption in aluminum varies very rapidly with p and the center of the B band is shifted. This is possibly the explanation of the high values of p found from films 3 and 5.

The expression on the right side of (1) is the force on the particle in the velocity selector and $1/\rho'$ is the curvature of the path in the selector:

$$pm_0\beta^2c^2/\rho' e(1-\beta^2)^{\frac{1}{2}} = e(H\beta c - E). \quad (1)$$

There are two solutions for $\rho' = \infty$: (a) $\beta = E/Hc$ and (b) $\beta = 1$. For each solution there is a maximum tolerance given by $\rho' = l^2/8w$, where l is the length and w the distance apart of the selector plates. For film 5 the tolerance for (b) is $\beta = 0.964$ to $\beta = 1$, when $p = 1$. This should give a band from $s = 0$ to 0.32 cm. No such band appears. Moreover the maximum β for Ra E is 0.945. The conclusion that the B band is due to heavy electrons seems inescapable.

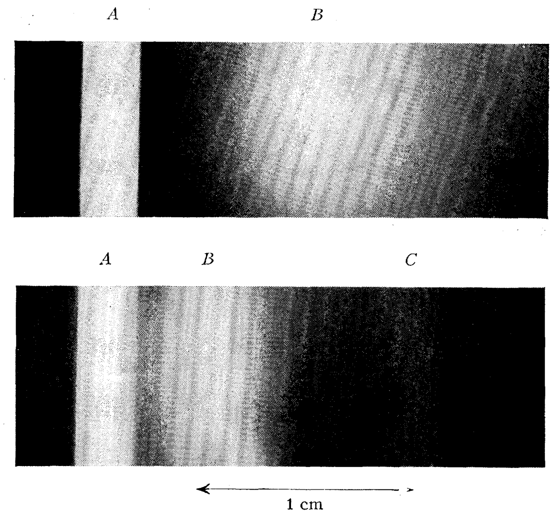

FIG. 1. Mass spectra of electrons. Film 5, top; film 8, bottom.

Comparing B and C of film 8, we find a width in the band due to the heavies over and above the width of the line due to the ordinaries. I suggest that part of this extra width may be due to the heavies changing back to the ordinaries. Following the theory outlined in my first two letters,[2] the conservation principles yield

$$\alpha' = (p^2-1)/2p_{\max}(1-\beta\cos\phi), \quad (2)$$

where $\alpha' m_0c^2$ is the energy of a photon emitted in a direction ϕ with the direction of the velocity βc of a heavy electron of mass pm_0 when it returns to mass m_0 and recoils with a velocity $\beta' c$ in a direction θ. The change from pm_0 to m_0 may occur at any point along the arc either in the selector or in the magnetic field. That ordinary electrons of the selector velocity are produced in the selector has been shown by placing $\frac{1}{2}$ mil of aluminum first in front of the film when the line for the ordinaries of $\beta = 0.44$ was missing on the film and then transferring the aluminum foil to a position between the Ra E and the selector when the line for the ordinaries appeared again on the film. These ordinaries are produced as secondaries at the plates of the selector or are produced from the heavies. Ordinaries would always be found in Doctor Zahn's arrangement. In closing, I repeat my statement at Indianapolis that evidence for heavy beta-rays is shown in Bucherer's papers.[3]

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Washington University,
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January 14, 1938.

[1] Jauncey, Phys. Rev. **53**, 197 (1938).
[2] Jauncey, Phys. Rev. **52**, 1256(L) (1937); **53**, 106(L) (1938).
[3] Bucherer, Ann. d. Physik **30**, 974 (1909).

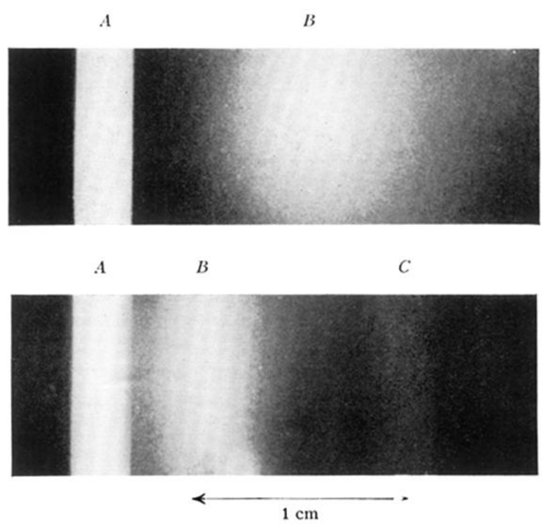

Fig. 1. Mass spectra of electrons. Film 5, top; film 8, bottom.