Evidence for a Particle of Intermediate Mass

While making observations on the stopping power of lead for recoil electrons produced by the 17 Mev gamma-rays from $Li+H^1$, the track shown in Fig. 1 appeared in our cloud chamber. Although the continuous, dense ionization is suggestive of a proton or an alpha-particle, its radius of curvature is only 9 cm in a 2850 gauss field. The radius of curvature for a proton of range equal to the visible length of this track is about 65 cm, and for an alpha-particle about 130 cm. The fact that its curvature is continuous makes it seem improbable that its curvature is due to scattering in the gas. Judging from the width and photographic density of the track we believe that the particle arrived after the chamber had expanded and after the camera had opened. This eliminates any possibility that its curvature is due to turbulence of the gas in the chamber.

The radius of curvature of the track decreases in going in a direction away from the lead plate (horizontal line across center of chamber). If this change of curvature is due to loss of energy by ionization along the path, the direction of motion can be assumed to be away from the plate, which means that it is a positively charged particle. A measurement of the rate of change of radius of curvature gives 0.6 ± 0.2 cm/cm. This value, together with the radius of curvature, gives a unique solution for the mass of the particle, provided it is singly charged. It is 120 ± 15 times the electron mass. If we use more liberal limits of error for the rate of change of radius of curvature, namely 0.6 ± 0.4, the mass is found to be $120\pm30m_0$. This is nearly the same as the mass of a negative particle found by Street and Stevenson,[1] but is much smaller than those found by Corson and Brode[2] and by Nishina, Takeuchi and Ichimiya.[3]

We suppose that this track is associated with cosmic radiation for two reasons: 1. The energy of the lithium gamma-ray is insufficient to create such a particle. 2. Another track, similar in density and curvature, but much shorter, can be seen in the same picture, and it is more probable that two would appear simultaneously in a cosmic-ray shower, than that they would be produced simultaneously by the gamma-radiation.

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[1] Street and Stevenson, Phys. Rev. **52**, 1003 (1937).
[2] Corson and Brode, Abstract, Stanford Meeting, Dec. 18, 1937.
[3] Nishina, Takeuchi and Ichimiya, Phys. Rev. **52**, 1198 (1937).

Fig. 1. Photograph showing a heavily ionizing, curved track in the lower half of the chamber. The path of the particle seems to make about a 15° angle with the plane of the chamber, because it passes out of the light beam near the edge of the chamber. The lead plate, 0.4 mm thick appears as a horizontal line across the center of the chamber. Several electron tracks are visible, which are produced by the 17 Mev gamma-radiation from $Li+H^1$. The small blobs scattered throughout the chamber are due to low energy electrons produced by x-rays.

Analysis of Neutron Absorption in Boron

It is the purpose of this note to suggest a method for the determination of slow neutron energy distributions and of the energy shapes of capture cross sections in certain elements. Consider a beam of slow neutrons, filtered through a thickness x of boron and detected by the activity $A(x)$ produced in a thin layer of an element which has a capture cross section $\sigma(E)$ depending on the energy E. Supposing the number of neutrons incident on the boron per sq. cm per sec. in the energy range dE to be $p(E)dE$ and assuming that boron captures as $1/E^{\frac{1}{2}}$ we have

$$A(x)/A(0)=c\int_0^\infty \sigma(E)p(E)\exp(-kx/E)^{\frac{1}{2}}dE,$$

where c normalizes the expression on the right to unity when $x=0$ and k is known from the absorption in boron at thermal energies. The change of variable $y=1/E^{\frac{1}{2}}$ gives

$$A(x)/A(0)=\int_0^\infty \varphi(y)\exp(-kxy)dy,$$

where $$\varphi(y)=2c\sigma(1/y^2)p(1/y^2)/y^3.$$

This can be considered as an integral equation in the unknown function $\varphi(y)$. A numerical solution for this equation has been devised by Eckart,[1] who has performed necessary preliminary calculations. It has the advantages of simplicity and validity over a wide range in the variable y. Supposing that boron is first used as detector, we have $\sigma(E)\propto 1/E^{\frac{1}{2}}$, so that $\varphi(y)\propto p(1/y^2)/y^2$. Eckart's solution then serves to determine $p(E)$. A second experiment with some other element as detector will determine $\sigma(E)$ for that element.

The method, unfortunately, is valid only when $\varphi(y)$ has no sharp peaks or breaks, and so it is of little use when $\sigma(E)$ contains very sharp resonances, as is generally the case. It should, however, be extremely useful in the important case of cadmium and should serve to remove present uncertainties in regard to the shape of the low energy resonance.[2] Furthermore, if one can be reasonably certain that a single resonance is responsible for the cross section in a given case, a preferable alternative method would be as follows. First find the background $p(E)$ as suggested above and then determine the resonance energy and width by a least square fit to the observed absorption curve. The latter mode of attack should be valid even for fairly sharp resonance.

Numerous other applications, such as the investigation of "thermal" distributions and of possible negative levels suggest themselves. Finally, it should be possible to obtain an experimental check on the validity of the $1/v$ law in boron at energies higher than one volt by analyzing in this fashion and with boron detection the distribution in a cadmium filtered beam. The result for $p(E)$ should be comparable to the Fermi distribution $p(E) \propto 1/E$. The assumption is made that cadmium does not absorb appreciably above one volt. It is perhaps safer to assume the $1/v$ law in boron and use the method to test the truth of the latter statement. In any case, success is more or less dependent on the care taken in making proper geometrical corrections.

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[1] C. Eckart, Phys. Rev. **45**, 851 (1934).
[2] J. G. Hoffman and M. S. Livingston, Phys. Rev. **52**, 1228 (1937).