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The Specific Charge of the Positron

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Previous measurements of the specific charge of beta-particles have been supplemented to include data on positrons by making a direct comparison between electrons and positrons. The positrons and electrons were obtained from artificially radioactive copper. Comparisons were made for beta-particles having approximately the velocity $\beta = 0.72$. The results indicate that the ratio e/m_0 for positrons is the same as for electrons within an error of approximately two percent.

Introduction

A comparison of the specific charges of negative and positive beta-rays by a deflection method was made by J. Thibaud[1] shortly after the discovery of the positron. Employing the trochoid method of collecting charged particles in a magnetic field, he observed the deflections of positrons and electrons in a combination of magnetic and electric fields and concluded that the specific charges did not differ by more than fifteen percent. Another experiment reported by E. Rupp[2] presented results indicating equality to within five percent. This work together with other articles on positrons was, however, retracted.[3] From cloud-chamber data Chadwick and his co-workers[4] obtained a comparison not of the specific charges but of the masses of positron and electron and these were found to be the same to within ten percent.

Experimental Procedure

In view of the rather low accuracy of these previous determinations it was decided worth while to attempt measurements yielding more precise results. The method and apparatus used in the previous work on the specific charge of beta-rays[5] proved sufficient for this purpose. For convenience the method is here briefly reviewed. When the Lorentz mass formula is introduced into the formula for the curvature k of the circular orbit that a charged particle e takes in a uniform magnetic field H, one obtains:

$$e/m_0 = c^2 k\beta / H(1-\beta^2)^{\frac{1}{2}}.$$

Upon the determination of k and β for a fixed magnetic field H this formula yields a value of the specific charge of the particle. In the experimental arrangement employed, a diagram of which is given in Fig. 1, the curvature k is determined by geometric conditions in the magnetic field before the rays enter the velocity selector represented by the electric condenser. These geometric conditions include the relative position of the beta-ray source and the condenser, the size of the source, and the condenser spacing. Because of the latter two features the rays that are permitted to enter the condenser will have, not just a single curvature k_{00}, but curvatures in a spread dk about a curvature k_{00}. This curvature is that of a central ray which leaves the source at the center and enters the condenser in the central plane, in a direction parallel to the condenser plates.

According to the above formula for e/m_0, a definite value of $k = k_{00}$ as thus determined for a fixed field intensity H and the assumption that e/m_0 is a constant, determine a value of $\beta = \beta_{00}$. Therefore since at all times only particles having approximately $k = k_{00}$ enter the condenser space (the region of crossed electric and magnetic

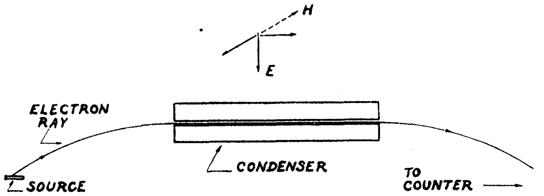

Fig. 1. Diagram of experimental arrangement.

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[3] E. Rupp, Zeits. f. Physik **95**, 801 (1935).

[4] Chadwick, Blackett and Occhialini, Proc. Roy. Soc. **144**, 235 (1934).

[5] C. T. Zahn and A. H. Spees, Phys. Rev. **53**, 357 (1938); **53**, 366 (1938). In the present article these references are referred to as papers I and II.

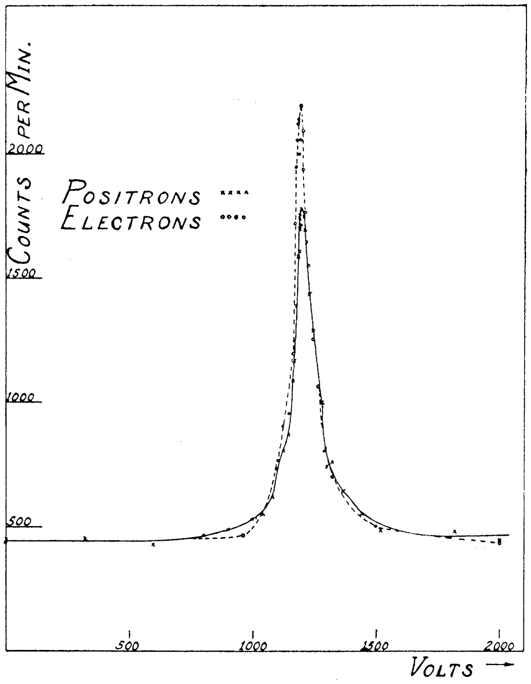

FIG. 2. Transmission peaks for positrons and electrons from a Cu source.

fields) it follows that the particles transmitted by the condenser will have approximately a velocity $\beta=\beta_{00}$. But this transmission, it is to be remembered, may occur only for a compensating setting of the electric field E, namely when $\beta_{00}=E/H$. As a consequence of such action a plot of the counts of particles emerging from the condenser space against various settings of the electric field (magnetic field constant) should show a peak indicating maximum transmission at a certain value $E=E_{00}$. An intensity peak obtained in this manner must, due to the finite resolution of an actual apparatus, have a definite spread. The quantity E determined experimentally in the fashion just outlined gives a measure of the velocity β_{00} which is to be inserted in the formula for e/m_0. Particles having different specific charges will obviously yield peaks that have different values of E_{00}.

The procedure for the problem of comparing the specific charges of electron and positron was based on the use of a beta-ray source which emits both kinds of particles. Copper when bombarded with deuterons has just this property. The unstable isotope Cu^{64} that is produced decays with the emission of both positrons and electrons, the half-life being 12.8 hours. For the present experiment this branching reaction was convenient because measurements on both kinds of particles could be made without disturbing the geometry of the apparatus. In order to change from an electron to a positron source all that was required was a reversal of the electric and magnetic fields. The procedure, therefore, was to obtain a transmission peak for the electrons and then after reversing the fields to obtain another for the positrons. The relative positions of two such peaks should give a direct comparison of the specific charges that is practically independent of any geometrical features.

The particular beta-ray sources used in the experiment were obtained from copper soldered to the end of a water-cooled probe that was placed directly between the duants of the Michigan cyclotron. With this arrangement a bombardment of 8 hours with a beam of 9-Mv deuterons gave a source of several millicuries strength. In the apparatus the source had to be shielded with lead in order to absorb some of the 0.5-Mv positron annihilation radiation that would have produced a very high background count in the particle counter.

OBSERVATIONS

The experimental peaks for two sets of measurements are given in Figs. 2 and 3. The sets differ in that the positions of the sources were slightly different and hence correspond to slightly different values of k_{00} and β_{00}. The measured points of the present peaks are slightly more scattered than those of paper II obtained from a Ra E source. This resulted from the necessity of using shorter counting periods due to the time limitation set by the shorter half-life of 12.8 hours and the additional requirement of obtaining two peaks instead of just one. As for the spreads, the present peaks are seen to have a ten percent half-width as compared with the four percent of the Ra E peaks. This change is to be expected because of an increase in source size. It was necessary to use a 1-cm square copper source because of intensity considerations; whereas the Ra E source was a 1-cm length of 0.5-mm wire. In view of this relatively large increase in source size it is indeed surprising at first sight that the peaks turned out to be as narrow as they did. According to resolution and intensity calculations for a finite source of 1 cm the expected half-width for over-all resolution is about 6.5 percent which is to be compared with the previous result of 2 percent for a line source. As previously, the greater width of the observed peaks may be attributed to scattering. It might have been possible to increase the resolving power in the present case by using the defining slits mentioned in paper II. These, however, had to be removed to make way for the lead shielding and so were not available for the measurements with positrons.

In the transmission curves of paper II there occurred some pronounced subsidiary peaks to each side of the main peaks. An examination of the present peaks gives a slight indication of the same features. The principal reason they are not more pronounced is that the time factor did not permit drawing them out. In some preliminary work with a small condenser it was, however, definitely established that the side peaks also occur for an extended source. Thus since the side peaks arise from sources differing in size and shape, as do the Cu and Ra E sources, they can hardly be ascribed to source conditions. Furthermore an extended and more thorough resolution calculation precludes the explanation that the side peaks may arise from some second-order effect inherent in the characteristics of the instrument as a whole. Their origin, therefore, is probably the one mentioned in previous discussion, namely, scattering from the condenser plates.

Since the present investigation is concerned with relative values of the specific charge it was considered unnecessary to attempt an accurate determination of absolute values. It seems worth while, however, to discuss briefly the results in this connection. For the extended copper source used it is rather difficult to choose a proper central curvature k_{00} in that one has to allow for a non-uniform distribution of radioactivity. Hence one cannot expect the accuracy that was attained with the small Ra E source. The measured values of k_{00} for the two source positions used for Figs. 2 and 3 were corrected for stray electric field and non-uniform magnetic field, in the manner outlined in paper II. The corrected values were then used with values of the velocity as given by the graphs, namely, $\beta_{00}=0.71$ for Fig. 2 and $\beta_{00}=0.73$ for Fig. 3, to obtain values of e/m_0. In the former case the obtained value is lower than the accepted precision value by about 7 percent and in the latter case by about 10 percent. In the previous investigation with the Ra E source the observed peak position differed from the expected position by about 2.5 percent which means a discrepancy with the accepted value of e/m_0 of about five percent.

CONCLUSION

In conclusion, the answer to the main problem of how the specific charges of the electron and the positron compare may be read from Figs. 2 and 3. The peaks for electrons and positrons have positions on the voltage scale that correspond to voltages differing by no more than one percent. To find the corresponding difference in terms of specific charge one uses the following formula derived from the above formula for e/m_0:

$$\Delta(e/m_0)/(e/m_0)=[1/(1-\beta_{00}^2)][\Delta V/V_{00}].$$

Thus the percentage difference in e/m_0 is larger

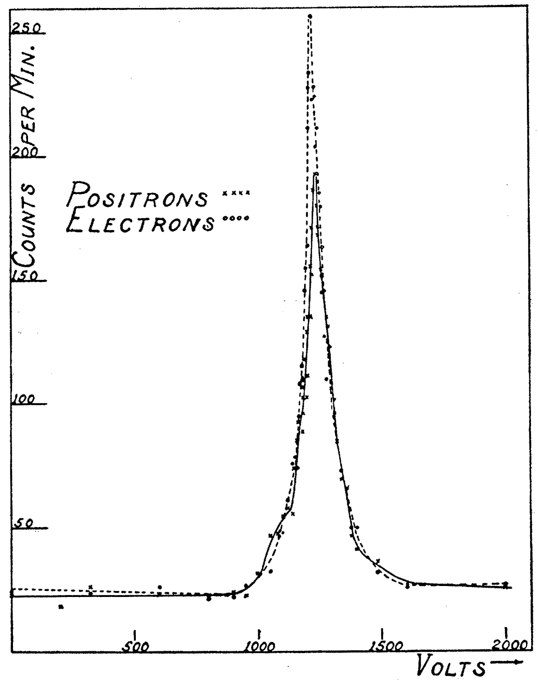

FIG. 3. Transmission peaks for positrons and electrons from a source position slightly different from that of Fig. 2.

than that in the voltages by a factor containing the compensated central velocity β_{00}. For the actual values of β_{00} used in the experiment this factor is approximately 2.0. From the percentage difference in voltage of about one percent one would therefore conclude that the specific charge of the positron is the same as that of the electron to within approximately two percent.

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Successive Transformations in Nuclear Fission

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If it be assumed that fission of heavy nuclei takes place in competition with the escape of a neutron from the highly excited compound system, we should expect that, for sufficiently high excitation of the system, fission of the residual nucleus left after neutron escape may still occur. Since, in this second stage of the process, the conditions for the competition with neutron escape are in several cases more favorable than in the first stage, such effects may give rise to much increased cross sections for the fission process.

As has been shown in earlier papers,[1] it is possible to explain the principal features of the fission of heavy nuclei on the basis of the assumption that the process involves a comparatively long-lived intermediate state of the compound system in which the excitation energy is distributed over all degrees of freedom, as in temperature equilibrium. In fact, the excessive deformations of the compound nucleus leading to rupture are to be attributed to fluctuations in this energy distribution occasionally resulting in the concentration of a considerable part of the excitation energy in particular modes of oscillation of the closely coupled system of nuclear particles. The probability that a fission of the compound system takes place is therefore determined by a competition with other disintegrative or radiative processes leading to a decrease in the excitation energy of the residual system to such an extent that fission is no longer possible.

In the ordinary cases, where the compound system has an energy not greatly exceeding that required for fission, the occurrence of one or the other competing process will reduce the energy available below the critical value. If, however, the excitation of the compound system is very high, the residual system may have a sufficient excitation to permit fission. In the second stage, the probability of fission will, of course, again depend on a competition with other disintegrative or radiative processes. Such progressive transformations have already been briefly discussed (BW, p. 449) especially in connection with deuteron incited fission, but at that time no experimental evidence for their occurrence was available. Recent experiments on fission with high speed neutrons as well as with deuterons seem, however, to afford definite evidence of successive transformation and, as they at the

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[1] N. Bohr, Nature **143**, 330 (1939); Phys. Rev. **55**, 418 (1939), and especially N. Bohr and J. A. Wheeler, Phys. Rev. **56**, 426, 1065 (1939), (referred to in the following as BW).