The Single Elastic Scattering of Positrons by Nitrogen Nuclei

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The nuclear scattering of positrons from Rh^{102} by nitrogen was investigated by the cloud chamber method. The number of photographs taken was about 5000, yielding 5212 positrons of energy lying between 0.53 Mev and 0.98 Mev with a total track length of 712 meters.

The number of cases of scattering observed was 85.0, whereas Massey's theory predicted 8.19. The ratio of the experimental results, which covered the angular range 15° to 85°, to the theory was 0.96. This agreement favors the assumption of Massey that the scattering of positrons takes place on the interaction of the Dirac particle of positive charge with the field of the nucleus.

INTRODUCTION

THE single elastic scattering of the electron by the field of the nucleus has been the subject of investigation over a long period. The importance of this investigation lies in the fact that it gives information concerning the type of interaction between the electron and the nucleus. The first theoretical treatment was given by Rutherford in his $\mathrm{cosec}^4\frac{1}{2}\theta$ law, derived from the consideration of classical mechanics. This formula was later modified by Darwin, taking into account the relativistic effect, but the theory was still found to be inadequate to explain the observed facts. Mott[1] gave a treatment for the scattering formula on the basis of the spin-relativistic effect, making use of the Dirac equation for the electron and assuming that only the Coulomb field of the nucleus interacts with the incident particle. On the basis of Born's approximation, he derived an expression for the scattering probability as a series of Legendre polynomials, which is valid for light elements and, according to Mott, for all angles. Several experiments[2–7] have been performed with nitrogen nuclei for the purpose of verifying this formula of Mott. The results obtained are summarized in Table I. It can be seen from the table that in these experiments the agreement with the theory is reasonable.

A theory on the scattering of the positron by the nucleus has been deduced by Massey,[8] on the assumption of the interaction of the Dirac particle of positive charge with the field of the nucleus. The object of the present experiment is to investigate the large angle single elastic scattering of fast positrons by nitrogen nuclei and to compare the results with this theory of Massey.

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EXPERIMENTAL ARRANGEMENTS

For this experiment on the scattering of positrons a rubber piston type cloud chamber of 24 cm in diameter and 4 cm in height was constructed. The illumination, provided by a pair of Siemens S.F.5 tubes placed at opposite sides of the chamber, had a depth of 0.5 cm, with a flash duration of 100 μsec. Each tube was charged across a condenser of 60 μf, 2000 volts, and was discharged to synchronize with the expansion. A vertical camera fitted with Ilford H.P.3 films photographed the tracks. The cloud chamber, completely automatic, had a cycle of 55 sec for the main expansions, between which sets of three clearing expansions were made. A pair of coils of internal diameter 31.0 cm, external diameter 51.0 cm, and height 10.0 cm, placed 6.5 cm apart, and having 729 turns each, supplied the magnetic field of 33.96 gauss per ampere. For the present experiment the field used was 739.6 gauss.

The positron source Rh^{102}, which emits 45 percent positrons and 55 percent electrons, was kept inside a brass container having a hole 1 mm in diameter at one end and curved in such a way as to allow mostly high energy positrons to enter the chamber, while the electrons were bent away from it. The Rh^{102} was prepared according to the reaction $Rh^{103}(n,2n)Rh^{102}$ by bombarding a thin foil of Rh^{103} with fast neutrons, obtained from the deuteron beam of the Amsterdam synchrocyclotron.

Table I. Previous experimental results on the single elastic scattering of electrons by nitrogen nuclei.

Author	Energy of β-particle in Mev	Angles in degrees	Track length in meters	Number of deflections	Ratio of experiment to theory	Reference
Champion	0.4–1.1	20–180	875	201	0.85	a
Stepanowa	0.2–1.1	20–180	82	113	1.7	b
Borisov *et al.*	0.3–2.5	20–180	294	47	0.7	c
Bleuler	0.2–3.11	15–180	367	41	1.5	d
Bleuler *et al.*	0.2–3.0	15–180	515	42	1.3	e
Champion and Roy	0.5–1.1	85–180	100,000	131	1.2	f

[a] See reference 2.
[b] See reference 3.
[c] See reference 4.
[d] See reference 5.
[e] See reference 6.
[f] See reference 7.

TABLE II. Theoretical and experimental single elastic scattering of positrons by nitrogen nuclei.

Angular range	Theoretical Relativistic-Rutherford	Massey	Experimental
15°–25°	77.3	59	58
25°–35°	14.9	74	16
35°–45°	6.0	5.3	7
45°–55°	2.4	1.3	2
55°–65°	1.27	1.18	1
65°–75°	0.73	0.67	0.50
75°–85°	0.49	0.45	0.50

The measurements of the angles and the curvatures of the tracks were made after the usual reprojection.

METHOD OF CALCULATION

If a particle moves with a velocity βc, through a medium containing N scattering nuclei per unit volume of atomic number Z, then the probability $P(\theta)d\theta$ that it will be scattered once through an angle lying between θ and $\theta+d\theta$ in traversing the unit length is given by

$$P(\theta)d\theta=Nf(Z,\beta)F(\theta)2\pi\sin\theta d\theta. \tag{1}$$

Most of the scattering experiments for β-particles have been performed with the cloud chamber using two cameras to record the event of scattering in space, but a single camera, with its optical axis perpendicular to the plane of the cloud chamber, can also be used. In this case, the angle ϕ which is the projection of the actual angle of scattering θ on the plane of the chamber is to be measured. The probability distribution for ϕ, $P(\phi)$, has been given by O'Ceallaigh and MacCarthaigh,[9] and by Barker.[10]

According to O'Ceallaigh and MacCarthaigh the modification of (1) for the projected angle distribution is

$$P(\phi)d\phi=\frac{2Nf(Z,\beta)}{a}\sec^2\phi\int_{-a}^{a}dy\int_{\phi}^{\theta_M}\frac{F(\theta)\sin\theta d\theta d\phi}{(\sec^2\theta-\sec^2\phi)^{\frac{1}{2}}}, \tag{2}$$

where

$$\cos\theta_M=\frac{\lambda_c\cos\phi}{[\lambda_c^2+(a\pm y)^2]^{\frac{1}{2}}}, \tag{3}$$

and where the planes $y=\pm a$ are the boundaries of the illuminated region of the cloud chamber, and λ_c is the minimum projected length of the tracks to be included in the measurements.

The function $F(\theta)$ can be expressed as

$$F(\theta)=\sum_1^4 C_n \operatorname{cosec}^n\tfrac{1}{2}\theta, \tag{4}$$

where in general $C_n=C_n(\beta)$. For the particular case of large angle single elastic scattering of electrons (Mott), $C_4=1$, $C_3=\pi Z\beta/137$, $C_2=-\beta^2$, and $C_1=-\pi Z\beta/137$. Similarly, for positrons (Massey),

$C_4=1$, $C_3=-\pi Z\beta/137$, $C_2=-\beta^2$, and $C_1=\pi Z\beta/137$.

The $n=4$ term in Eq. (4) corresponds in these cases to the relativistic Rutherford formula.

Let $P_n(\phi)$ be the expression for (2), and let $\operatorname{cosec}^n\frac{1}{2}\theta$ be substituted for $F(\theta)$, so that with (4),

$$P(\phi)=\sum_1^4 C_nP_n(\phi). \tag{5}$$

The function $P_n(\phi)/Nf(Z,\beta)$ has been tabulated by Barker for different values of $\lambda_c/2a$, which are, of course, independent of N, Z, and β. In the present experiment the value $\lambda_c/2a=2$.

Let $\nu(\phi_1,\phi_2)$ be the number of collisions in a length of track L which gives rise to scattering in an angular range ϕ_1 to ϕ_2; we shall have consistently $\phi_2-\phi_1=10°$ $=\pi/18$. Then on integrating (2) with (5), for a definite β we shall have

$$\frac{1}{N}\cdot\frac{1}{f(Z,\beta)}\cdot\frac{1}{L}\nu(\phi_1,\phi_2)=\sum_1^4 C_n\int_{\phi_1}^{\phi_2}\frac{P_n(\phi)}{Nf(Z,\beta)}d\phi \tag{6}$$

$$=\sum_1^4 C_n\frac{\pi}{18}\left\langle\frac{P_n(\phi)}{Nf(Z,\beta)}\right\rangle_{\text{Av}}^{(\phi_1,\phi_2)} \tag{7}$$

In our case β is not constant but lies in the range $0.86<\beta<0.94$, so that on averaging over β and after rearrangement,

$$\nu(\phi_1,\phi_2)=\frac{\pi}{18}LN\sum_1^4\langle f(Z,\beta)C_n(\beta)\rangle \times\left\langle\frac{P_n(\phi)}{Nf(Z,\beta)}\right\rangle_{\text{Av}}^{(\phi_1,\phi_2)_{\text{Av}}(\beta)} \tag{8}$$

The averages with respect to β in (8) have been plotted graphically, using Barker's tables to determine $P_n(\phi)/Nf(Z,\beta)$. They should, of course, be taken subject to the probability distribution arising from the energy spectrum of Rh^{102} positrons in the energy range adopted; a rough estimate shows that for our energy range the distribution is nearly uniform.

RESULTS AND DISCUSSION

The number of photographs taken was about 5000, yielding 5212 positrons of energy 0.53 Mev to 0.98 Mev, and with a total track length of 712 meters. The results are given in Table II.

Column I gives the angular range and columns II and III show the values derived from Rutherford's formula with relativistic correction, and from Massey's formula for positrons. In the last column are the values observed in the experiment.

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[9] C. O'Ceallaigh and M. D. MacCarthaigh, Proc. Roy. Irish Acad. **A50**, 131 (1944).
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From the table it can be seen that the ratio of the experimental results to Rutherford's predictions is 0.82; they are, rather, closer to Massey's values, the ratio being 0.96 in the angular range 15° to 85°, thus confirming Massey's assumption that the scattering of positrons takes place on the interaction of the Dirac particle of positive charge with the field of the nucleus.

The difference between the theories for the scattering of electrons due to Mott and of positrons due to Massey lies in the sign of the spin interaction terms, and calculations show that it is small for light elements like nitrogen; consequently it would not be evident in cloud-chamber experiments, considering the statistical error involved. It should, however, easily be detectable in heavy elements such as lead, and experiments to observe it are in progress in this laboratory.

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Possibility of Obtaining Experimental Information Concerning the Meson-Meson Interaction*

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The observation of correlated pairs of mesons associated with high energy stars is suggestive of a strong attractive interaction between pairs of π-mesons. If such an interaction exists, it should appear in a relatively simple manner in the production of pairs of mesons by protons or γ-rays near the energetic threshold. The observation of a marked correlation in energy and angle between the mesons of a pair produced in a single event should lead to quantitative information concerning the meson-meson interaction.

DANYSZ, Lock, and Yekutieli[1] have recently reported evidence for marked correlation in the directions and energies of emission of π-meson pairs produced in stars by particles of cosmic-ray origin. This was interpreted as possibly implying the existence of a neutral particle which decays into a π^+ and a π^- meson with a Q value of the order of 2 to 5 Mev. It would appear, however, that these observations could also be interpreted on the basis of an assumed strong, attractive interaction between pairs of π-mesons.

Similar effects involving correlation in the motion of outgoing particles in a reaction have been observed in the production of π^+ mesons in proton-proton collisions[2] and in the absorption of stopped π^- mesons by deuterons.[3] In both cases it appeared possible to describe the phenomena[4,5] by treating the interaction of the outgoing particles separately from the mechanism of the primary event which initiated the reaction. These analyses indicated that such interactions can in a very striking manner control the relative angles of emission and energies of the outgoing particles—and that the effect may be expressed in terms of the phase shifts which would describe the scattering of the two correlated outgoing particles. Estimates of the effect of a strong attractive interaction between π-mesons indicate that this can account for the observations of Danysz *et al.*[1]

Regardless of whether this is the correct interpretation of the above phenomena,[1] it seems worth remarking that for the production of pairs of π-mesons near the energetic threshold any interaction between π-mesons should make itself felt relatively strongly (accelerators with sufficient energy to produce meson pairs by γ-rays and by protons are expected to be available in the near future). The possibility of interpreting an observed correlation in energy and angle in terms of a meson-meson interaction rests upon the argument that near the energetic threshold the primary production process will involve only the lowest order spherical harmonics for the meson angular variables. Thus a marked correlation between the mesons (i.e., involving an anomalously

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