The Scattering of Alpha-Particles by Nitrogen

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A study has been made of the scattering of alpha-particles by nitrogen into four angular ranges of mean angles 53°, 66°, 88°, and 104°. Anomalies in the scattering are observed for energies as low as 3.5 Mev. Curves showing the ratio of observed to Coulombian scattering as a function of energy show several maxima and minima. The form of the curves varies greatly with the scattering angle.

NEXT to those elements which may be obtained in the form of thin foils, elements which exist in gaseous form are the most convenient for use in investigations of scattering. Nitrogen is such an element, and one of the lightest. Although, presumably, the scattering of alpha-particles by nitrogen nuclei would show marked anomalies, it was not investigated during the early work on alpha-particle scattering since the scintillation screen then used as a detector of the scattered particles would not distinguish sharply between scattered alpha-particles and the protons produced by the transmutation of nitrogen. The development in recent years of electrical detectors which will distinguish between the two kinds of particles has made it possible to study the scattering of alpha-particles by nitrogen nuclei. Such studies have been carried out by Devons,[1] who has investigated the scattering at 90°, and by the author.

In the present work the scattering at four different mean angles has been studied. The apparatus used has been previously described.[2] The detectors used were toroidal proportional counters which detected particles scattered from a small volume on the axis of the toroid. The counters were filled with the gas whose scattering was being studied. Proper adjustment of the voltage applied to the counters and the amplification of the impulses produced by them made it possible to detect alpha-particles but not protons.

The use of two of the toroidal counters made it possible simultaneously to observe particles scattered into two different angular ranges. By changing the positions of the edges defining incident and scattered beams of particles, scattering into two other angular ranges could be studied. The scattering of alpha-particles having energies between 3.5 Mev and 7.0 Mev into four somewhat overlapping angular ranges whose mean angles are 53°, 66°, 88°, and 104° was studied.

Since its original description, the apparatus has been altered to improve its resolving power. The size of the angular ranges has been reduced by use of an alpha-particle source 3 mm instead of 9 mm in diameter, and by slightly reducing the angular width of the beam of scattered particles. These changes have also reduced somewhat the spread in energy of incident particles in the scattering volume. The total spread in scattering angle for the 53°, 66°, 88°, and 104° ranges, respectively, are 35°, 36°, 41°, and 37°. A computation of the number of recorded scattered particles as a function of scattering angle, on the assumption of Coulomb forces, shows that, unless the scattering differs a great deal from Coulomb scattering, very few particles are recorded which have been scattered through the very smallest or very largest angles in each angular range. The effective angles of scattering, may, then, be given as $53°\pm11°$, $66°\pm12°$, $88°\pm14°$, and $104°\pm12°$.

The spread in energy of the incident particles is due to the thickness of the scattering volume and to the straggling of the alpha-particles. The thickness of the scattering volume in each case was about 2 mm air equivalent. For an alpha-particle energy of 5 Mev this amounts to 0.2 Mev spread in energy. At the same energy the straggling in energy of the alpha-particles amounts to about 0.09 Mev. The total spread

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[1] S. Devons, Proc. Roy. Soc. **A172**, 127 (1939).
[2] Gordon Brubaker, Phys. Rev. **54**, 1011 (1938).

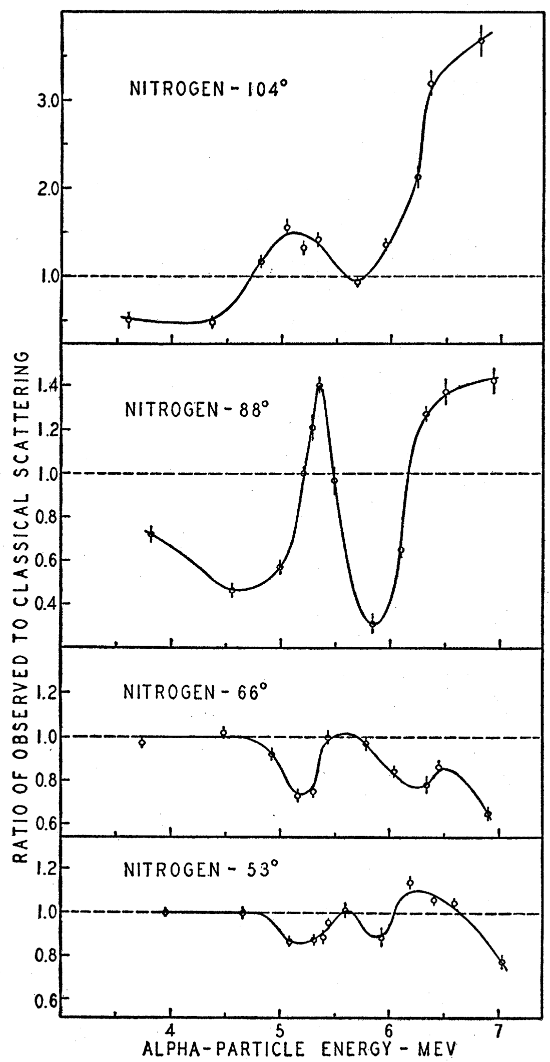

FIG. 1. Experimental results for the scattering of alpha-particles by nitrogen.

in energy of incident particles in the scattering volume was, therefore, about 0.38 Mev.

For calibration of the apparatus, the scattering of alpha-particles by argon was used. The number of particles scattered by argon at energies near 4 Mev (for which the scattering is known to be classical) was determined and, by use of the Rutherford scattering formula, the number which would be scattered by nitrogen on the assumption of Coulomb forces was calculated.

To make sure that no protons were being detected, a foil thick enough to stop the scattered alpha-particles but not the protons was placed between the scattering volume and detectors and alpha-particles of various energies were allowed to pass through the scattering volume. It was found that no protons were counted.

RESULTS

The results which were obtained are shown in the curves of Fig. 1, in which the ratio of observed to Coulomb scattering is plotted against the energy of the incident alpha-particles. From 200 to 1500 particles were counted for each of the experimental points. The curves show that anomalies in the scattering exist for energies as low as 3.5 Mev, as is to be expected since the penetrability of the nuclear potential barrier for this energy is at least 10 percent, and that the course of the anomalies with increasing energy of the particles is very irregular. Particularly noteworthy is the high and narrow peak at 5.3 Mev in the curve for 88° mean scattering angle, the appearance of which strongly suggests that it is due to resonance. The whole curve is similar to that obtained by Devons[1] at 90° mean angle of scattering. The second smaller resonance peak at about 4.6 Mev shown in Devons' curve does not appear here, probably because of lack of experimental points in that region. The difference in height of the higher peak as shown in Devons' curve and in Fig. 1 may be caused by differences in resolving power of the two sets of apparatus.

A somewhat broader peak occurs in the curve for mean scattering angle 104° with its maximum at about 5.0 Mev. It is possible that this is composed of two peaks and that further and more accurate data would separate the two. The subsequent rise in the curve at higher energies is similar to that found in the scattering by oxygen at these same angles,[2] and to those found by Riezler[3] in the scattering at high angles by beryllium, boron, and carbon.

The curves for the scattering into the two lower angular ranges resemble each other, but bear little resemblance to the curves for the two higher angular ranges. The first anomaly evident from the data is a depression of the scattering ratio below unity having its minimum at about 5.2 Mev. Following this there are two maxima in each of the curves. More data are needed to

[3] W. Riezler, Ann. d. Physik **23**, 198 (1935).

determine the exact positions and heights of these maxima. It seems probable that the depression at 5.2 Mev is produced by the same resonance level as is responsible for the high peak in the curve for angle 88°. The difference (0.1 Mev) in the positions of the minimum and the maximum is felt to be real and not the result of experimental error. Such an error could arise only through errors in the measurement of the dimensions of the apparatus. This measurement was carefully repeated and found to be correct.

Discussion

Bethe[4] has given a formula based on the many-body theory of scattering which is valid in the neighborhood of resonance for any spin of scattering nucleus and incident particle but for only zero orbital angular momentum of the particle. For the particular case of nitrogen this formula is

$$\frac{\sigma(\theta)}{\sigma_0}=1+\frac{\rho^2+2\rho\sin\zeta+2\rho x\cos\zeta}{1+x^2},$$

where $\sigma(\theta)/\sigma_0$ is the ratio of actual to Coulomb scattering, $\zeta=\alpha\log\sin^2\theta/2$, $\alpha=e^2zZ/\hbar v$, θ is the angle of scattering in the center of gravity system,

$$\rho=(2/\alpha)(\Gamma^r{}_{Pp}/\Gamma_r)\sin^2\theta/2,\quad x=2(E-E_r)/\Gamma_r,$$

and $\Gamma^r{}_{Pp}/\Gamma_r$ is the ratio of the partial width of the resonance level corresponding to scattering to the total level width.

Consideration of this formula shows that, a given resonance energy having been assumed, the behavior of $\sigma(\theta)/\sigma_0$ as the energy is varied slightly from the resonance value is as follows:

For angles θ greater than a certain high value θ_1, the numerator of the fraction is positive and $\sigma(\theta)/\sigma_0$ decreases as E either increases or decreases: that is, the evidence of resonance is a peak in the curve of $\sigma(\theta)/\sigma_0$ against E.

For another range of angles $\theta_2<\theta<\theta_1$ the numerator is negative and the evidence of resonance is a depression in the curve.

This alteration in the character of the curve continues as the angle is further decreased.

In the curves of Fig. 1 there is apparent evidence of resonance in the high peak of the curve for angle 88°, and further evidence of the same resonance level in the depression at approximately the same energy in the curves for the two lower angles. This change from a peak to a depression agrees qualitatively with the behavior predicted by the theory. Quantitatively, however, the formula cited above predicts only depressions at an assumed resonance energy of 5.3 Mev for all the angles concerned. This indicates that incident particles of zero angular momentum are not involved in the resonance process. This is not in disagreement with the conclusion of Devons that particles of angular momentum two are involved.

The irregularities at the higher energies in the curves for the two lower angular ranges are not well defined by the present data. For this reason and because of the variability in the character of evidence for resonance discussed above, no assignment of the energies of the resonance level or levels presumably responsible for the irregularities has been made.

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[4] H. A. Bethe, Rev. Mod. Phys. 9, 176 (1937).