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The Angular Distribution of Alphas from $Li^7(p, \alpha)\alpha$

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The tracks formed in photographic emulsions by alphas from the reaction $Li^7(p, \alpha)\alpha$ at various angles from the beam were observed at bombarding energies E between 400 and 900 kev. The angular distribution proportional to $1+A(E)\cos^2\theta$, as found by Young, Ellett, and Plain at lower voltages, was also observed here, and a maximum of $A(E)$ was found at 675 kev.

ONE of the simplest reactions yielding disintegration products whose angular distribution is of some theoretical interest is:

$$Li^7+H^1=He^4+He^4+17 \text{ Mev.} \quad (1)$$

The alphas from this reaction have a range of about 8 cm in standard air. This reaction has been studied by several observers,[1] and especially carefully by Young, Ellett, and Plain,[2] who employed proton energies up to 400 kev and showed that in this energy range the intensity as a function of angle $I(\theta)$ was very well represented by

$$I(\theta)\sim 1+A(E)\cos^2(\theta). \quad (2)$$

Here θ is the angle between the incident proton and the observed alpha in the center-of-mass coordinate system, and $A(E)$ is a factor depending only on the energy E of the proton. Their values of $A(E)$ are represented by the small circles in Fig. 2. Although the statistical uncertainties were too great to allow a definite conclusion on this point, the curve seemed to level off as it approached their maximum bombarding voltage, 400 kev, which suggested the existence of a maximum nearby.

Critchfield and Teller,[3] in a theoretical discussion of this reaction, correlated this apparent maximum with a resonance at about 400 kev indicated by the yield curve[4] together with a theoretical treatment of the penetration factor. They showed that both of these observations could be explained by simple assumptions involving only a broad S and a narrow P state of the compound nucleus Be^8.

The protons with energies up to 900 kev were provided by the pressure insulated Van de Graaff generator[5] in the Johns Hopkins University Physics Department. The target chamber assembly is shown diagrammatically in Fig. 1. The beam entered the chamber through a slit 2 mm high by 6 mm wide. The inclination of the target block made the target spot about 5 by 6 mm. The thin lithium targets used were made by evaporating metallic lithium onto a hexagonal target block made of copper, which could be turned to present any one of its faces to the beam or to the furnace. The evaporation was done in vacuum with a simple lithium stove as shown. The metallic lithium had to be packed very tightly into the cavity of the furnace to insure a steady and slow evaporation. With small pieces of lithium merely dropped into the stove, much more power was needed, and the pieces disintegrated in an explosive fashion. A rough check by means of the 440-kev gamma-ray resonance indicated that the target thickness was usually equivalent to about 20 to 60 kev.

The bombarding voltage was measured by magnetic deflection of the proton beam. The deflecting field was held constant and voltage was indicated by the angular displacement of the target chamber necessary to put the proton spot on the entrance slit. The deflection was calibrated by the 440-kev gamma-resonance[6] of Li and

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[1] F. Kirchner, Physik. Zeits. **34**, 785 (1933); J. Giarratana and C. G. Brennecke, Phys. Rev. **49**, 35 (1936); H. Neuert, Ann. d. Physik **36**, 437 (1939).
[2] Young, Ellett, and Plain, Phys. Rev. **58**, 498 (1940).
[3] C. L. Critchfield and E. Teller, Phys. Rev. **60**, 10 (1941).
[4] Rumbaugh, Roberts, and Hafstad, Phys. Rev. **54**, 651 (1938); Herb, Parkinson, and Kerst, Phys. Rev. **48**, 118 (1935); Heydenburg, Zahn, and King, Phys. Rev. **49**, 100 (1936).
[5] A description will be published in *The Review of Scientific Instruments*.
[6] Hafstad, Heydenburg, and Tuve, Phys. Rev. **50**, 504 (1936).

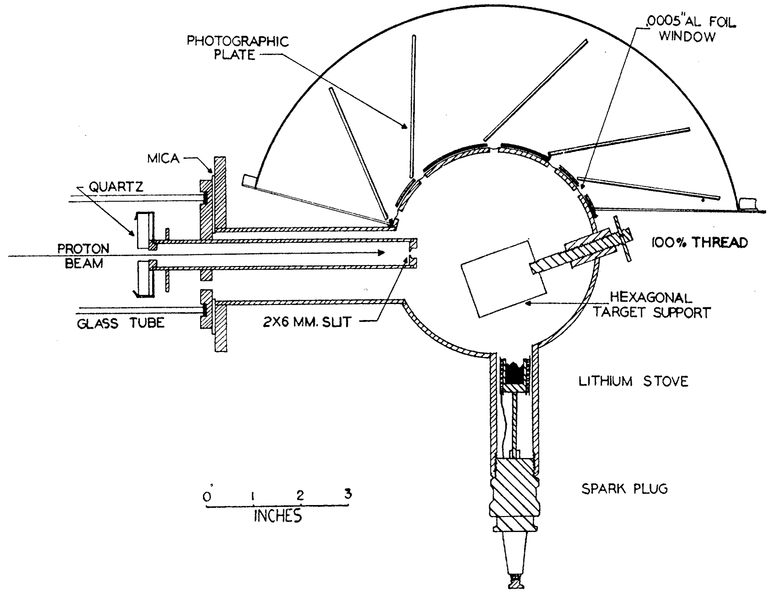

FIG. 1. The angular distribution of alphas from Li^2 $(p, \alpha)\alpha$. Target chamber.

verified by the 334-kev and 660-kev resonances[6,7] of F. Two values of the magnetic field were used to secure convenient deflections over the whole range of energies used. The accuracy of this method of measurement was limited by erratic fluctuations in the position of the undeflected beam position. The uncertainties in voltage arising from voltage fluctuation and inaccurate measurement are expressed by the width of the circles in Fig. 2.

The alphas were detected simultaneously at five different angles by means of photographic plates placed opposite each of the five thin aluminum windows as shown in Fig. 1. Since the range of these alphas in air is about 8 cm and the air equivalent of the 0.0005″ aluminum foil is about 2.5 cm, there is a residual range in the emulsion quite sufficient to produce a track of satisfactory length.

The angle of incidence was made 45° as a mean between normal incidence, in which the track would appear as just one point, and grazing incidence, in which the track would be lost in the surface fog. The plateholder was designed to fit around the target chamber with an aperture opposite each thin-foil window. The apertures were closed by a shutter to allow removal of the plateholder for loading. The plates used were Eastman fine grain Alpha Particle Plates 1″ by 3″. It was found necessary to store the plates in a dry and fairly cool place to avoid fogging which, although still invisible without the microscope, would interfere with the counting of alpha-tracks. After exposure the plates were developed in a specially constructed rack of glass rods, and after drying the exposed parts were protected with a cover glass.

The tracks were counted under a microscope with dark-field illumination and 400-fold mag-

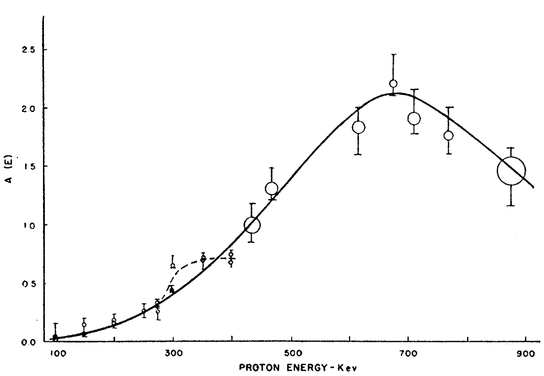

FIG. 2. $A(E)$ as a function of bombarding energy. Small circles and broken curve: data and curve of Young, Ellett, and Plain.

[7] Bennett, Herb, and Parkinson, Phys. Rev. **54**, 398 (1938).

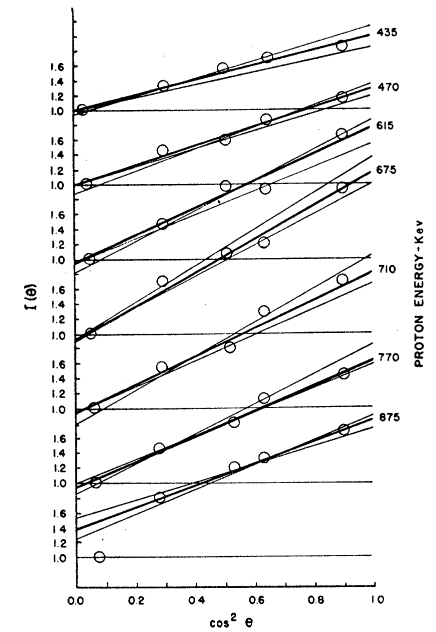

FIG. 3. Angular distribution of alphas from $Li^7(p, \alpha)He^4$ at several bombarding voltages.

nification. The ocular had a diaphragm with a rectangular opening traversed by a cross-hair. The plate was moved by a mechanical stage, and the number of tracks passing the cross-hair in a swath of fixed width was counted as the stage moved through unit distance. About a thousand tracks were counted on each plate.

The photographic method was chosen in preference to electrical counting methods because of its simplicity and because the simultaneous exposure of five plates required less operating time of the generator than the customary electrical counting at only two windows simultaneously. This advantage is, however, partially offset by the tedious task of counting the tracks at leisure.

The data so obtained were transformed[8] to the center-of-mass coordinate system. This introduces modifications up to almost 20 percent in spite of the great energy liberated.

[8] Haxby, Allen, and Williams, Phys. Rev. **55**, 140 (1939).

Figure 3 shows the intensity $I(\theta)$ plotted against $\cos^2\theta$. The results are shown for several different bombarding energies. In most cases it was not possible to draw a straight line through all five of the circles (whose radii equal the standard deviation) which represent the data. In some cases the best straight line passes rather far outside of some of the circles, and there is only a small probability that, at the same time, Eq. (2) applies and no experimental error has occurred other than statistical fluctuations. There is a tendency for one or two of the circles to fall below a straight line through the other four or three, but there is no apparent regularity in these deviations. We prefer to attribute them to experimental error (such as non-uniformity of plates or of development which might possibly persist in spite of precautions), rather than to deviations from (2). In particular, the lowest circle in the set at the highest voltage falls seriously below the line determined by the other four, and we have arbitrarily ignored it. In all cases, the slopes in Fig. 3 were determined by personal judgment. Through each set appear three lines to represent what we consider the most probable and the two extreme admissible slopes.

Figure 2 shows $A(E)$ as a function of bombarding energy E. The circles represent values of A (the slopes of the lines in Fig. 3) which were regarded as the most probable. The length of the vertical lines represents the estimated range of admissible slopes. It can be seen that the curve passes through a moderately sharp maximum and then comes down rather rapidly as predicted.[3] However, the maximum occurs not around 400 kev, but at about 675 kev (which corresponds to about 590 kev in the center-of-mass coordinate system). Our data are not sufficiently detailed to confirm or reject the inflection at 400 kev suggested by the data of Young, Ellett, and Plain, and indicated by the dotted line in Fig. 2.

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