The (α, n) Cross Sections of Beryllium, Magnesium, and Aluminum

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The (α, n) cross sections in beryllium, magnesium, and aluminum were measured by counting the number of neutrons emitted from fairly thin targets of these elements for a given incident flux of alpha-particles. The energy of the alpha-particles was variable up to the full energy of polonium alpha-particles, 5.3 Mev.

I. INTRODUCTION

THE (α, n) cross sections in beryllium, magnesium, and aluminum were measured by the method described in the preceding paper by R. L. Walker.[1] A thin polonium alpha-source was mounted at the center of a spherical chamber onto the inner surface of which the target material was evaporated. The neutrons emitted by the target were slowed down and counted in a graphite block, and it was possible to vary the energy of the alpha-particles striking the target by adjusting the pressure of the gas that filled the chamber. The gas chosen for this purpose was nitrogen, because nitrogen reacts with neither source nor target materials and also because it has a low (α, n) cross section.

II. THE SOURCES AND TARGETS

The polonium alpha-sources were prepared by Mr. L. Treiman, who also determined their strength. The strengths of the several sources that were used are listed in Table I, together with their equivalent thicknesses in centimeters of air for polonium alpha-particles. The target thicknesses were determined by weighing and also are given in the table.

It was unfortunately necessary to use thicker sources and targets with the magnesium and aluminum than it was with the beryllium. The (α, n) cross sections in these heavier elements are considerably lower than they are in beryllium, mainly because of the increased effect of coulomb repulsion of the alpha-particles. It is a weakness of all such experiments, in which natural sources are used, that with heavier targets the resolution must be compromised for reasons of intensity. In general, it would be desirable to increase rather than to decrease the resolution, because of the closer-level spacing in heavier elements.

From Table I, it is seen that the targets were all made thicker than were the sources. This was done in order to introduce about the same energy spread in the sources and targets. Although the alpha-particles enter the targets nearly perpendicularly, their average path length in the source is roughly three times the thickness of the source. The width of the alpha-particle energy distribution introduced into the beryllium measurement by the thickness of both source and target was about 6 percent of the energy of the polonium alpha-particles; whereas, in the magnesium and aluminum measurements, it was about 13 percent.

Only a negligible additional energy spread was introduced by the non-uniformity of the source and target thickness. There was, however, another somewhat serious cause of resolution loss; namely, the finite size of the small nickel sphere onto which the polonium was plated. The alpha-particle path lengths through the chamber differ by as much as the radius of the nickel sphere. The relative energy spread $\Delta E/E$ introduced by this effect becomes rapidly larger at the low-energy (high-pressure) points, both because of the decrease in E and because of the increase in ΔE as the pressure is raised. Fortunately, only with beryllium were points taken at low enough energies for this loss in resolution to be comparable to that due to source and target thickness. Finally, there was a resolution loss caused by the natural straggling of the alpha-particles. However, this loss was smaller than any of those already mentioned.

III. NEUTRON COUNTING

The neutrons produced in the disintegrations were counted by placing both the disintegration chamber and a detector of thermal neutrons in a large graphite block. This method of neutron counting is described in detail by R. L. Walker.[1] It has the advantage that it can be made to permit neutron-counting rates that are fairly independent of the initial neutron energy. This allows the determination of strengths of neutron sources by calibration against standardized sources that need not have the same neutron-energy spectrum. The standard source used in this experiment was a radium-beryllium source whose neutron emission was known to approximately 5 percent.

The energy independence, or "flatness," of the

TABLE I. Source and target thickness.

Target material	Target thickness mg/cm²	Target thickness cm air equiv.*	Source strength when made (curies)	Source thickness cm air equiv.*
Beryllium	0.22	0.17	0.496	0.05
Magnesium	0.50	0.32	1.14	0.10
Aluminum	0.63	0.38	1.14	0.10

* The full range of polonium alpha-particles is 3.84 cm.

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[1] R. L. Walker, Phys. Rev. (to be published).

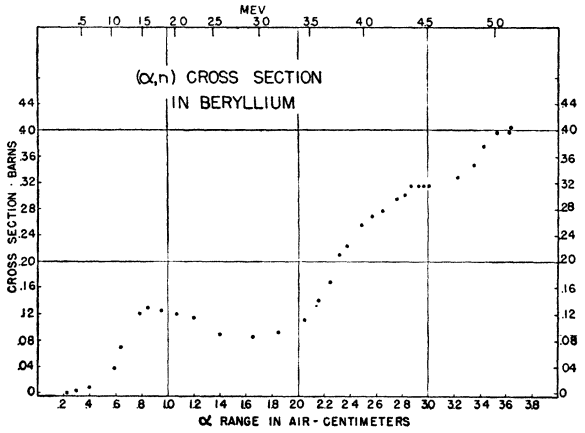

FIG. 1. (α, n) cross section in beryllium.

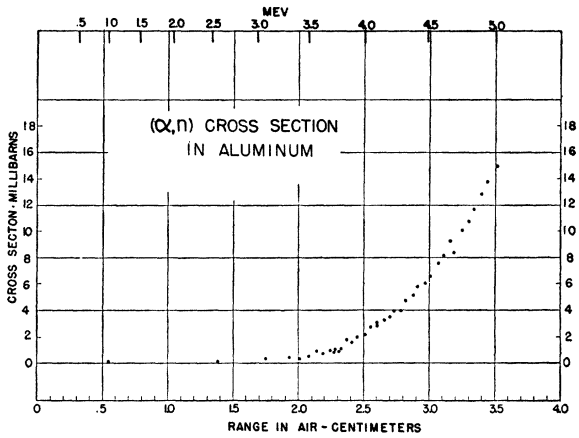

FIG. 3. (α, n) cross section in aluminum.

graphite-block method of neutron detection arises somewhat as follows. The fast neutrons that are emitted by a source in graphite are slowed down by collisions until they reach thermal energies, and then they diffuse until they are captured or leak out of the graphite. If a detector of thermal neutrons is placed in the graphite at a fixed distance from the source, the sensitivity of such a detector will in general depend upon the initial neutron energy. Very fast neutrons would get too far from both the source and the thermal-neutron detector before slowing down enough to be counted efficiently.

On the other hand, neutrons with energies near thermal would be slightly absorbed by capture in the carbon before reaching the detector. Neutrons of some intermediate energy would count with maximum efficiency; and, in the neighborhood of this maximum, the response of the neutron-counting system would be essentially energy independent. In fact, a detailed calculation shows that this maximum is very flat, especially on the low-energy side. For example, for the source-to-detector spacing used in the present experiment, neutrons with initial energies from a fraction of a volt to about 4 Mev could be expected to count within 10 percent of maximum efficiency. If the distance from the source to the detector were increased, this energy region of flat response would also increase, but the absolute counting rate would be reduced. A compromise must be made between flatness and intensity. In the present experiment, the necessary compromise is probably more serious in the magnesium and aluminum measurements than it is in the beryllium measurement. This is mainly because the neutron spectra from the polonium-beryllium measurement and radium-beryllium standard source are probably not too different. However, there is a considerable number of rather high-energy neutrons (about 10 Mev) from both of these sources that are not counted efficiently, probably leading to an overestimate of the cross sections of magnesium and aluminum.

A proportional counter filled to 20-centimeter mercury pressure of boron trifluoride was used as the thermal-neutron detector. The pulses of the detector were amplified and fed through a pulse-height discriminator to a scaler and recorder.

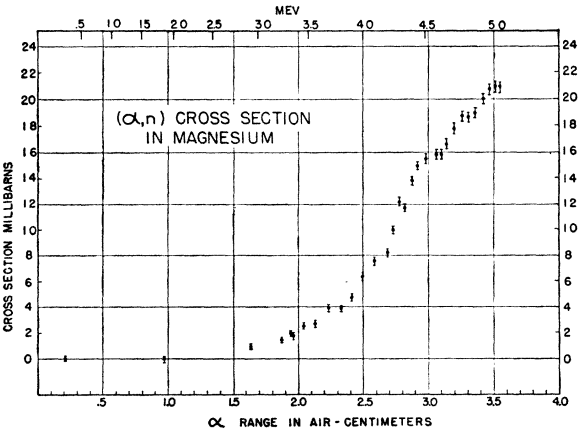

FIG. 2. (α, n) cross section in magnesium.

IV. RESULTS

The (α, n) reaction on beryllium was one of the earliest nuclear reactions found to exhibit resonances. An excitation curve was first given by Bernardini.[2] Subsequent

TABLE II. Neutrons per million polonium alpha-particles.

Authors	Type of target	Particles counted	Beryllium (0.61)	Magnesium (1.4)	Aluminum (1.5)
J. Roberts[6]	Thick	Neutrons	77	1.3	0.7
E. Segrè and C. Wiegand[7]	Thick	Neutrons	73	—	—
A. Szalay[8]	Thick	Positrons (from the residual nucleus)	—	—	0.22
This work	Thin	Neutrons	50	0.5	0.25

[6] J. H. Roberts, Manhattan District Report CN. 1190.
[7] E. Segrè and C. Wiegand, LADC 61.
[8] A. Szalay, Zeits, F. Physik **112**, 29 (1939).

[2] G. Bernardini, Zeits. F. Physik **85**, 557 (1933).

curves[3–5] all showed essentially the same shape as the curve drawn by Bernardini, except that there was a systematic discrepancy along the energy axis of the type that would seem to indicate a disagreement on the stopping powers of the gases used. The present curve, plotted in Fig. 1, agrees with the later curves. If it is assumed that the lowest resonance in this curve can be described in terms of a resonance formula, such as the Breit-Wigner formula, it becomes possible to make a rough estimate of the total angular momentum of the level in C^{13} corresponding to this resonance. This level would have odd-half angular momentum, but it can be shown, for example, that a value of $J=\frac{1}{2}$ would be too small to account for the observed cross section.** From a consideration of yields and energies of the neutrons and gamma-rays observed in the decay of the C^{13}, it appears that values of J higher than 5/2 are unlikely. The total angular momentum of the observed level is therefore probably either 3/2 or 5/2.

Figures 2 and 3 show the results for magnesium and aluminum. (It should be remarked that in all three figures, the height of the zero ordinate above the abscissa represents the constant background that had to be subtracted from the data.) The statistical errors based on the number of counts are indicated for magnesium, where they were the largest. Because of the poor resolution, no resonances are readily apparent in either the magnesium or aluminum curves. The cross section given for magnesium is for the normal isotopic mixture. The (α, n) reaction in the most abundant isotope Mg^{24}, however, is too endoergic to be possible with polonium alpha-particles. Mg^{25} and Mg^{26} have abundances totaling only a little more than 20 percent, and probably both contribute to the observed (α, n) cross section. Therefore, in terms of Mg^{25} and Mg^{26} alone, the cross section is about five times as large as that given. Aluminum has only one isotope; therefore, there is no ambiguity about the assignment of the cross section.

In order to compare the values obtained for the cross sections in this article with those of previous experiments in which thick targets were used, it is convenient to convert thin-target results into thick-target yields, and these are presented in Table II.

The above table gives the number of neutrons per million polonium alpha-particles reported by a number of authors. In parentheses below the target element is given the atomic stopping power in relation to air that was used in the conversion of the thin-target results. The discrepancies that appear in the table are rather large compared with the errors that might otherwise be assigned to the individual measurements, and it is therefore not readily apparent how these discrepancies may be explained.

[3] J. Chadwick, Proc. Roy. Soc. **142A**, 1 (1933).
[4] T. Bjerge, Proc. Roy. Soc. **164A**, 243 (1938).
[5] E. Stuhlinger, Zeits, F. Physik **114**, 185 (1939).
** The author is indebted to Dr. D. C. Peaslee for pointing this out.

ACKNOWLEDGMENTS

The author is indebted to Mr. L. Treiman for his careful preparation and calibration of the polonium sources used in this measurement and also to Dr. R. L. Walker for the preparation of much of the original instrumentation. I wish also to thank Professor H. H. Barschall for suggesting this measurement and for his continued interest in the work.

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The Clustering of Ions and the Mobilities in Gaseous Mixtures

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It is shown by direct analysis that the deviations from Blanc's law for mobilities of ions in mixtures of gases observed when a strongly polarizable gas is mixed with one less polarizable cannot be ascribed to a statistical clustering effect as proposed by Loeb. Analysis involving the assumption that the ion undergoes labile clustering of the simplest type indicates that the observed results can be completely accounted for within the realms of simple theory. Thus assuming that the active gas can attach a single molecule to the ion and that this attachment molecule may be detached with different probabilities by collisions with the two types of gas molecules leads to an equation for the resultant mobilities which will cover practically all cases observed. The forces assumed can be dielectric but may also be secondary valence or van der Waals' forces. It is indicated how, with appropriate experimental procedures possible under modern techniques, most of the constants required for the solution of the equation can be directly determined or computed.

FOR many decades controversy raged as to whether gaseous ions were molecular clusters of large radii or charged single molecules retarded in their motion by dielectric forces with the gas. These forces were usually assumed to be attractive and of the inverse fifth power type, their effect being to increase the effective collision