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September 19, 1946

This document contains 12 pages

(α,n) CROSS-SECTIONS OF BERYLLIUM, MAGNESIUM AND ALUMINUM

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Abstract

The (α,n) cross-sections for Be, Mg and Al were measured as a function of α energy up to the full energy of polonium α's. The cross-sections were determined by counting the neutrons released in the reactions in a graphite block with a slow neutron counter. The energy response of the counting apparatus was reasonably "flat" as it would have to be to give significant results.

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(γ,n) CROSS-SECTIONS OF BERYLLIUM, MAGNESIUM AND ALUMINUM

A number of excitation curves for (γ,n) reactions in light nuclei appear in the literature.[1,2,3,4] The emphasis has usually been placed on the location of thresholds and resonances rather than on the measurement of cross-sections. This is due in part to the difficulty of measuring the necessary neutron yields to determine the cross-sections. In the present experiment an attempt has been made to measure the neutron yields. The method used was such that some sacrifices in energy resolution had to be made (especially in the cases of Mg and Al) and the identification of resonances was made more difficult.

In some (γ,n) reactions, it is true, the final nucleus is left radioactive and a measurement of the intensity of decay allows the calculation of a cross-section.[3,4] But even in some of these cases it might be preferable (and for other nuclei, it would, of course, be necessary) to measure the neutron yield directly, in order to determine the cross-section. Such a measurement requires the ability to count neutrons with a known efficiency and this efficiency must be independent of neutron energy.

In the present experiment, a fair degree of energy-independence of counting efficiency, or "flatness", was obtained by placing both the

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1) Bernardini, Zeits. für Phys., 85, 557, (1933) (Beryllium)
2) Bjerge, Proc. Roy. Soc., 164A, 243, (1938) (Beryllium)
3) Ellis and Henderson, Proc. Roy. Soc., 156, 358, (1936) (Magnesium)
4) Waring, J.R.S., and Chang W.Y., Proc. Roy. Soc., 157, 652, (1936) (Aluminum)

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cross-section chamber (i.e. the source of neutrons) and a slow neutron counter at appropriate positions in a large graphite block. The degree of flatness of any particular arrangement of source and counter in a block can be calculated to good approximation by means of elementary pile theory. Throughout a block in which there is a small source of fast neutrons of energy E, there will be a distribution of thermal neutrons which have originally come from the source and have been slowed down. This distribution depends on the size and shape of the block and upon E. For every distance $\vec{r}$ from the source, a value of E, E_m can be found that renders the thermal flux at $\vec{r}$ a maximum. This maximum arises from the combined effects of the slowing down and absorption of neutrons in graphite. To count neutrons with a given energy spectrum, one would place the thermal neutron counter at such a distance from the source that E_m falls somewhere within the spectrum. A detailed calculation for the size of graphite block used in this experiment (5' x 5' x10') shows that with a source at the middle of the block, and the counter 55 cm. away along the long axis of the block, E_m is .5 Mev and that the counting efficiency for 4 Mev neutrons would still be over 90% of maximum.

The counting was done by a conventional BF_3-filled counting-tube whose pulses were amplified and fed into a discriminator and scalar. A BF_3 counter is essentially a counter of slow neutrons and the above discussion applies. The overall counting efficiency of the apparatus was determined by means of a standardized RaBe neutron source whose total neutron yield had been carefully measured to within 2%.

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The cross-section chamber was spherical (Fig. 1) and contained an α source in the form of a thin layer of polonium plated onto a small nickel sphere. The source was accurately held at the center of the chamber. Enclosing it were two hemispherical steel spinnings onto the inside surface of which were evaporated the targets. The pressure of gas in the chamber was varied so that the cross-section could be determined as a function of α-energy. The stopping gas used was nitrogen for its neutron yield from polonium α's is harmlessly small. A few remarks about the energy resolution of such a spherical cross-section chamber are given below.

The curve for beryllium (Fig. 2) gives the (α,n) cross-section as a function of the average residual α range at the target. The counting rate was such that the statistical probable error could be kept below 2% for most of the points on the graph. The α source for this part of the experiment was 0.496 curies of polonium uniformly plated onto the nickel ball of Fig. 1. The target, too, was fairly uniform in thickness (0.22 mg/cm^2). Tungsten coils of several shapes and sizes were tested for evaporating the targets and one with reasonably "point source" properties was chosen. The evaporation was done into one hemisphere at a time from this coil properly centered. The curve of Fig. 2 can reasonably be regarded as a thin target excitation curve for the (α,n) reaction in Be inasmuch as the target was only 0.25 cm (air equivalant) thick. The shape of the curve resembles closely that obtained by Bernardini[1)] and by Bjerge.[2)] These two papers do not, however, locate the curves in the same way with respect to the energy axis. In the first paper the first resonance peak, for example, occurs

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at 2 cm. α range, whereas in the second it appears at 1 cm. The present results tend to agree with those of Bjerge and when integrated are in very close agreement with the recent thick target results of Segrè and Wiegand.[5]

The vertical lines through each point in the curve for magnesium (Fig. 5) indicate the statistical probable error based on the number of counts taken to determine the particular point. The cross-section for the (α,n) reaction in Mg is considerably smaller than that in Be. To assure adequate counting rates a thicker target (.50 mg/cm^2 = .32 cm. air) and a thicker source (1.14 curies = .10 cm air) had to be used. This thickening of source and target for heavier element targets (necessitated largely by the Coulomb barrier reduction of cross-sections) reduces the energy resolution of the apparatus. This is rather unfortunate since for heavier elements, resonance levels are closer together and good energy resolution is very desirable. In the present experiment the extent of the smoothing out of the curve is such as to make the location of resonance levels rather uncertain. There may be resonances (Fig. 3) at 3.0, 3.25 and 3.5 cm.

The target for aluminum (.63 mg/cm^2 = .3[illegible] cm. Air) had to be made even thicker than for magnesium and no resonances are apparent. The cross-section plotted in Fig. 4 may be regarded as an average cross-section in the neighborhood of any point on the avscissa.

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In this type of experiment there is a spread in energy of those α particles causing transformations which is due to the varying fractions of their range spent by different α's in the source and target. In addition, the finite sise of the source ball makes it possible for varying path lengths through the gas in the chamber. Difficulties may also arise from improper positioning of the source and target. Superimposed on all these is the natural straggling of α particles when passing through matter. The problem of positioning can be overcome and the inherent straggling amounts at most to about 2% of the maximum range. But the other causes of decreased energy resolution are more serious. Under normal circumstances, the required counting rate and the maximum size of the cross-section chamber would be given. From these it is possible to calculate the optimum size of the source ball and the optimum thickness of polonium and target for best resolution. In the Be experiment such a calculation showed that the narrowest distribution of α energies with the chamber filled to half an atmosphere had a width at half-maximum of 5% of the α energy. (It should be mentioned that if the cross-section chamber were made reasonably larger, or if several counters were used simultaneously at proper distances from the source, the resolution could be slightly improved.) It should also be pointed out that the straggling in the present arrangement gets increasingly bad as the pressure is raised. As a result, the resolution at low energy (high pressure) is much worse than at the high energy end.

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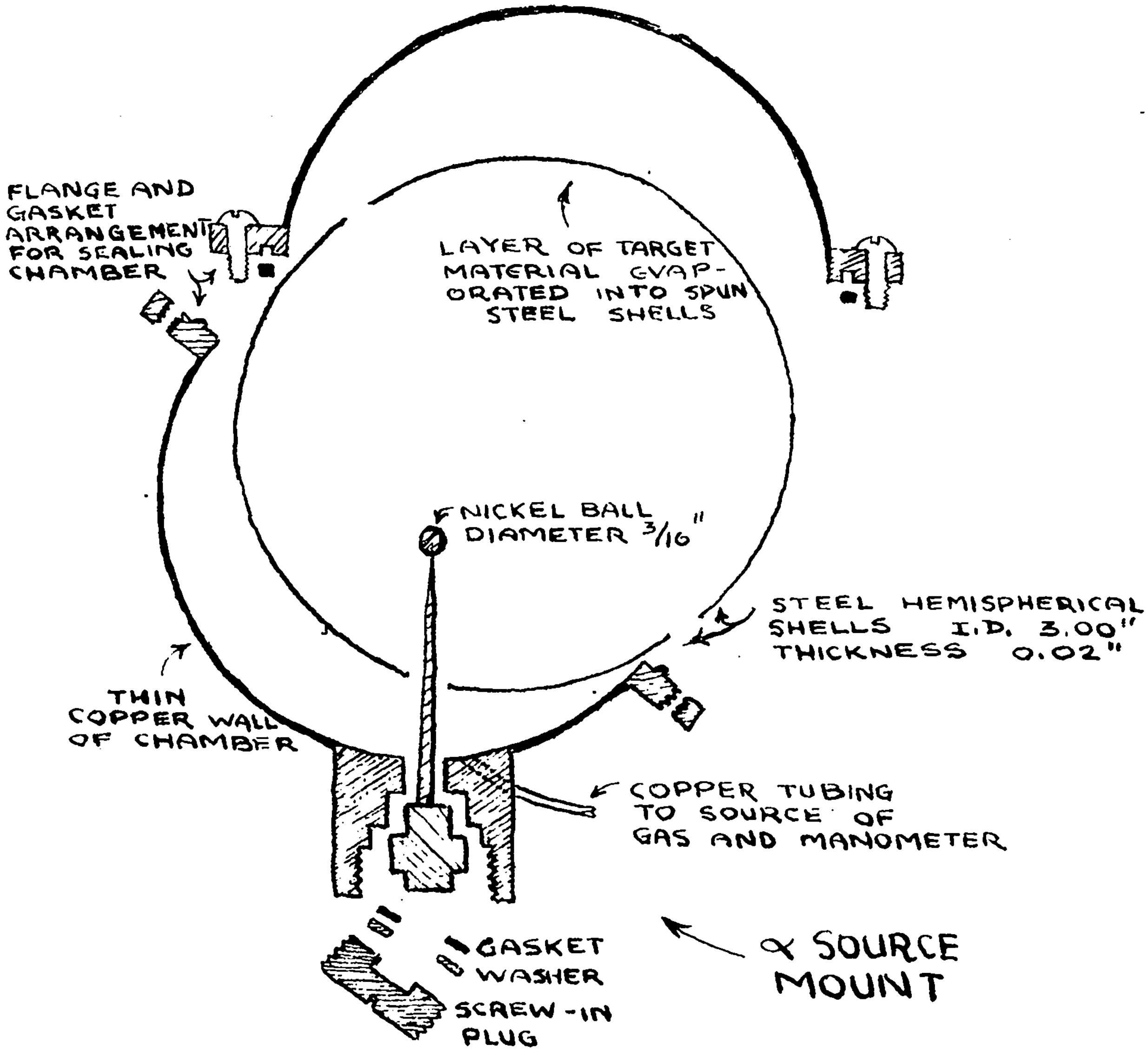
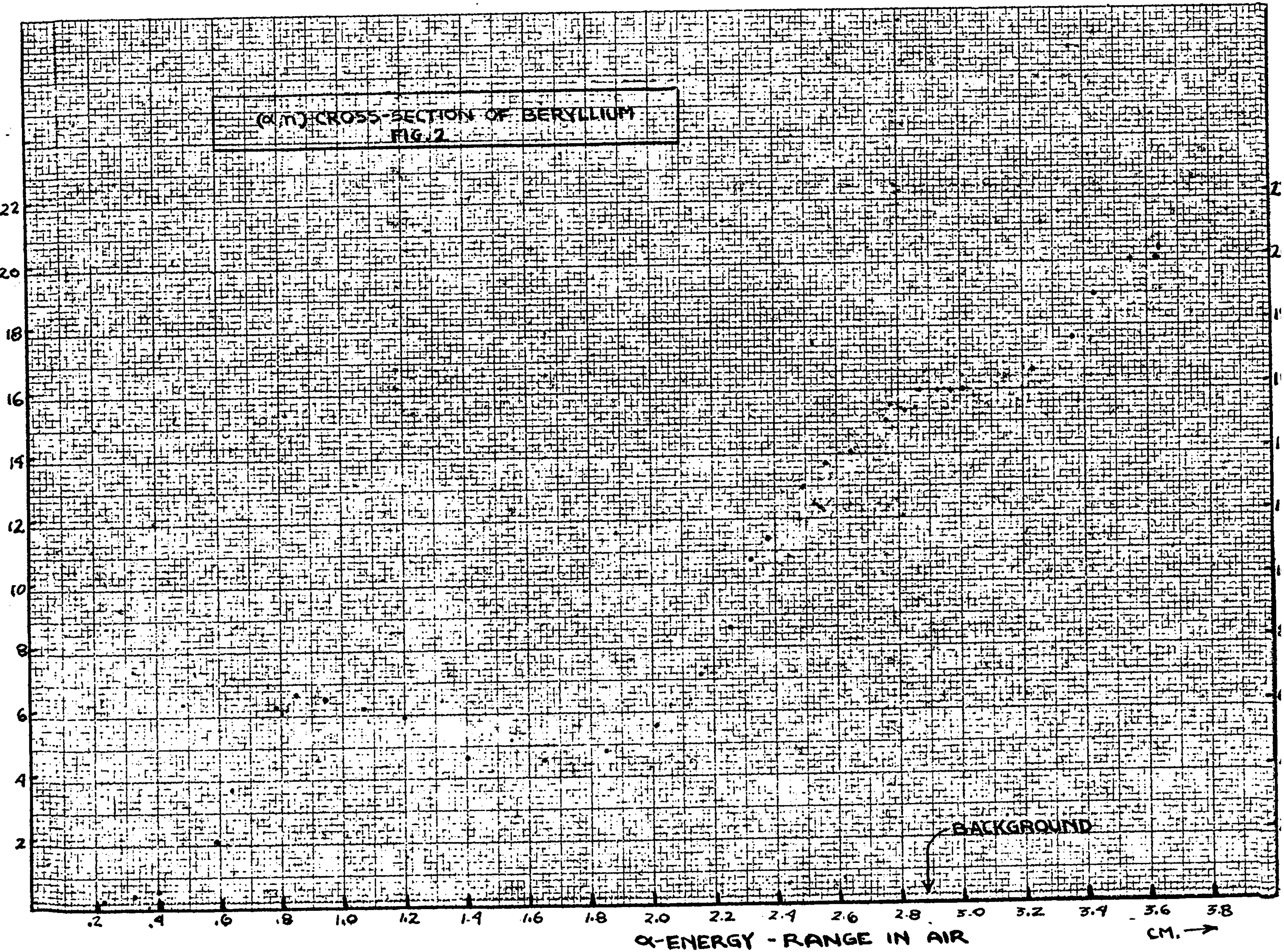
I should like to thank Prof. H. H. Barschall for suggesting this experiment and Mr. R. L. Walker for preparing most of its instrumentation. Prof. D. Lipkin kindly offered several helpful suggestions for the evaporation of the targets. I should also like to thank Mr. L. Treiman for the very fine polonium sources he prepared for this experiment.

FIG. 1 EXPLODED VIEW OF CROSS-SECTION CHAMBER





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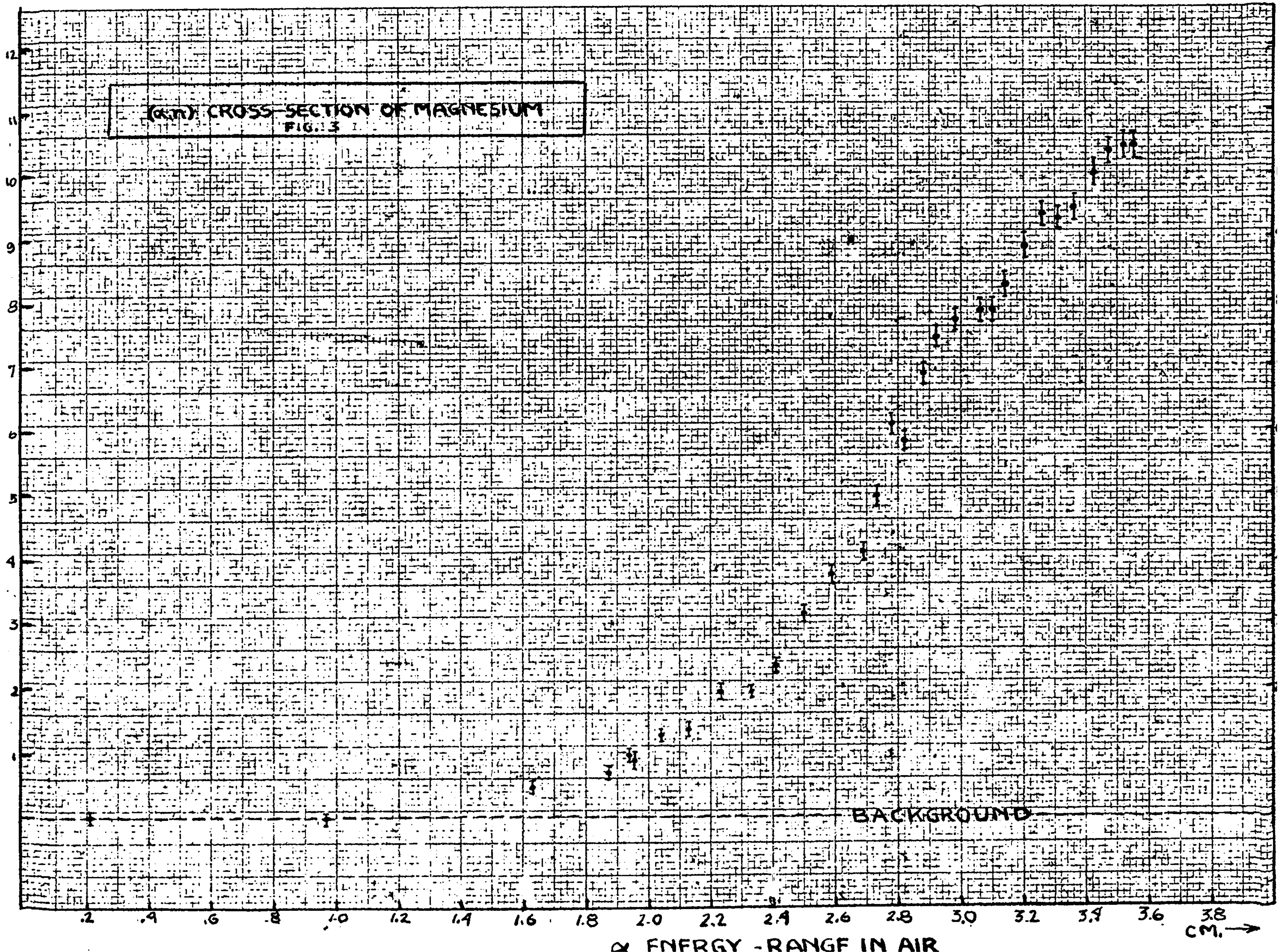

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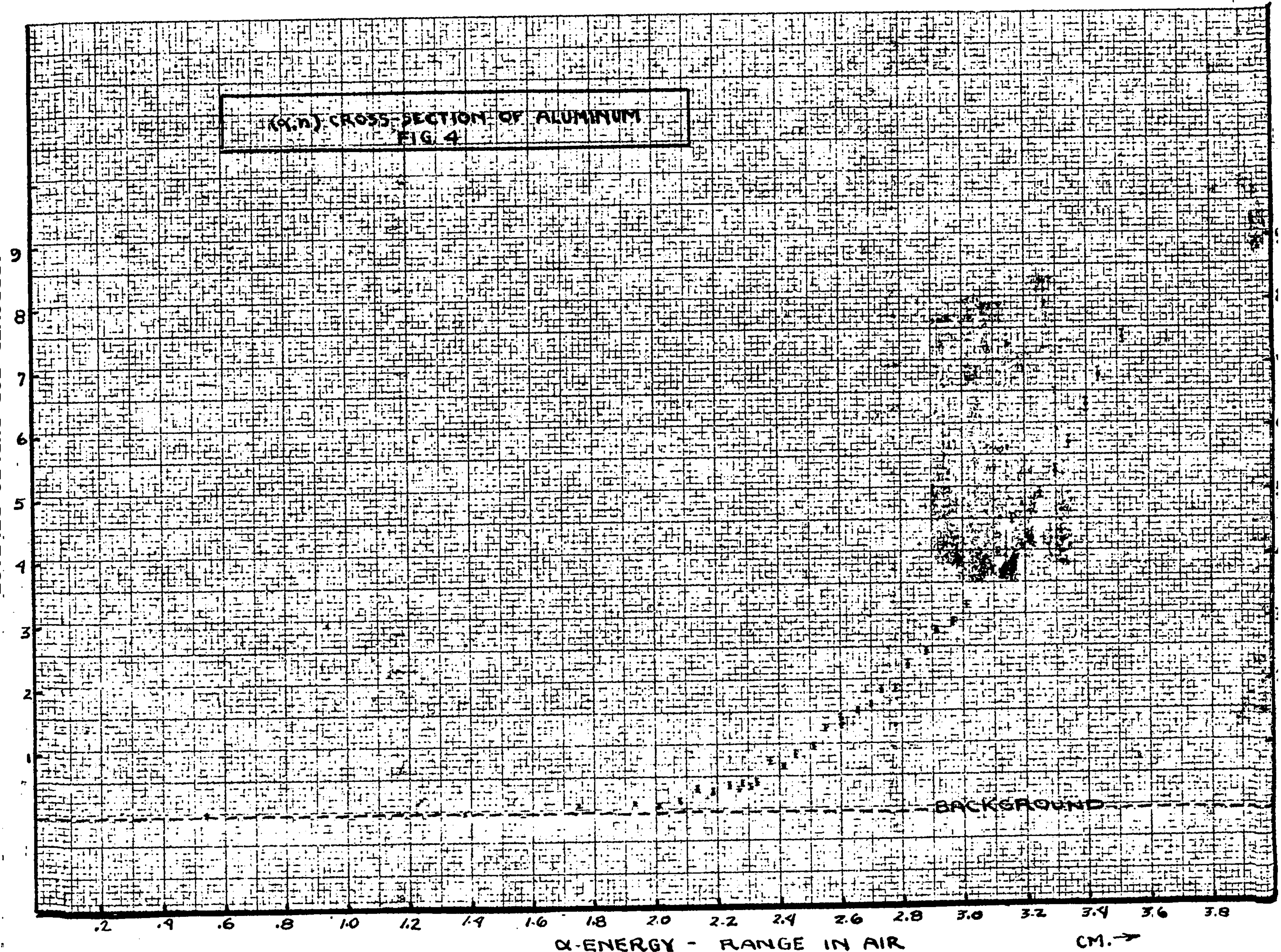

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