The Absorption of Na^{24} Gamma-Radiation in Lead, Copper, and Aluminum

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The absorption of sodium (24) gamma-radiation has been measured with a Geiger-Müller counter out to 16 cm of lead, 22 cm of copper, and 61.5 cm of aluminum. Each of the curves obtained can be analyzed into two components. These give absorption coefficients 0.454 ± 0.004 cm^{-1} and 0.62 ± 0.01 cm^{-1} for lead, 0.311 ± 0.005 cm^{-1} and 0.46 ± 0.01 cm^{-1} for copper, and 0.088 ± 0.001 cm^{-1} and 0.144 ± 0.005 cm^{-1} for aluminum. All of these are in agreement with theoretical values as obtained from Heitler's curves for the sodium gamma-rays of energies 2.76 Mev and 1.38 Mev, respectively.

1. INTRODUCTION

THE absorption of gamma-rays in various materials provides an experimental check on theoretical predictions of absorption coefficients. Such calculations have been performed by Heitler who gives[1] absorption coefficient curves for lead, tin, copper, and aluminum over a wide range of gamma-ray energies. McMillan, using the 5.4 Mev gamma-ray from the proton bombardment of fluorine, obtained[2] absorption coefficients for all four of these elements in agreement with Heitler's curves at this energy. His results furnished a check on pair-production absorption at 5.4 Mev, assuming the validity of the theory of Compton scattering as formulated[3] by Klein and Nishina and applied by Heitler.

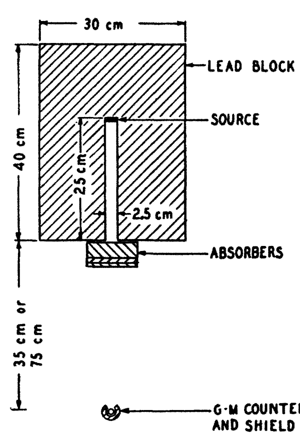


FIG. 1. Experimental arrangement for gamma-ray absorption measurements.

More recently, sodium (24) has been used for absorption studies. Accurate measurements[4] by Siegbahn, employing a magnetic electron lens spectrometer, have shown the sodium (24) gamma-ray energies to have the values 1.380 Mev and 2.758 Mev and to be present in equal numbers indicating a cascade transition process. A study of the absorption of this radiation in lead and copper was made[5] by Cork and Pidd who also used zinc (65) and cobalt (60) sources. They obtained absorption coefficients in agreement with Heitler's curves in all cases except the 2.8-Mev component of sodium. For this energy they obtained coefficients 0.285 cm^{-1} and 0.405 cm^{-1} for copper and lead, respectively, both ten percent lower than theoretical values. The discrepancy was attributed to a deficiency in the Klein-Nishina formula for Compton scattering. As a detector they employed an ionization chamber having a 50 percent greater efficiency for the lower energy gamma-ray.

Later, Groetzinger and Smith measured[6] the absorption of the 2.8-Mev component of sodium at four thicknesses of lead from 9.5 cm to 19 cm, and obtained a coefficient of 0.467 ± 0.009 cm^{-1} in agreement with Heitler's theoretical curve.

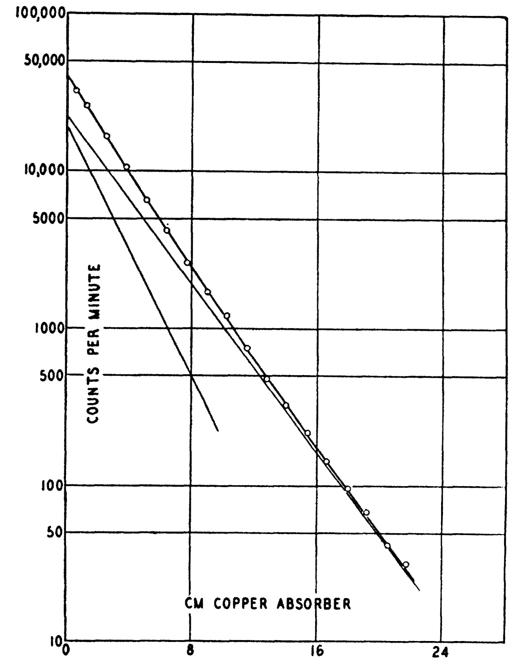
The high sensitivity of a Geiger-Müller counter makes it desirable for measurements at large absorber thicknesses. In the present ap-

* Assisted by the Office of Naval Research under Contract N6ori-44.
[1] W. Heitler, *The Quantum Theory of Radiation* (Clarendon Press, Oxford, 1936).
[2] Edwin McMillan, Phys. Rev. **46**, 863 (1934).
[3] O. Klein and Y. Nishina, Zeits. f. Physik **52**, 853 (1929).
[4] Kai Siegbahn, Phys. Rev. **70**, 129 (1946).
[5] J. M. Cork and R. W. Pidd, Phys. Rev. **66**, 227 (1944).
[6] Gerhardt Groetzinger and Lloyd Smith, Phys. Rev. **67**, 53 (1945).

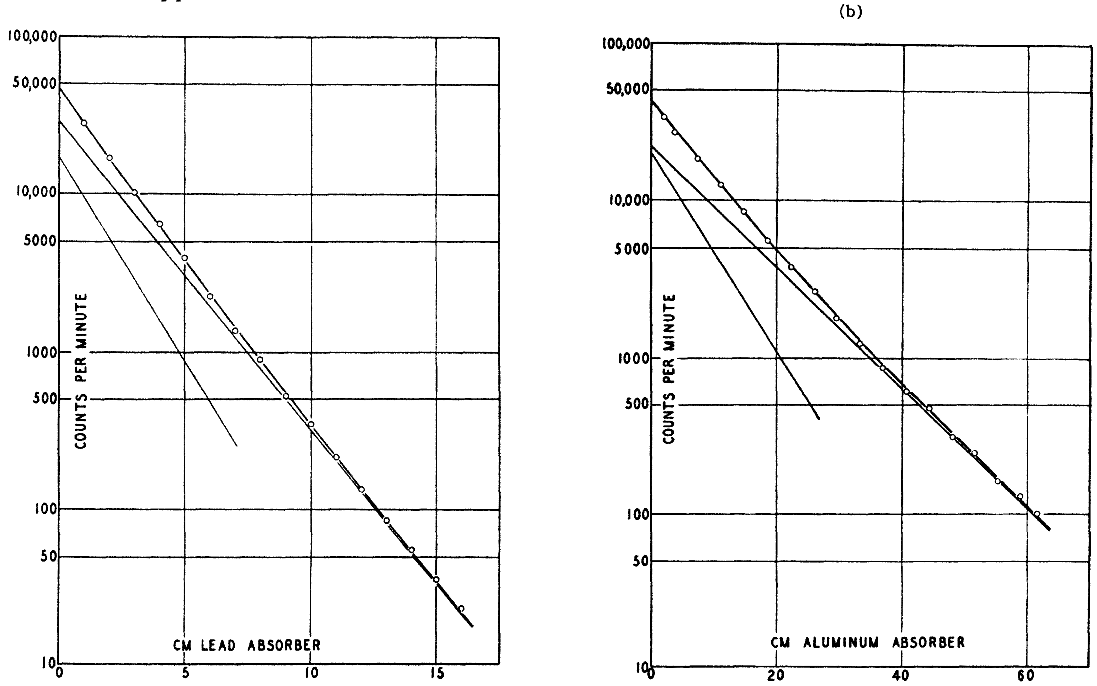
plication the further inherent advantage is gained that a counter discriminates against the lower energy gamma-ray. Bradt *et al* have shown[7] that for a brass cathode the efficiency of a Geiger-Müller counter for gamma-radiation of energy 2.76 Mev is 1.55 percent, while at 1.38 Mev it is 0.76 percent. A logarithmic plot of the composite absorption curve will, for this reason, display higher curvature in the low absorption region and at high absorption will more quickly approach a straight line corresponding to the harder component.

2. EXPERIMENTAL

The experimental arrangement is shown in Fig. 1. The gamma-ray source is placed in a lead block approximately 30 cm square and 40 cm long, having a centrally located hole 2.5 cm square and 25 cm deep. Absorbers are placed in front of the hole so as to intercept the collimated beam. A Geiger-Müller counter with a copper cathode, 3 cm long and 1 cm in diameter, is located on a line with the hole at a distance of 60 cm from the source for lead absorbers and 100 cm for copper and aluminum absorbers. The counter is shielded except on the side exposed to the radiation. A Higinbotham circuit is used for high voltage, scaling, and recording.



(b)



(a) (c)

FIG. 2. Absorption of sodium (24) gamma-radiation in lead, copper, and aluminum showing resolution into two components.

[7] Bradt, Gugelot, Huber, Medicus, Preiswerk, and Scherrer, Helv. Phys. Acta. 19, 77 (1946).

Lead absorbers were made from castings by machining to 10 cm square and various integral thicknesses. The average density of the absorbers was found to be 11.24 g per cm^3 which is 0.9 percent below the published value of 11.347 g per cm^3 for compressed lead. Four-inch square pieces of $\frac{1}{4}$-inch copper bus-bar were bolted together to form a conveniently handled set of copper absorbers. The aluminum absorbers were similarly constructed from pieces of 2s aluminum plate approximately $\frac{3}{8}$ inch thick.

Sources were made by cyclotron bombardment of metallic sodium with deuterons. For both lead and copper data were taken out to an absorption where the counting rate was approximately three times background, these points having thicknesses of 16 cm and 22 cm, respectively. In the case of aluminum a practical limit of 61.5 cm of absorption was used, at which point the counting rate was eleven times background. To test the shielding effectiveness of the lead block containing the source 27 cm of lead absorber was placed in front of the hole in order to reduce direct radiation to a fraction of a count per minute. The counting rate then observed was equal to the background counting rate with no source present (9.3 counts per minute) within the expected deviation, indicating that the amount of radiation filtered through the lead block and scattered from the walls of the room into the counter was negligible. A number of readings were taken at each value from medium to high absorption over a ten-hour period following preparation of the source. Low absorption and overlap check points were obtained several days later when sufficient decay had occurred that the counting rate was not excessive. Using 14.8 hours as the half-life of sodium (24), readings were corrected for decay and referred to a standard source strength.

3. RESULTS

Two runs were made with lead absorbers and one with copper and aluminum absorbers. The results are shown in Fig. 2. Points at zero absorption were high because of the presence of beta-rays and have, therefore, been omitted. At high absorption all three curves clearly become tangent to a straight line. Making a 0.9 percent correction for the density of the lead absorbers, the average of two runs gives an absorption coefficient for the lead tangent line of 0.454 ± 0.004 cm^{-1}. By subtracting this from the experimental curve a second straight line is obtained corresponding to an absorption coefficient of 0.62 ± 0.01 cm^{-1}. It may be noted that flaws or low density impurities in the lead absorbers would make the observed absorption coefficients appear too low.

The curves obtained using copper and aluminum absorbers may similarly be resolved, as shown in Fig. 2, into components having absorption coefficients 0.311 ± 0.005 cm^{-1} and 0.46 ± 0.01 cm^{-1} for copper, and 0.088 ± 0.001 cm^{-1} and 0.144 ± 0.005 cm^{-1} for aluminum. All of the absorption coefficients obtained appear to be in agreement with Heitler's theoretical curves at the sodium gamma-ray energies of 2.76 Mev and 1.38 Mev, respectively. It is seen from the curves that in all cases the 2.76-Mev gamma-ray gives a greater yield at zero absorption, but that the ratio of hard to soft component yields is somewhat lower than would be expected from the efficiency curves previously mentioned. This may be caused in part by a difference in counter cathode material and gas filling. Also the observed efficiency ratio is quite sensitive to the slope of the tangent line, a one percent variation in slope making a change of approximately twenty-five percent in the yield ratio.