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The Absorption of Gamma-Radiation in Copper and Lead

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The absorption coefficients for the gamma-rays emitted by certain activated elements have been accurately measured in copper and lead. The energies of the gamma-rays used, have all been determined by use of the beta-ray spectrometer. These gamma-rays are as follows: 1.14 Mev from zinc 65, 1.30 Mev from cobalt 60, and 1.38–2.85 Mev from sodium 24. The absorption coefficients for zinc and cobalt are in close agreement with the calculated values of Heitler. For the high energy component of the sodium radiation, values of 0.285 cm^{-1} and 0.405 cm^{-1} were obtained for the absorption coefficients in copper and lead, respectively. These values are more than ten percent less than the Heitler values. Since absorption in copper at this energy is due almost entirely to Compton scattering it is indicated that the Klein-Nishina formula is not completely valid.

THE absorption of gamma-radiation in matter has been the subject of many investigations. On passage through matter, the over-all absorption may be attributed to the combination of three effects, namely, the Compton effect, the photoelectric effect, and the production of electron pairs.

The absorption due to Compton scattering has been formulated[1] by Klein and Nishina. Experimental observations,[2] usually by counting ejected positrons in a Wilson chamber, have substantiated the theoretical calculations[3] for pair production. The contribution of the photoelectric effect to the absorption coefficient has been variously estimated.[4] The combination of these effects to obtain the total absorption coefficient has been fully discussed[5] by Heitler. The values as proposed by him in the energy range 1 Mev to 5 Mev for copper and lead are collected in Table I. These same values are shown graphically for lead in Fig. 1, and for copper in Fig. 2.

The contribution due to the photoelectric effect in this energy range is vanishingly small in copper, and rather small in lead. The photoelectric values for lead, proposed by Heitler, are admittedly interpolations. They were adjusted so that the over-all effect was in agreement with what was regarded as the most reliable experimental data available, namely, that of Gray.[6]

[1] O. Klein and Y. Nishina, Zeits. f. Physik **52**, 853 (1928).
[2] I. Curie and F. Joliot, Comptes rendus **196**, 1581 (1933); J. Chadwick, P. Blackett, and G. Occhialini, Proc. Roy. Soc. **144**, 235 (1934); and S. de Benedetti, Comptes rendus **200**, 1389 (1935).
[3] P. Dirac, Proc. Camb. Phil. Soc. **30**, 150 (1934); W. Heisenberg, Zeits. f. Physik **90**, 209 (1934); W. Furry and J. R. Oppenheimer, Phys. Rev. **45**, 245 (1934); and H. Bethe and W. Heitler, Proc. Roy. Soc. **146**, 83 (1934).
[4] F. Sauter, Ann. d. Physik **11**, 454 (1931); H. Hall, Phys. Rev. **45**, 620 (1934); H. R. Hulme, J. McDougall, R. A. Buckingham, and R. H. Fowler, Proc. Roy. Soc. **149**, 131 (1935); and J. G. Jaeger and H. Hulme, Proc. Roy. Soc. **148**, 708 (1935).
[5] W. Heitler, *The Quantum Theory of Radiation* (Clarendon Press, Oxford, 1936).
[6] L. H. Gray, Proc. Camb. Phil. Soc. **27**, 103 (1931).

TABLE I. Absorption in cm^{-1} due to photoelectric effect, Compton scattering, and pair production.

Energy in Mev	1		1.5		2.5		5	
	Cu	Pb	Cu	Pb	Cu	Pb	Cu	Pb
Photoelectric effect	0.0067	0.205	0.0032	0.100	0.0015	0.047	0.0006	0.018
Compton scattering	0.503	0.555	0.412	0.455	0.308	0.340	0.199	0.220
Pair production	—	—	0.0035	0.0109	0.025	0.076	0.079	0.247
Total	0.510	0.760	0.419	0.566	0.335	0.463	0.279	0.485

The Heitler values have been subjected to experimental verification by several investigations making use of x-rays[7] and by experiments using gamma-ray sources of radium and thorium.[8] None of these sources is monochromatic and the uncertainty in the composition of the radiation introduces a possible source of error. The gamma-radiation from radium[9] is far from monochromatic, possessing several discrete energies in the range from 1.1 Mev up to 2.42 Mev. Thorium (C+C″) has often been regarded as a monochromatic source of radiation of energy 2.65 Mev, but it is now known[10] that there is also present a component of as much as 15 percent, at an energy about 1.68 Mev.

The beta-ray spectrometer has now been used to measure the energies of several gamma-rays emitted by various induced radioactive sources. This makes it possible to check absorption coefficients with greater certainty as to the energy being investigated. In this investigation the following gamma-rays are employed: 1.14 Mev from[11] zinc (65), 1.30 Mev from[12] cobalt (60), and 1.38–2.85 Mev from[13] sodium (24). The energy 2.85 Mev for the high energy component of sodium is the average of the two most recently reported values.

EXPERIMENTAL

The value obtained for the absorption coefficient to some extent depends upon the geometry employed. In the Klein-Nishina formula the reacting photons are considered lost. Actually they are scattered with a well-known distribution and some of these scattered photons of lower energy are received by the detector. To minimize the solid angle subtended by the detector, and hence any disturbing effect due to Compton scattering, the pressure ionization chamber is kept small in size and is placed as far from the absorber as is practicable.

The experimental arrangement used is shown in Fig. 3. The source is placed in a hole 1 cm in

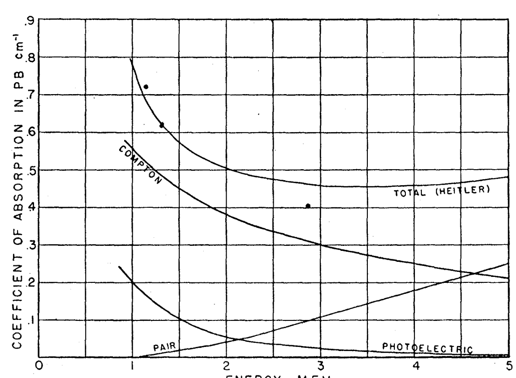

FIG. 1. The absorption of gamma-radiation in lead.

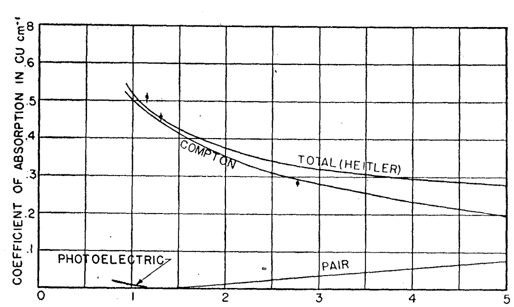

FIG. 2. The absorption of gamma-radiation in copper.

[7] A. Petrauskas, L. C. VanAtta, and F. E. Myers, Phys. Rev. **63**, 389 (1943).
[8] L. Meitner and H. Hupfield, Zeits. f. Physik **67**, 147 (1931); C. Y. Chao, Proc. Nat. Acad. **16**, 431 (1930); W. Gentner and J. Starkiewicz, J. de phys. et rad. **6**, 340 (1935); W. Gentner, J. de phys. et rad. **6**, 274 (1935).
[9] A. I. Alichanow and G. R. Latychev, J. Phys. U.S.S.R. **3**, 263 (1940).
[10] A. Alichanow and V. Dzelepov, Comptes rendus Acad. Sci. U.S.S.R. **20**, 163 (1938); G. C. Curran, P. I. Dee, and J. E. Strothers, Proc. Roy. Soc. **A174**, 546 (1940).
[11] C. E. Mandeville, Phys. Rev. **64**, 265 (1943).
[12] C. E. Mandeville and H. W. Fulbright, Phys. Rev. **64**, 265 (1943); M. Deutsch and L. G. Elliott, Phys. Rev. **62**, 558 (1942).
[13] C. E. Mandeville, Phys. Rev. **62**, 309 (1942); **63**, 387 (1943); L. G. Elliott, M. Deutsch, and A. Roberts, Phys. Rev. **63**, 386 (1943).

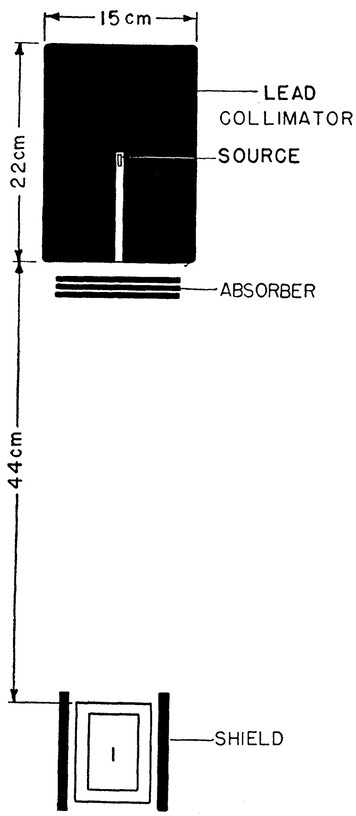

FIG. 3. Arrangement of apparatus to measure absorption coefficient.

diameter and 15 cm deep symmetrically situated in a solid cylindrical lead block. The absorbers are placed in position as shown so that adding them in turn the final plate is at a distance of 44 cm from the top of the ionization chamber.

The intensity of the sources, made in the cyclotron, was such that readings could be made in a reasonably short time although the radiation traversed several centimeters of lead. Sodium (24) could easily be made of strength equivalent to several grams of radium and the absorption was followed through 12 cm of lead. The absorption coefficient was measured by using increasingly thick absorbers and noting the activity in the pressure ionization chamber connected to a string electrometer. A background reading was obtained with an absorber of 25 cm of lead. Under this condition the background reading was practically the same whether the source was present or not, indicating a negligible scattering from the walls and neighboring bodies.

Some small part of the radiation received by the ionization chamber will be Compton scattered photons. On using successive thicknesses of lead, however, an equilibrium ratio will be reached between scattered and unscattered photons in the forward direction. This should then introduce no error in the finally observed absorption coefficient.

RESULTS

The results obtained for the absorption coefficients of zinc and cobalt radiations are within experimental error what would have been predicted by theory. These values are 0.72 cm^{-1} and 0.64 cm^{-1} in lead and 0.51 cm^{-1} and 0.46 cm^{-1} in copper, for zinc and cobalt radiations, respectively. Sodium gamma-radiation has been shown to consist of two components of energy 1.38 Mev and 2.85 Mev. Moreover, coincidence measurements indicate that for each photon of energy 1.38 Mev there is one photon of energy 2.85 Mev. The result obtained by plotting the intensity of the transmitted radiation as a function of the thickness of the lead absorber is shown in Fig. 4. The intensity is plotted logarithmically and had there been a single monoenergy gamma-ray, the values would lie along a straight line. It is ap-

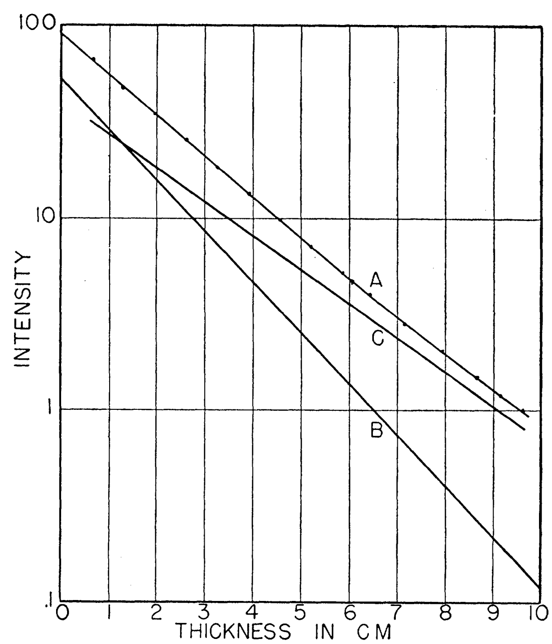

FIG. 4. Resolution of the absorption of gamma-radiation from sodium (24).

parent that the slope changes as the thickness increases. To find the absorption coefficient of the 2.85-Mev radiation it is necessary to subtract the contribution due to the 1.38-Mev radiation. If it be assumed that for zero thickness there are present equal numbers of photons of the two components, then, of the total initial activity, the contribution of each type of photon will be in the ratio of the absorption coefficients for the two radiations. Thus for the figure shown, the zero thickness intensity for the combined radiation is 92.0 in arbitrary units. This should then be resolvable into two components of initial intensities 54.0 and 38.0 expressed in the same units, for the 1.38 Mev and 2.85 Mev, respectively, since the absorption coefficients are approximately in the ratio of 60 to 40.

Since the absorption coefficient of the 1.38-Mev radiation is fairly accurately known, the decrease of this radiation with increasing thickness of lead can be predicted. This is shown in curve B, Fig. 4. On subtracting this activity from that actually observed shown in curve A, the values shown in curve C are obtained. This is then the true absorption curve for the 2.85-Mev radiation. The absorption coefficient obtained for lead in this way is found to be 0.405 cm^{-1}. In a similar manner the absorption coefficient, for the 2.85-Mev radiation in copper is found to be 0.285 cm^{-1}. The radiation was followed through 10 cm of copper in addition to 5 cm of lead. These values are more than 10 percent less than the Heitler summation values and are shown as points in Figs. 1 and 2. They would not be greatly changed by assuming slightly altered ratios for the intensities of the components.

The values here reported are believed to be not in disagreement with other measurements reported on the radiation from thorium ($C+C''$). Gray and Tarrant reported a value at 2.65 Mev of 0.465 cm^{-1} for lead. They used absorbers only up to 6 cm in thickness. Had they gone to greater thickness and corrected for the lesser energy component it is quite reasonable to expect their value might have been reduced to a value compatible with the results reported here. Chao reported a value for lead of 0.477 cm^{-1}. He also used a thickness of lead only up to 6.37 cm. The geometry of his apparatus was very favorable, having a distance of 2 meters between absorber and detector. However, a background reading was subtracted from each reading which was obtained by simply changing the direction of the primary beam so as to miss the detector. Because of the Compton scattering this would not be a true background but would be too large so that the net absorption curve would be too steep, yielding an absorption coefficient too large.

Since this difference appears clearly to be greater than the experimental error in the measurement, its explanation raises grave questions. Had it occurred only in lead then one might have attributed it to inaccuracy in the calculation of the photoelectric contribution. It would have required reducing to zero, the value attributed to lead by Heitler, for this energy. Since it also occurs in copper at an energy where the photoelectric effect is vanishingly small and where pair production is not appreciably large it is more reasonable to attribute it to some insufficiency in the Klein-Nishini formula for this energy.

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