numerical calculations on the basis of Eq. (20) have been performed for incident gamma-rays of 17-Mev energy diffusing through water. The curves of angular distribution as given by the number of gamma-rays per unit *energy* interval (energy measured in Mev) and per unit solid angle are plotted in Fig. 2 for energies of 15, 10, and 5 Mev and $\zeta=1$, 2, 4, 8, 16, and 32. It will be noted that the angular distribution is very close to Gaussian even for relatively small thicknesses of material.

For a complete picture of the energy and angular distribution one must add to the above curves the contributions of the two terms containing delta-functions in (20) representing the unscattered and singly scattered gamma-rays.

VI. CONCLUDING REMARKS

The principal source of error in the solution obtained above results from the approximation made in going from Eq. (4) to Eq. (5). Going back to the fundamental equations, this corresponds to approximating the factor $\frac{1}{2}(\epsilon'/\epsilon)^2[\epsilon/\epsilon'+\epsilon'/\epsilon]$ in the Klein-Nishina formula [I, Eq. (3)] by ϵ'/ϵ (neglecting the term in $\sin^2\Theta$). The extent of this error is shown in Fig. 3 where both factors are plotted. Some improvement in the results might be obtained if one used in place of ϵ'/ϵ, the quantity $c\epsilon'/\epsilon$ where c is a number lying between 0.5 and 1.

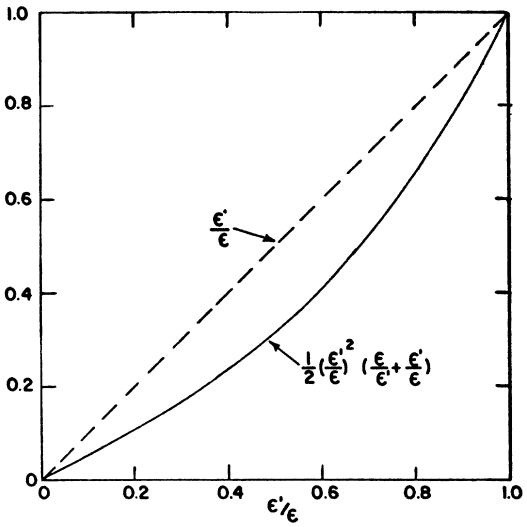

FIG. 3. Extent of approximation to Klein-Nishina formula involved in solution of the diffusion equation.

It would be of value to determine the corrections due to the difference between the approximate expression used and the correct expression by a perturbation treatment. A calculation of this type is planned for the future.

We wish to express our thanks to Mr. G. F. Bing for his aid with the numerical calculations.

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Measurements of Gamma-Ray Absorption Coefficients*†

CHARLOTTE MEAKER DAVISSON‡ AND ROBLEY D. EVANS
Massachusetts Institute of Technology, Cambridge, Massachusetts
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The absorption of γ-rays in Al, Cu, Sn, Ta, and Pb was measured using γ-rays from I^{131}, Cu^{64}, Mn^{54}, Co^{60}, Zn^{65}, and Na^{24}. Tests showed that scattering from nearby objects and from the absorber were negligible. Tests of the absorption of radium γ-rays in Pb showed good agreement with other workers and with theory. The absorption curves of I^{131} showed the presence of a 0.65-Mev γ-ray about 15 percent as abundant as the 0.367-Mev γ-ray. Absorption coefficients measured with the other sources showed agreement within 0.5 percent to 2 percent with theory. An anomalous absorption coefficient (5 percent less than expected) with tantalum absorber ($Z=73$) and Zn^{65} and Co^{60} sources ($h\nu\sim1.2$ Mev) needs reinvestigation.

I. INTRODUCTION

WITH the increasing use of radioactive materials, it is becoming important to know with greater accuracy how the interaction of γ-rays with matter varies with γ-ray energy and with atomic number. In the energy range of most radioactive γ-rays, that is, from 0.1 Mev to 6 Mev, the processes to be considered are the Compton effect, the photoelectric effect, and pair production. Theoretical analyses of these processes have been made, and from them values of absorption coefficients can be found for comparison with experiment. A summary of most of these theories has been given by Heitler.[1] We have made a detailed study of the results of the theories and shall publish elsewhere[2] our calculations in the form of equations, tables, and curves.

Early experimental studies of absorption coefficients

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† Presented at the April, 1948, meetings of the American Physical Society.
‡ Present address: care of Dr. J. W. Davisson, Crystal Branch, Naval Research Laboratory, Washington 20, D. C.

[1] W. Heitler, *The Quantum Theory of Radiation* (Oxford University Press, London, 1936), pp. 119 *et seq.*
[2] C. M. Davisson and R. D. Evans, Revs. Modern Phys. (to be published).

were made with sources of radium, RdTh, and x-rays. Recently, strong sources of artificially radioactive substances have been made available; and with these it is now possible, with single energy γ-rays, to extend absorption studies beyond the energy range practicable with x-rays.

II. PRESENT EXPERIMENT

With absorbers of aluminum, copper, tin, tantalum, and lead we have rechecked the results of other workers with sources of Zn^{65} (1.14 Mev), Co^{60} (1.16 and 1.31 Mev), and Na^{24} (1.38 and 2.76 Mev), and in addition have studied the absorption of the γ-rays from I^{131} (0.367-Mev and others), Cu^{64} (annihilation radiation), and Mn^{54} (0.835 Mev).

A. Sources

The sources of I^{131}, Cu^{64}, Zn^{65}, and Na^{24} were obtained from the Atomic Energy Commission at Oak Ridge, while the Mn^{54} and Co^{60} sources were prepared in the M.I.T. cyclotron by deuteron bombardment of chromium and cobalt, respectively. The decay curves of I^{131}, Cu^{64}, and Na^{24} showed the characteristic half-lives of each isotope, and corrections were made for decay during the readings. The Mn^{54} sample was allowed to stand for several months before being used, so that the 6.5-day activity of Mn^{52} was less than 0.1 percent of the activity of Mn^{54} at the time of the measurements.

The sources were placed in 10-mm Pyrex tubing, sealed off, and placed in an aluminum container which fitted into a brass-lined hole in the lead source block (Fig. 1). In the case of long sources which emitted two γ-rays (Co^{60}, I^{131}, and Na^{24}), correction was made for different self-absorption in the source before comparing results with theory.

B. Absorbers

The five absorbers, aluminum, copper, tin, tantalum, and lead, were chosen because they could be obtained easily in pure form and because they covered the full range of Z values in satisfactory steps. They were carefully machined to the desired lengths, and their densities determined from measurements of length, diameter, and weight. In addition spectroscopic analyses were made of the tantalum and lead absorbers; and their densities were measured at the National Bureau of Standards.

The qualitative spectroscopic analysis of Ta, made by the M.I.T. Spectroscopy Laboratory, showed traces (<0.01 percent) of Al, Ca, Cu, Fe, K, Mn, and Na; and Si as a minor constituent (>0.01 percent). Calculations showed that the presence of these contaminations, even at abundances greater or less by a factor of 10, should not affect the measured absorption coefficient by more than 0.5 percent. A further chemical analysis by Mr. D. Guernsey of the M.I.T. Metallurgy Department showed that at least 99.5 percent of the sample was tantalum.

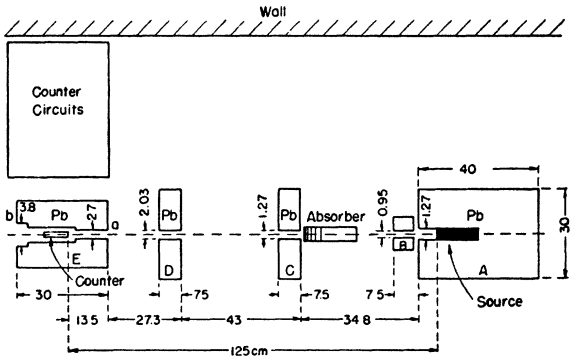

FIG. 1. Schematic plan view of apparatus and collimating system, approximately to scale. All dimensions are shown in cm.

An analysis of one of the lead absorbers by the New England Spectrochemical Laboratories showed that the absorber contained from 0.1 to 10 percent of bismuth. The measured density of 11.29 gm/cc would indicate that about 4 percent of the sample was bismuth. Calculations show, however, that even if the sample were 10 percent bismuth, the absorption coefficients expected theoretically would not differ from those we have used for pure lead by more than 0.5 percent.

C. Detectors

The counters used had copper mesh cathodes and were filled with a mixture of argon and alcohol. The efficiency of copper counters is substantially proportional to the photon energy,[3] and this was assumed for our counters in comparing experimental results with theory. The single counter used for I^{131}, Cu^{64}, Mn^{54}, and Co^{60} was of the cylindrical type, 2 cm in diameter, with an effective length of about 8 cm. To eliminate annihilation radiation from the Zn^{65} readings and the 1.38-Mev γ-rays from the Na^{24} readings, coincidence counters were used. These were of the bell type geometry with very thin glass "bubble" windows. They were 2 cm in diameter, and had an effective length of about 3 cm. They were arranged end on, with the thin windows facing each other, in an arrangement such that thin copper absorbers could be placed between them.

The voltage supplies were well regulated, and a daily check was made to be sure the counters were operating on their voltage plateaus. When necessary, counting rates were corrected for the deadtime of the single counter and the resolving time of the coincidence counters.

D. Geometry

The geometry of apparatus for measuring absorption coefficients must be such that the scattered radiation which reaches the detector is either negligible or can be quantitatively determined.

[3] See, e.g., Roberts, Elliott, Downing, Peacock, and Deutsch, Phys. Rev. 64, 268 (1943); and Bradt, Gugelot, Huber, Medicus, Preiswerk, and Scherrer, Helv. Phys. Acta 19, 77 (1946).

TABLE I. Cross sections and maximum angle of scattering for a transmission of 0.001 with 2.76-Mev γ-rays, for various ratios S/B of scattered to transmitted photons.

Element	Electrons per cc	Absorber thickness for T =0.001 (cm)	$N_e x_0$ (electrons per cm²)	Cross section in cm²/electron if S/B is 0.001	0.01	0.1
Al	7.86×10^{23}	69.7	5.48×10^{25}	1.82×10^{-29}	1.82×10^{-28}	1.82×10^{-27}
Cu	2.46×10^{24}	21.2	5.20×10^{25}	1.92×10^{-29}	1.92×10^{-28}	1.92×10^{-27}
Sn	1.85×10^{24}	25.5	4.72×10^{25}	2.12×10^{-29}	2.12×10^{-28}	2.12×10^{-27}
Pb	2.71×10^{24}	14.8	4.00×10^{25}	2.50×10^{-29}	2.50×10^{-28}	2.50×10^{-27}
Maximum scattering angle, θ_0				0.5°	1.6°	5°–6°

A diagram of our geometry is shown in Fig. 1. To prevent radiation scattered from nearby objects from reaching the detector, we surrounded both the source and the detector with lead. The least a scattered ray could pass through was 15 cm, which would reduce the intensity of 2.76-Mev γ-rays to 0.1 percent, and softer scattered rays to negligible proportions. That they were negligible was shown by the following tests with the Co^{60} source. With 20 cm or more of lead in the absorber position, the counting rate was the same as the background, within the experimental error of 1.5 percent. Addition of a large aluminum sheet placed parallel to and at different distances from the γ-ray beam, with the 20 cm of lead in the absorber position, produced no change from the background counting rate.

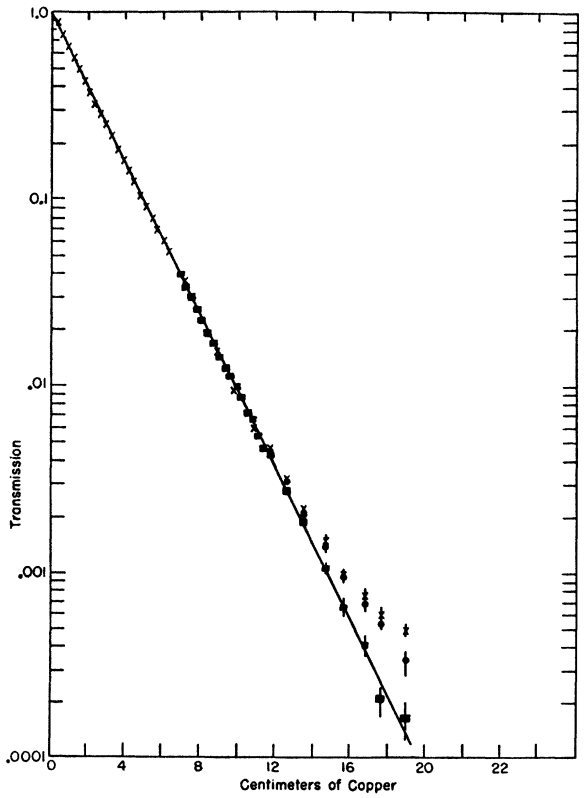

FIG. 2. Transmission of γ-rays of Co^{60} through copper, as measured with different degrees of final collimation. The solid line represents the values expected theoretically if no secondary quanta reach the detector. Crosses: with counter at near end (a) of lead block (E), no collimation after absorber. Solid circles: with counter withdrawn 13.5 cm into lead block (E), no collimation after absorber. Solid squares: with counter in lead block, and collimators C and D of Fig. 1 in place.

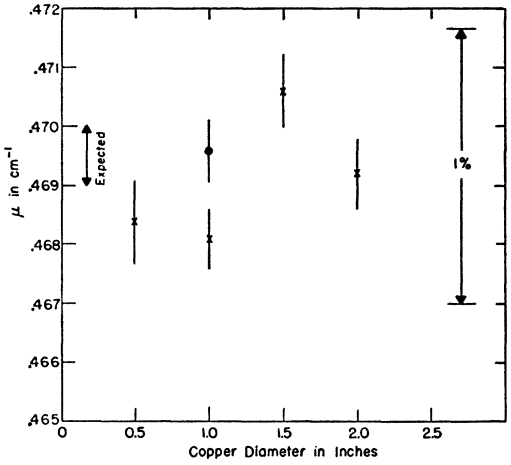

FIG. 3. Absorption coefficient of γ-rays of Co^{60} in copper absorbers of various diameters, showing that multiple scattering is effectively excluded by the collimation shown in Fig. 1. Crosses: data calculated using a deadtime of 149 μsec. Solid circle: data calculated using 119 μsec deadtime.

Compton singly scattered radiation is the most important of the secondary radiations produced in the absorber itself which might reach the detector. An analysis of the amount reaching the detector has been made by Tarrant.[4] If it is assumed that the angles involved are small, that the absorber is not very close to either the source or the detector, and that the efficiency of the detector is proportional to the energies of the photons, then the ratio of the number of scattered photons, S, to the number of transmitted photons, B, actuating the detector is

$$S/B = N_e x_0 \, {}_e\sigma_s^{\theta_0}, \tag{1}$$

where N_e is the number of electrons per unit volume in the absorber, x_0 is the length of the absorber, and ${}_e\sigma_s^{\theta_0}$ is the cross section for the total photon energy scattered between 0 and θ_0. The equation for ${}_e\sigma_s^{\theta_0}$ will be published elsewhere.[2] For small angles it is[5]

$${}_e\sigma_s^{\theta_0} = \pi r_0^2 \theta_0^2 [1-(\theta_0^2/12)(9\alpha+4)], \tag{2}$$

where α is $h\nu/m_0c^2$, and r_0 is e^2/m_0c^2.

From Eq. (2) we can estimate the maximum allowable angle, θ_0, for any arbitrarily chosen value of S/B. This

[4] G. T. P. Tarrant, Proc. Camb. Phil. Soc. 28, 475 (1932).

[5] This does not agree with the equation given by Tarrant, which is

$${}_e\sigma_s^{\theta_0} = \pi r_0^2 \theta_0^2 \{1+(\theta_0^2/4)[(11/2)\alpha-1]\}.$$

We can find no mistake in our algebra. Also, values calculated from his equation deviate from the correct values more than the still poorer approximation

$${}_e\sigma_s^{\theta_0} = \pi r_0^2 \theta_0^2.$$

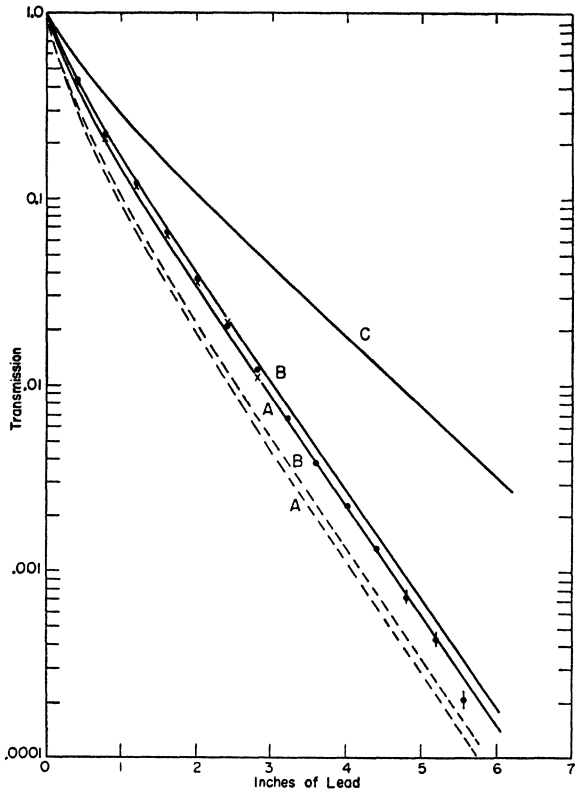

FIG. 4. Transmission of γ-rays of radium, in equilibrium with its decay products, through lead, in very narrow-beam geometry. *Crosses:* Experimental points using 1.76 mg Ra salt in glass tube. *Solid circles:* Experimental points using 27.7 mg Ra in a platinum cylinder of unknown wall thickness. Various theoretical transmission curves are shown, each calculated using the transmission through 0.5-mm Pt as unity. *Dashed curves:* Assume detector sensitivity is independent of photon energy. *Solid curves:* Assume detector sensitivity is linearly proportional to photon energy. *Curves A:* the number *vs* energy distribution in the γ-ray spectrum is taken from the data of C. D. Ellis and M. A. Aston (Proc. Roy. Soc. **129A**, 180 (1930)) as compiled by R. D. Evans (Nucleonics **1**, No. 2, 32 (1947)). For each individual γ-ray component, the effective absorption coefficient is taken as $(\tau+\kappa+\sigma)$. *Curves B:* The γ-ray spectrum is a blend of Ellis and Aston for the low energy components up to 1.12 Mev, and of G. D. Latyshev (Revs. Modern Phys. **19**, 132 (1947)) for the high energy components. Individual absorption coefficients $(\tau+\kappa+\sigma)$. *Curve C:* Spectrum of Ellis and Aston: effective absorption coefficients taken as $(\tau+\kappa+\sigma-\sigma_s)$, i.e., as broad-beam with no scattered radiation excluded from the counter. The best fit is with the solid curve *A*; i.e., all scattered radiation assumed excluded from the counter, counter sensitivity proportional to photon energy, and Ellis and Aston spectrum. The transmission curve is not strongly sensitive to the assumed γ-ray spectrum, as shown by the position of the solid curve *B*.

is done in Table I for 2.76-Mev γ-rays and a transmission of 0.1 percent. With available source strengths it is unlikely that a transmission of 0.001 could be measured to better than 1 percent, so with a scattering angle of 1.5° to 2°, no correction would need to be made for single scattering.[6]

[6] Analysis of multiply scattered photons, or of secondary radiation due to annihilation radiation or bremsstrahlung which reach the detector is more difficult. We have made no estimate of this for our geometry, but our scattering tests indicate that it must be negligible.

From the dimensions given in Fig. 1, the maximum angle, θ_0, at which a γ-ray could be scattered from the edge of the absorber next to the lead shield *C* and still reach the detector was 1.3° for a γ-ray from the center of the source scattered to the center of the detector (2.6° from edge of source to edge of detector). Thus, it seemed reasonable to suppose that no correction would need to be made for radiation scattered from the absorber.

Tests for such radiation scattered from the absorbers were made both by taking transmission measurements with lead collimators in different positions, and, with the final amount of collimation, by taking transmission measurements with different diameters of copper absorbers. Transmission curves for different amounts of lead collimation are shown in Fig. 2. Without the lead collimation after the absorber (*C* and *D* in Fig. 1), some scattered radiation was reaching the detector; but with this shielding the measurements agree with the expected values to transmissions as low as 0.0002. The average absorption coefficients measured with copper absorbers of different diameters are plotted in Fig. 3. The results show no consistent variation with absorber diameter, are the same within 1 percent, and show excellent agreement with the value expected theoretically.

As a further scattering check, and for comparison of our results with previous workers, a study was made of the absorption of radium γ-rays in lead. Our measured transmissions are plotted in Fig. 4, where they are compared with the transmissions to be expected theoretically, making different assumptions as to γ-ray spectra, counter sensitivity, and amount of scattered radiation reaching the detector. Our results agree well with the curves for no scattering, indicating again that in our geometry scattered radiation was negligible.

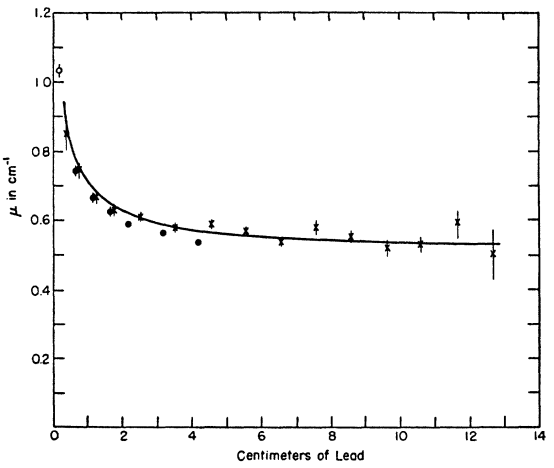

FIG. 5. Theoretical and experimental dependence of the absorption coefficients for the γ-rays of radium (and its decay products) on Pb filtration. Initial filtration 0.5 mm Pt. *Solid Curve:* derived from the slope of the solid curve *A* of Fig. 4. *Crosses:* values from slope between adjacent experimental points of Fig. 4. *Solid Circles:* experimental values of Roberts (reference 7).

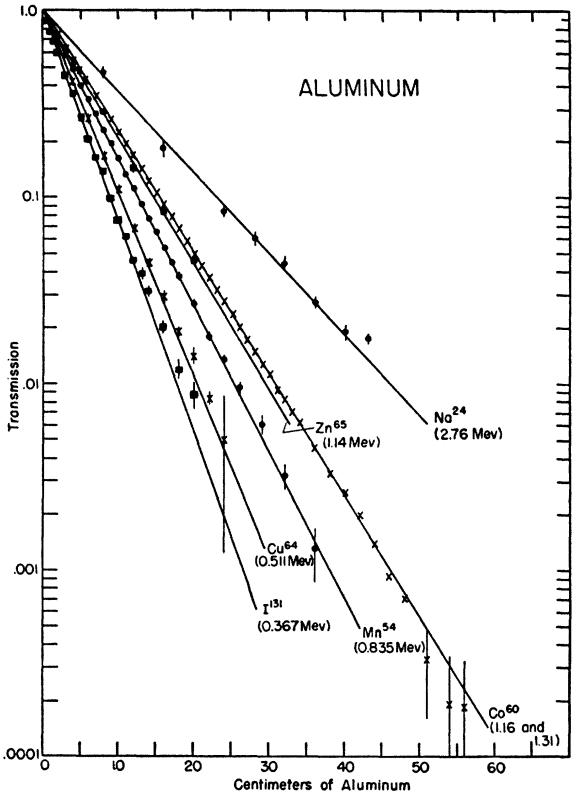

FIG. 6. Transmission of γ-rays from various radionuclides through Al. Solid curves: theoretical transmission for the γ-ray energy shown opposite each curve.

However, our measurements were not accurate enough to show which of the radium γ-ray spectra is the better.

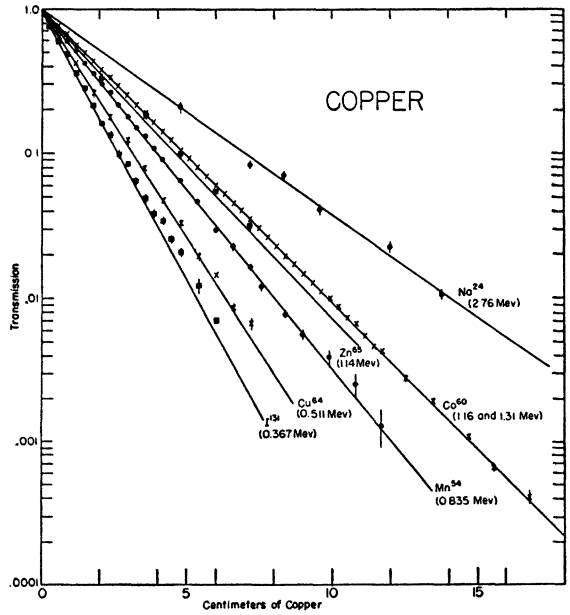

FIG. 7. Transmission of γ-rays from various radionuclides through Cu. Solid curves: theoretical transmission for the γ-ray energy shown opposite each curve.

In Fig. 5 are plotted the absorption coefficients calculated from the change in transmission between points for two adjacent absorber thicknesses. They are compared with values expected theoretically, and also with the values of μ measured in a similar manner by Roberts.[7] Roberts' values are consistently less than ours, and less than those expected theoretically. His geometry was such that he had to make corrections for scattering, and it is possible that all the scattered radiation was not accounted for. Our values also fall very well on the curve for absorption coefficient *vs* absorber given by Mayneord and Cipriani.[8] The weighted average of the absorption coefficients plotted in Fig. 5 was 0.569 ± 0.008 cm^{-1} or $(2.115\pm0.030)\times10^{-25}$ cm^2/electron for more than 2 cm of lead, and

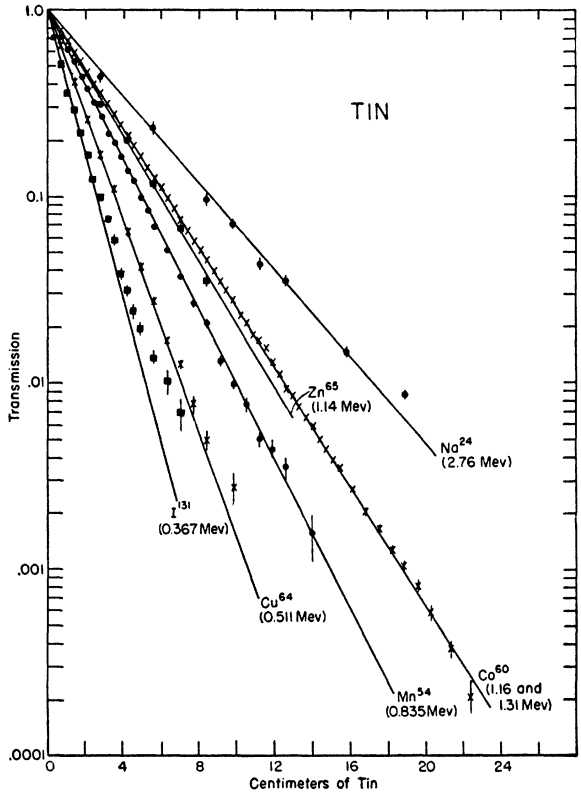

FIG. 8. Transmission of γ-rays from various radionuclides through Sn. Solid curves: theoretical transmission for the γ-ray energy shown opposite each curve.

was 0.556 ± 0.008 cm^{-1} or $(2.065\pm0.028)\times10^{-25}$ cm^2/electron for more than 5 cm of lead. These are in reasonable agreement with those of other workers.[9]

[7] J. E. Roberts, Proc. Roy. Soc. **183A**, 338 (1945).
[8] W. V. Mayneord and A. J. Cipriani, Can. J. Research **25A**, 303 (1947).
[9] See, e.g., K. W. F. Kohlrausch, Sitzber. Akad. Wiss. Wien **126IIa**, 441, 683, 887 (1917); Handbuch Exp. Phys. **15**, 78 (1928); J. S. Rogers, Proc. Phys. Soc. London **44**, 349 (1932); I. Zlotowski, J. phys. rad. **6**, 242 (1935); Ketelaar, Piccard, and Stahel, J. phys. rad. **5**, 385 (1934); and L. Meitner and H. H. Hupfeld, Z. Physik **67**, 147 (1931).

E. Experimental Procedure

At the beginning and end of each day, and sometimes more frequently, the circuits were checked, the counter plateau was determined, and the background and the counting rate without absorber were measured.

The transmission was calculated as the ratio of the corrected counting rate with the absorber to that with no absorber, and the absorption coefficients were calculated from the transmissions.

The errors calculated are the standard deviations, and combine in the usual way the errors in the counting rate and in the measured counter deadtime. In averaging the absorption coefficients the values were weighted according to the inverse of their errors, and the standard deviation of the average calculated from the equations given in the *Handbook of Chemistry and Physics*.

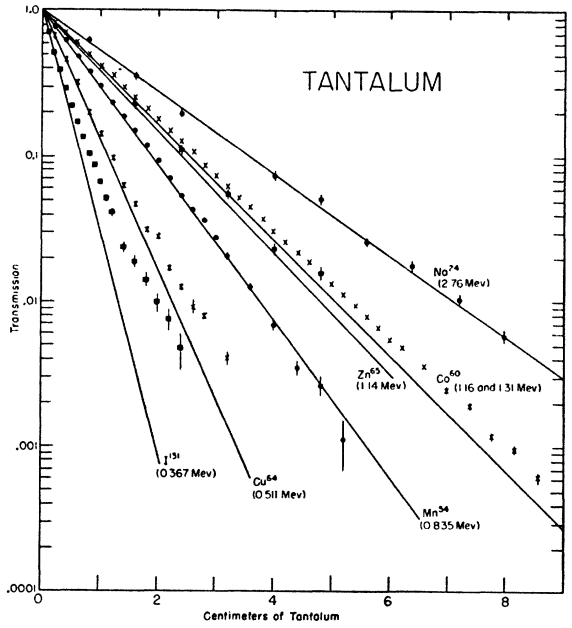

FIG. 9. Transmission of γ-rays from various radionuclides through Ta. Solid curves: theoretical transmission for the γ-ray energy shown opposite each curve.

III. EXPERIMENTAL RESULTS

Our measured transmissions in each absorber are shown in Figs. 6 to 10; the average absorption coefficients are summarized in Table II; and the measured electronic coefficients, plotted against atomic number, are shown in Fig. 11. The solid lines in these figures indicate the results expected according to existing theories. The measurements were made in 1947.

The I^{131} results were unexpected, since in 1947 the highest energy which I^{131} was known to emit was 0.367 Mev.[10] The transmissions in lead could be repeated

[10] Downing, Deutsch, and Roberts, Phys. Rev. **61**, 686 (1942).

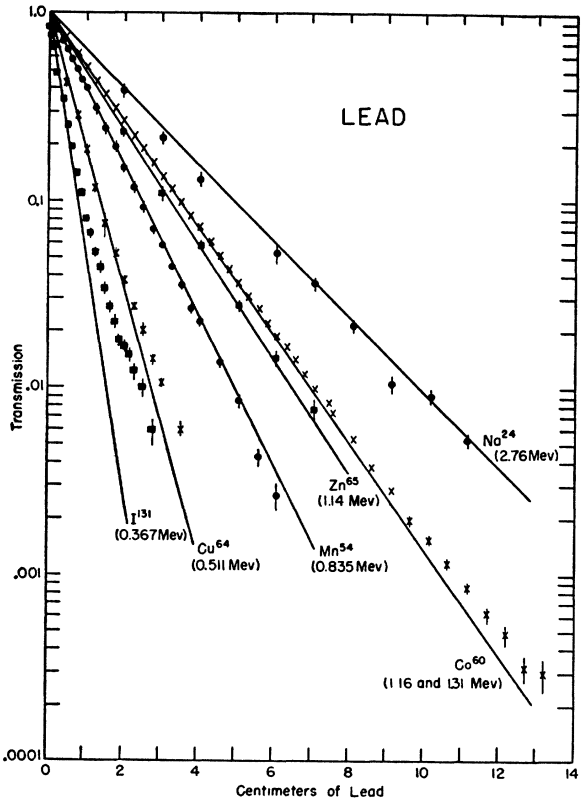

FIG. 10. Transmission of γ-rays from various radionuclides through Pb. Solid curves: theoretical transmission for the γ-ray energy shown opposite each curve.

TABLE II. Measured absorption coefficients compared with those expected theoretically.[a]

Source	Element	Meas. μ (cm^{-1})	Theor. μ (cm^{-1})	% difference
Mn^{54}	Al	0.1823±0.0003	0.1820	+0.16
(0.835	Cu	0.5782±0.0013	0.5718	+1.12
Mev)	Sn	0.4683±0.0014	0.4628	+1.19
	Ta	1.210 ±0.004	1.228	−1.47
	Pb	0.9368±0.0041	0.9256	+1.21
Zn^{65}	Al	0.1571±0.0022	0.1559	+0.77
(1.14	Cu	0.4862±0.0070	0.4914	−1.06
Mev)	Sn	0.3923±0.0054	0.3858	+1.69
	Ta	0.9127±0.0100	0.9536	−4.30
	Pb	0.7068±0.0051	0.7057	+0.11
Co^{60}	Al	0.1502±0.0001	0.1495−0.1501	+0.47 to +0.07
(1.16	Cu	0.4693±0.0003	0.469 −0.470	+0.06 to −0.15
and	Sn	0.3686±0.0003	0.369 −0.372	−0.11 to −0.92
1.31	Ta	0.8694±0.0007	0.910 −0.916	−4.5 to −5.1
Mev)	Pb	0.6497±0.0006	0.659 −0.669	−1.4 to −2.9
Na^{24}	Al	0.0956±0.0026	0.1001	−4.50
(2.76	Cu	0.3164±0.0080	0.3273	−3.33
Mev)	Sn	0.2668±0.0045	0.2692	−0.89
	Ta	0.6433±0.0055	0.6467	−0.53
	Pb	0.4776±0.0045	0.4644	+2.84

[a] Use of the more recent values (Lind, Brown, and DuMond, Phys. Rev. **76**, 591 (1949)) of 1.17 and 1.33 Mev for the energies of the gamma-rays of Co^{60} would decrease the theoretical values of μ by about 1 percent, and would slightly improve the over-all agreement between theory and experiment. The newer value[13] of 1.12 Mev for the gamma-ray energy of Zn^{65} would increase the theoretical absorption coefficients for this nuclide by an average of about 1.5 percent.

after 7 and 13 days, so the higher energy was from I^{131} also. A β-ray spectrometer study by Professor Deutsch showed a γ-ray of about 0.65 Mev; and the comparison, in Fig. 12, of our results with theoretical relative abundance curves indicates it to be about 15 percent as strong as the 0.367-Mev radiation. More recent spectrometer studies[11] have shown the presence of still another γ-ray of 0.283-Mev energy. This is consistent with our results, since our experimental points drop more steeply at first than the 15 percent curve.

The deviation of the Cu^{64} results from the curves for annihilation radiation can be explained by the higher energy radiation produced in the annihilation of fast positrons and by the low abundant nuclear γ-ray of 1.35 Mev.[12] Assuming that it is all caused by the 1.35-Mev γ-rays, our results in lead indicate them to be 1.23 percent as abundant as the annihilation radiation, in agreement with Deutsch's report.[12]

The Mn^{54} and Na^{24} results show good agreement with theory, although the low counting rates with Na^{24} gave poor statistical accuracy.

With a few exceptions, the Co^{60} and Zn^{65} results show good agreement with theory. The deviation of 2 percent for the lead values with the Co^{60} source may or may not be real. It is much greater than the statistical error of about 0.1 percent, but it is difficult to say whether or not there might have been a consistent error of this magnitude.

The disagreement of 5 percent with Co^{60} and tantalum, however, is far outside the statistical experimental error of 0.1 percent which was based on the variations among 60 independent measurements. Measurements made at different times, and calculations using a counter deadtime greater by 25 percent do not differ from each other by more than the experimental error. The results with Zn^{65} and tantalum also differ from theory. The coincidence counting rate was low, but the measured absorption coefficient was less than theory by 3 times the standard deviation of the average value (obtained from 7 independent observations). It is improbable that this deviation would be due purely to statistical fluctuations. Assuming the Zn^{65} energy[13] to be 1.12 Mev, our results would still agree with theory within 2 percent except for tantalum, which would deviate by 5 percent. An error in the physical conversion coefficients for tantalum would have caused deviations at other energies. We have checked the possible presence of inner x-rays[14] but find the energies and intensities of these to be much too small to affect our results. If the deviation we have found in tantalum is real, it indicates the presence of anomalously small absorption in tantalum of γ-rays of about 1.2-Mev energy. At this energy

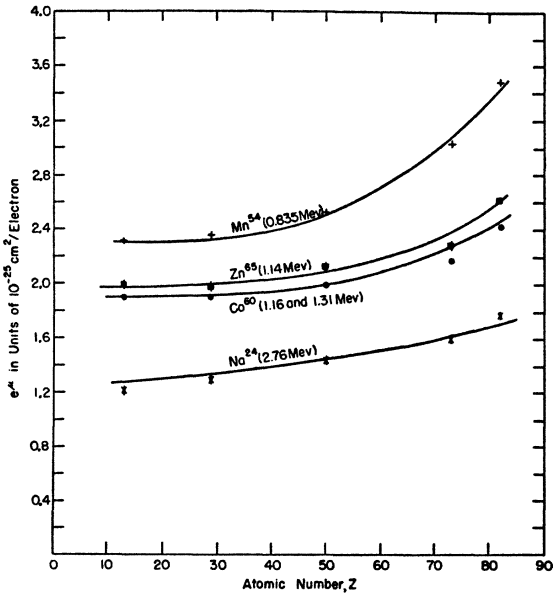

FIG. 11. Experimental and theoretical (narrow-beam) total absorption coefficients ($_e\tau + _e\kappa + _e\sigma$), in 10^{-25} cm^2/electron.

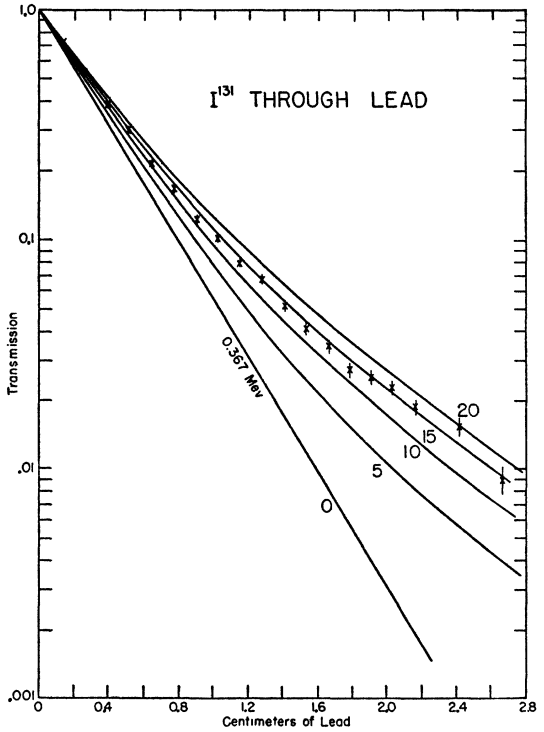

FIG. 12. Experimental and theoretical transmission of the γ-rays of I^{131} through Pb. Solid curves: expected transmission for homogeneous 0.367-Mev photons (marked 0), and for 5, 10, 15, and 20 photons of 0.65 Mev per 100 photons of 0.367 Mev. Initial filtration 0.122-cm Pb taken as unit transmission. These data were the first evidence for the presence of the 0.638-Mev γ-ray component in I^{131}, and their curvature at low filtration is consistent with the presence of the weak 0.283-Mev component as found subsequently by Metzger and Deutsch (reference 11).

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TABLE III. Measured absorption coefficients compared with those of other workers (in units of cm^{-1}).

Source	Element	Meas.	Groetzinger and Smith[a]	Mayneord and Cipriani[b]	Alburger[c]	Cork and Pidd[d]	Cork[e]	Cowan[f]	Parkinson[g]
Zn^{65}	Al	0.1571±0.0022						0.155	0.156 ±0.001
(1.14	Cu	0.4862±0.0070				0.51	0.460	0.478	
Mev)	Sn	0.3923±0.0054						0.372	
	Ta	0.9127±0.0100							
	Pb	0.7068±0.0051				0.72	0.678	0.724	
Co^{60}	Al	0.1502±0.0001		0.150±0.002					
(1.16	Cu	0.4693±0.0003		0.475±0.005		0.46	0.440		
and	Sn	0.3686±0.0003							
1.31	Ta	0.8694±0.0007							
Mev)	Pb	0.6497±0.0006		0.651±0.007		0.64	0.610		
Na^{24}	Al	0.0956±0.0026			0.088±0.001				0.0996±0.0008
(2.76	Cu	0.3164±0.0080			0.311±0.005				
Mev)	Sn	0.2668±0.0048						0.265	
	Ta	0.6433±0.0055							
	Pb	0.4776±0.0045	0.467±0.009		0.454±0.004			0.479	

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[b] W. V. Mayneord and A. J. Cipriani, Can. J. Research **25A**, 303 (1947).
[c] D. E. Alburger, Phys. Rev. **73**, 344 (1948).
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the absorption in tantalum is primarily due to Compton encounters ($\sigma/\mu=0.84$; $\tau/\mu=0.15$; $\kappa/\mu=0.01$), If the entire deviation observed were assigned to inaccuracy in theoretical knowledge of the photoelectric absorption coefficient τ, then a reduction of τ by one-third would be required. This seems unlikely in view of the more reasonable agreement between the theoretical and experimental values in lead.

IV. COMPARISON WITH OTHER WORKERS

In Table III our results are compared with those of other workers who have used the same sources. On the whole the agreement is good. In most cases where there is a large disagreement we feel that the difference can be attributed to poorer shielding which allowed appreciable scattered radiation to reach the detector,[15–17] or to the method of separating the Na^{24} energies.[15]

V. CONCLUSION

Our results with the γ-rays from Cu^{64}, Mn^{54}, Zn^{65}, Co^{60}, and Na^{24} show that experiment agrees with theory in the energy range from 0.5 Mev to 2.8 Mev, and thus that in general the present theories of Compton effect, photoelectric effect, and pair production give absorption coefficient values which are in good agreement with experiment. In most cases our agreement was within 1.5 percent, although with Na^{24}, where the experimental errors were large, the agreement was within 4 percent. The one exception was with tantalum absorbers and the 1.14-Mev radiation of Zn^{65} and the 1.16- and 1.31-Mev radiation of Co^{60}. We could find no experimental cause for this deviation. However, in view of the anomalous absorption in magnesium which was found by Meitner and Hupfeld,[9] but could not later be duplicated,[18,19] we hesitate to state that this anomalous result is real. Further tests should be made with a stronger source of Zn^{65}, and with an entirely different tantalum absorber.

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