SUPPLEMENT TO NBS CIRCULAR 583

X-ray Attenuation Coefficients From 10 kev to 100 Mev

86-5

UNITED STATES DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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A revision is given of the X-ray attenuation coefficients presented in National Bureau of Standards Circular 583. Table 4 of that publication is eliminated, and a new table is given for each material for photon energies less than 100 kev. The uncertainties in the estimates of attenuation coefficients at low energies are from 3 to 5 percent, which is the same as was previously given at higher energies. The cross sections for scattering are unchanged. Two values are listed for the photoelectric cross section, one calculated from the Sauter-Stobbe formulas and the other derived from new experimental evidence. The procedures for smoothing experimental data are described and are generally the same as were used in Circular 583. In addition to the systematic coverage of the region from 10 kev to 100 Mev, some data are included for a number of elements based on experimental measurements below 10 kev and above 100 Mev. A comparison is made between calculated and experimental total attenuation coefficients at energies above 10 Mev.

1. Introduction

The estimates of X-ray attenuation coefficients presented in National Bureau of Standards Circular 583 [1] were based on a combination of theoretical calculations and available experimental evidence, with judicious interpolations between them. Inaccuracies in the values below 50 kev were thought to approach 10 percent, especially for light elements, but probably not to exceed 3 to 5 percent above 100 kev. Experimental data obtained in the past few years enable us to revise the estimates at low energies so that they are of the same accuracy as the others. The main tables in this revision are intended to replace the low-energy portions of the tables in Circular 583. The footnotes to these tables are omitted even though they still apply. The columns giving the cross sections for coherent and incoherent scattering are unchanged. The same general procedures are used here as in the original publication for the energy region from 10 kev to 100 Mev. In addition, we include some data for a number of elements based on experimental measurements below 10 kev and some information up to 1 Bev. No attempt is made to break down these total attenuation coefficients into contributions from individual absorption and scattering processes.

No revision is required at this time for the intermediate energy region from 100 kev to 20 Mev. There are no new measurements of total attenuation coefficients at these energies. The estimates just below 1 Mev have been substantiated to within an experimental error of 2 percent in recent direct measurements of the photoelectric cross sections of Cu, Mo, Ag, Ta, and Au for Cs^{137} radiation [2]. A direct measurement of the photoelectric cross section for Pb at 0.511 Mev is also in reasonable agreement with the estimates already given [3].

The empirical corrections to calculated photoelectric cross sections at energies below 100 kev for low-Z materials given in table 4 of Circular 583 were based on a small number of experimental data, all of which were obtained by obsolete techniques. This low-energy region has now been studied quite extensively below 30 or 40 kev by modern experimental methods [4, 5, 6, 7, 8]. It appears that calculations based on the Sauter-Stobbe formula are in somewhat better accord with experiment for low-Z materials and for 10 to 40 kev photons than was previously indicated. On the other hand, data at low energies for the high-Z materials require considerable revision of attenuation coefficients below the K absorption edges. The reason for this is that a hydrogen-like approximation, such as is made in the Stobbe formulas, is not nearly so good for L and M shells as for the K shell. Increases ranging from 17 to 38 percent are indicated for Mo, Sn, and I and from 40 to over 100 percent for the very-high-Z elements ($Z \geqq 74$). The estimates for elements Mo through U below the K edges are the only ones for which the accuracy of the estimates given in Circular 583 falls below the stated amount.

Considerable new experimental data are also now available above 20 Mev [9, 10, 11, 12]. There is a general trend in the region below 100 Mev for the experimental values of the total attenuation coefficients in low-Z elements to be several percent higher than estimated in Circular 583. We give here a brief account of recent developments and indicate attempts that have been made to understand the measurements. A revision of the estimates of Circular 583 at higher energies will be given in a future publication when, it is hoped, the theoretical picture may be clarified.

2. Low Energies ($h\nu < 40$ kev)

Table 1 shows the range of recent good measurements of X-ray attenuation coefficients at energies below 40 kev [4, 5, 6, 7, 8]. The accuracy claimed by each experimenter is listed in table 2. Most of the data are due to Alan J. Bearden and R. D. Deslattes who claim estimated uncertainties of less than 1 percent [4, 5]. Each will give the details of his work in a forthcoming paper in the *Physical Review;* Bearden is currently extending his measurements below 10 kev to other elements

and somewhat lower energies. French measured mass-attenuation coefficients for Cu and Al down to 13.2 kev; Hopkins extended these data to 7.5 kev and to the other elements listed in the table [6]. The data of Roof for Th, U, and Pu are consistent with those available for W, Pt, and Au; however most of his measurements for the light elements at 17.48 kev (Mo $K_{\alpha 1}$ radiation) depart substantially from those of other experiments [7].

The experimantal coverage is far from complete so that extensive interpolation with respect to energy and atomic number is required for a systematic tabulation of attenuation coefficients. For each element listed in table 1, all the experimental data were plotted on a large graph as functions of energy. The critical absorption edges were located at the energies listed in table 1. A smooth curve was drawn through the points between edges. Values read off this curve at 3, 4, 5, 6, 8, 10, 15, 20, and 30 kev were converted to cross sections per atom by multiplying by A/N_A, where N_A is Avogadro's number and A is the atomic weight. At each energy the cross sections per atom should be smooth functions of Z so that one can interpolate for missing elements. The two-way smoothing versus energy and Z was done by successive approximations for different groups of data. At a particular energy, starting with the lightest elements, those whose K edges lie at lower energies form one group, those whose K edges lie at higher energies and L edges at lower energies form another, and so on. For example, at 3 kev elements below Cl at $Z=17$ form one group and at 10 kev elements below $Z=30$ (Zn) form another.

There have been no calculations of the effect of binding on scattering cross sections below 10 kev. Therefore, in this region the total cross sections per atom were smoothed graphically as functions of Z. The fitting was aided by log-log plots of the attenuation coefficients versus energy, which form straight lines at 10 kev and below. The results below 10 kev given in table 3 fit smoothly with the higher energy values in the other tables.

More precise smoothing of the data was possible at 10, 15, 20, and 30 kev. The three groups of interest which the elements form for these energies are those with $Z \leqq 30$, $40 \leqq Z \leqq 53$, and $Z \geqq 74$. (Elements with Z between 53 and 74 are omitted.) The total scattering (coherent plus incoherent) corrected for binding effects, which is given both here and in Circular 583 in the second column of the table for each element, was subtracted from the experimental cross section per atom to give an experimental photoelectric cross section. For $Z \leqq 30$, the relative deviation of this quantity from the photoelectric cross section calculated by the Sauter-Stobbe formulas was smoothed as a function of Z by a least-squares fit for a straight line. The smoothed experimental photoelectric cross sections are given in column 5 of tables 4 through 29 and are used to calculate the totals in columns 6 and 7; for comparison, the calculated photoelectric cross sections are listed in column 4. The new experimental data for Zr (40) through Sn (50) were used to revise the tables for Mo, Sn, and I. At each energy the logarithm of the experimental photoelectric cross section is a good linear function of Z in this region so that a straight-line fit by the method of least squares was determined. These lines were extrapolated to $Z=53$ to obtain new values for I. Due account was taken of the absorption edges and log-log plots of the adjusted photoeffect cross sections as functions of energy aided in completing the tables. There is less than 2-percent difference between any experimental point and the corresponding point obtained by the least-squares fit. Below the K edges the new values for the mass-attenuation coefficients for these elements are 20 to 40 percent higher than those calculated from the Stobbe formulas. Perhaps this straight-line extrapolation is not good. Incidentally, the new values do agree well with those compiled by Allen for Compton and Allison's book [14].

The new estimates of the mass-attenuation coefficients for the heaviest elements ($Z \geqq 74$) depend upon the experimental data for W, Pt, Au, Th, U, and Pu [4, 5, 7], which are not very complete. The L-absorption edges break up the region so that smoothing versus Z is possible only at 10, 15, and 30 kev. This was done graphically by means of a semilog plot of the experimental photoelectric cross section (in barns per atom) as a function of Z. Values for Tl and Pb interpolated from these curves were added to the total scattering cross sections, and the totals were plotted on log-log paper as functions of energy for each element. These form straight lines between edges. The results of this two-way smoothing and interpolating are given in tables 22 through 26. The agreement with Allen's values is very good for Pb, good for W and Pt away from the edges, fair for Pt, and poor for Th. Although the new estimates may be too high, they are based on the only experimental values that are available. The experimental procedure of reference [7] will be discussed in reference [4].

3. Intermediate Energies ($30 < h\nu < 100$ kev)

The only new experimental data at energies above 30 kev are for Al, Cu, Sn, and Au at 40 Kev. These data together with the new values at 30 kev for all Z must be made consistent with the older data of high accuracy mentioned in Circular 583. Over 20 years ago, Cuykendall [15] measured low-Z materials at energies between 60 and 250 kev with probable errors no greater than 2 percent, and Jones [16] covered the high-Z range at energies from 67 to 447 kev with an average probable error of 0.8 percent. There is nothing of comparable accuracy between 40 and 60 kev. A comparison between Cuykendall's low-Z data and predictions based on the Sauter-Stobbe formulas

shows that the experimental values are from 1 to 10 percent higher than the calculated ones, that this difference goes to zero at about 100 kev, and that for Cu the difference is zero at all these energies. Cuykendall's data from 60 to 90 kev are larger relative to the calculated values than the newer data are at about 35 kev. However, the uncertainty in the calculations is about the same from about 35 to 100 kev, provided the entire region is far above the K-absorption edges. Therefore, the current estimates for the attenuation coefficients for elements with $Z<30$ are obtained by smoothing between the predictions of the Sauter-Stobbe formulas above 40 kev and the recent experimental values below that energy. Jones' data for Mo and Sn above about 70 kev agree with the estimates given in Circular 583. There are no new experimental data for these materials above 30 kev so that calculated values are assumed above the K edges. Jones' data for Pb in the vicinity of the K edge agree with the revised values given in table 25.

4. High Energies ($h\nu > 10$ Mev)

Attenuation coefficients for a range of elements at energies above 10 Mev are given in figure 1. The solid curves are the totals estimated in Circular 583, and the points are the experimental data now available. The latter are quite consistent and indicate clearly that for low-Z materials the values based on the theory assumed in Circular 583 are too low by several percent. This discrepancy was indicated in Circular 583 but not considered to be serious because of the limited experimental information available at that time and the general difficulty of assigning a definite cross section to each of the various processes that contributes to the total attenuation coefficient.

Present evidence confirms the earlier trend and points to a substantial problem above 10 Mev. Wolff measured the total attenuation coefficients of C and H_2O at 20.3 and 20.8 Mev, which is in the region of strong photonuclear absorption [12]. Wyckoff and Koch made very extensive and accurate measurements for C, Al, H_2O, and H from 13 to 82 Mev [12]. The other new data below 100 Mev were obtained by Moffatt, et al., at 94 Mev for a range of elements from H to U [10]. Information about high-Z elements is still not adequate. The measurements above the photonuclear region (35 Mev) for C, Al, and H_2O are especially accurate with maximum uncertainties of about 0.9 percent [10, 11].

It is unclear at this time what the best estimates are for calculated values of the cross sections for individual processes at high energies, particularly for electron pair production in the field of the atomic electrons. In the first report of this series [28], calculations from the Borsellino results for free electrons were used up to 50 Mev [29], with an extrapolation to higher energies aided by the results of Wheeler and Lamb [30].

In Circular 583, calculations of the pair cross section in the field of electrons were made by using the formulas of Votruba for the limiting cases of photon energies near the threshold value and large compared to mc^2 [31]. A graphical interpolation was made for the intermediate energy region. This was accomplished by extrapolating the curves for the limiting cases and using the calculations of Borsellino [29] as a guide to the shape of the curve in the intermediate region. This general procedure was recommended by Rohrlich. More recently he and Joseph re-evaluated the exchange correction in the high energy limit showing that the constant in eq 13, Circular 583, is exactly 100/9 instead of 11.3 ± 0.5 [33]. In the case of hydrogen, this correction raises the cross section for pair production in the field of the electrons at 30, 40, 60, 80, and 100 Mev by 0.1 mb and at 50 Mev by 0.2 mb. Neglecting the effect of binding on the atomic electrons, revised values of this cross section for other elements are obtained by multiplying that for hydrogen by Z. The same result is obtained above 20 Mev by numerical integration of the formulas of Wheeler and Lamb [30] for hydrogen over the energy of the positron and subtraction of the exchange correction of Joseph and Rohrlich [33].

Recently Suh and Bethe, following the work of Borsellino, have studied the theory of electron pair production in the field of a particle of arbitrary mass [29, 35]. The recoil-momentum-distribution function for high-incident photon energies which they obtained for the case of a recoil electron originally bound in an atom agrees with that of Wheeler and Lamb [30]. Measurements of electron pair production in the nuclear field and in the electron field in a hydrogen-filled cloud chamber by Hart, Cocconi, et al., between 10 and 100 Mev are also in agreement with the Wheeler-Lamb calculations [34]. Malamud compares the results of accurate experiments above 40 Mev with calculations of total attenuation coefficients at these energies [9]. He finds that measurements in Be and C clearly agree with the Wheeler-Lamb prediction and disagree with the Wheeler-Lamb result reduced by the exchange correction of Joseph and Rohrlich. Measurements in H and Li are inconclusive.

An experiment was designed in this laboratory to decide whether the discrepancy between experiment and current estimates should be assigned to nuclear or electronic effects [11]. The result of this was that even though an upper limit was taken for pair production in the electron field, the nuclear pair cross section was still too low by 2.25 percent (for C and Al). An exploration was made to see what the effect would be of replacing Thomas-Fermi form factors by Hartree form factors in the screening calculation for nuclear pair

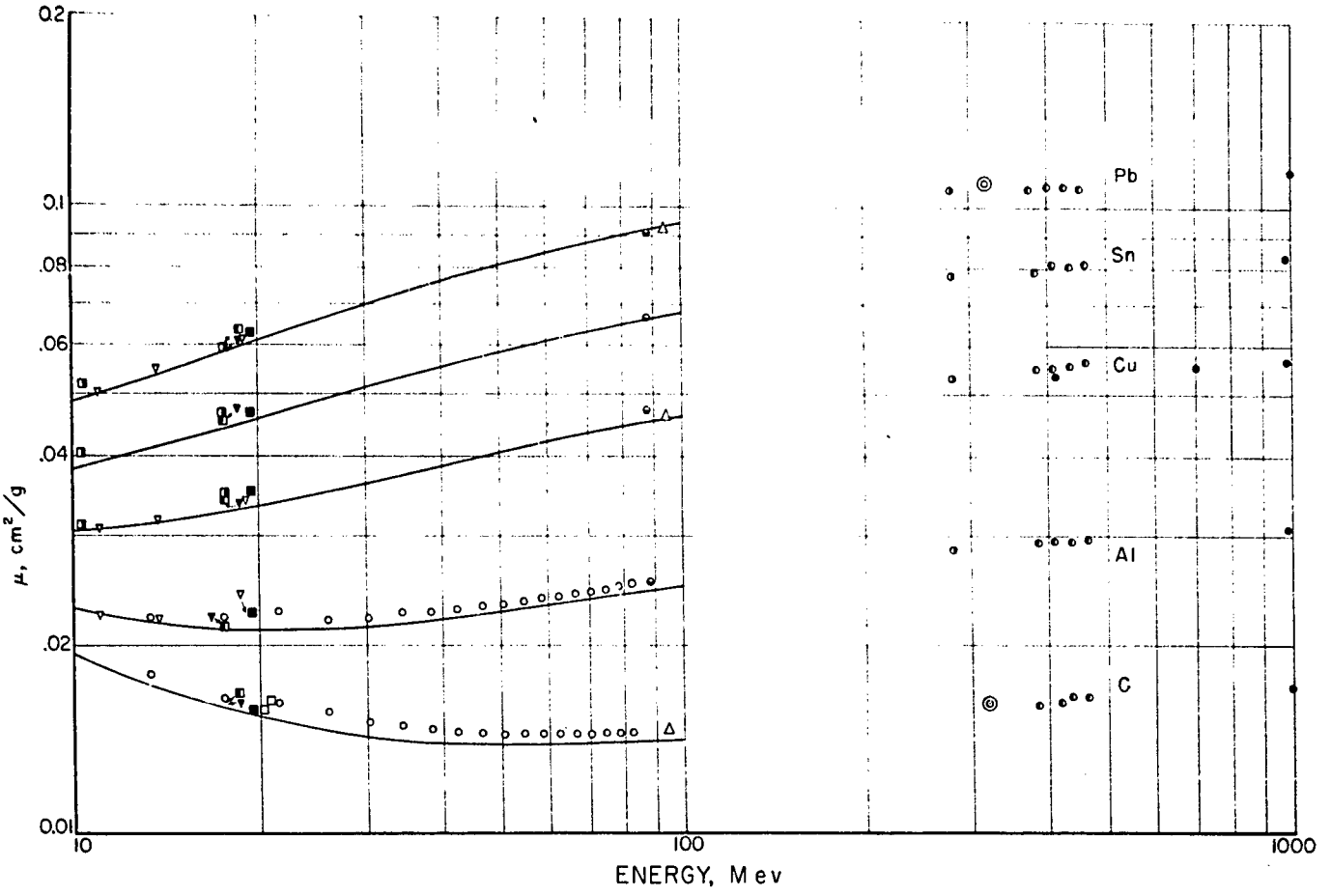

FIGURE 1. *Total attenuation coefficients from 10 Mev to 1 Bev.*

The solid curves are the totals given in NBS Circular 583. The points are experimental data from the following sources:

- ● Malamud [9]
- △ Moffatt, Thresher, Weeks, Wilson [10]
- ○ Wyckoff and Koch [11]
- □ Wolff [12]
- ◒ Lawson [17]
- ◑ Dewire, Ashkin, Beach [18]
- ○ Anderson, et al. [19, 20]
- ◐ Cooper [12]
- ◧ Rosenblum [22]
- ◧ Walker [23]
- ▼ Colgate [24]
- ■ Berman [25]
- ▽ Adams [26]

production and also replacing the high-energy approximation made in Bethe and Heitler's formula 114, reference [27], by the exact no screening expression, eq 110, reference [27]. A sample calculation for C and Al at 60 Mev shows that these two effects nearly cancel so that the net result is to decrease the pair cross sections given in Circular 583 by 0.7 percent.

In view of these considerations, a revision of the attenuation coefficients at high energies seems unwarranted at this time.

The author thanks the many scientists who have sent her reports on their research and preprints of their publications and the members of this laboratory who have helped her by contributing generously of their time and information.

5. References

[1] G. White Grodstein, X-ray attenuation coefficients from 10 kev to 100 Mev, NBS Circ. 583 (1957).
[2] W. F. Titus, Phys. Rev. **114** (1959).
[3] K. W. Seemann, Bull. Am. Phys. Soc. **1**, 4, 198, NA8 (1956).
[4] Alan J. Bearden, Bull. Am. Phys. Soc., [II] **4**, 67 (1959); Phys. Rev. (to be published).
[5] R. D. Deslattes, An experimental study of X-ray attenuation coefficients, 8–30 kev, AFOSR Report No. TN–58–784; Phys. Rev. (to be published).
[6] J. I. Hopkins, J. Appl. Phys. **30,** 185 (1959); R. L. French, The scintillation counter as a means of determining low energy X-ray mass-absorption coefficients, Thesis (Vanderbilt University, June 1955).
[7] R. B. Roof, Jr., Phys. Rev. **113,** 820 (1959); **113,** 826 (1959).
[8] J. H. Hubbell, private communication.
[9] E. Malamud, Phys. Rev. **114** (1959).
[10] J. Moffatt, J. J. Thresher, G. C. Weeks, and R. Wilson, Proc. Roy. Soc. [A] **244,** 245 (1958); J. Moffatt, G. C. Weeks, Proc. Phys. Soc. (London) **73,** 114 (1959).
[11] J. M. Wyckoff, H. W. Koch, Bull. Am. Phys. Soc., [II] **3,** 174 (1958); Phys. Rev. (to be published).
[12] M. M. Wolff, Total photon absorption in C^{12} and O^{16}, University of Pennsylvania, Technical Report No. 4, Contract Nonr 551 (17), Code NR–022–019 (1958).

[13] S. Fine and C. F. Hendee, Nucleonics **13,** 36 (1955).
[14] A. H. Compton and S. K. Allison, X-rays in theory and experiment (P. Van Nostrand Co., Inc., New York, N.Y., 1935).
[15] T. R. Cuykendall, Phys. Rev. **50,** 105 (1936).
[16] M. T. Jones, Phys. Rev. **50,** 110 (1936).
[17] J. L. Lawson, Phys. Rev. **75,** 433 (1949).
[18] J. W. Dewire, A. Ashkin, and L. A. Beach, Phys. Rev. **83,** 505 (1951).
[19] J. D. Anderson, R. W. Kenney, and C. A. McDonald, Jr., Phys. Rev. **102,** 1626 (1956).
[20] J. D. Anderson, R. W. Kenney, C. A. McDonald, Jr., and R. F. Post, Phys. Rev. **102,** 1632 (1956).
[21] D. H. Cooper, Thesis, Cal. Inst. of Tech. (June 1955).
[22] E. S. Rosenblum, E. F. Shrader, and R. M. Warner, Jr., Phys. Rev. **88,** 612 (1952).
[23] R. L. Walker, Phys. Rev. **76,** 527 (1949); **76,** 1440 (1949).
[24] S. A. Colgate, Phys. Rev. **87,** 592 (1952).
[25] A. I. Berman, Phys. Rev. **90,** 210 (1953).
[26] G. D. Adams, Phys. Rev. **74,** 1707 (1948).
[27] Experimental Nuclear Physics, Vol. I, E. Segrè, Editor (J. Wiley & Sons, Inc., New York, N.Y., 1953).
[28] G. R. White, X-ray attenuation coefficients from 10 kev to 100 Mev, unpublished NBS Report. The information in this report has been published in Handbook of radiology, edited by R. H. Morgan and K. E. Corrigan (The Year Book Publishers, Inc., 200 East Illinois Street, Chicago, Ill., 1955) and in Beta- and gamma-ray spectroscopy, edited by K. Siegbahn (North-Holland Publishing Co., Amsterdam, Holland, 1955).
[29] A. Borsellino, Helv. Phys. Acta **20,** 136 (1947); Nuovo Cimento **4,** 112 (1947); Rev. univ. nac. Tucumàn [A] **6,** 7 (1947).
[30] J. A. Wheeler and W. E. Lamb, Phys. Rev. **55,** 858 (1939); **101,** 1836 (1956).
[31] V. Votruba, Bull. intern. acad. Tcheque sci. **49,** 19 (1948).
[32] F. Rohrlich and J. Joseph, Bull. Am. Phys. Soc. **30,** 7 (1955); Phys. Rev. **100,** 1241 (1955).
[33] J. Joseph and F. Rohrlich, Rev. Mod. Phys. **30,** 354 (1958).
[34] E. Hart, G. Cocconi, V. T. Cocconi, and J. M. Sellen, Phys. Rev. **114** (1959).
[35] K. S. Suh and H. A. Bethe, Bull. Am. Phys. Soc., [II] **4,** 13 (1959); Phys. Rev. **114** (1959).

TABLE 1. *Sources of low-energy experimental data*

Experimenters: a. Alan J. Bearden, b. Deslattes, c. Hopkins & French, d. Roof, and e. Hubbell

Element	Z	Experimenters	Limits of energy range		Number of measurements	Absorption edges of interest [a]			
						K	L_1	L_2	L_3
			kev	*kev*		*kev*	*kev*	*kev*	*kev*
He	2	a	3	8	6				
Be	4	a	3	8	6				
		e	8	17	2				
C	6	a	3	8	6				
		e	7	17	3				
Ne	10	a	3	8	6				
Mg	12	b	8	30	19				
Al	13	a	3	40	15				
		b	8	30	19				
		c	7.5	40	19				
		e	7	17	3				
A	18	a	3	8	6	3.203			
Ti	22	b	8	30	23	4.964			
		e	8	8	1				
Cr	24	c	6	14	9	5.988			
Fe	26	b	8	30	20	7.111			
Co	27	c	6	14	10	7.709			
Ni	28	b	8	30	22	8.331			
		c	6	14	9				
		e	8	8	1				
Cu	29	a	8	40	9	8.980			
		b	8	30	21				
		c	6	40	24				
Zn	30	c	6	14	10	9.660			
Zr	40	b	11.2	30	13	17.998			
Mo	42	b	8.9	30	20	20.002			
Pd	46	b	8	30	19	24.347			
Ag	47	b	8	30	19	25.517			
Cd	48	b	8	30	20	26.712			
Sn	50	a	8	40	9	29.190			
		b	11	30.5	14				
		c	20	35	9				
		e	8	11	2				
W	74	b	8	30	18	69.508	12.080	11.535	10.198
Pt	78	b	8	30	19	78.379	13.873	13.268	11.559
Au	79	a	8	40	9	80.713	14.353	13.733	11.919
		b	8	30	19				
Th	90	d	5.4	25	12	.....	20.460	19.688	16.296
U	92	d	5.4	25	12	.....	21.753	20.943	17.163
Pu	94	d	5.4	25	12	.....	23.097	22.262	18.066
Molecules									
H_2	.....	a	3	8	6				
N_2	.....	a	3	8	6				
O_2	.....	a	3	8	6				

[a] S. Fine and C. F. Hendee, Nucleonics **13,** 36 (1955).

TABLE 2. *Accuracy claimed by experimenters at low energies*

a. Alan J. Bearden [4]
Probable error < 1.0 percent
b. Deslattes [5]
Standard deviation ≦ 1.0 percent
c. Hopkins and French [6]
Probable error about 5 percent
d. Roof [7]
Probable error ≦ about 3 percent
e. Hubbell [8]
Probable error about 2 percent

TABLE 3. *Total X-ray attenuation coefficients at photon energies below 10 kev (with coherent scattering) in cm²/g.*
(When two values are given for the same energy, they represent the maximum and minimum values at a critical absorption limit.)

Element \ Photon energy *kev*	3	3.20 [a]	4	5	6	8
Be	22.5		9.20	4.65	2.70	1.10
C	89.0		37.5	18.6	10.0	4.3
N	147.4		63.3	31.7	17.2	7.40
O	221		100	50.5	29.0	11.8
Ne	415		182	97.0	50.7	22.3
Al	762		351	185	112	52.3
A	200	54				
		1740	956	500	295	126

Element \ Photon energy *kev*	5.988 [b]	6.00	7.709 [c]	8.00	8.331 [d]	8.96 [e]	9.00	9.660 [f]	10.00
Mg				40.2			28.5		21.1
Ti				205			149		115
Cr	518			258			195		146
Fe				322			238		180
Co		92	44						
			392	360			270		193
Ni		107		46	38.5				
					343		280		210
Cu		116		51.5		37.0			
						306	296		225
Zn		130		61.7				35.3	
								265	240
Pd				204			149		112
Ag				217			160		123
Cd				230			170		120
Sn				258			188		147
W				177			128		93.4
Pt				201			147		115
Au				208			155		122
Th		808		400			300		219
U		820		407			306		244
Pu		1080		510			370		278

[a] *K* edge for A.
[b] *K* edge for Cr.
[c] *K* edge for Co.
[d] *K* edge for Ni.
[e] *K* edge for Cu.
[f] *K* edge for Zn.

TABLE 4. *Beryllium*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation *K* & *L* shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	3.54	2.56	4.75	5.23	0.586	0.520
.015	3.01	2.52	1.25	1.34	.291	.258
.02	2.77	2.47	0.48	0.51	.219	.190
.03	2.53	2.39	.12	.13	.178	.168
.04	2.38	2.31	.05	.05	.162	.158
.05	2.29	2.24	.02	.02	.154	.151
.06	2.21	2.18	.01	.01	.148	.146
.08	2.10	2.07	.....	.....	.140	.138

TABLE 5. *Carbon*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation *K* & *L* shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	6.88	3.84	34.2	37.3	2.22	2.06
.015	5.30	3.77	9.20	9.75	0.755	0.678
.02	4.64	3.71	3.60	3.82	.424	.378
.03	4.04	3.58	0.95	1.00	.253	.230
.04	3.71	3.47	.36	0.37	.205	.193
.05	3.50	3.37	.17	.17	.184	.178
.06	3.37	3.28	.093	.093	.174	.169
.08	3.18	3.10	.036	.036	.161	.157
.10	3.02	2.96	.017	.017	.152	.149

TABLE 6. *Nitrogen*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K & L shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	8.96	4.48	70.6	77.0	3.70	3.50
.015	6.72	4.40	19.2	20.4	1.17	1.07
.02	5.73	4.33	7.57	8.02	0.591	0.531
.03	4.84	4.18	2.02	2.12	.299	.271
.04	4.45	4.05	0.77	0.79	.225	.208
.05	4.14	3.93	.37	.37	.191	.185
.06	3.98	3.82	.20	.20	.180	.173
.08	3.73	3.62	.08	.08	.164	.159
.10	3.54	3.45	.04	.04	.151	.170

TABLE 7. *Oxygen*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K & L shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	11.5	5.12	130	142	5.78	5.54
.015	8.28	5.03	36.0	38.2	1.75	1.63
.02	6.95	4.94	14.2	14.9	0.823	0.747
.03	5.77	4.78	3.85	4.04	.369	.332
.04	5.18	4.62	1.48	1.48	.251	.230
.05	4.80	4.49	0.70	0.70	.207	.195
.06	4.61	4.37	.39	.39	.188	.179
.08	4.30	4.14	.15	.15	.168	.162
.10	4.06	3.94	.07	.07	.156	.151

TABLE 8. *Sodium*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	20	7.04	530	572	15.5	15.2
.015	14	6.92	155	164	4.66	4.48
.02	11.2	6.80	62.6	65.7	2.01	1.90
.03	8.8	6.57	17.1	17.8	0.697	0.638
.04	7.8	6.36	6.7	6.7	.380	.342
.05	7.1	6.17	3.2	3.2	.270	.245
.06	6.67	6.01	1.81	1.81	.222	.205
.08	6.08	5.69	0.72	0.72	.178	.168
.10	5.70	5.42	.34	.34	.158	.151

TABLE 9. *Magnesium*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	25	7.68	763	826	21.1	20.6
.015	17	7.55	226	239	6.34	6.11
.02	13	7.42	92.3	96.3	2.71	2.57
.03	10.2	7.16	25.7	27.8	0.941	0.866
.04	8.7	6.94	10.1	10.1	.466	.422
.05	7.9	6.73	4.9	4.9	.317	.288
.06	7.4	6.55	2.7	2.7	.250	.229
.08	6.66	6.20	1.08	1.08	.192	.180
.10	6.24	5.91	0.52	0.52	.167	.159

TABLE 10. *Aluminum*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	29	8.32	1,060	1,145	26.2	25.8
.015	19	8.18	316	335	7.91	7.67
.02	15	8.03	131	136	3.37	3.22
.03	11.5	7.76	36.8	38.3	1.11	1.03
.04	9.8	7.51	14.5	14.5	0.543	0.492
.05	8.8	7.29	7.0	7.0	.353	.319
.06	8.1	7.10	3.9	3.9	.268	.246
.08	7.26	6.72	1.57	1.57	.197	.185
.10	6.79	6.41	0.77	0.77	.169	.160

TABLE 11. *Silicon*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	33	8.96	1,440	1,555	34.1	33.6
.015	22	8.81	434	460	10.3	10.1
.02	17	8.65	181	188	4.40	4.22
.03	12.8	8.36	51.4	53.5	1.42	1.33
.04	10.8	8.09	20.4	20.4	0.670	0.610
.05	9.7	7.85	9.9	9.9	.421	.381
.06	8.9	7.64	5.6	5.6	.311	.284
.08	8.0	7.24	2.2	2.2	.219	.203
.10	7.38	6.90	1.09	1.09	.182	.172

TABLE 12. *Phosphorus*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	38	9.60	1,900	2,047	40.6	40.0
.015	25	9.44	573	605	12.3	12.0
.02	19	9.27	242	251	5.25	5.06
.03	14.3	8.96	70.1	72.6	1.69	1.59
.04	12.0	8.67	27.4	27.4	0.766	0.702
.05	10.6	8.42	13.3	13.3	.465	.422
.06	9.7	8.19	7.6	7.6	.336	.307
.08	8.6	7.76	3.0	3.0	.226	.209
.10	7.98	7.39	1.52	1.52	.185	.173

TABLE 13. *Sulfur*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	44	10.24	2,480	2,670	51.0	50.4
0.015	29	10.06	759	800	15.6	15.2
.02	22	9.89	321	332	6.65	6.42
.03	15.9	9.55	93.1	96.2	2.11	1.99
.04	13.2	9.25	36.7	36.7	0.938	0.863
.05	11.6	8.98	17.9	17.9	.554	.505
.06	10.7	8.74	10.3	10.3	.395	.358
.08	9.3	8.27	4.1	4.1	.252	.232
.10	8.6	7.89	2.1	2.1	.201	.188

TABLE 14. *Argon*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	56	11.52	3,950	4,230	64.6	64.0
.015	36	11.32	1,230	1,290	20.0	19.6
.02	28	11.12	527	543	8.61	8.36
.03	19	10.75	156	161	2.71	2.59
.04	15.8	10.40	62.0	62.0	1.17	1.09
.05	13.6	10.10	30.5	30.5	0.665	0.612
.06	12.4	9.83	17.5	17.5	.451	.412
.08	10.8	9.31	7.1	7.1	.270	.247
.10	9.85	8.87	3.59	3.59	.203	.188

TABLE 15. *Potassium*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	63	12.16	4,870	5,208	81.2	80.1
.015	40	11.95	1,542	1,620	25.6	25.1
.02	31	11.74	658	674	10.9	10.6
.03	21	11.34	196	202	3.44	3.29
.04	17.1	10.98	78.4	80.0	1.50	1.40
.05	14.7	10.66	38.9	38.9	0.826	0.764
.06	13.3	10.37	22.3	22.3	.549	.503
.08	11.6	9.82	9.0	9.0	.317	.290
.10	10.5	9.37	4.5	4.5	.231	.214

TABLE 16. *Calcium*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	69	12.80	5,920	6,330	96.2	95.3
.015	44	12.58	1,890	1,980	30.5	29.9
.02	33	12.36	814	827	12.9	12.6
.03	23	11.94	243	250	4.10	3.94
.04	18.5	11.56	98.4	101	1.79	1.69
.05	15.8	11.22	49.0	49.4	0.980	0.911
.06	14.3	10.92	28.1	28.1	.637	.586
.08	12.3	10.34	11.4	11.4	.356	.327
.10	11.1	9.86	5.9	5.9	.256	.237

TABLE 17. *Iron*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	120	16.64	15,600	16,600	180	179
.015	75	16.35	5,130	5,335	58.4	57.7
.02	55	16.07	2,280	2,300	25.4	25.0
.03	37	15.52	706	718	8.15	7.91
.04	29	15.03	300	306	3.61	3.46
.05	24	14.59	152	152	1.90	1.80
.06	20.7	14.20	89.1	89.1	1.18	1.11
.08	17.2	13.44	37.5	37.5	0.590	0.550
.10	15.4	12.82	18.9	18.9	.370	.342

TABLE 18. *Copper*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	150	18.56	22,500	23,600	225	224
.015	96	18.24	7,690	8,000	76.7	76.0
.02	70	17.92	3,460	3,460	33.5	33.0
.03	46	17.31	1,090	1,100	10.9	10.6
.04	35	16.76	465	465	4.74	4.57
.05	28	16.27	238	238	2.52	2.41
.06	24	15.83	141	141	1.56	1.49
.08	20.2	14.99	59.7	59.7	0.757	0.708
.10	17.9	14.29	30.5	30.5	.459	.425

TABLE 19. *Molybdenum*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	340	26.9	11,400	13,400	86.3	84.3
.015	220	26.4	3,480	4,370	28.8	27.6
[a].0200	160	26.0	1,510	1,871	12.8	11.9
.0200	160	26.0	13,000	13,200	83.9	83.0
.03	98	25.1	4,200	4,360	28.0	27.5

[a] K edge; at this and lower energies data for the L and M shells are given while at this and higher energies data for the L, M, and K shells are given.

TABLE 20. *Tin*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm² g*	*cm²/g*
0.01	510	32.0	24,000	28,500	147	145
.015	340	31.4	7,410	9,[illegible]60	47.7	46.1
.02	240	30.9	3,220	4,040	21.7	20.7
[a].02919	150	30.0	1,050	1,400	7.87	7.26
.02919	150	30.0	8,580	9,000	46.4	45.8
.03	140	29.8	8,150	8,220	42.4	41.9

[a] K edge; at this and lower energies data for the L and M shells are given while at this and higher energies data for the L, M, and K shells are given.

TABLE 21. *Iodine*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	500	33.9	29,800	37,700	182	179
.015	380	33.3	9,360	11,900	58.3	56.6
.02	270	32.8	4,130	5,300	26.9	25.7
.03	160	31.6	1,260	1,700	9.11	8.50
[a].03316	150	31.3	933	1,340	7.07	6.51
.03316	150	31.3	7,510	7,510	36.4	35.8

[a] K edge; at this and lower energies data for the L and M shells are given while at this and higher energies data for the L, M, and K shells are given.

TABLE 22. *Tungsten*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	1,300	47.4	17,700	27,200	93.4	89.3
[a].01020	1,200	47.3	16,800	26,000	89.0	85.0
[b].01289	1,000	46.9	61,700	74,700	248	245
.015	840	46.5	36,000	42,200	141	138
.02	590	45.7	16,000	19,000	67.0	65.2
.03	350	44.2	5,040	6,670	23.1	22.0
.04	240	42.8	2,220	3,020	10.7	10.0
.05	180	41.5	1,160	1,660	6.03	5.57
.06	145	40.4	674	984	3.70	3.36
[c].07951	122	39.4	437	656	2.55	2.28

[a] L_3 edge; at this and lower energies data for the M shell are given.
[b] L_1 edge; from this energy to the K-edge energy data for the L and M shells are given.
[c] K edge; at this and higher energies data for the L, M, and K shells are given.

TABLE 23. *Platinum*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	1,400	49.9	22,000	36,000	115	111
[a].01156	1,200	49.6	14,800	23,400	76.0	72.0
[b].01387	1,000	49.2	53,900	61,900	194	191
.015	940	49.1	43,800	50,300	158	155
.02	670	48.2	19,700	23,800	75.5	73.6
.03	400	46.6	6,240	8,100	26.2	25.1
.04	280	45.1	2,720	3,770	12.5	11.8
.05	210	43.8	1,440	2,030	6.91	6.43
.06	163	42.6	836	1,217	4.26	3.89
[c].07838	117	40.6	380	560	2.09	1.85

[a] L_3 edge; at this and lower energies data for the M shell are given.
[b] L_1 edge; from this energy to the K edge energy data for the L and M shells are given.
[c] K edge; at this and higher energies data for the L, M, and K shells are given.

TABLE 24. *Thallium*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	1,500	51.8	23,000	44,200	135	130
[a].01206	1,200	51.3	13,400	24,600	76	73
[b].01535	990	50.7	47,200	54,000	162	159
.02	730	50.1	22,700	27,100	82.0	80.0
.03	430	48.4	7,220	9,840	30.3	29.2
.04	300	46.8	3,200	4,580	14.1	13.6
.05	220	45.4	1,660	2,460	7.9	7.4
.06	180	44.2	976	1,480	4.9	4.5
.08	124	41.9	420	622	2.2	2.0
[c].08552	114	41.3	341	530	1.9	1.7
.08552	114	41.3	2,577		7.03	7.72

[a] L_3 edge; at this and lower energies data for the M shell are given.
[b] L_1 edge; from this energy to the K-edge energy data for the L and M shells are given.
[c] K edge; at this and higher energies data for the L, M, and K shells are given.

TABLE 25. *Lead*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	1,600	52.5	27,500	47,200	142	137
[a].01304	1,200	51.8	13,200	23,200	71.0	67.6
[b].01587	980	51.3	45,400	57,800	171	168
.02	750	50.7	24,000	30,900	92	90
.03	450	49.0	7,620	10,500	31.8	30.6
.04	310	47.4	3,310	4,880	15.1	14.3
.05	230	46.0	1,740	2,690	8.49	7.96
.06	180	44.8	1,040	1,580	5.12	4.72
.08	127	42.4	444	688	2.37	2.12
[c].08800	113	41.6	331	523	1.85	1.64
.08809	113	41.6	2,510	....	7.63	7.42

[a] L_3 edge; at this and lower energies data for the M shell are given.
[b] L_1 edge; from this energy to the K-edge energy data for the L and M shells are given.
[c] K edge; at this and higher energies data for the L, M, and K shells are given.

TABLE 26. *Uranium*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	2,100	58.9	44,000	94,400	244	239
.015	1,400	57.9	14,500	33,800	89.1	85.7
[a].01716	1,200	57.4	10,000	23,800	63.4	60.4
[b].02175	880	56.5	29,400	46,180	119	117
.03	590	54.9	12,000	20,300	52.9	51.5
.04	400	53.2	5,250	9,910	26.1	25.2
.05	300	51.6	2,780	5,666	15.1	14.5
.06	230	50.2	1,640	3,550	9.57	9.11
.08	163	47.6	716	1,700	4.71	4.42
.10	123	45.3	374	948	2.71	2.51
[c].1156	103	43.8	239	640	1.88	1.73
.1156	103	43.8	1,790	....	4.79	4.64

[a] L_3 edge; at this and lower energies only the M shell data are given.
[b] L_1 edge; from this to the K-edge energy data for the L and M shells are given.
[c] K edge; at this and higher energies data for the L, M, and K shells are given.

TABLE 27. *Water*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	*cm²/g*	*cm²/g*
0.01	12.8	6.40	130	142	5.18	4.96
.015	9.54	6.20	36.0	38.2	1.60	1.49
.02	8.19	6.18	14.2	14.9	0.772	0.705
.03	6.96	5.97	3.85	4.04	.368	.335
.04	6.34	5.78	1.48	1.48	.262	.243
.05	5.92	5.61	0.70	0.70	.221	.211
.06	5.70	5.46	.39	.39	.204	.196
.08	5.33	5.17	.15	.15	.183	.178
.10	5.05	4.93	.07	.07	.171	.167

TABLE 28. *Sodium Iodide*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	cm^2/g	cm^2/g
0.01	610	41.0	30,300	38,300	156	154
.015	390	40.3	9,520	12,100	50.2	48.8
.02	280	39.6	4,190	5,460	23.1	22.1
.03	170	38.2	1,280	1,780	7.84	7.31
[a].03316	160	37.8	945	1,350	6.07	5.58
.03316	160	37.8	7,520	7,520	30.9	30.4
.04	130	37.0	4,500	4,500	18.6	18.2
.05	96	35.9	2,470	2,470	10.3	10.1
.06	70	34.9	1,500	1,500	6.35	6.17
.08	60	33.1	678	678	2.97	2.86
.10	50	31.5	360	360	1.65	1.57

[a] K edge of Iodine; at this and lower energies data for the L and M shells are given while at this and higher energies data for the L, M, and K shells are given.

TABLE 29. *Calcium Phosphate*

Photon energy	Scattering		Photoelectric		Total experiment	
	With coherent	Without coherent	Calculation K, L, & M shells	Experiment	With coherent	Without coherent
Mev	*Barns/atom*	*Barns/atom*	*Barns/atom*	*Barns/atom*	cm^2/g	cm^2/g
0.01	375	98.6	22,600	24,200	47.7	47.2
.015	248	96.9	7,100	7,460	15.0	14.7
.02	193	95.2	3,030	3,100	6.40	6.21
.03	144	91.9	900	928	2.08	1.98
.04	121	89.0	362	370	0.954	0.891
.05	107	86.4	179	180	.557	.517
.06	99.2	84.1	103	103	.393	.363
.08	88.5	79.6	41.4	41.4	.252	.235
.10	81.7	75.9	21.3	21.3	.200	.189

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TABLE 30. *Air*

0.755 N, 0.232 O, 0.013 A by weight

Photon energy	Total		Photon energy	Total	
	With coherent	Without coherent		With coherent	Without coherent
Mev	cm^2/g	cm^2/g	*Mev*	cm^2/g	cm^2/g
0.003	165		0.015	1.55	1.44
[a].0032	135		.020	0.749	0.683
.0032	157		.030	.347	.315
.004	83.4		.040	.243	.225
.005	42.1		.050	.203	.193
.006	23.5		.060	.185	.177
.008	9.96		.080	.166	.161
.010	4.97	4.76	.10	.155	.151

[a] K edge for Argon.

TABLE 31. *Concrete*

0.56% H, 49.83% O, 31.58% Si, 4.56% Al, 8.26% Ca, 1.22% Fe, 0.24% Mg, 1.71% Na, 1.92% K, 0.12% S by Weight. Density=2.35 g/cm³.

Photon energy	Incoherent scattering [a]	Total [b]		Photon energy	Incoherent scattering [a]	Total [b]	
		With coherent	Without coherent			With coherent	Without coherent
Mev	cm^2/g	cm^2/g	cm^2/g	*Mev*	cm^2/g	cm^2/g	cm^2/g
0.01	0.193	26.9	26.5	1.0	0.0637	0.0637	0.0637
.015	.190	8.32	8.12	1.5	.0517	....	.0519
.02	.186	3.59	3.45	2.0	.0441	....	.0447
.03	.180	1.21	1.13	3.0	.0347	....	.0364
.04	.174	0.593	0.548	4.0	.0289	....	.0318
.05	.169	.389	.351	5.0	.0250	....	.0288
.06	.165	.288	.268	6.0	.0221	....	.0268
.08	.156	.210	.198	8.0	.0181	....	.0242
.10	.149	.178	.170	10	.0154	....	.0228
.15	.134	.144	.139	15	.0114	....	.0211
.20	.123	.127	.125	20	.00912	....	.0206
.30	.107	.108	.107	30	.00663	....	.0205
.40	.0955	.0962	.0957	40	.00526	....	.0209
.50	.0872	.0875	.0872	50	.00439	....	.0213
.60	.0807	.0808	.0807	60	.00378	....	.0217
.80	.0709	.0710	.0709	80	.00298	....	.0225
				100	.00247	....	.0231

[a] Incoherent scattering is given by the Klein-Nishina formula for free electrons.

[b] The total is compiled from the last two columns in the tables for the elements.

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