4.2.3.5. *Comments*

For reliable experiments using XAFS and XANES to be undertaken, intense-radiation sources must be used. Synchrotron-radiation sources are such a source of highly intense X-rays. Their ready availability to experimenters and the comparative simplicity of the equipment required to perform the experiments have made experiments involving XAFS and XANES very much easier to perform than has hitherto been the case.

At some synchrotron-radiation sources, database and program libraries for the storage and analysis of XAFS and XANES data exist. These are usually part of the general computing facilities (Pantos, 1982).

Crystallographers seeking information concerning the nature and extent of these computer facilities can find such information by contacting the computer centre at one of the synchrotron-radiation establishments listed in Table 4.2.3.1.

4.2.4. X-ray absorption (or attenuation) coefficients (By D. C. Creagh and J. H. Hubbell)

4.2.4.1. *Introduction*

This data set is intended to supersede those data sets given in *International Tables for X-ray Crystallography*, Vols. III (Koch, MacGillavry & Milledge, 1962) and IV (Hubbell, McMaster, Del Grande & Mallett, 1974).

It is not intended here to give a detailed bibliography of experimental data that have been obtained in the past 90 years. This has been the subject of a number of publications, *e.g.* Saloman & Hubbell (1987), Hubbell, Gerstenberg & Saloman (1986), Saloman & Hubbell (1986), and Saloman, Hubbell & Scofield (1988). Further commentary on the validity and the quality of the experimental data in existing tabulations has been given by Creagh & Hubbell (1987) and Creagh (1987).

Existing tabulations of X-ray attenuation (or absorption) cross sections fall into three distinct categories: purely theoretical, purely experimental, and an evaluated mixture of theoretical and experimental data.

Compilations of the purely theoretically derived data exist for:

photo-effect absorption cross sections (Storm & Israel, 1970; Cromer & Liberman, 1970; Scofield, 1973; Hubbell, Veigele, Briggs, Brown, Cromer & Howerton, 1975; Band, Kharitonov & Trzhaskovskaya, 1979; Yeh & Lindau, 1985);

Compton scattering cross sections (Hubbell *et al.*, 1975);

Rayleigh scattering cross sections (Hubbell *et al.*, 1975; Hubbell & Øverbø, 1979; Schaupp, Schumacher, Smend, Rullhausen & Hubbell, 1983).

Many purely experimental compilations exist, and the cross-section data given in computer programs used in the analysis of results in X-ray-fluorescence spectroscopy, electron-probe microanalysis, and X-ray diffraction are usually (evaluated) compilations of several of the following compilations: Allen (1935, 1969), Victoreen (1949), Liebhafsky, Pfeiffer, Winslow & Zemany (1960), Koch *et al.* (1962), Heinrich (1966), Theisen & Vollath (1967), Veigele (1973), Leroux & Thinh (1977), Montenegro, Baptista & Duarte (1978), and Plechaty, Cullen & Howerton (1981). If a comparison is made between these data sets, significant discrepancies are found, and questions must be asked concerning the reliability of the data sets that are compared. Jackson & Hawkes (1981) and Gerward (1986) have produced sets of parametric tables to simplify the application of X-ray attenuation data for the solution of problems in computer-aided tomography and X-ray-fluorescence analysis.

Compilations by Henke, Lee, Tanaka, Shimambukuro & Fujikawa (1982) and the earlier tables of McMaster, Del Grande, Mallett & Hubbell (1969/1970) are examples of the judicious application of both theoretical and experimental data to produce a comprehensive data set of X-ray interaction cross sections.

Because of the discrepancies that appear to exist between experimental data sets, the IUCr Commission on Crystallographic Apparatus set up a project to establish which, if any, of the existing methods for measuring X-ray interaction cross sections (X-ray attenuation coefficients) and which theoretical calculations could be considered to be the most reliable. A discussion of some of the major results of this project is given in Section 4.2.3. A more detailed description of this project has been given by Creagh & Hubbell (1987, 1990).

In this section, tabulations of the total X-ray interaction cross sections σ and the mass absorption coefficient μ_m are given for a range of characteristic X-ray wavelengths [Ti $K\alpha$ 2.7440 Å (or 4.509 keV) to Ag $K\beta$ 0.4470 Å (or 24.942 keV)]. The interaction cross sections are expressed in units of barns/atom (1 barn $= 10^{-28}$ m^2) whilst the mass absorption coefficient is given in cm^2 g^{-1}. Table 4.2.4.1 sets out the wavelengths of the characteristic wavelengths used in Tables 4.2.4.2 and 4.2.4.3, which list values of σ and μ_m, respectively.

Users of these tables should be aware of three important facts.

(i) The values given in the tables are derived for the case of isolated atoms, and cooperative effects may become important in condensed phases (Section 4.2.3).

(ii) The values are based solely on theoretical calculations.

(iii) The limits to the reliability of the data when compared with experimental values are shown in Fig. 4.2.4.4.

The linear attenuation coefficient μ_l in units of cm^{-1} can be defined operationally as

$$\mu_l = \left(\ln \frac{I_o}{I}\right) \Big/ t \qquad (4.2.4.1)$$

from the exponential attenuation relationship

$$\frac{I}{I_0} = \exp(-\mu_l t) \qquad (4.2.4.2)$$

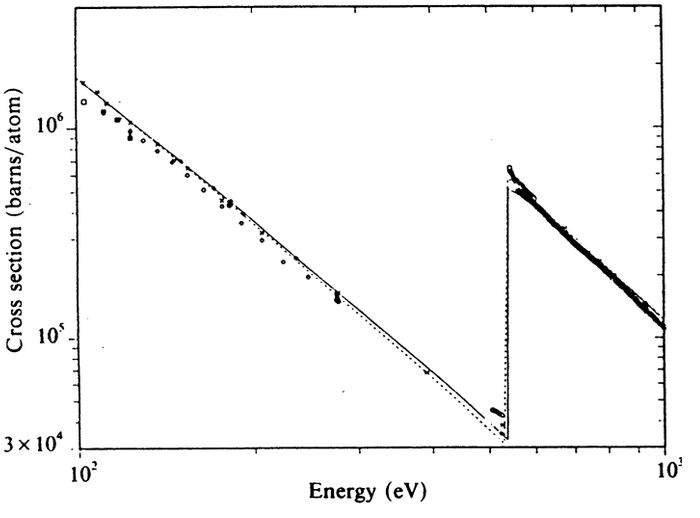

Fig. 4.2.4.1. Agreement between theory and experiment for oxygen ($Z = 8$) in the 'soft' X-ray region. The solid line is for the Scofield (1973) values without renormalization and the dotted line is for the semi-empirical data of Henke *et al.* (1982).

Table 4.2.4.1. *Table of wavelengths and energies for the characteristic radiations used in Tables 4.2.4.2 and 4.2.4.3*

Radiation	λ (Å)	E (keV)
Ag $K\bar{\alpha}$	0.5608	22.103
$K\beta_1$	0.4970	24.942
Pd $K\bar{\alpha}$	0.5869	21.125
$K\beta_1$	0.5205	23.819
Rh $K\bar{\alpha}$	0.6147	20.169
$K\beta_1$	0.5456	22.724
Mo $K\bar{\alpha}$	0.7107	17.444
$K\beta_1$	0.6323	19.608
Zn $K\bar{\alpha}$	1.4364	8.631
$K\beta_1$	1.2952	9.572
Cu $K\bar{\alpha}$	1.5418	8.041
$K\beta_1$	1.3922	8.905
Ni $K\bar{\alpha}$	1.6591	7.472
$K\beta_1$	1.5001	8.265
Co $K\bar{\alpha}$	1.7905	6.925
$K\beta_1$	1.6208	7.629
Fe $K\bar{\alpha}$	1.9373	6.400
$K\beta_1$	1.7565	7.038
Mn $K\bar{\alpha}$	2.1031	5.895
$K\beta_1$	1.9102	6.490
Cr $K\bar{\alpha}$	2.2909	5.412
$K\beta_1$	2.0848	5.947
Ti $K\bar{\alpha}$	2.7496	4.509
$K\beta_1$	2.5138	4.932

in which an idealized plane-parallel slab of material is interposed normally into a parallel beam of monoenergetic X-rays initially of intensity I_0, attenuated by the interposed slab to a reduced intensity I.

The linear attenuation coefficient μ_l for multi-element substances may be obtained in two ways. Through the mass absorption coefficients, we have

$$\mu_l = \rho \sum_i g_i(\mu_m)_i, \tag{4.2.4.3}$$

where g_i is the mass fraction of the element i for which the mass attenuation coefficient $(\mu_m)_i$ is in units of $\mathrm{cm^2\,g^{-1}}$, and ρ is the density of the material in units of $\mathrm{g\,cm^{-3}}$. The summation is over all the constituent elements. The mass attenuation coefficient μ_m is sometimes written as (μ_l/ρ).

For a crystal with unit-cell volume V_c,

$$\mu_l = \frac{1}{V_c}\sum_i \sigma_i, \tag{4.2.4.4}$$

where the summation is over all the atoms in the cell. If σ_i is in barns/atom and V_c is in $\mathrm{Å^3}$, then μ_l is in $\mathrm{cm^{-1}}$.

These tables list total interaction cross sections and mass attenuation coefficients for isolated atoms calculated for characteristic X-ray photon emissions ranging from Ti $K\alpha$ to Ag $K\beta$.

The total interaction cross section is defined by

$$\sigma = \sigma_{\mathrm{pe}} + \sigma_R + \sigma_C, \tag{4.2.4.5}$$

where σ_{pe} is the photo-effect cross section; σ_R is the Rayleigh (unmodified, elastic) cross section; σ_C is the Compton (modified, inelastic) cross section.

The reader's attention is drawn to the fact that in the neighbourhood of an absorption edge for aggregations of atoms significant deviations may be found because of cooperative effects (XAFS and XANES). A discussion of these effects is given in Section 4.2.3.

4.2.4.2. *Sources of information*

4.2.4.2.1. *Theoretical photo-effect data: σ_{pe}*

Of the many theoretical data sets in existence, those of Storm & Israel (1970), Cromer & Liberman (1970), and Scofield (1973) have often been used as bench marks against which both experimental and theoretical data have been compared. In particular, theoretical data produced using the **S**-matrix approach have been compared with these values. See, for example, Kissel, Roy & Pratt (1980). Some indication of the extent to which agreement exists between the different theoretical data sets is given in §4.2.6.2.4 (Tables 4.2.6.3 and 4.2.6.5). These tables show that the values of $f'(\omega, 0)$, which is proportional to σ, calculated using modern relativistic quantum mechanics, agree to better than 1%. It has also been demonstrated by Creagh & Hubbell (1987, 1990) in their analysis of the results of the IUCr X-ray Attenuation Project that there appears to be no rational basis for preferring one of these data sets over the other.

These tables do not list separately photo-effect cross sections. However, should these be required, the data can be found using Table 4.2.6.8. The cross section in barns/atom is related to $f'(\omega, 0)$ expressed in electrons/atom by $\sigma = 5636\lambda f'(\omega, 0)$, where λ is expressed in ångströms.

The values for σ_{pe} used in this compilation are derived from recent tabulations based on relativistic Hartree–Fock–Dirac–Slater calculations by Creagh. The extent to which this data set differs from other theoretical and experimental data sets has been discussed by Creagh (1990).

4.2.4.2.2. *Theoretical Rayleigh scattering data: σ_R*

If each of the atoms gives rise to scattering in which momentum but not energy changes occur, and if each of the atoms can be considered to scatter as if it were an isolated atom, the cross section may be written as

$$\sigma_R = \pi r_e^2 \int_{-1}^{1} (1 + \cos^2\varphi) f^2(q, Z)\, \mathrm{d}(\cos\varphi), \tag{4.2.4.6}$$

where

r_e is the classical radius of the electron;

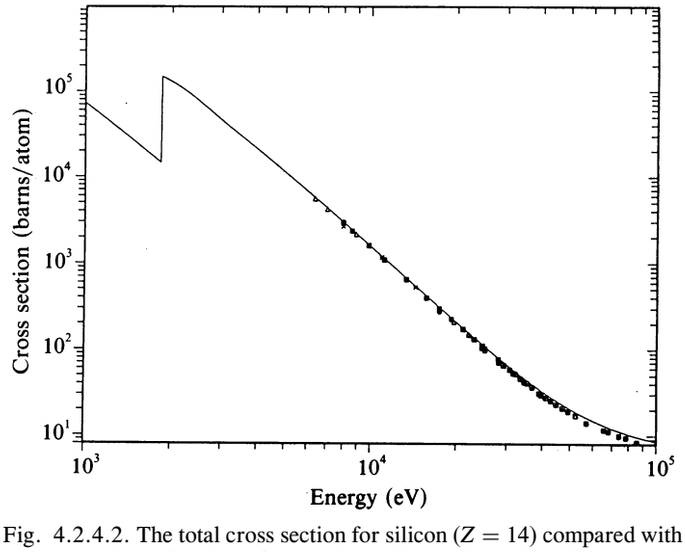

Fig. 4.2.4.2. The total cross section for silicon ($Z = 14$) compared with the unrenormalized Scofield values. The measured and theoretical attenuation coefficients show systematic differences of several percent for the photon energy range 10 to 100 keV.

φ is the angle of scattering ($= 2\theta$ if θ is the Bragg angle);

$2\pi\,\mathrm{d}(\cos\varphi)$ is the solid angle between cones with angles φ and $\varphi + \mathrm{d}\varphi$;

$f(q, Z)$ is the atomic scattering factor as defined by Cromer & Waber (1974);

q is $[\sin(\varphi/2)/\lambda]$, the momentum transfer parameter. Here λ is expressed in ångströms.

Reliable tables of $f(q, Z)$ exist and have been reviewed recently by Kane, Kissel, Pratt & Roy (1986). The most recent schematic tabulations of $f(q, Z)$ are those of Hubbell & Øverbø (1979) and Schaupp *et al.* (1983). The data used in these tables have been derived from the tabulation for $q = 0.02$ to 10^9 Å^{-1}, for all Z's from 1 to 100 by Hubbell & Øverbø (1979) based on the exact formula of Pirenne (1946) for H, and relativistic calculations by Doyle & Turner (1968), Cromer & Waber (1974), Øverbø (1977, 1978), and high-q extensions using the Bethe–Levinger expression in Levinger (1952).

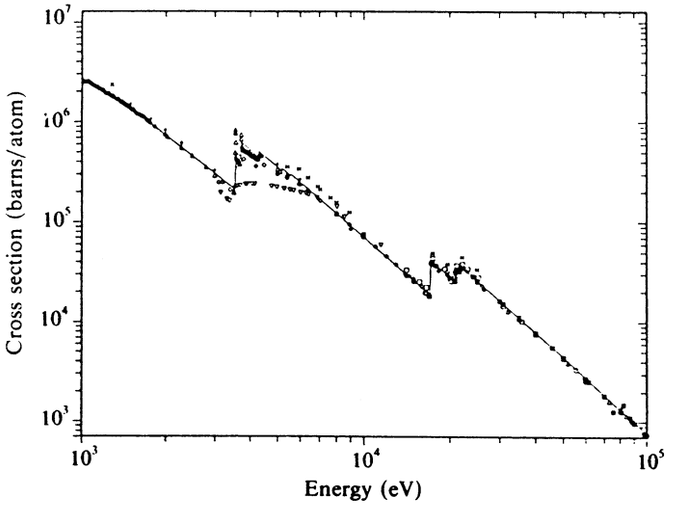

Fig. 4.2.4.3. The total cross section for uranium ($Z = 92$). The theoretical values (solid line) are partially obscured by the high density of available measurements. Deviations of the measured values from the theoretical predictions are mostly of the order of 5%, although a few data sets deviate by more than 30%.

As mentioned in Creagh & Hubbell (1987), the atoms in highly ordered single crystals do not scatter as though they are isolated atoms. Rather, cooperative effects become important. In this case, the Rayleigh scattering cross section must be replaced by two cross sections:

the Laue–Bragg cross section σ_{LB},

and the thermal diffuse scattering cross section σ_{TD}.

That is, σ_R is replaced by $\sigma_{\mathrm{LB}} + \sigma_{\mathrm{TD}}$.

These effects are discussed elsewhere (Subsection 4.2.3.2). Briefly,

$$\sigma_{\mathrm{LB}} = (r_e^2\lambda^2/2NV_c)\sum_H [C_p m d|F|^2 \exp(-2M)]_H. \qquad (4.2.4.7)$$

In equation (4.2.4.7), which is due to De Marco & Suortti (1971),

$C_p = \frac{1}{2}(1 + \cos^2\varphi)$;

d_H is the spacing of the (hkl) planes in the crystal;

m_H is the multiplicity of the hkl Bragg reflection;

F_H is the geometrical structure factor for the crystal structure that contains N atoms in a cell of volume V_c;

$\exp(-2M)_H$ is the Debye-Waller temperature factor.

It is assumed that the total thermal diffuse scattering is equal to the scattering lost from Laue–Bragg scattering because of thermal vibrations.

$$\sigma_{\mathrm{TD}} = (r_e^2\lambda^2/2NV_c)\sum_H \{C_p m d|F|^2[1 - \exp(-2M)]\}_H. \quad (4.2.4.8)$$

H[1] 20↑ 36↑																	He[2] 16↑ 2↓
Li[3] 7↑ 12	Be[4] 13 17↓											B[5] 1 *	C[6] 5↓ 6	N[7] 6↑ 5	O[8] 9 6↓	F[9] 6 3	Ne[10] 3↓ 5
Na[11] 11 *	Mg[12] 4↓ 5											Al[13] 4 7	Si[14] 8↓ 2↓	P[15] 7↓ *	S[16] 4↓ 3	Cl[17] 5↑ 2	Ar[18] 5 14↑
K[19] 4 *	Ca[20] 7↓ 12↓	Sc[21] 6 8↑	Ti[22] 3 8↑	V[23] 4↓ 5	Cr[24] 4 14	Mn[25] 5↓ *	Fe[26] 3↓ 29↑	Co[27] 5↓ 5	Ni[28] 5 6	Cu[29] 5 27	Zn[30] 5↑ 6↑	Ga[31] 17↑ *	Ge[32] 3↓ 12	As[33] 9 *	Se[34] 7↑ 8↑	Br[35] 6↑ 4↓	Kr[36] 2 9↑
Rb[37] * *	Sr[38] 5 *	Y[39] 2↑ 3	Zr[40] 3↑ 3	Nb[41] 3 3	Mo[42] 5↑ 9↑	Tc[43] * *	Ru[44] * *	Rh[45] 4 25	Pd[46] 3↑ 6↑	Ag[47] 5↑ 10↑	Cd[48] 4↑ 13	In[49] 7↑ 22	Sn[50] 5↑ 7↑	Sb[51] 6↑ 42	Te[52] 9↑ 17↑	I[53] 5↑ 6↓	Xe[54] 3 10
Cs[55] * *	Ba[56] 4↓ 12↑	La[57] 7↓ 23↓	Hf[72] 3 10	Ta[73] 4 9↓	W[74] 5 8	Re[75] * 21↑	Os[76] * *	Ir[77] 3 *	Pt[78] 5↑ 14↓	Au[79] 4↓ 11↑	Hg[80] 9 2↑	Tl[81] 3 *	Pb[82] 4↑ 6↑	Bi[83] 7↑ 8↑	Po[84] * *	At[85] * *	Rn[86] * *
Fr[87] * *	Ra[88] * *	Ac[89] * *															

Ce[58] 4↑ 3↑	Pr[59] 2 5	Nd[60] 3 7↑	Pn[61] * *	Sm[62] 4↑ 5↑	Eu[63] * *	Gd[64] 3↑ 8↑	Tb[65] 2 *	Dy[66] 2 3	Ho[67] 3 10↑	Er[68] 3 3	Tm[69] 2 *	Yb[70] 3 24↑	Lu[71] * 80
Th[90] 4↓ 11↑	Pa[91] * *	U[92] 6 25↑	Np[93]	Pu[94]	Am[95]	Cm[96]	Bk[97]	Cf[98]	Es[99]	Fn[100]	Md[101]	No[102]	Lr[103]

Fig. 4.2.4.4. Comparison between this tabulation and experimental data contained in Saloman & Hubbell (1986). The upper set corresponds to the average percent deviation between the experimental data and this tabulation for the energy range 10 to 100 keV. The lower set corresponds to the energy range 1 to 10 keV. For explanation of symbols see text.

Table 4.2.4.2. *Total photon interaction cross section (barns/atom)*

Radiation	Energy (MeV)	1 Hydrogen	2 Helium	3 Lithium	4 Beryllium	5 Boron	6 Carbon	7 Nitrogen	8 Oxygen
Ag $K\beta_1$	2.494E−02	6.10E−01	1.26E+00	2.01E+00	2.97E+00	4.40E+00	6.59E+00	1.00E+01	1.52E+01
Pd $K\beta_1$	2.382E−02	6.10E−01	1.26E+00	2.01E+00	2.99E+00	4.44E+00	6.68E+00	1.02E+01	1.55E+01
Rh $K\beta_1$	2.272E−02	6.12E−01	1.27E+00	2.04E+00	3.06E+00	4.47E+00	6.78E+00	1.05E+01	1.62E+01
Ag $K\bar{\alpha}$	2.210E−02	6.14E−01	1.28E+00	2.06E+00	3.13E+00	4.79E+00	7.45E+00	1.17E+01	1.82E+01
Pd $K\bar{\alpha}$	2.112E−02	6.16E−01	1.29E+00	2.09E+00	3.23E+00	5.05E+00	8.02E+00	1.28E+01	2.02E+01
Rh $K\bar{\alpha}$	2.017E−02	6.18E−01	1.30E+00	2.13E+00	3.35E+00	5.35E+00	8.68E+00	1.41E+01	2.25E+01
Mo $K\beta_1$	1.961E−02	6.19E−01	1.31E+00	2.16E+00	3.42E+00	5.56E+00	9.14E+00	1.50E+01	2.41E+01
Mo $K\bar{\alpha}$	1.744E−02	6.24E−01	1.34E+00	2.28E+00	3.83E+00	6.61E+00	1.15E+01	1.96E+01	3.25E+01
Zn $K\beta_1$	9.572E−03	6.47E−01	1.69E+00	4.19E+00	1.07E+01	2.54E+01	5.37E+01	1.03E+02	1.80E+02
Cu $K\beta_1$	8.905E−03	6.50E−01	1.78E+00	4.74E+00	1.28E+01	3.10E+01	6.64E+01	1.27E+02	2.24E+02
Zn $K\bar{\alpha}$	8.631E−03	6.51E−01	1.82E+00	5.02E+00	1.38E+01	3.39E+01	7.28E+01	1.40E+02	2.46E+02
Ni $K\beta_1$	8.265E−03	6.53E−01	1.89E+00	5.46E+00	1.54E+01	3.83E+01	8.28E+01	1.59E+02	2.80E+02
Cu $K\bar{\alpha}$	8.041E−03	6.55E−01	1.94E+00	5.76E+00	1.66E+01	4.15E+01	8.99E+01	1.73E+02	3.04E+02
Co $K\beta_1$	7.649E−03	6.58E−01	2.04E+00	6.40E+00	1.90E+01	4.80E+01	1.04E+02	2.01E+02	3.54E+02
Ni $K\bar{\alpha}$	7.472E−03	6.59E−01	2.09E+00	6.73E+00	2.02E+01	5.14E+01	1.12E+02	2.16E+02	3.80E+02
Fe $K\beta_1$	7.058E−03	6.63E−01	2.23E+00	7.65E+00	2.37E+01	6.09E+01	1.33E+02	2.57E+02	4.51E+02
Co $K\bar{\alpha}$	6.925E−03	6.64E−01	2.28E+00	7.99E+00	2.50E+01	6.45E+01	1.41E+02	2.72E+02	4.78E+02
Mn $K\beta_1$	6.490E−03	6.69E−01	2.48E+00	9.34E+00	3.01E+01	7.84E+01	1.72E+02	3.31E+02	5.81E+02
Fe $K\bar{\alpha}$	6.400E−03	6.70E−01	2.53E+00	9.67E+00	3.13E+01	8.18E+01	1.79E+02	3.46E+02	6.06E+02
Cr $K\beta_1$	5.947E−03	6.77E−01	2.83E+00	1.16E+01	3.88E+01	1.02E+02	2.24E+02	4.32E+02	7.56E+02
Mn $K\bar{\alpha}$	5.895E−03	6.78E−01	2.87E+00	1.19E+01	3.99E+01	1.05E+02	2.30E+02	4.44E+02	7.76E+02
Cr $K\bar{\alpha}$	5.412E−03	6.89E−01	3.31E+00	1.50E+01	5.14E+01	1.36E+02	2.99E+02	5.75E+02	1.00E+03
Ti $K\beta_1$	4.932E−03	7.04E−01	3.94E+00	1.94E+01	6.82E+01	1.81E+02	3.98E+02	7.62E+02	1.33E+03
Ti $K\bar{\alpha}$	4.509E−03	7.24E−01	4.73E+00	2.51E+01	8.97E+01	2.39E+02	5.23E+02	1.00E+03	1.73E+03
		9 Fluorine	10 Neon	11 Sodium	12 Magnesium	13 Aluminium	14 Silicon	15 Phosphorus	16 Sulfur
Ag $K\beta_1$	2.494E−02	2.27E+01	3.33E+01	4.77E+01	6.68E+01	9.16E+01	1.23E+02	1.62E+02	2.10E+02
Pd $K\beta_1$	2.382E−02	2.32E+01	3.40E+01	4.88E+01	6.85E+01	9.40E+01	1.26E+02	1.67E+02	2.16E+02
Rh $K\beta_1$	2.272E−02	2.50E+01	3.62E+01	5.07E+01	8.26E+01	1.05E+02	1.40E+02	1.85E+02	2.02E+02
Ag $K\bar{\alpha}$	2.210E−02	2.77E+01	4.12E+01	5.96E+01	8.42E+01	1.16E+02	1.56E+02	2.06E+02	2.67E+02
Pd $K\bar{\alpha}$	2.112E−02	3.11E+01	4.65E+01	6.75E+01	9.55E+01	1.32E+02	1.78E+02	2.35E+02	3.05E+02
Rh $K\bar{\alpha}$	2.017E−02	3.50E+01	5.26E+01	7.67E+01	1.09E+02	1.51E+02	2.03E+02	2.69E+02	3.49E+02
Mo $K\beta_1$	1.961E−02	3.76E+01	5.68E+01	5.30E+01	1.18E+02	1.63E+02	2.20E+02	2.92E+02	3.78E+02
Mo $K\bar{\alpha}$	1.744E−02	5.15E+01	7.86E+01	1.16E+02	1.65E+02	2.29E+02	3.10E+02	4.10E+02	5.32E+02
Zn $K\beta_1$	9.572E−03	2.95E+02	4.57E+02	6.77E+02	9.67E+02	1.34E+03	1.79E+03	2.36E+03	3.03E+03
Cu $K\beta_1$	8.905E−03	3.66E+02	5.67E+02	8.39E+02	1.20E+03	1.65E+03	2.21E+03	2.90E+03	3.72E+03
Zn $K\bar{\alpha}$	8.631E−03	4.02E+02	6.22E+02	9.20E+02	1.31E+03	1.81E+03	2.42E+03	3.17E+03	4.06E+03
Ni $K\beta_1$	8.265E−03	4.58E+02	7.08E+02	1.05E+03	1.49E+03	2.05E+03	2.75E+03	3.59E+03	4.60E+03
Cu $K\bar{\alpha}$	8.041E−03	4.98E+02	7.68E+02	1.14E+03	1.61E+03	2.22E+03	2.97E+03	3.88E+03	4.97E+03
Co $K\beta_1$	7.649E−03	5.78E+02	8.92E+02	1.32E+03	1.87E+03	2.57E+03	3.43E+03	4.48E+03	5.72E+03
Ni $K\bar{\alpha}$	7.472E−03	6.20E+02	9.56E+02	1.41E+03	2.00E+03	2.75E+03	3.67E+03	4.78E+03	6.11E+03
Fe $K\beta_1$	7.058E−03	7.36E+02	1.13E+03	1.67E+03	2.36E+03	3.24E+03	4.32E+03	5.62E+03	7.17E+03
Co $K\bar{\alpha}$	6.925E−03	7.79E+02	1.20E+03	1.76E+03	2.50E+03	3.42E+03	4.56E+03	5.93E+03	7.56E+03
Mn $K\beta_1$	6.490E−03	9.46E+02	1.45E+03	2.13E+03	3.02E+03	4.13E+03	5.49E+03	7.12E+03	9.06E+03
Fe $K\bar{\alpha}$	6.400E−03	9.86E+02	1.51E+03	2.22E+03	3.14E+03	4.29E+03	5.71E+03	7.41E+03	9.42E+03
Cr $K\beta_1$	5.947E−03	1.23E+03	1.88E+03	2.75E+03	3.88E+03	5.30E+03	7.03E+03	9.10E+03	1.15E+04
Mn $K\bar{\alpha}$	5.895E−03	1.26E+03	1.93E+03	2.83E+03	3.98E+03	5.43E+03	7.20E+03	9.33E+03	1.18E+04
Cr $K\bar{\alpha}$	5.412E−03	1.62E+03	2.48E+03	3.62E+03	5.09E+03	6.93E+03	9.16E+03	1.18E+04	1.50E+04
Ti $K\beta_1$	4.932E−03	2.14E+03	3.26E+03	4.74E+03	6.64E+03	9.01E+03	1.19E+04	1.53E+04	1.93E+04
Ti $K\bar{\alpha}$	4.509E−03	2.79E+03	4.23E+03	6.13E+03	8.57E+03	1.16E+04	1.52E+04	1.95E+04	2.45E+04

Table 4.2.4.2. *Total photon interaction cross section (barns/atom) (cont.)*

Radiation	Energy (MeV)	17 Chlorine	18 Argon	19 Potassium	20 Calcium	21 Scandium	22 Titanium	23 Vanadium	24 Chromium
Ag $K\beta_1$	2.494E−02	2.68E+02	3.36E+02	4.17E+02	5.12E+02	6.20E+02	7.44E+02	8.85E+02	1.04E+03
Pd $K\beta_1$	2.382E−02	2.75E+02	3.45E+02	4.29E+02	5.26E+02	6.37E+02	7.64E+02	9.09E+02	1.07E+03
Rh $K\beta_1$	2.272E−02	3.15E+02	3.84E+02	4.84E+02	6.30E+02	7.25E+02	8.63E+02	9.98E+02	1.19E+03
Ag $K\bar{\alpha}$	2.210E−02	3.41E+02	4.29E+02	5.32E+02	6.52E+02	7.89E+02	9.47E+02	1.12E+03	1.33E+03
Pd $K\bar{\alpha}$	2.112E−02	3.89E+02	4.89E+02	6.06E+02	7.42E+02	8.99E+02	1.08E+03	1.28E+03	1.51E+03
Rh $K\bar{\alpha}$	2.017E−02	4.45E+02	5.59E+02	6.93E+02	8.48E+02	1.03E+03	1.23E+03	1.46E+03	1.72E+03
Mo $K\beta_1$	1.961E−02	4.83E+02	6.06E+02	7.52E+02	9.20E+02	1.11E+03	1.33E+03	1.58E+03	1.86E+03
Mo $K\bar{\alpha}$	1.744E−02	6.78E+02	8.51E+02	1.05E+03	1.29E+03	1.56E+03	1.86E+03	2.20E+03	2.58E+03
Zn $K\beta_1$	9.572E−03	3.82E+03	4.74E+03	5.80E+03	7.02E+03	8.38E+03	9.93E+03	1.16E+04	1.33E+04
Cu $K\beta_1$	8.905E−03	4.68E+03	5.80E+03	7.09E+03	8.57E+03	1.02E+04	1.21E+04	1.41E+04	1.60E+04
Zn $K\bar{\alpha}$	8.631E−03	5.11E+03	6.34E+03	7.73E+03	9.34E+03	1.11E+04	1.32E+04	1.53E+04	1.73E+04
Ni $K\beta_1$	8.265E−03	5.78E+03	7.15E+03	8.72E+03	1.05E+04	1.25E+04	1.48E+04	1.72E+04	1.96E+04
Cu $K\bar{\alpha}$	8.041E−03	6.24E+03	7.72E+03	9.40E+03	1.13E+04	1.35E+04	1.39E+04	1.85E+04	2.13E+04
Co $K\beta_1$	7.649E−03	7.17E+03	8.86E+03	1.08E+04	1.30E+04	1.54E+04	1.80E+04	2.11E+04	2.53E+04
Ni $K\bar{\alpha}$	7.472E−03	7.66E+03	9.46E+03	1.15E+04	1.38E+04	1.64E+04	1.91E+04	2.25E+04	2.74E+04
Fe $K\beta_1$	7.058E−03	8.97E+03	1.11E+04	1.34E+04	1.61E+04	1.91E+04	2.20E+04	2.62E+04	3.32E+04
Co $K\bar{\alpha}$	6.925E−03	9.46E+03	1.17E+04	1.41E+04	1.69E+04	2.01E+04	2.31E+04	2.75E+04	3.53E+04
Mn $K\beta_1$	6.490E−03	1.13E+04	1.39E+04	1.69E+04	2.01E+04	2.39E+04	2.74E+04	3.26E+04	4.15E+04
Fe $K\bar{\alpha}$	6.400E−03	1.18E+04	1.44E+04	1.75E+04	2.09E+04	2.47E+04	2.85E+04	3.37E+04	4.25E+04
Cr $K\beta_1$	5.947E−03	1.44E+04	1.76E+04	2.13E+04	2.54E+04	3.01E+04	3.53E+04	4.05E+04	5.79E+03
Mn $K\bar{\alpha}$	5.895E−03	1.47E+04	1.80E+04	2.18E+04	2.60E+04	3.08E+04	3.63E+04	4.14E+04	5.93E+03
Cr $K\bar{\alpha}$	5.412E−03	1.86E+04	2.27E+04	2.74E+04	3.26E+04	3.85E+04	4.69E+04	6.32E+03	7.50E+03
Ti $K\beta_1$	4.932E−03	2.38E+04	2.91E+04	3.49E+04	4.15E+04	4.87E+04	6.79E+03	8.16E+03	9.68E+03
Ti $K\bar{\alpha}$	4.509E−03	3.01E+04	3.69E+04	4.41E+04	5.20E+04	6.03E+04	8.68E+03	1.04E+04	1.24E+04

		25 Manganese	26 Iron	27 Cobalt	28 Nickel	29 Copper	30 Zinc	31 Gallium	32 Germanium
Ag $K\beta_1$	2.494E−02	1.22E+03	1.42E+03	1.64E+03	1.88E+03	2.14E+03	2.43E+03	2.74E+03	3.08E+03
Pd $K\beta_1$	2.382E−02	1.25E+03	1.46E+03	1.68E+03	1.93E+03	2.20E+03	2.49E+03	2.81E+03	3.16E+03
Rh $K\beta_1$	2.272E−02	1.37E+03	1.65E+03	1.89E+03	2.19E+03	2.49E+03	2.88E+03	3.21E+03	3.55E+03
Ag $K\bar{\alpha}$	2.210E−02	1.55E+03	1.80E+03	2.07E+03	2.38E+03	2.71E+03	3.07E+03	3.46E+03	3.87E+03
Pd $K\bar{\alpha}$	2.112E−02	1.76E+03	2.04E+03	2.35E+03	2.70E+03	3.07E+03	3.47E+03	3.91E+03	4.38E+03
Rh $K\bar{\alpha}$	2.017E−02	2.01E+03	2.33E+03	2.68E+03	3.07E+03	3.49E+03	3.95E+03	4.44E+03	4.97E+03
Mo $K\beta_1$	1.961E−02	2.17E+03	2.52E+03	2.90E+03	3.31E+03	3.77E+03	4.26E+03	4.80E+03	5.37E+03
Mo $K\bar{\alpha}$	1.744E−02	3.02E+03	3.49E+03	4.01E+03	4.57E+03	5.18E+03	5.86E+03	6.60E+03	7.38E+03
Zn $K\beta_1$	9.572E−03	1.55E+04	1.78E+04	2.02E+04	2.27E+04	2.53E+04	3.90E+03	4.46E+03	5.08E+03
Cu $K\beta_1$	8.905E−03	1.88E+04	2.15E+04	2.43E+04	2.72E+04	4.13E+03	4.75E+03	5.44E+03	6.19E+03
Zn $K\bar{\alpha}$	8.631E−03	2.05E+04	2.34E+04	2.63E+04	2.94E+04	4.50E+03	5.18E+03	5.92E+03	6.75E+03
Ni $K\beta_1$	8.265E−03	2.29E+04	2.61E+04	2.93E+04	4.41E+03	5.07E+03	5.83E+03	6.67E+03	7.60E+03
Cu $K\bar{\alpha}$	8.041E−03	2.46E+04	2.80E+04	3.14E+04	4.76E+03	5.47E+03	6.29E+03	7.19E+03	8.19E+03
Co $K\beta_1$	7.649E−03	2.80E+04	3.17E+04	4.71E+03	5.46E+03	6.27E+03	7.21E+03	8.24E+03	9.38E+03
Ni $K\bar{\alpha}$	7.472E−03	2.97E+04	3.35E+04	5.02E+03	5.82E+03	6.68E+03	7.68E+03	8.79E+03	1.00E+04
Fe $K\beta_1$	7.058E−03	3.42E+04	5.04E+03	5.87E+03	6.80E+03	7.81E+03	8.98E+03	1.03E+04	1.17E+04
Co $K\bar{\alpha}$	6.925E−03	3.58E+04	5.31E+03	6.18E+03	7.16E+03	8.23E+03	9.46E+03	1.08E+04	1.23E+04
Mn $K\beta_1$	6.490E−03	5.40E+03	6.34E+03	7.39E+03	8.56E+03	9.83E+03	1.13E+04	1.29E+04	1.47E+04
Fe $K\bar{\alpha}$	6.400E−03	5.62E+03	6.59E+03	7.68E+03	8.89E+03	1.02E+04	1.17E+04	1.34E+04	1.53E+04
Cr $K\beta_1$	5.947E−03	6.87E+03	8.06E+03	9.40E+03	1.09E+04	1.25E+04	1.43E+04	1.64E+04	1.86E+04
Mn $K\bar{\alpha}$	5.895E−03	7.04E+03	8.26E+03	9.62E+03	1.11E+04	1.28E+04	1.47E+04	1.68E+04	1,91E+04
Cr $K\bar{\alpha}$	5.412E−03	8.90E+03	1.04E+04	1.22E+04	1.41E+04	1.61E+04	1.85E+04	2.12E+04	2.41E+04
Ti $K\beta_1$	4.932E−03	1.15E+04	1.35E+04	1.57E+04	1.81E+04	2.08E+04	2.39E+04	2.72E+04	3.09E+04
Ti $K\bar{\alpha}$	4.509E−03	1.47E+04	1.72E+04	2.00E+04	2.31E+04	2.65E+04	3.04E+04	3.46E+04	3.93E+04

Table 4.2.4.2. *Total photon interaction cross section (barns/atom) (cont.)*

Radiation	Energy (MeV)	33 Arsenic	34 Selenium	35 Bromine	36 Krypton	37 Rubidium	38 Strontium	39 Yttrium	40 Zirconium
Ag $K\beta_1$	2.494E−02	3.44E+03	3.84E+03	4.26E+03	4.72E+03	5.21E+03	5.72E+03	6.25E+03	6.79E+03
Pd $K\beta_1$	2.382E−02	3.53E+03	3.94E+03	4.37E+03	4.84E+03	5.34E+03	5.86E+03	6.41E+03	6.96E+03
Rh $K\beta_1$	2.272E−02	4.04E+03	4.53E+03	5.00E+03	5.50E+03	5.98E+03	6.48E+03	7.27E+03	7.80E+03
Ag $K\bar{\alpha}$	2.210E−02	4.33E+03	4.82E+03	5.35E+03	5.92E+03	6.52E+03	7.15E+03	7.80E+03	8.47E+03
Pd $K\bar{\alpha}$	2.112E−02	4.89E+03	5.45E+03	6.04E+03	6.68E+03	7.35E+03	8.06E+03	8.79E+03	9.52E+03
Rh $K\bar{\alpha}$	2.017E−02	5.55E+03	6.18E+03	6.83E+03	7.55E+03	8.30E+03	9.09E+03	9.90E+03	1.07E+04
Mo $K\beta_1$	1.961E−02	5.99E+03	6.66E+03	7.36E+03	8.13E+03	8.94E+03	9.78E+03	1.06E+04	1.15E+04
Mo $K\bar{\alpha}$	1.744E−02	8.22E+03	9.11E+03	1.00E+04	1.10E+04	1.21E+04	1.32E+04	1.43E+04	2.47E+03
Zn $K\beta_1$	9.572E−03	5.77E+03	6.52E+03	7.34E+03	8.24E+03	9.21E+03	1.03E+04	1.14E+04	1.26E+04
Cu $K\beta_1$	8.905E−03	7.03E+03	7.94E+03	8.94E+03	1.00E+04	1.12E+04	1.25E+04	1.39E+04	1.54E+04
Zn $K\bar{\alpha}$	8.631E−03	7.65E+03	8.64E+03	9.73E+03	1.09E+04	1.22E+04	1.36E+04	1.51E+04	1.67E+04
Ni $K\beta_1$	8.265E−03	8.62E+03	9.73E+03	1.10E+04	1.23E+04	1.37E+04	1.53E+04	1.70E+04	1.88E+04
Cu $K\bar{\alpha}$	8.041E−03	9.29E+03	1.05E+04	1.18E+04	1.32E+04	1.48E+04	1.65E+04	1.83E+04	2.03E+04
Co $K\beta_1$	7.649E−03	1.06E+04	1.20E+04	1.35E+04	1.52E+04	1.69E+04	1.89E+04	2.09E+04	2.32E+04
Ni $K\bar{\alpha}$	7.472E−03	1.13E+04	1.28E+04	1.44E+04	1.61E+04	1.80E+04	2.01E+04	2.23E+04	2.47E+04
Fe $K\beta_1$	7.058E−03	1.32E+04	1.49E+04	1.68E+04	1.88E+04	2.10E+04	2.34E+04	2.60E+04	2.87E+04
Co $K\bar{\alpha}$	6.925E−03	1.39E+04	1.57E+04	1.77E+04	1.98E+04	2.22E+04	2.47E+04	2.73E+04	3.02E+04
Mn $K\beta_1$	6.490E−03	1.66E+04	1.88E+04	2.11E+04	2.36E+04	2.64E+04	2.94E+04	3.26E+04	3.60E+04
Fe $K\bar{\alpha}$	6.400E−03	1.73E+04	1.95E+04	2.19E+04	2.45E+04	2.74E+04	3.05E+04	3.38E+04	3.74E+04
Cr $K\beta_1$	5.947E−03	2.11E+04	2.38E+04	2.67E+04	2.99E+04	3.34E+04	3.72E+04	4.12E+04	4.55E+04
Mn $K\bar{\alpha}$	5.895E−03	2.16E+04	2.44E+04	2.74E+04	3.07E+04	3.42E+04	3.81E+04	4.22E+04	4.66E+04
Cr $K\bar{\alpha}$	5.412E−03	2.72E+04	3.07E+04	3.45E+04	3.85E+04	4.30E+04	4.78E+04	5.29E+04	5.84E+04
Ti $K\beta_1$	4.932E−03	3.50E+04	3.94E+04	4.42E+04	4.94E+04	5.51E+04	6.12E+04	6.77E+04	7.47E+04
Ti $K\bar{\alpha}$	4.509E−03	4.44E+04	5.00E+04	5.61E+04	6.27E+04	6.98E+04	7.75E+04	8.56E+04	9.43E+04
		41 Niobium	42 Molybdenum	43 Technetium	44 Ruthenium	45 Rhodium	46 Palladium	47 Silver	48 Cadmium
Ag $K\beta_1$	2.494E−02	7.41E+03	9.36E+03	8.65E+03	9.33E+03	1.00E+04	1.00E+04	2.00E+03	2.18E+03
Pd $K\beta_1$	2.382E−02	7.59E+03	9.61E+03	8.86E+03	9.56E+03	1.03E+04	1.88E+03	2.05E+03	2.23E+03
Rh $K\beta_1$	2.272E−02	8.57E+03	9.30E+03	9.95E+03	1.07E+04	1.18E+03	2.10E+03	2.29E+03	2.49E+03
Ag $K\bar{\alpha}$	2.210E−02	9.22E+03	1.15E+04	1.07E+04	1.92E+03	2.10E+03	2.30E+03	2.51E+03	2.73E+03
Pd $K\bar{\alpha}$	2.112E−02	1.04E+04	1.23E+04	1.20E+04	2.17E+03	2.38E+03	2.60E+03	2.84E+03	3.09E+03
Rh $K\bar{\alpha}$	2.017E−02	1.16E+04	1.27E+04	2.24E+03	2.46E+03	2.70E+03	2.94E+03	3.21E+03	3.50E+03
Mo $K\beta_1$	1.961E−02	1.25E+04	2.19E+03	2.42E+03	2.65E+03	2.91E+03	3.18E+03	3.47E+03	3.78E+03
Mo $K\bar{\alpha}$	1.744E−02	2.73E+03	3.00E+03	3.32E+03	3.64E+03	3.99E+03	4.36E+03	4.76E+03	5.18E+03
Zn $K\beta_1$	9.572E−03	1.40E+04	1.54E+04	1.69E+04	1.85E+04	2.02E+04	2.21E+04	2.40E+04	2.61E+04
Cu $K\beta_1$	8.905E−03	1.70E+04	1.87E+04	2.05E+04	2.25E+04	2.45E+04	2.67E+04	2.91E+04	3.16E+04
Zn $K\bar{\alpha}$	8.631E−03	1.85E+04	2.03E+04	2.23E+04	2.44E+04	2.67E+04	2.91E+04	3.16E+04	3.44E+04
Ni $K\beta_1$	8.265E−03	2.07E+04	2.28E+04	2.51E+04	2.74E+04	3.00E+04	3.27E+04	3.55E+04	3.86E+04
Cu $K\bar{\alpha}$	8.041E−03	2.23E+04	2.46E+04	2.70E+04	2.95E+04	3.23E+04	3.52E+04	3.82E+04	4.15E+04
Co $K\beta_1$	7.649E−03	2.55E+04	2.81E+04	3.08E+04	3.37E+04	3.68E+04	4.01E+04	4.36E+04	4.73E+04
Ni $K\bar{\alpha}$	7.472E−03	2.72E+04	2.99E+04	3.28E+04	3.59E+04	3.92E+04	4.27E+04	4.64E+04	5.03E+04
Fe $K\beta_1$	7.058E−03	3.17E+04	3.48E+04	3.82E+04	4.18E+04	4.56E+04	4.96E+04	5.39E+04	5.84E+04
Co $K\bar{\alpha}$	6.925E−03	3.33E+04	3.66E+04	4.02E+04	4.39E+04	4.79E+04	5.21E+04	5.66E+04	6.14E+04
Mn $K\beta_1$	6.490E−03	3.96E+04	4.36E+04	4.77E+04	5.22E+04	5.69E+04	6.19E+04	6.72E+04	7.28E+04
Fe $K\bar{\alpha}$	6.400E−03	4.12E+04	4.52E+04	4.95E+04	5.42E+04	5.91E+04	6.42E+04	6.97E+04	7.55E+04
Cr $K\beta_1$	5.947E−03	5.01E+04	5.50E+04	6.02E+04	6.58E+04	7.17E+04	7.79E+04	8.45E+04	9.15E+04
Mn $K\bar{\alpha}$	5.895E−03	5.13E+04	5.63E+04	6.16E+04	6.73E+04	7.34E+04	7.97E+04	8.64E+04	9.36E+04
Cr $K\bar{\alpha}$	5.412E−03	6.42E+04	7.05E+04	7.71E+04	8.41E+04	9.16E+04	9.94E+04	1.08E+05	1.17E+05
Ti $K\beta_1$	4.932E−03	8.21E+04	8.99E+04	9.83E+04	1.07E+05	1.17E+05	1.27E+05	1.37E+05	1.48E+05
Ti $K\bar{\alpha}$	4.509E−03	1.04E+05	1.13E+05	1.24E+05	1.35E+05	1.47E+05	1.59E+05	1.72E+05	1.86E+05

Table 4.2.4.2. *Total photon interaction cross section (barns/atom) (cont.)*

Radiation	Energy (MeV)	49 Indium	50 Tin	51 Antimony	52 Tellurium	53 Iodine	54 Xenon	55 Caesium	56 Barium
Ag $K\beta_1$	2.494E−02	2.37E+03	2.57E+03	2.79E+03	3.02E+03	3.26E+03	3.52E+03	3.79E+03	4.08E+03
Pd $K\beta_1$	2.382E−02	2.43E+03	2.64E+03	2.86E+03	3.09E+03	3.34E+03	3.61E+03	3.89E+03	4.18E+03
Rh $K\beta_1$	2.272E−02	2.64E+03	3.00E+03	3.20E+03	3.50E+03	3.71E+03	4.04E+03	4.04E+03	4.76E+03
Ag $K\bar{\alpha}$	2.210E−02	2.97E+03	3.23E+03	3.50E+03	3.78E+03	4.09E+03	4.41E+03	4.75E+03	5.11E+03
Pd $K\bar{\alpha}$	2.112E−02	3.36E+03	3.65E+03	3.95E+03	4.28E+03	4.62E+03	4.98E+03	5.37E+03	5.78E+03
Rh $K\bar{\alpha}$	2.017E−02	3.81E+03	4.13E+03	4.48E+03	4.85E+03	5.24E+03	5.65E+03	6.09E+03	6.55E+03
Mo $K\beta_1$	1.961E−02	4.11E+03	4.46E+03	4.84E+03	5.23E+03	5.65E+03	6.09E+03	6.57E+03	7.06E+03
Mo $K\bar{\alpha}$	1.744E−02	5.63E+03	6.11E+03	6.62E+03	7.16E+03	7.73E+03	8.34E+03	8.98E+03	9.65E+03
Zn $K\beta_1$	9.572E−03	2.83E+04	3.06E+04	3.31E+04	3.57E+04	3.84E+04	4.13E+04	4.44E+04	4.76E+04
Cu $K\beta_1$	8.905E−03	3.43E+04	3.71E+04	4.00E+04	4.32E+04	4.64E+04	4.99E+04	5.36E+04	5.74E+04
Zn $K\bar{\alpha}$	8.631E−03	3.72E+04	4.03E+04	4.35E+04	4.69E+04	5.04E+04	5.42E+04	5.81E+04	6.23E+04
Ni $K\beta_1$	8.265E−03	4.18E+04	4.52E+04	4.88E+04	5.25E+04	5.65E+04	6.07E+04	6.51E+04	6.98E+04
Cu $K\bar{\alpha}$	8.041E−03	4.50E+04	4.86E+04	5.25E+04	5.65E+04	6.07E+04	6.52E+04	7.00E+04	7.50E+04
Co $K\beta_1$	7.649E−03	5.12E+04	5.54E+04	5.98E+04	6.43E+04	6.92E+04	7.42E+04	7.96E+04	8.52E+04
Ni $K\bar{\alpha}$	7.472E−03	5.45E+04	5.89E+04	6.35E+04	6.84E+04	7.35E+04	7.88E+04	8.45E+04	9.04E+04
Fe $K\beta_1$	7.058E−03	6.32E+04	6.83E+04	7.37E+04	7.94E+04	8.52E+04	9.14E+04	9.77E+04	1.04E+05
Co $K\bar{\alpha}$	6.925E−03	6.64E+04	7.18E+04	7.74E+04	8.34E+04	8.96E+04	9.60E+04	1.03E+05	1.09E+05
Mn $K\beta_1$	6.490E−03	7.87E+04	8.50E+04	9.17E+04	9.88E+04	1.06E+05	1.13E+05	1.21E+05	1.29E+05
Fe $K\bar{\alpha}$	6.400E−03	8.17E+04	8.82E+04	9.51E+04	1.02E+05	1.10E+05	1.18E+05	1.26E+05	1.34E+05
Cr $K\beta_1$	5.947E−03	9.90E+04	1.07E+05	1.15E+05	1.24E+05	1.33E+05	1.42E+05	1.60E+05	1.47E+05
Mn $K\bar{\alpha}$	5.895E−03	1.01E+05	1.09E+05	1.18E+05	1.27E+05	1.36E+05	1.45E+05	1.63E+05	1.50E+05
Cr $K\bar{\alpha}$	5.412E−03	1.26E+05	1.36E+05	1.46E+05	1.57E+05	1.68E+05	1.57E+05	1.77E+05	1.34E+05
Ti $K\beta_1$	4.932E−03	1.60E+05	1.73E+05	1.85E+05	1.98E+05	2.11E+05	2.48E+05	5.70E+04	7.16E+04
Ti $K\bar{\alpha}$	4.509E−03	2.00E+05	2.15E+05	2.00E+05	1.60E+05	6.17E+04	5.78E+04	7.28E+04	7.62E+04
		57 Lanthanum	58 Cerium	59 Praseodymium	60 Neodymium	61 Promethium	62 Samarium	63 Europium	64 Gadolinium
Ag $K\beta_1$	2.494E−02	3.97E+03	4.26E+03	4.56E+03	4.89E+03	5.22E+03	5.57E+03	5.93E+03	6.32E+03
Pd $K\beta_1$	2.382E−02	4.05E+03	4.82E+03	5.15E+03	5.51E+03	5.90E+03	6.29E+03	6.71E+03	7.15E+03
Rh $K\beta_1$	2.272E−02	5.10E+03	5.47E+03	5.85E+03	6.25E+03	6.69E+03	7.14E+03	7.59E+03	8.09E+03
Ag $K\bar{\alpha}$	2.210E−02	5.49E+03	5.89E+03	6.29E+03	6.73E+03	7.20E+03	7.69E+03	8.17E+03	8.72E+03
Pd $K\bar{\alpha}$	2.112E−02	6.20E+03	6.63E+03	7.11E+03	7.62E+03	8.14E+03	8.69E+03	9.23E+03	9.84E+03
Rh $K\bar{\alpha}$	2.017E−02	7.03E+03	7.69E+03	8.07E+03	8.62E+03	9.22E+03	9.84E+03	1.05E+04	1.11E+04
Mo $K\beta_1$	1.961E−02	7.59E+03	8.12E+03	8.70E+03	9.29E+03	9.94E+03	1.06E+04	1.13E+04	1.20E+04
Mo $K\bar{\alpha}$	1.744E−02	1.04E+04	1.11E+04	1.19E+04	1.27E+04	1.36E+04	1.44E+04	1.54E+04	1.63E+04
Zn $K\beta_1$	9.572E−03	5.10E+04	5.42E+04	5.78E+04	6.15E+04	6.57E+04	6.97E+04	9.93E+04	7.83E+04
Cu $K\beta_1$	8.905E−03	6.14E+04	6.56E+04	7.00E+04	7.42E+04	7.90E+04	8.36E+04	8.88E+04	9.40E+04
Zn $K\bar{\alpha}$	8.631E−03	6.67E+04	7.12E+04	7.58E+04	8.04E+04	8.44E+04	9.06E+04	9.59E+04	1.02E+05
Ni $K\beta_1$	8.265E−03	7.47E+04	7.96E+04	8.49E+04	9.00E+04	9.56E+04	1.01E+05	1.07E+05	9.84E+04
Cu $K\bar{\alpha}$	8.041E−03	8.03E+04	8.56E+04	9.12E+04	9.68E+04	1.03E+05	1.08E+05	1.02E+05	1.05E+05
Co $K\beta_1$	7.649E−03	9.11E+04	9.70E+04	1.03E+05	1.09E+05	1.16E+05	1.07E+05	1.21E+05	8.75E+04
Ni $K\bar{\alpha}$	7.472E−03	9.68E+04	1.03E+05	1.09E+05	1.16E+05	1.23E+05	1.14E+05	8.70E+04	9.29E+04
Fe $K\beta_1$	7.058E−03	1.11E+05	1.19E+05	1.26E+05	1.18E+05	1.22E+05	9.56E+04	1.03E+05	3.99E+04
Co $K\bar{\alpha}$	6.925E−03	1.17E+05	1.24E+05	1.32E+05	1.21E+05	9.63E+04	9.89E+04	4.04E+04	4.20E+04
Mn $K\beta_1$	6.490E−03	1.38E+05	1.27E+05	1.39E+05	1.05E+05	1.13E+05	4.39E+04	4.67E+04	4.93E+04
Fe $K\bar{\alpha}$	6.400E−03	1.43E+05	1.31E+05	1.02E+05	1.09E+05	4.19E+04	4.59E+04	4.87E+04	5.09E+04
Cr $K\beta_1$	5.947E−03	1.48E+05	1.15E+05	1.22E+05	4.74E+04	5.01E+04	5.52E+04	5.65E+04	6.14E+04
Mn $K\bar{\alpha}$	5.895E−03	1.50E+05	1.19E+05	4.52E+04	4.86E+04	5.18E+04	5.64E+04	6.03E+04	6.29E+04
Cr $K\bar{\alpha}$	5.412E−03	5.19E+04	5.54E+04	5.57E+04	6.01E+04	6.43E+04	6.97E+04	7.54E+04	7.78E+04
Ti $K\beta_1$	4.932E−03	6.55E+04	6.98E+04	7.02E+04	7.52E+04	8.11E+04	8.74E+04	9.34E+04	9.76E+04
Ti $K\bar{\alpha}$	4.509E−03	8.19E+04	8.31E+04	8.77E+04	9.51E+04	1.02E+05	1.09E+05	1.16E+05	1.22E+05

Table 4.2.4.2. *Total photon interaction cross section (barns/atom) (cont.)*

Radiation	Energy (MeV)	65 Terbium	66 Dysprosium	67 Holmium	68 Erbium	69 Thulium	70 Ytterbium	71 Lutetium	72 Hafnium
Ag $K\beta_1$	2.494E−02	6.66E+03	7.15E+03	7.59E+03	8.05E+03	8.52E+03	9.02E+03	9.53E+03	1.01E+04
Pd $K\beta_1$	2.382E−02	7.52E+03	8.07E+03	8.57E+03	9.08E+03	9.62E+03	1.02E+04	1.08E+04	1.14E+04
Rh $K\beta_1$	2.272E−02	8.15E+03	9.15E+03	9.69E+03	1.03E+04	1.08E+04	1.15E+04	1.22E+04	1.29E+04
Ag $K\bar{\alpha}$	2.210E−02	9.16E+03	9.85E+03	1.01E+04	1.11E+04	1.17E+04	1.24E+04	1.31E+04	1.38E+04
Pd $K\bar{\alpha}$	2.112E−02	1.03E+04	1.11E+04	1.18E+04	1.25E+04	1.32E+04	1.40E+04	1.48E+04	1.56E+04
Rh $K\bar{\alpha}$	2.017E−02	1.17E+04	1.26E+04	1.33E+04	1.41E+04	1.50E+04	1.58E+04	1.67E+04	1.76E+04
Mo $K\beta_1$	1.961E−02	1.26E+04	1.35E+04	1.43E+04	1.52E+04	1.61E+04	1.70E+04	1.80E+04	1.90E+04
Mo $K\bar{\alpha}$	1.744E−02	1.72E+04	1.84E+04	1.95E+04	2.07E+04	2.19E+04	2.31E+04	2.44E+04	2.57E+04
Zn $K\beta_1$	9.572E−03	8.20E+04	8.74E+04	9.20E+04	8.53E+04	6.59E+04	6.90E+04	7.26E+04	7.70E+04
Cu $K\beta_1$	8.905E−03	9.87E+04	9.31E+04	7.17E+04	7.42E+04	8.27E+04	3.10E+04	3.52E+04	3.56E+04
Zn $K\bar{\alpha}$	8.631E−03	9.29E+04	1.02E+05	7.78E+04	7.97E+04	3.28E+04	3.36E+04	3.81E+04	3.85E+04
Ni $K\beta_1$	8.265E−03	1.08E+05	8.53E+04	8.60E+04	3.42E+04	3.67E+04	3.76E+04	4.24E+04	4.30E+04
Cu $K\bar{\alpha}$	8.041E−03	8.38E+04	9.23E+04	3.53E+04	3.67E+04	3.93E+04	4.08E+04	4.53E+04	4.59E+04
Co $K\beta_1$	7.649E−03	9.40E+04	3.72E+04	4.00E+04	4.14E+04	4.46E+04	4.57E+04	5.17E+04	5.21E+04
Ni $K\bar{\alpha}$	7.472E−03	3.89E+04	3.94E+04	4.24E+04	4.39E+04	4.47E+04	4.86E+04	5.49E+04	5.54E+04
Fe $K\beta_1$	7.058E−03	4.22E+04	4.53E+04	4.87E+04	5.05E+04	5.50E+04	5.63E+04	6.33E+04	6.40E+04
Co $K\bar{\alpha}$	6.925E−03	4.43E+04	4.75E+04	5.12E+04	5.30E+04	5.78E+04	5.92E+04	6.65E+04	6.73E+04
Mn $K\beta_1$	6.490E−03	5.22E+04	5.59E+04	6.02E+04	6.22E+04	6.82E+04	7.01E+04	7.84E+04	7.91E+04
Fe $K\bar{\alpha}$	6.400E−03	5.44E+04	5.77E+04	6.24E+04	6.44E+04	7.10E+04	7.21E+04	8.13E+04	8.21E+04
Cr $K\beta_1$	5.947E−03	6.46E+04	6.93E+04	7.45E+04	7.75E+04	8.55E+04	8.73E+04	9.85E+04	9.90E+04
Mn $K\bar{\alpha}$	5.895E−03	6.68E+04	7.07E+04	7.67E+04	7.92E+04	8.75E+04	8.94E+04	1.01E+05	1.01E+05
Cr $K\bar{\alpha}$	5.412E−03	8.29E+04	8.77E+04	9.51E+04	9.78E+04	1.08E+05	1.11E+05	1.25E+05	1.26E+05
Ti $K\beta_1$	4.932E−03	1.05E+05	1.11E+05	1.20E+05	1.23E+05	1.39E+05	1.41E+05	1.59E+05	1.60E+05
Ti $K\bar{\alpha}$	4.509E−03	1.31E+05	1.39E+05	1.50E+05	1.54E+05	1.73E+05	1.78E+05	2.00E+05	2.01E+05
		73 Tantalum	74 Tungsten	75 Rhenium	76 Osmium	77 Iridium	78 Platinum	79 Gold	80 Mercury
Ag $K\beta_1$	2.494E−02	1.17E+04	1.24E+04	1.30E+04	1.37E+04	1.44E+04	1.52E+04	1.60E+04	1.68E+04
Pd $K\beta_1$	2.382E−02	1.20E+04	1.27E+04	1.34E+04	1.41E+04	1.48E+04	1.56E+04	1.64E+04	1.72E+04
Rh $K\beta_1$	2.272E−02	1.35E+04	1.45E+04	1.52E+04	1.59E+04	1.69E+04	1.78E+04	1.77E+04	1.94E+04
Ag $K\bar{\alpha}$	2.210E−02	1.46E+04	1.54E+04	1.62E+04	1.71E+04	1.80E+04	1.89E+04	1.99E+04	2.09E+04
Pd $K\bar{\alpha}$	2.112E−02	1.65E+04	1.74E+04	1.83E+04	1.93E+04	2.02E+04	2.13E+04	2.24E+04	2.35E+04
Rh $K\bar{\alpha}$	2.017E−02	1.86E+04	1.96E+04	2.07E+04	2.17E+04	2.28E+04	2.40E+04	2.52E+04	2.65E+04
Mo $K\beta_1$	1.961E−02	2.00E+04	2.11E+04	2.22E+04	2.34E+04	2.46E+04	2.58E+04	2.71E+04	2.84E+04
Mo $K\bar{\alpha}$	1.744E−02	2.72E+04	2.86E+04	3.01E+04	3.16E+04	3.31E+04	3.48E+04	3.65E+04	3.82E+04
Zn $K\beta_1$	9.572E−03	3.30E+04	3.29E+04	3.67E+04	3.73E+04	4.01E+04	4.08E+04	4.24E+04	4.29E+04
Cu $K\beta_1$	8.905E−03	3.76E+04	3.97E+04	4.43E+04	4.48E+04	4.83E+04	4.89E+04	5.08E+04	5.18E+04
Zn $K\bar{\alpha}$	8.631E−03	4.05E+04	4.26E+04	4.78E+04	4.84E+04	5.20E+04	5.28E+04	5.58E+04	5.58E+04
Ni $K\beta_1$	8.265E−03	4.41E+04	4.80E+04	5.34E+04	5.41E+04	5.81E+04	5.66E+04	6.14E+04	6.20E+04
Cu $K\bar{\alpha}$	8.041E−03	4.85E+04	5.13E+04	5.72E+04	5.80E+04	6.24E+04	6.34E+04	6.69E+04	6.68E+04
Co $K\beta_1$	7.649E−03	5.39E+04	5.83E+04	6.50E+04	6.55E+04	7.09E+04	6.87E+04	7.49E+04	6.91E+04
Ni $K\bar{\alpha}$	7.472E−03	5.84E+04	6.19E+04	6.88E+04	6.97E+04	7.51E+04	7.62E+04	8.03E+04	8.02E+04
Fe $K\beta_1$	7.058E−03	6.60E+04	7.15E+04	7.95E+04	8.03E+04	8.68E+04	8.45E+04	9.17E+04	9.14E+04
Co $K\bar{\alpha}$	6.925E−03	6.92E+04	7.51E+04	8.33E+04	8.44E+04	9.11E+04	9.20E+04	9.71E+04	9.71E+04
Mn $K\beta_1$	6.490E−03	8.16E+04	8.82E+04	9.83E+04	9.94E+04	1.07E+05	1.04E+05	1.14E+05	1.09E+05
Fe $K\bar{\alpha}$	6.400E−03	8.46E+04	9.15E+04	1.02E+05	1.02E+05	1.11E+05	1.12E+05	1.18E+05	1.19E+05
Cr $K\beta_1$	5.947E−03	1.01E+05	1.10E+05	1.22E+05	1.23E+05	1.34E+05	1.31E+05	1.41E+05	1.36E+05
Mn $K\bar{\alpha}$	5.895E−03	1.06E+05	1.12E+05	1.25E+05	1.27E+05	1.37E+05	1.34E+05	1.45E+05	1.42E+05
Cr $K\bar{\alpha}$	5.412E−03	1.31E+05	1.40E+05	1.55E+05	1.57E+05	1.70E+05	1.66E+05	1.79E+05	1.80E+05
Ti $K\beta_1$	4.932E−03	1.64E+05	1.77E+05	1.96E+05	1.99E+05	2.15E+05	2.11E+05	2.23E+05	2.33E+05
Ti $K\bar{\alpha}$	4.509E−03	2.60E+05	2.18E+05	2.46E+05	2.49E+05	2.65E+05	2.66E+05	2.80E+05	2.98E+05

Table 4.2.4.2. *Total photon interaction cross section (barns/atom) (cont.)*

Radiation	Energy (MeV)	81 Thallium	82 Lead	83 Bismuth	84 Polonium	85 Astatine	86 Radon	87 Francium	88 Radium
Ag $K\beta_1$	2.494E−02	1.76E+04	1.84E+04	1.93E+04	2.02E+04	2.11E+04	2.20E+04	2.30E+04	2.41E+04
Pd $K\beta_1$	2.382E−02	1.80E+04	1.89E+04	1.98E+04	2.07E+04	2.16E+04	2.26E+04	2.36E+04	2.46E+04
Rh $K\beta_1$	2.272E−02	1.99E+04	2.05E+04	2.27E+04	2.37E+04	2.49E+04	2.55E+04	2.60E+04	2.68E+04
Ag $K\bar{\alpha}$	2.210E−02	2.19E+04	2.29E+04	2.40E+04	2.51E+04	2.62E+04	2.73E+04	2.85E+04	2.98E+04
Pd $K\bar{\alpha}$	2.112E−02	2.46E+04	2.58E+04	2.70E+04	2.82E+04	2.94E+04	3.07E+04	3.20E+04	3.34E+04
Rh $K\bar{\alpha}$	2.017E−02	2.78E+04	2.91E+04	3.04E+04	3.18E+04	3.31E+04	3.45E+04	3.60E+04	3.76E+04
Mo $K\beta_1$	1.961E−02	2.98E+04	3.12E+04	3.27E+04	3.41E+04	3.56E+04	3.71E+04	3.87E+04	4.03E+04
Mo $K\bar{\alpha}$	1.744E−02	4.01E+04	4.19E+04	4.38E+04	4.58E+04	4.07E+04	3.98E+04	3.22E+04	3.30E+04
Zn $K\beta_1$	9.572E−03	4.83E+04	5.11E+04	5.42E+04	5.66E+04	5.56E+04	6.22E+04	6.55E+04	6.56E+04
Cu $K\beta_1$	8.905E−03	5.81E+04	6.15E+04	6.51E+04	6.80E+04	6.68E+04	7.48E+04	7.87E+04	7.80E+04
Zn $K\bar{\alpha}$	8.631E−03	6.29E+04	6.66E+04	7.04E+04	7.35E+04	7.21E+04	8.11E+04	8.92E+04	8.55E+04
Ni $K\beta_1$	8.265E−03	7.03E+04	7.44E+04	7.86E+04	8.22E+04	8.04E+04	9.06E+04	9.94E+04	9.53E+04
Cu $K\bar{\alpha}$	8.041E−03	7.54E+04	7.98E+04	8.43E+04	8.81E+04	8.65E+04	9.72E+04	1.02E+05	1.02E+05
Co $K\beta_1$	7.649E−03	8.58E+04	9.01E+04	9.57E+04	1.00E+05	9.82E+04	1.11E+05	1.16E+05	1.16E+05
Ni $K\bar{\alpha}$	7.472E−03	9.11E+04	9.64E+04	1.02E+05	1.06E+05	1.04E+05	1.17E+05	1.23E+05	1.23E+05
Fe $K\beta_1$	7.058E−03	1.05E+05	1.12E+05	1.17E+05	1.22E+05	1.20E+05	1.36E+05	1.42E+05	1.43E+05
Co $K\bar{\alpha}$	6.925E−03	1.11E+05	1.17E+05	1.23E+05	1.29E+05	1.26E+05	1.43E+05	1.49E+05	1.49E+05
Mn $K\beta_1$	6.490E−03	1.31E+05	1.39E+05	1.46E+05	1.51E+05	1.49E+05	1.69E+05	1.77E+05	1.76E+05
Fe $K\bar{\alpha}$	6.400E−03	1.36E+05	1.48E+05	1.51E+05	1.57E+05	1.54E+05	1.75E+05	1.82E+05	1.83E+05
Cr $K\beta_1$	5.947E−03	1.64E+05	1.74E+05	1.82E+05	1.89E+05	1.86E+05	2.11E+05	2.21E+05	2.19E+05
Mn $K\bar{\alpha}$	5.895E−03	1.68E+05	1.78E+05	1.86E+05	1.93E+05	1.91E+05	2.16E+05	2.23E+05	2.25E+05
Cr $K\bar{\alpha}$	5.412E−03	2.22E+05	2.22E+05	2.32E+05	1.99E+05	2.37E+05	2.70E+05	2.82E+05	2.79E+05
Ti $K\beta_1$	4.932E−03	2.66E+05	2.82E+05	2.94E+05	2.88w+05	2.99E+05	3.43E+05	3.56E+05	3.53E+05
Ti $K\bar{\alpha}$	4.509E−03	3.36E+05	3.56E+05	3.67E+05	3.17E+05	3.78E+05	4.33E+05	4.49E+05	4.99E+05
		89 Actinium	90 Thorium	91 Protactinium	92 Uranium	93 Neptunium	94 Plutonium	95 Americium	96 Curium
Ag $K\beta_1$	2.494E−02	2.51E+04	2.62E+04	2.73E+04	2.84E+04	2.95E+04	3.07E+04	3.18E+04	2.89E+04
Pd $K\beta_1$	2.382E−02	2.57E+04	2.68E+04	2.79E+04	2.90E+04	3.02E+04	3.14E+04	3.26E+04	2.96E+04
Rh $K\beta_1$	2.272E−02	2.83E+04	3.09E+04	3.00E+04	3.54E+04	3.42E+04	3.03E+04	3.34E+04	2.36E+04
Ag $K\bar{\alpha}$	2.210E−02	3.11E+04	3.23E+04	3.42E+04	3.50E+04	2.99E+04	2.27E+04	2.50E+04	2.46E+04
Pd $K\bar{\alpha}$	2.112E−02	3.48E+04	3.62E+04	3.77E+04	3.40E+04	4.08E+04	4.24E+04	4.39E+04	4.05E+04
Rh $K\bar{\alpha}$	2.017E−02	3.92E+04	4.07E+04	4.24E+04	2.74E+04	4.58E+04	4.76E+04	4.93E+04	4.57E+04
Mo $K\beta_1$	1.961E−02	3.42E+04	3.80E+04	4.55E+04	2.96E+04	4.91E+04	5.10E+04	5.29E+04	4.92E+04
Mo $K\bar{\alpha}$	1.744E−02	5.40E+04	3.70E+04	3.87E+04	4.03E+04	2.57E+04	1.62E+04	1.89E+04	2.01E+04
Zn $K\beta_1$	9.572E−03	1.07E+05	6.57E+04	6.74E+04	7.11E+04	7.47E+04	7.29E+04	7.63E+04	7.95E+04
Cu $K\beta_1$	8.905E−03	1.14E+05	8.70E+04	8.11E+04	8.54E+04	8.92E+04	8.75E+04	9.27E+04	9.51E+04
Zn $K\bar{\alpha}$	8.631E−03	1.16E+05	9.84E+04	8.78E+04	9.23E+04	9.67E+04	9.48E+04	1.01E+05	1.03E+05
Ni $K\beta_1$	8.265E−03	1.19E+05	1.10E+05	9.82E+04	1.03E+05	1.08E+05	1.06E+05	1.14E+05	1.15E+05
Cu $K\bar{\alpha}$	8.041E−03	1.43E+05	1.18E+05	1.06E+05	1.12E+05	1.23E+05	1.13E+05	1.44E+05	1.38E+05
Co $K\beta_1$	7.649E−03	1.50E+05	1.34E+05	1.19E+05	1.26E+05	1.32E+05	1.28E+05	1.46E+05	1.41E+05
Ni $K\bar{\alpha}$	7.472E−03	1.67E+05	1.42E+05	1.27E+05	1.33E+05	1.40E+05	1.36E+05	1.48E+05	1.47E+05
Fe $K\beta_1$	7.058E−03	1.47E+05	1.54E+05	1.46E+05	1.54E+05	1.61E+05	1.57E+05	1.73E+05	1.73E+05
Co $K\bar{\alpha}$	6.925E−03	1.74E+05	1.72E+05	1.53E+05	1.61E+05	1.69E+05	1.65E+05	1.81E+05	1.79E+05
Mn $K\beta_1$	6.490E−03	1.96E+05	1.87E+05	1.81E+05	1.90E+05	1.98E+05	1.94E+05	2.15E+05	2.11E+05
Fe $K\bar{\alpha}$	6.400E−03	2.00E+05	1.96E+05	1.88E+05	1.97E+05	2.17E+05	2.02E+05	2.43E+05	2.42E+05
Cr $K\beta_1$	5.947E−03	2.32E+05	2.35E+05	2.27E+05	2.37E+05	2.48E+05	2.43E+05	2.72E+05	2.62E+05
Mn $K\bar{\alpha}$	5.895E−03	2.37E+05	2.40E+05	2.31E+05	2.43E+05	2.53E+05	2.48E+05	2.78E+05	2.68E+05
Cr $K\bar{\alpha}$	5.412E−03	2.79E+05	2.96E+05	2.88E+05	3.03E+05	3.14E+05	3.08E+05	3.49E+05	3.33E+05
Ti $K\beta_1$	4.932E−03	3.32E+05	3.77E+05	3.83E+05	3.82E+05	3.97E+05	3.90E+05	4.47E+05	4.22E+05
Ti $K\bar{\alpha}$	4.509E−03	3.95E+05	4.76E+05	4.84E+05	4.88E+05	3.79E+05	3.65E+05	4.26E+05	4.03E+05

Table 4.2.4.2. *Total photon interaction cross section (barns/atom) (cont.)*

Radiation	Energy (MeV)	97 Berkelium	98 Californium
Ag $K\beta_1$	2.494E−02	2.13E+04	3.06E+04
Pd $K\beta_1$	2.382E−02	2.18E+04	3.44E+04
Rh $K\beta_1$	2.272E−02	2.41E+04	3.86E+04
Ag $K\bar{\alpha}$	2.210E−02	2.50E+04	2.89E+04
Pd $K\bar{\alpha}$	2.112E−02	2.98E+04	4.62E+04
Rh $K\bar{\alpha}$	2.017E−02	3.37E+04	5.21E+04
Mo $K\beta_1$	1.961E−02	3.64E+04	5.59E+04
Mo $K\bar{\alpha}$	1.744E−02	2.01E+04	2.09E+04
Zn $K\beta_1$	9.572E−03	7.63E+04	8.67E+04
Cu $K\beta_1$	8.905E−03	9.27E+04	1.04E+04
Zn $K\bar{\alpha}$	8.631E−03	1.01E+05	1.13E+05
Ni $K\beta_1$	8.265E−03	1.13E+05	1.26E+05
Cu $K\bar{\alpha}$	8.041E−03	1.43E+05	1.50E+05
Co $K\beta_1$	7.649E−03	1.46E+05	1.52E+05
Ni $K\bar{\alpha}$	7.472E−03	1.48E+05	1.61E+05
Fe $K\beta_1$	7.058E−03	1.73E+05	1.87E+05
Co $K\bar{\alpha}$	6.925E−03	1.82E+05	1.96E+05
Mn $K\beta_1$	6.490E−03	2.16E+05	2.30E+05
Fe $K\bar{\alpha}$	6.400E−03	2.43E+05	2.53E+05
Cr $K\beta_1$	5.947E−03	2.72E+05	2.86E+05
Mn $K\bar{\alpha}$	5.895E−03	2.78E+05	2.93E+05
Cr $K\bar{\alpha}$	5.412E−03	3.49E+05	3.63E+05
Ti $K\beta_1$	4.932E−03	4.47E+05	4.59E+05
Ti $K\bar{\alpha}$	4.509E−03	4.26E+05	4.38E+05

This equation is not in a convenient form for computation and the alternative formalism presented by Sano, Ohtaka & Ohtsuki (1969) is often used in calculations. In this formalism,

$$\sigma_{\rm TD} = 2\pi r_e^2 \int_{-1}^{1} C_p f^2(q, Z)\{1 - \exp[-2M(q)]\}\, {\rm d}(\cos\varphi). \tag{4.2.4.9}$$

The values of $f(q, Z)$ are those of Cromer & Waber (1974).

Cross sections calculated using equation (4.2.4.8) tend to oscillate at low energy and this corresponds to the inclusion of Bragg peaks in the summation or integration. Eventually, these oscillations abate and $\sigma_{\rm TD}$ becomes a smoothly varying function of energy.

Creagh & Hubbell (1987) and Creagh (1987) have stressed that, before cross sections are calculated for a given ensemble of atoms, care should be taken to ascertain whether single-atom or single-crystal scattering is appropriate for that ensemble.

4.2.4.2.3. *Theoretical Compton scattering data: σ_C*

The bound-electron Compton scattering cross section is given by

$$\begin{aligned}\sigma_C = \pi r_e^2 \int_{-1}^{1} &[1 + k(1 - \cos\varphi)]^{-2} \\ &\times \{+\cos^2\varphi + k^2(1 - \cos\varphi)^2 \\ &\times [1 + k(1 - \cos\varphi)]^{-1}\} I(q, z)\, {\rm d}(\cos\varphi).\end{aligned} \tag{4.2.4.10}$$

Here $k = \hbar\omega/mc^2$ and $I(q, z)$ is the incoherent scattering intensity expressed in electron units. The other symbols have the meanings defined in §§4.2.4.2.1 and 4.2.4.2.2.

Values of σ_C incorporated into the tables of total cross section σ have been computed using the incoherent scattering intensities from the tabulation by Hubbell *et al.* (1975) based on the calculations by Cromer & Mann (1967) and Cromer (1969).

4.2.4.3. *Comparison between theoretical and experimental data sets*

Saloman & Hubbell (1986) and Saloman *et al.* (1988) have published an extensive comparison of the experimental database with the theoretical values of Scofield (1973, 1986) for photon energies between 0.1 and 100 keV. Some examples taken from Saloman & Hubbell (1986) are shown in Figs. 4.2.4.1, 4.2.4.2, and 4.2.4.3.

Comparisons between theory and experiment exist for about 80 elements and space does not permit reproduction of all the available information. This information has been summarized in Fig. 4.2.4.4. Superimposed on the Periodic Table of the elements are two sets of data. The upper set corresponds to the average percent deviation between experiment and theory for the photon energy range 10 to 100 keV. The lower set corresponds to the average percent deviation between experiment and theory for the photon energy range 1 to 10 keV. An upwards pointing arrow $\uparrow$ means that $(\sigma_{\rm exp} - \sigma_{\rm theor}) > 0$. No arrow implies that $(\sigma_{\rm exp} - \sigma_{\rm theor}) = 0$. A downwards pointing arrow $\downarrow$ means that $(\sigma_{\rm exp} - \sigma_{\rm theor}) < 0$. An asterisk means no experimental data set was available.

For example: for tin ($Z = 50$), the experimental data are on average 5% higher than the theoretical predictions for the range of photon energies from 10 to 100 keV. For the range 1 to 10 keV, the experimental data are on average 7% higher than the theoretical predictions.

Fig. 4.2.4.4 is given as a rapid means of comparing theory and experiment. For more detailed information, see Saloman & Hubbell (1986), Saloman *et al.* (1988), and Creagh (1990).

4.2.4.4. *Uncertainty in the data tables*

It is not possible to generalize on the accuracy of the experimental data sets. Creagh & Hubbell (1987) have shown that many experiments for which the precision quoted by the author is high differ from other accurate measurements by a considerable amount. It must be stressed that the experimental apparatus has to be chosen so that it is appropriate for the atomic system being investigated. Details concerning the proper choice of measuring system are given in Section 4.2.3. Within about 200 eV of an absorption edge, deviations of up to 200% may be observed between theory and experiment. This is the region in which XAFS and XANES oscillations occur.

With respect to the theoretical data: the detailed agreement between the several methods for calculating the photo-effect cross sections is quite remarkable and it is estimated that the reliability of these data is to within 2% for the energy range considered in this compilation. Some problems may exist, however, close to the absorption edges. Errors in the calculation of the Rayleigh and the Compton scattering cross sections are assessed to be of the order of 5%. Because the greater proportion of total attenuation is photoelectric, the accuracy of the total scattering cross section should be much better than 5% and usually close to 2%.

4.2.5. Filters and monochromators (By D. C. Creagh)

4.2.5.1. *Introduction*

All sources of X-rays, whether they be produced by conventional sealed tubes, rotating-anode systems, or synchrotron-radiation sources, emit over a broad spectral range. In many cases, this spectral diversity is of concern, and techniques have been developed to minimize the problem. These techniques