International Tables for Crystallography (2006). Vol. C, Section 4.2.5.1, pp. 229–236.

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,

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

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

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

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

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Table 4.2.4.3. *Mass attenuation coefficients* ($cm^2\ g^{-1}$)

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	3.63E−01	1.89E−01	1.72E−01	1.95E−01	2.37E−01	3.15E−01	4.04E−01	3.29E−01
Pd $K\beta_1$	2.382E−02	3.65E−01	1.90E−01	1.74E−01	2.00E−01	2.47E−01	3.35E−01	4.37E−01	5.82E−01
Rh $K\beta_1$	2.272E−02	3.66E−01	1.92E−01	1.77E−01	2.05E−01	2.59E−01	3.58E−01	4.77E−01	6.44E−01
Ag $K\bar{\alpha}$	2.210E−02	3.67E−01	1.93E−01	1.79E−01	2.09E−01	2.67E−01	3.74E−01	5.03E−01	6.85E−01
Pd $K\bar{\alpha}$	2.112E−02	3.68E−01	1.94E−01	1.82E−01	2.16E−01	2.81E−01	4.02E−01	5.51E−01	7.60E−01
Rh $K\bar{\alpha}$	2.017E−02	3.69E−01	1.96E−01	1.85E−01	2.24E−01	2.98E−01	4.35E−01	6.07E−01	8.48E−01
Mo $K\beta_1$	1.961E−02	3.70E−01	1.97E−01	1.87E−01	2.29E−01	3.09E−01	4.58E−01	6.45E−01	9.08E−01
Mo $K\bar{\alpha}$	1.744E−02	3.73E−01	2.02E−01	1.98E−01	2.56E−01	3.68E−01	5.76E−01	8.45E−01	1.22E+00
Zn $K\beta_1$	9.572E−03	3.86E−01	2.55E−01	3.64E−01	7.16E−01	1.41E+00	2.69E+00	4.42E+00	6.78E+00
Cu $K\beta_1$	8.905E−03	3.88E−01	2.68E−01	4.12E−01	8.53E−01	1.73E+00	3.33E+00	5.48E+00	8.42E+00
Zn $K\bar{\alpha}$	8.631E−03	3.89E−01	2.74E−01	4.36E−01	9.23E−01	1.89E+00	3.65E+00	6.01E+00	9.25E+00
Ni $K\beta_1$	8.265E−03	3.90E−01	2.85E−01	4.73E−01	1.03E+00	2.14E+00	4.15E+00	6.85E+00	1.05E+01
Cu $K\bar{\alpha}$	8.041E−03	3.91E−01	2.92E−01	5.00E−01	1.11E+00	2.31E+00	4.51E+00	7.44E+00	1.15E+01
Co $K\beta_1$	7.649E−03	3.93E−01	3.07E−01	5.55E−01	1.27E+00	2.67E+00	5.24E+00	8.66E+00	1.33E+01
Ni $K\bar{\alpha}$	7.472E−03	3.94E−01	3.14E−01	5.84E−01	1.35E+00	2.87E+00	5.62E+00	9.29E+00	1.43E+01
Fe $K\beta_1$	7.058E−03	3.96E−01	3.35E−01	6.63E−01	1.58E+00	3.39E+00	6.68E+00	1.10E+01	1.70E+01
Co $K\bar{\alpha}$	6.925E−03	3.97E−01	3.43E−01	6.93E−01	1.67E+00	3.59E+00	7.07E+00	1.17E+01	1.80E+01
Mn $K\beta_1$	6.490E−03	4.00E−01	3.74E−01	8.10E−01	2.01E+00	4.37E+00	8.62E+00	1.42E+01	2.19E+01
Fe $K\bar{\alpha}$	6.400E−03	4.00E−01	3.81E−01	8.39E−01	2.09E+00	4.55E+00	8.99E+00	1.49E+01	2.28E+01
Cr $K\beta_1$	5.947E−03	4.05E−01	4.25E−01	1.01E+00	2.59E+00	5.69E+00	1.12E+01	1.86E+01	2.84E+01
Mn $K\bar{\alpha}$	5.895E−03	4.05E−01	4.31E−01	1.03E+00	2.66E+00	5.84E+00	1.16E+01	1.91E+01	2.92E+01
Cr $K\bar{\alpha}$	5.412E−03	4.12E−01	4.98E−01	1.30E+00	3.44E+00	7.59E+00	1.50E+01	2.47E+01	3.78E+01
Ti $K\beta_1$	4.932E−03	4.21E−01	5.92E−01	1.68E+00	4.56E+00	1.01E+01	1.99E+01	3.28E+01	4.99E+01
Ti $K\bar{\alpha}$	4.509E−03	4.33E−01	7.12E−01	2.18E+00	6.00E+00	1.33E+01	2.62E+01	4.30E+01	6.52E+01
		9 Fluorine	10 Neon	11 Sodium	12 Magnesium	13 Aluminium	14 Silicon	15 Phosphorus	16 Sulfur
Ag $K\beta_1$	2.494E−02	6.60E−01	9.06E−01	1.13E+00	1.50E+00	1.85E+00	2.38E+00	2.84E+00	3.55E+00
Pd $K\beta_1$	2.382E−02	7.35E−01	1.02E+00	1.28E+00	1.70E+00	2.10E+00	2.71E+00	3.24E+00	4.05E+00
Rh $K\beta_1$	2.272E−02	8.22E−01	1.15E+00	1.45E+00	1.93E+00	2.39E+00	3.09E+00	3.70E+00	4.64E+00
Ag $K\bar{\alpha}$	2.210E−02	8.79E−01	1.23E+00	1.56E+00	2.09E+00	2.59E+00	3.35E+00	4.01E+00	5.02E+00
Pd $K\bar{\alpha}$	2.112E−02	9.84E−01	1.39E+00	1.77E+00	2.37E+00	2.94E+00	3.81E+00	4.57E+00	5.72E+00
Rh $K\bar{\alpha}$	2.017E−02	1.11E+00	1.57E+00	2.01E+00	2.70E+00	3.36E+00	4.36E+00	5.23E+00	6.55E+00
Mo $K\beta_1$	1.961E−02	1.19E+00	1.69E+00	2.17E+00	2.92E+00	3.64E+00	4.73E+00	5.67E+00	7.11E+00
Mo $K\bar{\alpha}$	1.744E−02	1.63E+00	2.35E+00	3.03E+00	4.09E+00	5.11E+00	6.64E+00	7.97E+00	9.99E+00
Zn $K\beta_1$	9.572E−03	9.35E+00	1.36E+01	1.77E+01	2.40E+01	2.98E+01	3.85E+01	4.58E+01	5.68E+01
Cu $K\beta_1$	8.905E−03	1.16E+01	1.69E+01	2.20E+01	2.96E+01	3.68E+01	4.75E+01	5.64E+01	6.98E+01
Zn $K\bar{\alpha}$	8.631E−03	1.28E+01	1.86E+01	2.41E+01	3.25E+01	4.03E+01	5.20E+01	6.17E+01	7.63E+01
Ni $K\beta_1$	8.265E−03	1.45E+01	2.11E+01	2.74E+01	3.69E+01	4.58E+01	5.89E+01	6.98E+01	8.63E+01
Cu $K\bar{\alpha}$	8.041E−03	1.58E+01	2.29E+01	2.97E+01	4.00E+01	4.96E+01	6.37E+01	7.55E+01	9.33E+01
Co $K\beta_1$	7.649E−03	1.83E+01	2.66E+01	3.45E+01	4.63E+01	5.73E+01	7.36E+01	8.70E+01	1.07E+02
Ni $K\bar{\alpha}$	7.472E−03	1.97E+01	2.85E+01	3.69E+01	4.96E+01	6.13E+01	7.87E+01	9.30E+01	1.15E+02
Fe $K\beta_1$	7.058E−03	2.33E+01	3.38E+01	4.37E+01	5.85E+01	7.23E+01	9.27E+01	1.09E+02	1.35E+02
Co $K\bar{\alpha}$	6.925E−03	2.47E+01	3.58E+01	4.62E+01	6.19E+01	7.64E+01	9.78E+01	1.15E+02	1.42E+02
Mn $K\beta_1$	6.490E 03	3.00E+01	4.34E+01	5.59E+01	7.47E+01	9.21E+01	1.18E+02	1.39E+02	1.70E+02
Fe $K\bar{\alpha}$	6.400E−03	3.13E+01	4.52E+01	5.82E+01	7.78E+01	9.59E+01	1.22E+02	1.44E+02	1.77E+02
Cr $K\beta_1$	5.947E−03	3.89E+01	5.61E+01	7.21E+01	9.62E+01	1.18E+02	1.51E+02	1.77E+02	2.17E+02
Mn $K\bar{\alpha}$	5.895E−03	3.99E+01	5.76E+01	7.40E+01	9.87E+01	1.21E+02	1.54E+02	1.81E+02	2.22E+02
Cr $K\bar{\alpha}$	5.412E−03	5.15E+01	7.41E+01	9.49E+01	1.26E+02	1.55E+02	1.96E+02	2.30E+02	2.81E+02
Ti $K\beta_1$	4.932E−03	6.78E+01	9.72E+01	1.24E+02	1.65E+02	2.01E+02	2.55E+02	2.97E+02	3.62E+02
Ti $K\bar{\alpha}$	4.509E−03	8.84E+01	1.26E+02	1.61E+02	2.12E+02	2.59E+02	3.27E+02	3.79E+02	4.60E+02

Table 4.2.4.3. *Mass attenuation coefficients* ($cm^2\ g^{-1}$) *(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	4.09E+00	4.56E+00	5.78E+00	6.92E+00	7.47E+00	8.43E+00	9.42E+00	1.09E+01
Pd $K\beta_1$	2.382E−02	4.67E+00	5.21E+00	6.60E+00	7.90E+00	8.53E+00	9.61E+00	1.07E+01	1.24E+01
Rh $K\beta_1$	2.272E−02	5.35E+00	5.96E+00	7.56E+00	9.04E+00	9.76E+00	1.10E+01	1.23E+01	1.42E+01
Ag $K\bar{\alpha}$	2.210E−02	5.79E+00	6.46E+00	8.19E+00	9.79E+00	1.06E+01	1.19E+01	1.33E+01	1.54E+01
Pd $K\bar{\alpha}$	2.112E−02	6.61E+00	7.37E+00	9.33E+00	1.12E+01	1.20E+01	1.36E+01	1.51E+01	1.75E+01
Rh $K\bar{\alpha}$	2.017E−02	7.55E+00	8.42E+00	1.07E+01	1.27E+01	1.38E+01	1.55E+01	1.73E+01	1.99E+01
Mo $K\beta_1$	1.961E−02	8.20E+00	9.14E+00	1.16E+01	1.38E+01	1.49E+01	1.68E+01	1.87E+01	2.15E+01
Mo $K\bar{\alpha}$	1.744E−02	1.15E+01	1.28E+01	1.62E+01	1.93E+01	2.08E+01	2.34E+01	2.60E+01	2.99E+01
Zn $K\beta_1$	9.572E−03	6.48E+01	7.14E+01	8.94E+01	1.05E+02	1.12E+02	1.25E+02	1.37E+02	1.55E+02
Cu $K\beta_1$	8.905E−03	7.95E+01	8.75E+01	1.09E+02	1.29E+02	1.37E+02	1.52E+02	1.66E+02	1.85E+02
Zn $K\bar{\alpha}$	8.631E−03	8.69E+01	9.55E+01	1.19E+02	1.40E+02	1.49E+02	1.66E+02	1.81E+02	2.01E+02
Ni $K\beta_1$	8.265E−03	9.81E+01	1.08E+02	1.34E+02	1.58E+02	1.67E+02	1.86E+02	2.03E+02	2.27E+02
Cu $K\bar{\alpha}$	8.041E−03	1.06E+02	1.16E+02	1.45E+02	1.70E+02	1.80E+02	2.00E+02	2.19E+02	2.47E+02
Co $K\beta_1$	7.649E−03	1.22E+02	1.34E+02	1.66E+02	1.95E+02	2.06E+02	2.27E+02	2.50E+02	2.93E+02
Ni $K\bar{\alpha}$	7.472E−03	1.30E+02	1.43E+02	1.77E+02	2.08E+02	2.20E+02	2.40E+02	2.66E+02	3.18E+02
Fe $K\beta_1$	7.058E−03	1.52E+02	1.67E+02	2.07E+02	2.42E+02	2.56E+02	2.77E+02	3.09E+02	3.85E+02
Co $K\bar{\alpha}$	6.925E−03	1.61E+02	1.76E+02	2.18E+02	2.55E+02	2.69E+02	2.91E+02	3.25E+02	4.08E+02
Mn $K\beta_1$	6.490E−03	1.92E+02	2.10E+02	2.60E+02	3.03E+02	3.19E+02	3.45E+02	3.85E+02	4.80E+02
Fe $K\bar{\alpha}$	6.400E−03	2.00E+02	2.18E+02	2.70E+02	3.14E+02	3.32E+02	3.58E+02	3.99E+02	4.92E+02
Cr $K\beta_1$	5.947E−03	2.44E+02	2.66E+02	3.28E+02	3.82E+02	4.03E+02	4.44E+02	4.79E+02	6.70E+01
Mn $K\bar{\alpha}$	5.895E−03	2.50E+02	2.72E+02	3.36E+02	3.91E+02	4.12E+02	4.57E+02	4.89E+02	6.86E+01
Cr $K\bar{\alpha}$	5.412E−03	3.16E+02	3.42E+02	4.21E+02	4.90E+02	5.16E+02	5.90E+02	7.47E+01	8.68E+01
Ti $K\beta_1$	4.932E−03	4.04E+02	4.38E+02	5.38E+02	6.24E+02	6.52E+02	8.54E+01	9.65E+01	1.12E+02
Ti $K\bar{\alpha}$	4.509E−03	5.11E+02	5.56E+02	6.80E+02	7.81E+02	8.08E+02	1.09E+02	1.23E+02	1.43E+02

Radiation	Energy (MeV)	25 Manganese	26 Iron	27 Cobalt	28 Nickel	29 Copper	30 Zinc	31 Gallium	32 Germanium
Ag $K\beta_1$	2.494E−02	1.21E+01	1.38E+01	1.51E+01	1.74E+01	1.83E+01	2.02E+01	2.14E+01	2.31E+01
Pd $K\beta_1$	2.382E−02	1.37E+01	1.57E+01	1.72E+01	1.98E+01	2.08E+01	2.30E+01	2.43E+01	2.62E+01
Rh $K\beta_1$	2.272E−02	1.57E+01	1.79E+01	1.96E+01	2.26E+01	2.38E+01	2.62E+01	2.77E+01	2.98E+01
Ag $K\bar{\alpha}$	2.210E−02	1.70E+01	1.94E+01	2.12E+01	2.44E+01	2.56E+01	2.82E+01	2.98E+01	3.21E+01
Pd $K\bar{\alpha}$	2.112E−02	1.93E+01	2.20E+01	2.41E+01	2.77E+01	2.91E+01	3.20E+01	3.38E+01	3.64E+01
Rh $K\bar{\alpha}$	2.017E−02	2.20E+01	2.51E+01	2.74E+01	3.15E+01	3.30E+01	3.63E+01	3.84E+01	4.13E+01
Mo $K\beta_1$	1.961E−02	2.38E+01	2.71E+01	2.96E+01	3.40E+01	3.57E+01	3.93E+01	4.15E+01	4.46E+01
Mo $K\bar{\alpha}$	1.744E−02	3.31E+01	3.76E+01	4.10E+01	4.69E+01	4.91E+01	5.40E+01	5.70E+01	6.12E+01
Zn $K\beta_1$	9.572E−03	1.70E+02	1.92E+02	2.06E+02	2.33E+02	2.40E+02	3.59E+01	3.85E+01	4.22E+01
Cu $K\beta_1$	8.905E−03	2.07E+02	2.32E+02	2.48E+02	2.79E+02	3.92E+01	4.38E+01	4.70E+01	5.14E+01
Zn $K\bar{\alpha}$	8.631E 03	2.24E+02	2.52E+02	2.69E+02	3.02E+02	4.27E+01	4.77E+01	5.12E+01	5.59E+01
Ni $K\beta_1$	8.265E−03	2.51E+02	2.81E+02	3.00E+02	4.53E+01	4.80E+01	5.37E+01	5.76E+01	6.30E+01
Cu $K\bar{\alpha}$	8.041E 03	2.70E+02	3.02E+02	3.21E+02	4.88E+01	5.18E+01	5.79E+01	6.21E+01	6.79E+01
Co $K\beta_1$	7.649E−03	3.06E+02	3.42E+02	4.81E+01	5.60E+01	5.94E+01	6.64E+01	7.12E+01	7.78E+01
Ni $K\bar{\alpha}$	7.472E−03	3.25E+02	3.62E+02	5.13E+01	5.97E+01	6.33E+01	7.08E+01	7.59E+01	8.29E+01
Fe $K\beta_1$	7.058E−03	3.75E+02	5.43E+01	6.00E+01	6.98E+01	7.40E+01	8.27E+01	8.86E+01	9.69E+01
Co $K\bar{\alpha}$	6.925E−03	3.93E+02	5.72E+01	6.32E+01	7.35E+01	7.80E+01	8.71E+01	9.34E+01	1.02E+02
Mn $K\beta_1$	6.490E−03	5.92E+01	6.84E+01	7.55E+01	8.78E+01	9.31E+01	1.04E+02	1.11E+02	1.22E+02
Fe $K\bar{\alpha}$	6.400E−03	6.16E+01	7.10E+01	7.85E+01	9.13E+01	9.68E+01	1.08E+02	1.16E+02	1.27E+02
Cr $K\beta_1$	5.947E−03	7.53E+01	8.69E+01	9.60E+01	1.12E+02	1.18E+02	1.32E+02	1.42E+02	1.55E+02
Mn $K\bar{\alpha}$	5.895E−03	7.72E+01	8.90E+01	9.83E+01	1.14E+02	1.21E+02	1.35E+02	1.45E+02	1.58E+02
Cr $K\bar{\alpha}$	5.412E−03	9.75E+01	1.13E+02	1.24E+02	1.44E+02	1.53E+02	1.71E+02	1.83E+02	1.99E+02
Ti $K\beta_1$	4.932E−03	1.26E+02	1.45E+02	1.60E+02	1.86E+02	1.97E+02	2.20E+02	2.35E+02	2.56E+02
Ti $K\bar{\alpha}$	4.509E−03	1.61E+02	1.85E+02	2.04E+02	2.37E+02	2.51E+02	2.80E+02	2.99E+02	3.26E+02

Table 4.2.4.3. *Mass attenuation coefficients (cm² g⁻¹) (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	2.50E+01	2.65E+01	2.91E+01	3.07E+01	3.32E+01	3.56E+01	3.84E+01	4.07E+01
Pd $K\beta_1$	2.382E−02	2.84E+01	3.00E+01	3.29E+01	3.48E+01	3.76E+01	4.03E+01	4.34E+01	4.60E+01
Rh $K\beta_1$	2.272E−02	3.23E+01	3.41E+01	3.74E+01	3.95E+01	4.27E+01	4.57E+01	4.91E+01	5.20E+01
Ag $K\bar{\alpha}$	2.210E−02	3.48E+01	3.68E+01	4.03E+01	4.25E+01	4.59E+01	4.91E+01	5.29E+01	5.59E+01
Pd $K\bar{\alpha}$	2.112E−02	3.93E+01	4.16E+01	4.55E+01	4.80E+01	5.18E+01	5.54E+01	5.95E+01	6.29E+01
Rh $K\bar{\alpha}$	2.017E−02	4.46E+01	4.71E+01	5.15E+01	5.43E+01	5.85E+01	6.25E+01	6.71E+01	6.25E+01
Mo $K\beta_1$	1.961E−02	4.82E+01	5.08E+01	5.55E+01	5.84E+01	6.30E+01	6.72E+01	7.21E+01	7.61E+01
Mo $K\bar{\alpha}$	1.744E−02	6.61E+01	6.95E+01	7.56E+01	7.93E+01	8.51E+01	9.06E+01	9.70E+01	1.63E+01
Zn $K\beta_1$	9.572E−03	4.64E+01	4.97E+01	5.53E+01	5.92E+01	6.49E+01	7.06E+01	7.73E+01	8.35E+01
Cu $K\beta_1$	8.905E−03	5.65E+01	6.05E+01	6.74E+01	7.21E+01	7.90E+01	8.59E+01	9.40E+01	1.01E+02
Zn $K\bar{\alpha}$	8.631E−03	6.15E+01	6.59E+01	7.33E+01	7.85E+01	8.60E+01	9.35E+01	1.02E+02	1.10E+02
Ni $K\beta_1$	8.265E−03	6.93E+01	7.42E+01	8.26E+01	8.83E+01	9.68E+01	1.05E+02	1.15E+02	1.24E+02
Cu $K\bar{\alpha}$	8.041E−03	7.47E+01	8.00E+01	8.90E+01	9.52E+01	1.04E+02	1.13E+02	1.24E+02	1.39E+02
Co $K\beta_1$	7.649E−03	8.55E+01	9.16E+01	1.02E+02	1.09E+02	1.19E+02	1.30E+02	1.42E+02	1.54E+02
Ni $K\bar{\alpha}$	7.472E−03	9.11E+01	9.76E+01	1.09E+02	1.16E+02	1.27E+02	1.38E+02	1.51E+02	1.63E+02
Fe $K\beta_1$	7.058E−03	1.06E+02	1.14E+02	1.27E+02	1.35E+02	1.48E+02	1.61E+02	1.76E+02	1.91E+02
Co $K\bar{\alpha}$	6.925E−03	1.12E+02	1.20E+02	1.33E+02	1.42E+02	1.56E+02	1.70E+02	1.85E+02	2.00E+02
Mn $K\beta_1$	6.490E−03	1.34E+02	1.43E+02	1.59E+02	1.70E+02	1.86E+02	2.02E+02	2.21E+02	2.38E+02
Fe $K\bar{\alpha}$	6.400E−03	1.39E+02	1.49E+02	1.65E+02	1.76E+02	1.93E+02	2.10E+02	2.29E+02	2.47E+02
Cr $K\beta_1$	5.947E−03	1.70E+02	1.82E+02	2.02E+02	2.15E+02	2.36E+02	2.56E+02	2.79E+02	3.00E+02
Mn $K\bar{\alpha}$	5.895E−03	1.74E+02	1.86E+02	2.06E+02	2.20E+02	2.41E+02	2.62E+02	2.86E+02	3.08E+02
Cr $K\bar{\alpha}$	5.412E−03	2.19E+02	2.34E+02	2.60E+02	2.77E+02	3.03E+02	3.28E+02	3.58E+02	3.86E+02
Ti $K\beta_1$	4.932E−03	2.81E+02	3.00E+02	3.33E+02	3.55E+02	3.88E+02	4.21E+02	4.59E+02	4.93E+02
Ti $K\bar{\alpha}$	4.509E−03	3.57E+02	3.81E+02	4.23E+02	4.50E+02	4.92E+02	5.32E+02	5.80E+02	6.22E+02

Radiation	Energy (MeV)	41 Niobium	42 Molybdenum	43 Technetium	44 Ruthenium	45 Rhodium	46 Palladium	47 Silver	48 Cadmium
Ag $K\beta_1$	2.494E−02	4.36E+01	5.25E+01	4.84E+01	5.06E+01	5.35E+01	5.55E+01	1.01E+01	1.06E+01
Pd $K\beta_1$	2.382E−02	4.92E+01	6.03E+01	5.45E+01	5.69E+01	6.01E+01	1.06E+01	1.15E+01	1.20E+01
Rh $K\beta_1$	2.272E−02	5.56E+01	6.80E+01	6.15E+01	7.00E+01	1.14E+01	1.21E+01	1.30E+01	1.36E+01
Ag $K\bar{\alpha}$	2.210E−02	5.98E+01	7.20E+01	6.60E+01	1.14E+01	1.23E+01	1.30E+01	1.40E+01	1.46E+01
Pd $K\bar{\alpha}$	2.112E−02	6.71E+01	7.71E+01	7.41E+01	1.29E+01	1.39E+01	1.47E+01	1.58E+01	1.66E+01
Rh $K\bar{\alpha}$	2.017E−02	7.55E+01	7.95E+01	1.38E+01	1.47E+01	1.58E+01	1.67E+01	1.79E+01	1.88E+01
Mo $K\beta_1$	1.961E−02	8.10E+01	1.38E+01	1.49E+01	1.58E+01	1.70E+01	1.80E+01	1.94E+01	2.02E+01
Mo $K\bar{\alpha}$	1.744E−02	1.77E+01	1.88E+01	2.04E+01	2.17E+01	2.33E+01	2.47E+01	2.65E+01	2.78E+01
Zn $K\beta_1$	9.572E−03	9.04E+01	9.65E+01	1.04E+02	1.10E+02	1.18E+02	1.25E+02	1.34E+02	1.40E+02
Cu $K\beta_1$	8.905E−03	1.10E+02	1.17E+02	1.26E+02	1.34E+02	1.44E+02	1.51E+02	1.63E+02	1.69E+02
Zn $K\bar{\alpha}$	8.631E−03	1.20E+02	1.27E+02	1.37E+02	1.46E+02	1.56E+02	1.65E+02	1.77E+02	1.84E+02
Ni $K\beta_1$	8.265E−03	1.34E+02	1.43E+02	1.54E+02	1.63E+02	1.75E+02	1.85E+02	1.98E+02	2.07E+02
Cu $K\bar{\alpha}$	8.041E−03	1.45E+02	1.54E+02	1.66E+02	1.76E+02	1.89E+02	1.99E+02	2.13E+02	2.22E+02
Co $K\beta_1$	7.649E−03	1.66E+02	1.76E+02	1.90E+02	2.01E+02	2.16E+02	2.27E+02	2.43E+02	2.53E+02
Ni $K\bar{\alpha}$	7.472E−03	1.76E+02	1.88E+02	2.02E+02	2.14E+02	2.29E+02	2.41E+02	2.59E+02	2.69E+02
Fe $K\beta_1$	7.058E−03	2.05E+02	2.19E+02	2.35E+02	2.49E+02	2.67E+02	2.81E+02	3.01E+02	3.13E+02
Co $K\bar{\alpha}$	6.925E−03	2.16E+02	2.30E+02	2.47E+02	2.62E+02	2.80E+02	2.95E+02	3.16E+02	3.29E+02
Mn $K\beta_1$	6.490E−03	2.57E+02	2.73E+02	2.94E+02	3.11E+02	3.33E+02	3.50E+02	3.75E+02	3.90E+02
Fe $K\bar{\alpha}$	6.400E−03	2.67E+02	2.84E+02	3.05E+02	3.23E+02	3.46E+02	3.63E+02	3.89E+02	4.05E+02
Cr $K\beta_1$	5.947E−03	3.25E+02	3.45E+02	3.70E+02	3.92E+02	4.20E+02	4.41E+02	4.72E+02	4.90E+02
Mn $K\bar{\alpha}$	5.895E 03	3.32E+02	3.53E+02	3.79E+02	4.01E+02	4.29E+02	4.51E+02	4.83E+02	5.02E+02
Cr $K\bar{\alpha}$	5.412E−03	4.16E+02	4.42E+02	4.74E+02	5.01E+02	5.36E+02	5.63E+02	6.02E+02	6.26E+02
Ti $K\beta_1$	4.932E−03	5.32E+02	5.65E+02	6.04E+02	6.39E+02	6.83E+02	7.16E+02	7.65E+02	7.95E+02
Ti $K\bar{\alpha}$	4.509E−03	6.71E+02	7.12E+02	7.61E+02	8.04E+02	8.60E+02	9.01E+02	9.61E+02	9.95E+02

Table 4.2.4.3. *Mass attenuation coefficients ($cm^2\ g^{-1}$) (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	1.13E+01	1.18E+01	1.25E+01	1.29E+01	1.40E+01	1.46E+01	1.56E+01	1.62E+01
Pd $K\beta_1$	2.382E−02	1.27E+01	1.34E+01	1.41E+01	1.46E+01	1.59E+01	1.65E+01	1.76E+01	1.83E+01
Rh $K\beta_1$	2.272E−02	1.45E+01	1.52E+01	1.60E+01	1.66E+01	1.80E+01	1.88E+01	2.00E+01	2.08E+01
Ag $K\bar{\alpha}$	2.210E−02	1.56E+01	1.64E+01	1.73E+01	1.79E+01	1.94E+01	2.02E+01	2.15E+01	2.24E+01
Pd $K\bar{\alpha}$	2.112E−02	1.76E+01	1.85E+01	1.96E+01	2.02E+01	2.19E+01	2.29E+01	2.43E+01	2.54E+01
Rh $K\bar{\alpha}$	2.017E−02	2.00E+01	2.10E+01	2.22E+01	2.29E+01	2.18E+01	2.27E+01	2.42E+01	2.52E+01
Mo $K\beta_1$	1.961E−02	2.16E+01	2.26E+01	2.39E+01	2.47E+01	2.68E+01	2.80E+01	2.98E+01	3.10E+01
Mo $K\bar{\alpha}$	1.744E−02	2.95E+01	3.10E+01	3.27E+01	3.38E+01	3.67E+01	3.82E+01	4.07E+01	4.23E+01
Zn $K\beta_1$	9.572E−03	1.48E+02	1.55E+02	1.64E+02	1.68E+02	1.82E+02	1.90E+02	2.01E+02	2.09E+02
Cu $K\beta_1$	8.905E−03	1.80E+02	1.88E+02	1.98E+02	2.04E+02	2.20E+02	2.29E+02	2.43E+02	2.52E+02
Zn $K\bar{\alpha}$	8.631E−03	1.95E+02	2.04E+02	2.15E+02	2.21E+02	2.39E+02	2.49E+02	2.63E+02	2.73E+02
Ni $K\beta_1$	8.265E−03	2.19E+02	2.29E+02	2.41E+02	2.48E+02	2.68E+02	2.78E+02	2.95E+02	3.06E+02
Cu $K\bar{\alpha}$	8.041E−03	2.36E+02	2.47E+02	2.59E+02	2.67E+02	2.88E+02	2.99E+02	3.17E+02	3.25E+02
Co $K\beta_1$	7.649E−03	2.69E+02	2.81E+02	2.96E+02	3.04E+02	3.30E+02	3.43E+02	3.63E+02	3.76E+02
Ni $K\bar{\alpha}$	7.472E−03	2.86E+02	2.99E+02	3.14E+02	3.23E+02	3.49E+02	3.62E+02	3.83E+02	3.96E+02
Fe $K\beta_1$	7.058E−03	3.32E+02	3.47E+02	3.65E+02	3.74E+02	4.08E+02	4.22E+02	4.46E+02	4.61E+02
Co $K\bar{\alpha}$	6.925E−03	3.49E+02	3.64E+02	3.83E+02	3.94E+02	4.25E+02	4.40E+02	4.65E+02	4.80E+02
Mn $K\beta_1$	6.490E−03	4.13E+02	4.31E+02	4.54E+02	4.66E+02	5.03E+02	5.20E+02	5.49E+02	5.66E+02
Fe $K\bar{\alpha}$	6.400E−03	4.28E+02	4.47E+02	4.71E+02	4.83E+02	5.22E+02	5.40E+02	5.69E+02	5.86E+02
Cr $K\beta_1$	5.947E−03	5.19E+02	5.42E+02	5.70E+02	5.85E+02	6.31E+02	6.52E+02	6.86E+02	6.45E+02
Mn $K\bar{\alpha}$	5.895E−03	5.31E+02	5.54E+02	5.82E+02	5.98E+02	6.45E+02	6.66E+02	7.00E+02	6.60E+02
Cr $K\bar{\alpha}$	5.412E−03	6.63E+02	6.91E+02	7.23E+02	7.40E+02	7.96E+02	7.21E+02	7.60E+02	5.70E+02
Ti $K\beta_1$	4.932E−03	8.41E+02	8.76E+02	9.15E+02	9.32E+02	1.00E+03	1.03E+03	2.60E+02	3.14E+02
Ti $K\bar{\alpha}$	4.509E−03	1.05E+03	1.09E+03	9.91E+02	7.51E+02	2.83E+02	2.65E+02	3.30E+02	3.34E+02

Radiation	Energy (MeV)	57 Lanthanum	58 Cerium	59 Praseodymium	60 Neodymium	61 Promethium	62 Samarium	63 Europium	64 Gadolinium
Ag $K\beta_1$	2.494E−02	1.72E+01	1.83E+01	1.95E+01	2.04E+01	2.17E+01	2.23E+01	2.35E+01	2.42E+01
Pd $K\beta_1$	2.382E−02	1.95E+01	2.07E+01	2.20E+01	2.30E+01	2.45E+01	2.52E+01	2.66E+01	2.74E+01
Rh $K\beta_1$	2.272E−02	2.21E+01	2.35E+01	2.50E+01	2.61E+01	2.78E+01	2.86E+01	3.01E+01	3.10E+01
Ag $K\bar{\alpha}$	2.210E−02	2.38E+01	2.53E+01	2.69E+01	2.81E+01	2.99E+01	3.08E+01	3.24E+01	3.34E+01
Pd $K\bar{\alpha}$	2.112E−02	2.69E+01	2.86E+01	3.04E+01	3.18E+01	3.38E+01	3.48E+01	3.66E+01	3.77E+01
Rh $K\bar{\alpha}$	2.017E−02	3.05E+01	3.24E+01	3.45E+01	3.60E+01	3.83E+01	3.94E+01	4.15E+01	4.27E+01
Mo $K\beta_1$	1.961E−02	3.29E+01	3.49E+01	3.72E+01	3.88E+01	4.13E+01	4.24E+01	4.47E+01	4.60E+01
Mo $K\bar{\alpha}$	1.744E−02	4.49E+01	4.77E+01	5.07E+01	5.30E+01	5.63E+01	5.78E+01	6.09E+01	6.26E+01
Zn $K\beta_1$	9.572E−03	2.21E+02	2.33E+02	2.47E+02	2.57E+02	2.73E+02	2.79E+02	2.93E+02	3.00E+02
Cu $K\beta_1$	8.905E−03	2.66E+02	2.82E+02	2.99E+02	3.10E+02	3.28E+02	3.35E+02	3.52E+02	3.60E+02
Zn $K\bar{\alpha}$	8.631E−03	2.89E+02	3.06E+02	3.24E+02	3.36E+02	3.55E+02	3.63E+02	3.80E+02	3.89E+02
Ni $K\beta_1$	8.265E−03	3.24E+02	3.43E+02	3.63E+02	3.76E+02	3.97E+02	4.05E+02	4.24E+02	4.33E+02
Cu $K\bar{\alpha}$	8.041E−03	3.48E+02	3.68E+02	3.90E+02	4.04E+02	4.26E+02	4.34E+02	4.34E+02	4.03E+02
Co $K\beta_1$	7.649E−03	3.95E+02	4.17E+02	4.41E+02	4.57E+02	4.82E+02	3.54E+02	4.80E+02	3.35E+02
Ni $K\bar{\alpha}$	7.472E−03	4.19E+02	4.42E+02	4.68E+02	4.84E+02	5.11E+02	3.71E+02	3.75E+02	3.56E+02
Fe $K\beta_1$	7.058E−03	4.83E+02	5.10E+02	5.39E+02	4.92E+02	5.88E+02	1.63E+02	4.08E+02	1.53E+02
Co $K\bar{\alpha}$	6.925E−03	5.07E+02	5.35E+02	5.65E+02	5.05E+02	4.00E+02	1.76E+02	4.19E+02	1.61E+02
Mn $K\beta_1$	6.490E−03	5.97E+02	5.47E+02	6.16E+02	4.39E+02	4.68E+02	1.66E+02	1.95E+02	1.89E+02
Fe $K\bar{\alpha}$	6.400E−03	6.18E+02	5.61E+02	4.48E+02	4.55E+02	1.94E+02	2.04E+02	2.03E+02	1.95E+02
Cr $K\beta_1$	5.947E−03	7.44E+02	4.94E+02	1.88E+02	1.98E+02	2.32E+02	2.21E+02	2.44E+02	2.35E+02
Mn $K\bar{\alpha}$	5.895E−03	7.60E+02	5.12E+02	1.93E+02	2.03E+02	2.37E+02	2.25E+02	2.49E+02	2.41E+02
Cr $K\bar{\alpha}$	5.412E−03	2.25E+02	2.38E+02	2.38E+02	2.51E+02	2.94E+02	2.79E+02	3.09E+02	2.98E+02
Ti $K\beta_1$	4.932E−03	2.84E+02	3.00E+02	3.00E+02	3.14E+02	3.69E+02	3.50E+02	3.90E+02	3.74E+02
Ti $K\bar{\alpha}$	4.509E−03	3.55E+02	3.57E+02	3.75E+02	3.97E+02	4.62E+02	4.35E+02	4.88E+02	4.69E+02

Table 4.2.4.3. *Mass attenuation coefficients (cm^2 g^{-1}) (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	2.55E+01	2.65E+01	2.77E+01	2.90E+01	3.04E+01	3.14E+01	3.28E+01	3.40E+01
Pd $K\beta_1$	2.382E−02	2.88E+01	2.99E+01	3.13E+01	3.27E+01	3.43E+01	3.54E+01	3.71E+01	3.84E+01
Rh $K\beta_1$	2.272E−02	3.26E+01	3.39E+01	3.54E+01	3.71E+01	3.89E+01	4.01E+01	4.20E+01	4.35E+01
Ag $K\bar{\alpha}$	2.210E−02	3.51E+01	3.65E+01	3.81E+01	3.99E+01	4.18E+01	4.32E+01	4.51E+01	4.67E+01
Pd $K\bar{\alpha}$	2.112E−02	3.96E+01	4.12E+01	4.30E+01	4.50E+01	4.71E+01	4.87E+01	5.09E+01	5.27E+01
Rh $K\bar{\alpha}$	2.017E−02	4.49E+01	4.66E+01	4.87E+01	5.09E+01	5.33E+01	5.50E+01	5.75E+01	5.95E+01
Mo $K\beta_1$	1.961E−02	4.83E+01	5.02E+01	5.24E+01	5.48E+01	5.74E+01	5.93E+01	6.19E+01	6.41E+01
Mo $K\bar{\alpha}$	1.744E−02	6.58E+01	6.83E+01	7.13E+01	7.44E+01	7.79E+01	8.04E+01	8.40E+01	8.69E+01
Zn $K\beta_1$	9.572E−03	3.14E+02	3.24E+02	3.36E+02	3.49E+02	3.65E+02	3.75E+02	3.91E+02	1.00E+02
Cu $K\beta_1$	8.905E−03	3.76E+02	3.87E+02	4.02E+02	4.17E+02	1.08E+02	1.08E+02	1.21E+02	1.20E+02
Zn $K\bar{\alpha}$	8.631E−03	4.06E+02	4.19E+02	3.98E+02	2.87E+02	1.17E+02	1.17E+02	1.31E+02	1.30E+02
Ni $K\beta_1$	8.265E−03	4.52E+02	3.36E+02	4.44E+02	1.23E+02	1.31E+02	1.31E+02	1.46E+02	1.45E+02
Cu $K\bar{\alpha}$	8.041E−03	3.21E+02	3.62E+02	1.29E+02	1.32E+02	1.40E+02	1.42E+02	1.56E+02	1.55E+02
Co $K\beta_1$	7.649E−03	3.60E+02	1.38E+02	1.46E+02	1.49E+02	1.59E+02	1.59E+02	1.78E+02	1.76E+02
Ni $K\bar{\alpha}$	7.472E−03	1.49E+02	1.46E+02	1.55E+02	1.58E+02	1.69E+02	1.69E+02	1.89E+02	1.87E+02
Fe $K\beta_1$	7.058E−03	1.71E+02	1.68E+02	1.78E+02	1.82E+02	1.96E+02	1.96E+02	2.18E+02	2.16E+02
Co $K\bar{\alpha}$	6.925E−03	1.80E+02	1.76E+02	1.87E+02	1.91E+02	2.06E+02	2.06E+02	2.29E+02	2.27E+02
Mn $K\beta_1$	6.490E−03	2.11E+02	2.07E+02	2.20E+02	2.24E+02	2.43E+02	2.44E+02	2.70E+02	2.67E+02
Fe $K\bar{\alpha}$	6.400E−03	2.19E+02	2.14E+02	2.28E+02	2.32E+02	2.53E+02	2.51E+02	2.80E+02	2.77E+02
Cr $K\beta_1$	5.947E−03	2.63E+02	2.57E+02	2.72E+02	2.78E+02	3.05E+02	3.04E+02	3.39E+02	3.34E+02
Mn $K\bar{\alpha}$	5.895E−03	2.69E+02	2.62E+02	2.80E+02	2.85E+02	3.12E+02	3.11E+02	3.47E+02	3.41E+02
Cr $K\bar{\alpha}$	5.412E−03	3.32E+02	3.25E+02	3.47E+02	3.52E+02	3.86E+02	3.87E+02	4.31E+02	4.25E+02
Ti $K\beta_1$	4.932E−03	4.19E+02	4.10E+02	4.38E+02	4.43E+02	4.94E+02	4.92E+02	5.47E+02	5.39E+02
Ti $K\bar{\alpha}$	4.509E−03	5.24E+02	5.15E+02	5.47E+02	5.54E+02	6.21E+02	6.19E+02	6.88E+02	6.78E+02

		73 Tantalum	74 Tungsten	75 Rhenium	76 Osmium	77 Iridium	78 Platinum	79 Gold	80 Mercury
Ag $K\beta_1$	2.494E−02	3.54E+01	3.68E+01	3.83E+01	3.95E+01	4.11E+01	4.26E+01	4.44E+01	4.58E+01
Pd $K\beta_1$	2.382E−02	4.00E+01	4.15E+01	4.32E+01	4.45E+01	4.64E+01	4.80E+01	5.00E+01	5.16E+01
Rh $K\beta_1$	2.272E−02	4.53E+01	4.70E+01	4.89E+01	5.04E+01	5.24E+01	5.43E+01	5.65E+01	5.83E+01
Ag $K\bar{\alpha}$	2.210E−02	4.87E+01	5.05E+01	5.25E+01	5.41E+01	5.63E+01	5.83E+01	6.07E+01	6.26E+01
Pd $K\bar{\alpha}$	2.112E−02	5.48E+01	5.69E+01	5.92E+01	6.10E+01	6.34E+01	6.57E+01	6.83E+01	7.04E+01
Rh $K\bar{\alpha}$	2.017E−02	6.20E+01	6.43E+01	6.69E+01	6.89E+01	7.16E+01	7.41E+01	7.71E+01	7.95E+01
Mo $K\beta_1$	1.961E−02	6.67E+01	6.92E+01	7.19E+01	7.41E+01	7.70E+01	7.97E+01	8.29E+01	8.54E+01
Mo $K\bar{\alpha}$	1.744E−02	9.04E+01	9.38E+01	9.74E+01	1.00E+02	1.04E+02	1.07E+02	1.12E+02	1.15E+02
Zn $K\beta_1$	9.572E−03	1.02E+02	1.08E+02	1.19E+02	1.18E+02	1.23E+02	1.21E+02	1.30E+02	1.16E+02
Cu $K\beta_1$	8.905E−03	1.22E+02	1.30E+02	1.43E+02	1.42E+02	1.48E+02	1.45E+02	1.55E+02	1.41E+02
Zn $K\bar{\alpha}$	8.631E−03	1.32E+02	1.41E+02	1.55E+02	1.54E+02	1.60E+02	1.57E+02	1.68E+02	1.54E+02
Ni $K\beta_1$	8.265E−03	1.47E+02	1.57E+02	1.72E+02	1.71E+02	1.78E+02	1.75E+02	1.88E+02	1.74E+02
Cu $K\bar{\alpha}$	8.041E−03	1.58E+02	1.68E+02	1.87E+02	1.84E+02	1.91E+02	1.88E+02	2.01E+02	1.88E+02
Co $K\beta_1$	7.649E−03	1.79E+02	1.91E+02	2.09E+02	2.09E+02	2.16E+02	2.14E+02	2.29E+02	2.16E+02
Ni $K\bar{\alpha}$	7.472E−03	1.90E+02	2.03E+02	2.22E+02	2.21E+02	2.30E+02	2.27E+02	2.43E+02	2.30E+02
Fe $K\beta_1$	7.058E−03	2.20E+02	2.34E+02	2.57E+02	2.55E+02	2.65E+02	2.61E+02	2.79E+02	2.60E+02
Co $K\bar{\alpha}$	6.925E−03	2.31E+02	2.46E+02	2.68E+02	2.68E+02	2.78E+02	2.76E+02	2.95E+02	2.73E+02
Mn $K\beta_1$	6.490E−03	2.73E+02	2.88E+02	3.16E+02	3.14E+02	3.30E+02	3.25E+02	3.48E+02	3.27E+02
Fe $K\bar{\alpha}$	6.400E−03	2.83E+02	3.01E+02	3.27E+02	3.27E+02	3.40E+02	3.57E+02	3.61E+02	3.39E+02
Cr $K\beta_1$	5.947E−03	3.39E+02	3.61E+02	3.94E+02	3.92E+02	4.11E+02	4.23E+02	4.34E+02	4.16E+02
Mn $K\bar{\alpha}$	5.895E−03	3.46E+02	3.69E+02	4.05E+02	4.03E+02	4.18E+02	4.34E+02	4.45E+02	4.27E+02
Cr $K\bar{\alpha}$	5.412E−03	4.32E+02	4.57E+02	5.01E+02	4.99E+02	5.20E+02	5.41E+02	5.51E+02	5.41E+02
Ti $K\beta_1$	4.932E−03	5.46E+02	5.79E+02	6.33E+02	6.31E+02	6.59E+02	6.83E+02	6.99E+02	6.99E+02
Ti $K\bar{\alpha}$	4.509E−03	6.85E+02	7.25E+02	7.94E+02	7.92E+02	8.26E+02	8.19E+02	8.76E+02	8.97E+02

Table 4.2.4.3. *Mass attenuation coefficients (cm^2 g^{-1}) (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	4.72E+01	4.88E+01	5.06E+01	5.30E+01	5.51E+01	5.45E+01	5.67E+01	5.84E+01
Pd $K\beta_1$	2.382E−02	5.31E+01	5.49E+01	5.70E+01	5.96E+01	6.20E+01	6.12E+01	6.37E+01	6.56E+01
Rh $K\beta_1$	2.272E−02	6.00E+01	6.20E+01	6.44E+01	6.73E+01	7.00E+01	6.90E+01	7.18E+01	7.40E+01
Ag $K\bar{\alpha}$	2.210E−02	6.45E+01	6.66E+01	6.91E+01	7.23E+01	7.51E+01	7.21E+01	7.70E+01	7.93E+01
Pd $K\bar{\alpha}$	2.112E−02	7.25E+01	7.49E+01	7.77E+01	8.12E+01	8.43E+01	8.32E+01	8.64E+01	8.90E+01
Rh $K\bar{\alpha}$	2.017E−02	8.18E+01	8.45E+01	8.76E+01	9.15E+01	9.50E+01	9.36E+01	9.72E+01	1.00E+02
Mo $K\beta_1$	1.961E−02	8.79E+01	9.08E+01	9.41E+01	9.83E+01	1.02E+02	1.01E+02	1.04E+02	1.08E+01
Mo $K\bar{\alpha}$	1.744E−02	1.18E+02	1.22E+02	1.26E+02	1.32E+02	1.17E+02	1.08E+02	8.70E+01	8.80E+01
Zn $K\beta_1$	9.572E−03	1.45E+02	1.51E+02	1.57E+02	1.63E+02	1.71E+02	1.71E+02	1.77E+02	1.75E+02
Cu $K\beta_1$	8.905E−03	1.75E+02	1.81E+02	1.88E+02	1.96E+02	1.86E+02	2.05E+02	2.13E+02	2.10E+02
Zn $K\bar{\alpha}$	8.631E−03	1.89E+02	1.96E+02	2.04E+02	2.12E+02	2.07E+02	2.23E+02	2.30E+02	2.28E+02
Ni $K\beta_1$	8.265E−03	2.11E+02	2.16E+02	2.28E+02	2.37E+02	2.31E+02	2.49E+02	2.57E+02	2.54E+02
Cu $K\bar{\alpha}$	8.041E−03	2.26E+02	2.35E+02	2.44E+02	2.54E+02	2.48E+02	2.67E+02	2.77E+02	2.73E+02
Co $K\beta_1$	7.649E−03	2.57E+02	2.67E+02	2.76E+02	2.88E+02	2.82E+02	3.04E+02	3.12E+02	3.10E+02
Ni $K\bar{\alpha}$	7.472E−03	2.71E+02	2.83E+02	2.95E+02	3.05E+02	2.99E+02	3.21E+02	3.32E+02	3.29E+02
Fe $K\beta_1$	7.058E−03	3.14E+02	3.27E+02	3.39E+02	3.54E+02	3.45E+02	3.73E+02	3.84E+02	3.80E+02
Co $K\bar{\alpha}$	6.925E−03	3.31E+02	3.43E+02	3.55E+02	3.70E+02	3.63E+02	3.92E+02	4.03E+02	3.98E+02
Mn $K\beta_1$	6.490E−03	3.90E+02	4.06E+02	4.21E+02	4.35E+02	4.26E+02	4.60E+02	4.77E+02	4.70E+02
Fe $K\bar{\alpha}$	6.400E−03	4.03E+02	4.20E+02	4.34E+02	4.52E+02	4.44E+02	4.77E+02	4.93E+02	4.87E+02
Cr $K\beta_1$	5.947E−03	4.87E+02	5.07E+02	5.24E+02	5.44E+02	5.33E+02	5.76E+02	5.97E+02	5.85E+02
Mn $K\bar{\alpha}$	5.895E−03	5.00E+02	5.18E+02	5.35E+02	5.58E+02	5.45E+02	5.89E+02	6.02E+02	5.99E+02
Cr $K\bar{\alpha}$	5.412E−03	5.97E+02	6.43E+02	6.66E+02	6.91E+02	6.80E+02	7.34E+02	7.58E+02	7.43E+02
Ti $K\beta_1$	4.932E−03	7.15E+02	8.15E+02	8.44E+02	8.30E+02	8.60E+02	9.32E+02	9.61E+02	9.41E+02
Ti $K\bar{\alpha}$	4.509E−03	9.89E+02	1.03E+03	1.06E+03	1.10E+03	1.08E+03	1.18E+03	1.21E+03	1.33E+03

Radiation	Energy (MeV)	89 Actinium	90 Thorium	91 Protactinium	92 Uranium	93 Neptunium	94 Plutonium	95 Americium	96 Curium
Ag $K\beta_1$	2.494E−02	6.07E+01	6.19E+01	6.48E+01	6.55E+01	6.84E+01	7.05E+01	7.20E+01	7.35E+01
Pd $K\beta_1$	2.382E−02	6.82E+01	6.95E+01	7.27E+01	7.35E+01	7.67E+01	7.91E+01	8.08E+01	8.24E+01
Rh $K\beta_1$	2.272E−02	7.68E+01	7.82E+01	8.19E+01	8.27E+01	8.63E+01	8.89E+01	9.08E+01	6.00E+01
Ag $K\bar{\alpha}$	2.210E−02	8.24E+01	8.39E+01	8.78E+01	8.86E+01	9.25E+01	5.60E+01	5.95E+01	6.43E+01
Pd $K\bar{\alpha}$	2.112E−02	9.24E+01	9.41E+01	9.84E+01	9.93E+01	1.04E+02	1.07E+02	1.09E+02	1.11E+02
Rh $K\bar{\alpha}$	2.017E−02	1.04E+02	1.06E+02	1.11E+02	1.12E+02	1.16E+02	1.20E+02	1.22E+02	1.10E+02
Mo $K\beta_1$	1.961E−02	1.10E+02	9.87E+01	1.19E+02	7.49E+01	1.25E+02	1.29E+02	1.31E+02	1.34E+02
Mo $K\bar{\alpha}$	1.744E−02	9.08E+01	9.65E+01	1.01E+02	1.02E+02	4.22E+01	3.99E+01	4.81E+01	4.90E+01
Zn $K\beta_1$	9.572E−03	2.49E+02	1.70E+02	1.73E+02	1.85E+02	1.90E+02	1.80E+02	1.89E+02	1.94E+02
Cu $K\beta_1$	8.905E−03	2.85E+02	2.19E+02	2.08E+02	2.22E+02	2.27E+02	2.16E+02	2.27E+02	2.32E+02
Zn $K\bar{\alpha}$	8.631E−03	3.03E+02	2.55E+02	2.25E+02	2.40E+02	2.46E+02	2.34E+02	2.41E+02	2.51E+02
Ni $K\beta_1$	8.265E−03	3.09E+02	2.85E+02	2.52E+02	2.68E+02	2.75E+02	2.62E+02	2.73E+02	2.80E+02
Cu $K\bar{\alpha}$	8.041E−03	3.17E+02	3.06E+02	2.71E+02	2.88E+02	3.14E+02	2.80E+02	3.22E+02	3.38E+02
Co $K\beta_1$	7.649E−03	3.81E+02	3.48E+02	3.06E+02	3.26E+02	3.35E+02	3.17E+02	3.33E+02	3.43E+02
Ni $K\bar{\alpha}$	7.472E−03	3.99E+02	3.69E+02	3.25E+02	3.47E+02	3.55E+02	3.36E+02	3.52E+02	3.60E+02
Fe $K\beta_1$	7.058E−03	4.44E+02	3.89E+02	3.75E+02	4.00E+02	4.10E+02	3.89E+02	4.07E+02	4.21E+02
Co $K\bar{\alpha}$	6.925E−03	4.61E+02	4.06E+02	3.94E+02	4.20E+02	4.30E+02	4.08E+02	4.26E+02	4.37E+02
Mn $K\beta_1$	6.490E−03	5.21E+02	4.46E+02	4.65E+02	4.96E+02	5.05E+02	4.08E+02	5.03E+02	5.15E+02
Fe $K\bar{\alpha}$	6.400E−03	5.30E+02	4.85E+02	4.82E+02	5.28E+02	5.52E+02	4.98E+02	5.81E+02	5.90E+02
Cr $K\beta_1$	5.947E−03	6.18E+02	5.09E+02	5.82E+02	6.17E+02	6.30E+02	6.00E+02	6.27E+02	6.40E+02
Mn $K\bar{\alpha}$	5.895E−03	6.29E+02	6.23E+02	5.93E+02	6.32E+02	6.45E+02	6.12E+02	6.42E+02	6.55E+02
Cr $K\bar{\alpha}$	5.412E−03	7.39E+02	7.68E+02	7.38E+02	7.66E+02	8.00E+02	7.60E+02	7.95E+02	8.12E+02
Ti $K\beta_1$	4.932E−03	8.83E+02	9.78E+02	9.83E+02	9.66E+02	1.01E+03	9.62E+02	1.03E+03	1.03E+03
Ti $K\bar{\alpha}$	4.509E−03	1.05E+03	1.23E+03	1.24E+03	1.23E+03	9.65E+02	9.00E+02	9.55E+02	9.84E+02

Table 4.2.4.3. *Mass attenuation coefficients (cm^2 g^{-1}) (cont.)*

Radiation	Energy (MeV)	97 Berkelium	98 Californium
Ag $K\beta_1$	2.494E−02	6.66E+01	7.35E+01
Pd $K\beta_1$	2.382E−02	7.52E+01	8.24E+01
Rh $K\beta_1$	2.272E−02	8.51E+01	9.26E+01
Ag $K\bar{\alpha}$	2.210E−02	6.10E+01	6.92E+01
Pd $K\bar{\alpha}$	2.112E−02	1.03E+02	1.11E+02
Rh $K\bar{\alpha}$	2.017E−02	1.02E+02	1.25E+02
Mo $K\beta_1$	1.961E−02	1.25E+02	1.34E+02
Mo $K\bar{\alpha}$	1.744E−02	4.90E+01	5.00E+01
Zn $K\beta_1$	9.572E−03	1.86E+02	2.08E+02
Cu $K\beta_1$	8.905E−03	2.26E+02	2.49E+02
Zn $K\bar{\alpha}$	8.631E−03	2.46E+02	2.70E+02
Ni $K\beta_1$	8.265E−03	2.77E+02	3.01E+02
Cu $K\bar{\alpha}$	8.041E−03	3.52E+02	3.60E+02
Co $K\beta_1$	7.649E−03	3.57E+02	3.66E+02
Ni $K\bar{\alpha}$	7.472E−03	3.62E+02	3.86E+02
Fe $K\beta_1$	7.058E−03	4.22E+02	4.48E+02
Co $K\bar{\alpha}$	6.925E−03	4.43E+02	4.69E+02
Mn $K\beta_1$	6.490E−03	5.26E+02	5.52E+02
Fe $K\bar{\alpha}$	6.400E−03	5.92E+02	6.07E+02
Cr $K\beta_1$	5.947E−03	6.64E+02	6.87E+02
Mn $K\bar{\alpha}$	5.895E−03	6.78E+02	7.03E+02
Cr $K\bar{\alpha}$	5.412E−03	8.52E+02	8.71E+02
Ti $K\beta_1$	4.932E−03	1.09E+03	1.10E+03
Ti $K\bar{\alpha}$	4.509E−03	1.04E+03	1.05E+03

involve the use of filters, mirrors, and Laue and Bragg crystal monochromators, chosen so as to provide the best compromise between flux and spectral purity in a particular experiment. In other chapters, authors have discussed the use of techniques to improve the spectral purity of X-ray sources. This section does not purport to be a comprehensive exposition on the topic of filters and monochromators. Rather, it seeks to point the reader towards the information given elsewhere in this volume, and to add complementary information where necessary. A search of the Subject Index will find references to filters and monochromators that are not explicitly mentioned in the text of this section.

The ability to select photon energies, or bands of energies, depends on the scattering power of the atoms from which the monochromator is made and the arrangement of the atoms within the monochromator. The scattering powers of the atoms and their dependence on the energy of the incident photons were discussed in Sections 4.2.3 and 4.2.4 and are discussed more fully in Section 4.2.6. In brief, the scattering power of the atom, or *atomic scattering factor*, is defined, for a given incident photon energy, as the ratio of the scattering power of the atom to that of a free Thomson electron. The scattering power is denoted by the symbol $f(\omega, \Delta)$ and is a complex quantity, the real part of which, $f'(\omega, \Delta)$, is related to the elastic scattering cross section, and the imaginary part of which, $f''(\omega, \Delta)$, is related directly to the photoelectric scattering cross section and therefore the linear attenuation coefficient μ_l.

At an interface between, say, air and the material from which the monochromator is made, reflection and refraction of the incident photons can occur, as dictated by Maxwell's equations. There is an associated refractive index n given by

$$n = (1 + \chi)^{1/2}, \qquad (4.2.5.1)$$

where

$$\chi = -(r_e \lambda^2/\pi) \sum_j N_j f_j(\omega, \Delta), \qquad (4.2.5.2)$$

r_e is the classical radius of the electron, and N_j is the number density of atoms of type j.

An angle of total external reflection α_c exists for the material, which is a function of the incident photon energy, since $f_j(\omega, \Delta)$ is a function of photon energy. Thus, a polychromatic beam incident at the critical angle of one of the photon energies (E) will reflect totally those components having energies less than E, and transmit those components with energies greater than E. Fig. 4.2.5.1 shows calculations by Fukumachi, Nakano & Kawamura (1986) for the reflectivity of single layers of aluminium, copper and platinum as a function of incident energy for a fixed angle of incidence (0.2°). For the aluminium specimen, the reflectivity curve shows the rapid decrease in reflectivity as the critical angle is exceeded. The reflectivity in this region varies as E^{-2}. The effect of increasing atomic number can be seen: the higher the atomic factor $f(\omega, \Delta)$, the greater the energy that can be reflected from the surface. Also visible are the effects of the dispersion corrections $f'(\omega, \Delta)$ and $f''(\omega, \Delta)$ on reflectivity. For copper, the K shell is excited, and for platinum the $L_{\rm I}$, $L_{\rm II}$ and $L_{\rm III}$ shells are excited by the polychromatic beam.

Interfaces can therefore be used to act as low-pass energy filters. The surface roughness and the existence of impurities and contaminants on the interface will, however, influence the characteristics of the reflecting surface, sometimes significantly.

4.2.5.2. *Mirrors and capillaries*

Whilst neither of these classes of X-ray optical device is strictly speaking a monochromator, they nevertheless form component parts of monochromator systems in the laboratory and at synchrotron-radiation sources.

4.2.5.2.1. *Mirrors*

In the laboratory, mirrors are used in conjunction with conventional sealed tubes and rotating-anode sources, the emission from which consists of *Bremsstrahlung* upon which is superimposed the characteristic spectrum of the anode material (Subsection 2.3.5.2). The shape of the *Bremsstrahlung* spectrum can be significantly modified by mirrors, and the intensity emitted at harmonics of the characteristic wavelength can be

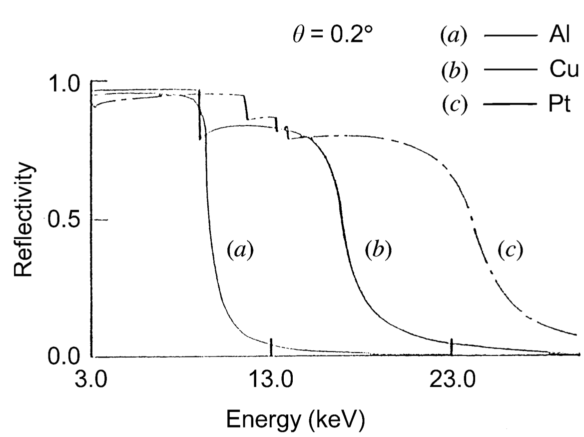

Fig. 4.2.5.1. The variation of specular reflectivity with incident photon energy is shown for materials of different atomic number and a constant angle of incidence of 0.2°. (*a*) Aluminium: note the rapid decrease of reflectivity with energy. (*b*) Copper: the sudden decrease of reflectivity is due to the modification of the scattering-length density owing to absorption at the K-absorption edge. (*c*) Platinum: the three discontinuities in the reflectivity curve are due to absorption at the $L_{\rm I}$-, $L_{\rm II}$-, and $L_{\rm III}$-absorption edges.

references