by using the identity:

$$\int_0^\infty j_l(kr) r^n \exp(-pr) 4\pi r^2 \, dr = \frac{\pi^{3/2}\Gamma(n+l+3)k^l}{2^{l-1}\Gamma(l+3/2)(k^2+p^2)^{(n+l+3)/2}} \times {}_2F_1\left(\frac{n+l+3}{2}; \frac{l-n+3}{2}; l+\frac{3}{2}; \frac{k^2}{k^2+p^2}\right). \quad (4.4.5.5)$$

The form factors have been calculated from these relationships in the range $(\sin\theta)/\lambda = 0$ to 1.5 Å^{-1} at intervals of 0.05 Å^{-1}, and the coefficients of the exponential expansion fitted by a least-squares procedure at the calculated points.

For the atoms of the rare-earth and actinide series, the wavefunctions and form factors have been calculated by Freeman & Desclaux (1979) and Desclaux & Freeman (1978) using Dirac–Fock theory. The constants given in Tables 4.4.5.3, 4.4.5.4, 4.4.5.7, 4.4.5.8, and 4.4.5.11–4.4.5.14 have been fitted to the results of these calculations. For the rare-earth ions, the form factors are given in the range $(\sin\theta)/\lambda = 0$ to 0.5 Å^{-1} at intervals of 0.5 Å^{-1} and in the range 0.5 to 1.2 Å^{-1} at intervals of 0.1 Å^{-1}. For the actinide ions, the calculations extend to 1.5 Å^{-1}. All the values given in the publications cited were included in the fitting procedure. The accuracy with which the exponential expansions fit the theoretical form factors can be judged from the value of the parameter e given in the tables, and defined by:

$$e = 100\left(\frac{\sum_i \delta_i^2}{N}\right)^{1/2}, \quad (4.4.5.6)$$

where δ_i is the difference between the ith fitted point and its theoretical value. The sum is over the N points included in the fitting procedure.

4.4.6. Absorption coefficients for neutrons (By B. T. M. Willis)

The cross sections σ discussed in Section 4.4.4 represent the area of each nucleus as seen by the neutron. To calculate the beam attenuation arising from absorption it is more convenient to use the macroscopic cross section Σ, which is the cross section per unit volume in units of cm^{-1}. Σ is derived by multiplying σ for the element by the number of atoms per unit volume. Thus, for element j, with density ρ_j and atomic weight A_j,

$$\Sigma_j = N_A \rho_j \sigma_j / A_j,$$

where N_A is Avogadro's number.

Table 4.4.6.1 gives the macroscopic absorption cross sections Σ_a of the elements. They are tabulated for a neutron velocity $v = 2200$ m s^{-1}, corresponding to a wavelength of 1.80 Å. The cross sections are larger at longer wavelengths (Section 4.4.4). Apart from a few exceptions, such as boron and cadmium, the absorption cross section is vastly smaller than for X-rays. The $1/e$ penetration depth (l) is listed separately – most metals, for example, have a penetration depth of several cm. The data in Table 4.4.6.1 have been derived from the review article by Hutchings & Windsor (1987).

Table 4.4.6.1. *Absorption of the elements for neutrons ($\lambda = 1.80$ Å)*

Atom	Σ_a (cm^{-1})	l (cm)	Atom	Σ_a (cm^{-1})	l (cm)
H	0.0141	0.288	Rh	10.544	0.092
D	0.0000	6.17	Pd	0.4687	1.29
He	0.0001	20.22	Ag	3.7120	0.249
Li	3.2698	0.300	Cd	116.80	0.008
Be	0.0009	1.059	In	7.4135	0.133
B	105.41	0.009	Sn	0.0231	4.87
C	0.0004	1.58	Sb	0.1689	3.20
N	0.0662	2.14	Te	0.1386	4.01
O	0.0001	5.52	I	0.1458	4.36
F	0.0003	6.82	Xe	0.3904	2.27
Ne	0.0017	8.71	Cs	0.2458	3.57
Na	0.0135	10.22	Ba	0.0189	13.39
Mg	0.0027	6.11	La	0.2402	2.00
Al	0.0139	9.48	Ce	0.0182	9.60
Si	0.0085	8.45	Pr	0.3333	2.46
P	0.0061	8.04	Nd	1.4763	0.496
S	0.0208	16.14	Sm	171.23	0.005
Cl	0.9109	0.731	Eu	95.715	0.010
Ar	0.0143	2.03	Gd	1474.1	0.000
K	0.0279	18.12	Tb	0.7334	1.05
Ca	0.0099	12.35	Dy	29.731	0.030
Sc	1.0906	0.491	Ho	2.0791	0.424
Ti	0.3453	1.74	Er	5.1861	0.182
V	0.3658	1.35	Tm	3.4919	0.269
Cr	0.2558	1.82	Yb	0.8513	0.717
Mn	1.0900	0.789	Lu	2.5889	0.354
Fe	0.2174	0.82	Hf	4.6648	0.195
Co	3.3440	0.260	Ta	1.1434	0.676
Ni	0.4104	0.475	W	1.1609	0.681
Cu	0.3202	1.00	Re	6.1692	0.143
Zn	0.0730	2.89	Os	1.1444	0.442
Ga	0.1480	2.04	Ir	30.064	0.032
Ge	0.1016	2.07	Pt	0.6843	0.682
As	0.2091	2.15	Au	5.8181	0.159
Se	0.4292	1.36	Hg	15.146	0.061
Br	0.1623	3.31	Tl	0.1200	2.15
Kr	0.3882	1.97	Pb	0.0056	2.68
Rb	0.0041	13.09	Bi	0.0009	3.84
Sr	0.0227	7.44	Ra	0.1706	2.95
Y	0.0388	3.66	Th	0.2244	1.68
Zr	0.0079	3.42	Pa	8.0405	0.118
Nb	0.0640	2.42	U	0.3650	1.26
Mo	0.1637	1.75	Np	9.0534	0.10
Tc	1.4281	0.542	Pu	14.481	0.069
Ru	0.1886	1.48	Am	2.5522	0.351

references