

4. PRODUCTION AND PROPERTIES OF RADIATIONS

the case of the mosaic crystal) must be used. The dynamical effects thus decrease when passing from electrons to X-rays and neutrons for a given crystal thickness.

(7) *Absorption length.* Absorption length is here estimated by the reciprocal values of the linear absorption coefficients. The value of the absorption length determines the size of the sample or the surface layer thickness accessible for diffraction analysis. The penetration of the electron beam into the crystal is severely limited by absorption or by diffraction when a strong reflection is excited and thus only 10–1000 Å surface layers contribute to the electron diffraction. Owing to the Borrmann effect, there occurs a substantial decrease of X-ray absorption for nearly perfect crystals in diffraction position. The relatively large crystals used for neutron diffraction in order to obtain useful diffraction intensities have been found to cause particularly important secondary-extinction effects due to disorientation of the mosaic blocks.

(8) *Width of rocking curve.* The range of angles between a crystal plane and the diffracted beam over which there is significant Bragg reflection is much larger for electrons than for X-rays or neutrons.

(9) *Refractive index.* The refractive index deviates slightly from unity for the radiations compared and the angle of refraction thus makes only a few angular minutes and increases with increasing wavelength. Negative values of δ for neutrons correspond to positive values of atomic scattering amplitudes and *vice versa*. The refraction effects will be considerable for the small angles of incidence of electrons needed in the Bragg case of diffraction (see *Bragg angles*) and the waves diffracted from planes parallel to the surface having spacings as small as 2 or 3 Å may suffer total internal reflection and be unable to leave the crystal.

(10) *Atomic scattering amplitudes.* The example given corresponds to the scattering of the atoms of lead at $(\sin \theta)/\lambda = 0.4 \text{ \AA}^{-1}$. The absolute values of the atomic scattering amplitudes for electrons are considerably greater

than for X-rays or neutrons; this is also reflected in the structure-amplitude values and in the corresponding intensities of the Bragg reflections. For the angular dependence of the atomic scattering amplitudes, see Fig. 4.1.3.1. The constant value of the atomic scattering amplitudes for neutrons (also often called the scattering length) makes neutron diffraction suitable for precise measurement of thermal parameters.

(11) *Dependence of atomic scattering amplitudes on the atomic number Z.* This kind of dependence is illustrated for neutral atoms in Fig. 4.1.3.2. Because of the relatively weaker dependence on the atomic number, the peaks of light atoms in the presence of heavy atoms are revealed more clearly in the Fourier synthesis of electron-density maps obtained by the electron-diffraction method than by X-ray diffraction. The same is generally true for neutron diffraction, which also enables atoms of elements with similar atomic numbers to be distinguished in certain cases (based on the irregular change of atomic scattering amplitudes with Z); different isotopes of the same element may also be distinguished.

(12) *Anomalous dispersion.* This effect is utilized for the solution of the phase problem in crystal structure analysis by X-ray diffraction. In the case of neutron diffraction, there are only a few stable isotopes convenient for this purpose (mainly ^{149}Sm , ^{157}Gd , and ^{113}Cd). The wavelength of the high-energy electrons is too short compared with the *K*-absorption edges of atoms and the resonance scattering of electrons is thus negligible.

(13) *Spectral breadth.* The value for X-rays corresponds to the characteristic lines of X-ray spectra. The spread of energies or wavelengths in the beam of neutrons obtained from a reactor is quite broad and for diffraction experiments a narrow range of wavelengths is usually selected by the use of a crystal monochromator or, especially for long wavelengths, by a time-of-flight chopper device that selects a range of neutron velocities.

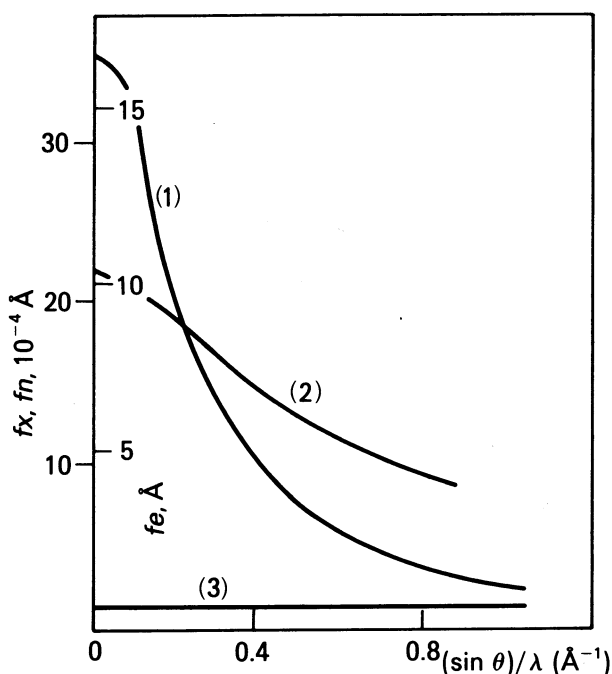


Fig. 4.1.3.1. Angular dependence of the atomic scattering amplitudes of lead for (1) electron, (2) X-ray, and (3) neutron scattering (in absolute values).

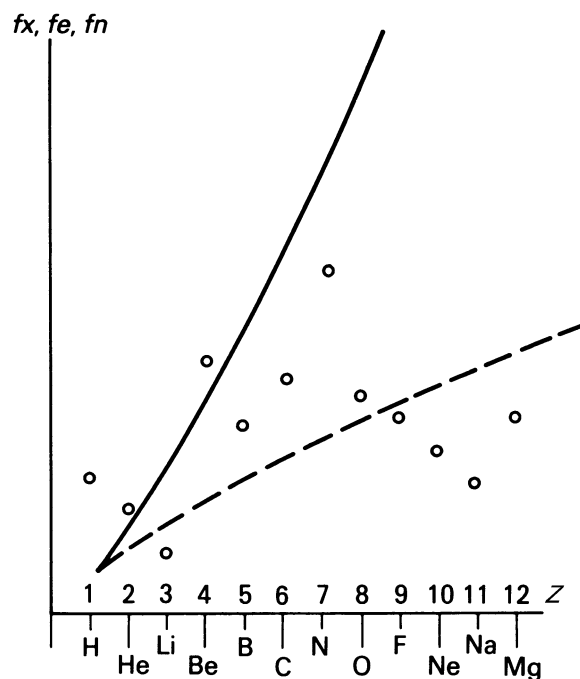


Fig. 4.1.3.2. Relative dependence of the average atomic scattering amplitudes on the atomic number Z for X-rays (—), electrons (---), and neutrons (⋯). The values plotted are averages over $(\sin \theta)/\lambda$.