

## 6. RADIATION SOURCES AND OPTICS

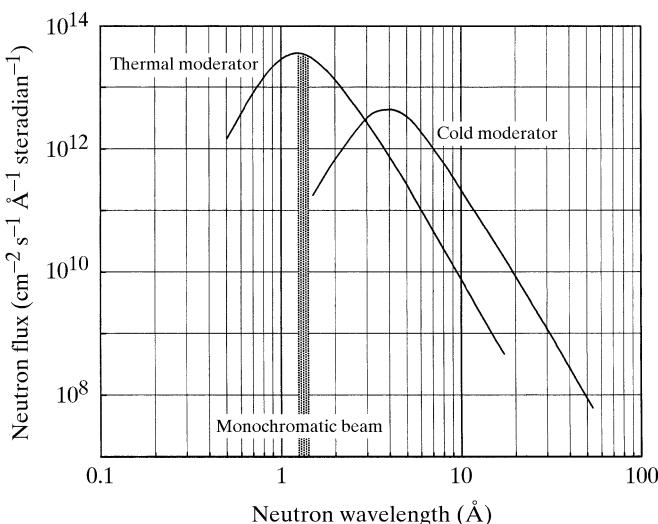


Fig. 6.2.1.2. Neutron wavelength distributions for a thermal (310 K) and a cold (30 K) neutron moderator in a ‘typical’ dedicated beam reactor. The Maxwellian distribution merges with a  $1/E$  slowing-down distribution at shorter wavelengths. A wavelength distribution for a monochromatic beam application on a thermal source is illustrated. It should be noted that, depending on the value of the mean wavelength for the monochromatic beam, harmonic contamination may be significant.

For neutron-beam applications,  $\text{D}_2\text{O}$  is the preferred reflector material since the moderation length is large and the absorption cross section low. Consequently, the thermal neutron flux peak is rather broad and occurs relatively distant from the core. While the exact position of the peak depends on the reactor core design, the peak width has a major impact on beam-tube orientation (Section 6.2.1.3). The combination of  $\text{D}_2\text{O}$  coolant/moderator– $\text{D}_2\text{O}$  moderator/reflector provides a distinct advantage; however, for a number of technical reasons, the  $\text{H}_2\text{O}$ – $\text{D}_2\text{O}$  combination is becoming more common, with the  $\text{D}_2\text{O}$  in a closed vessel surrounding the central  $\text{H}_2\text{O}$ -cooled core.

#### 6.2.1.2.1. Thermal moderators

Neutrons thermalized within a ‘semi-infinite’ moderator/reflector typical of a steady-state reactor source establish an equilibrium Maxwellian energy distribution characterized by the temperature ( $T$ ) of the moderator (Fig. 6.2.1.2). The wavelength,  $\lambda_m$ , at which the above distribution has a maximum is given by

$$\lambda_m = h/(5k_B T m_n)^{1/2}.$$

Depending on the width of the moderator and its composition, the Maxwellian distribution merges with the  $1/E$  slowing-down distribution from the reactor core to give a total distribution at the beam-tube entry.

Clearly, the neutron wavelength distribution will depend on the local equilibrium conditions. Since steady-state reactors typically operate with moderator/reflector temperatures in the range 308–323 K, the corresponding  $\lambda_m$  is about 1.4 Å (Fig. 6.2.1.2). However, it is possible to alter the neutron distribution by re-thermalizing the neutrons in special moderator regions, which are either cooled significantly below or heated significantly above the average moderator temperature. One such device of prime importance is the cold moderator in the form of a cold source.

#### 6.2.1.2.2. Cold moderators

The thermal neutron distribution shown in Fig. 6.2.1.2 is not ideal for all experiments, since the flux of 5 Å neutrons is almost

two orders of magnitude less than the peak. The solution is to introduce a cold region in the moderator/reflector. This is typically a volume of liquid  $\text{H}_2$  or  $\text{D}_2$  at  $\sim 10$ –30 K, and a Maxwellian distribution around this temperature results in a  $\lambda_m$  of  $\sim 4$  Å. The geometric design of a cold-source vessel has been shown to be very important, with substantial gains in neutron flux obtained by innovative design. A re-entrant geometry approximately 20 cm in diameter filled with liquid  $\text{D}_2$  at 10 K provides optimum neutron thermalization with superior coupling to neutron guides (Section 6.2.1.3.5) (Ageron, 1989; Lillie & Alsmiller, 1990; Alsmiller & Lillie, 1992).

#### 6.2.1.3. Beamline components

Until recently, instrument design has been largely based on experience; however, in many cases, it is now possible to formulate a comprehensive description of the instrument and explore the impact of various parameters on instrument performance using an extensive array of computational methods (Johnson & Stephanou, 1978; Sivia *et al.*, 1990; Hjelm, 1996). In practice, it is the instrument design that provides access to the fundamental scattering processes, as briefly outlined in the following.

If a neutron specified by a wavevector  $\mathbf{k}_1$  is incident on a sample with a scattering function  $S(\mathbf{Q}, \omega)$ , all neutron scattering can be reduced to the simple form

$$\frac{d^2\sigma}{d\Omega dE} = AS(\mathbf{Q}, \omega),$$

where  $A$  is a constant containing experimental information, including instrumental resolution effects. The basic quantity to be measured is the partial differential cross section, which gives the fraction of neutrons of incident energy  $E$  scattered into an element

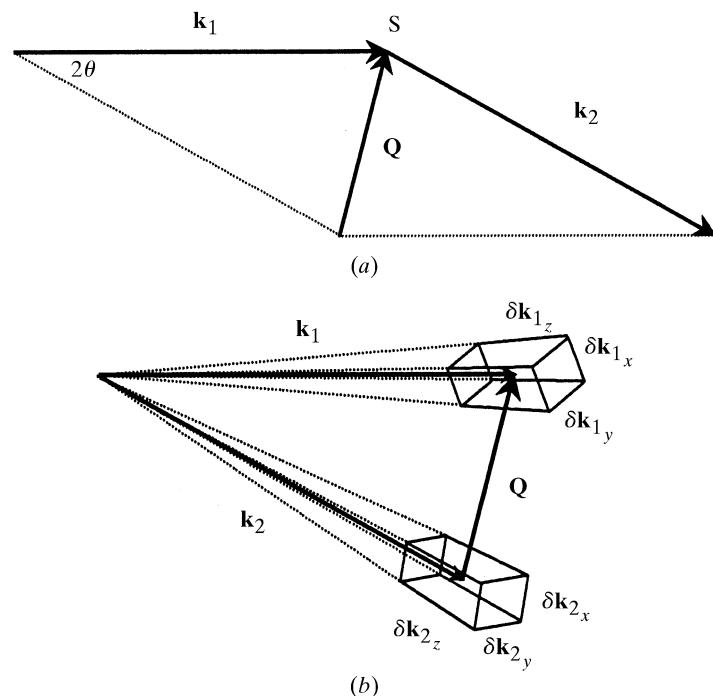


Fig. 6.2.1.3. (a) Schematic vector diagram for an elastic neutron-scattering event. A neutron,  $\mathbf{k}_1$ , is incident on a sample,  $S$ , and a scattered neutron,  $\mathbf{k}_2$ , is observed at an angle  $2\theta$  leading to a momentum transfer,  $\mathbf{Q}$ . (b) Schematic of an elastic neutron-scattering event illustrating the consequences of uncertainty in defining the incident neutron,  $\mathbf{k}_1$ , and determining the scattered neutron,  $\mathbf{k}_2$ . The volumes  $(\delta\mathbf{k}_{1_x}, \delta\mathbf{k}_{1_y}, \delta\mathbf{k}_{1_z})$  and  $(\delta\mathbf{k}_{2_x}, \delta\mathbf{k}_{2_y}, \delta\mathbf{k}_{2_z})$  constitute the instrument resolution function.