as X-ray concentrators, where a larger-diameter beam of X-rays enters the large end of a tapered capillary and is concentrated to a diameter of a few µm. Fused polycapillary bundles have been employed as focusing collimators for protein crystallography (MacDonald *et al.*, 1999). Both types of capillary optics are usually designed as multi-bounce devices, in which the X-rays undergo several, or many, reflections at the walls of the capillary; consequently the cross-fire half-angle at the output end has a value about equal to the critical angle for reflection at a glass surface or, perhaps, 4 mrad. This is sometimes too great for producing diffraction patterns with an optimum signal-to-background ratio.

Other methods of focusing X-rays, such as zone plates (Kirz, 1974) and refractive optics, are being investigated, but at present none of them can compare with toroidal reflectors for data collection from single crystals of macromolecules.

6.1.4.4. *Crystal monochromators*

When the X-rays from the tube target are specularly reflected by a mirror, the spectrum is cut off for X-rays below the shortest wavelength for which the critical angle is equal to the smallest angle of incidence on the mirror. For a typical mirror designed for Cu $K\alpha$ radiation, this cutoff wavelength might be about 0.75 Å, and the harder X-rays can be further attenuated by a β-filter. Of course, the more nearly monochromatic the radiation falling on the sample, the lower the radiation damage and the higher the spot-to-background ratio in the recorded patterns.

White radiation is almost completely eliminated by reflecting the primary X-ray beam using a natural or artificial (multilayer) crystal. The most commonly used type of plane monochromator for macromolecular crystallography is a single crystal of graphite. This material (HOPG, or highly ordered pyrolytic graphite) has a relatively large mosaic spread, typically about 0.4°, and it cannot separate the $K\alpha$ doublet. This separation is essential in most small-molecule investigations, but is unnecessary for macromolecular crystals, which rarely diffract beyond 1.5 Å, and disadvantageous where a high intensity of the beam reflected by the monochromator is the main consideration.

The intensity of the diffraction pattern obtained with a graphite monochromator is only about two or three times lower than that resulting from a β-filtered pinhole-collimated beam. The situation is different at synchrotron beam lines, which must incorporate a monochromator in order to select the desired X-ray energy band. Curved focusing crystals collect X-rays over a relatively large horizontal angular range and thus produce a beam with a horizontal convergence angle of up to several milliradians. Much more nearly parallel beams are produced by reflection at several crystals in tandem, often in the form of monolithic channel-cut monochromators. In present-day storage rings, the power density at the first optical element is of the order of 10 W mm^{-2} at wiggler and undulator beam lines. This amount of power can be dissipated by careful design of water-cooling channels (Quintana & Hart, 1995; van Silfhout, 1998). In addition, the monochromator crystal, usually of silicon or germanium, may be profiled to minimize distortions as a result of thermal stresses.

The next generation of insertion devices will subject the optical elements to loads of several hundred W mm^{-2}. Possible engineering solutions to the very severe heat-loading problem include the use of diamond crystals as reflecting elements. This material has a very high thermal conductivity, especially at low temperatures.

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