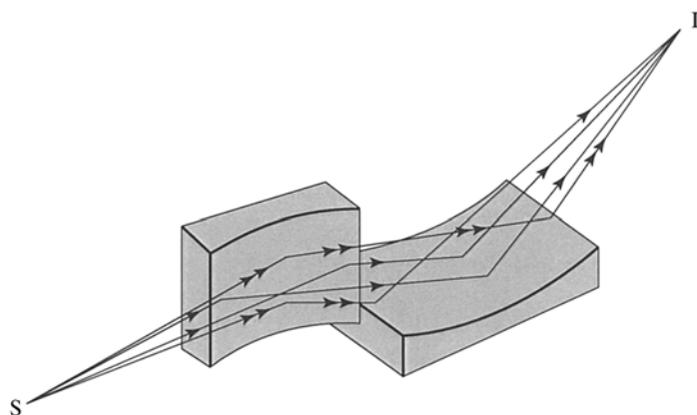


6. RADIATION SOURCES AND OPTICS

**Figure 6.1.4.1**

Production of a point focus by successive reflections at two orthogonal curved mirrors. Arrangement due to Kirkpatrick & Baez (1948) and to Franks (1955).

Intensity changes can be caused by mechanical movement of collimating components. Among these may be such unsuspected effects as flexing of the target surface with changes in cooling-water pressure.

The response of an incident-beam monitor may itself vary as a result of changes in temperature, barometric pressure, or humidity.

Synchrotron radiation from storage rings has a regular time-dependent modulation brought about by the rate of passage of bunches of electrons or positrons in the ring. For the great majority of measurements, this time structure has no effect, but at very high intensities, the counting losses are greater than they would be from a steady source.

6.1.4. Beam conditioning

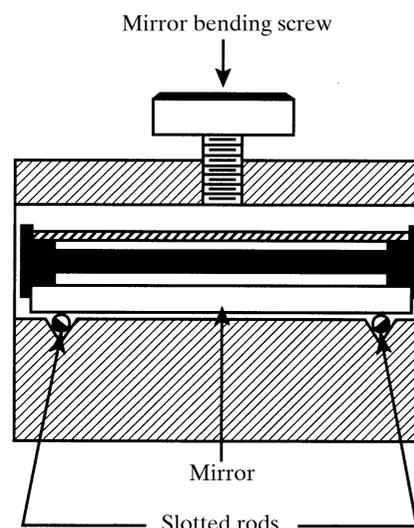
The primary X-ray beam from the source is conditioned by a variety of devices, such as filters, mirrors and monochromators, to produce the appropriate properties for the beam incident on the sample.

6.1.4.1. X-ray mirrors

It is usually necessary to focus the X-ray beam in two orthogonal directions. This can be achieved either by means of one mirror with curvatures in two orthogonal planes or by two successive reflections from two mirrors which are curved in one plane and planar in the other; the two planes of curvature must be at right angles to one another. In the arrangement adopted by Kirkpatrick & Baez (1948) and by Franks (1955), the two mirrors lie one behind the other (Fig. 6.1.4.1) and thus produce a different degree of collimation in the two planes. Instead of this tandem arrangement, the mirrors can lie side-by-side, as proposed by Montel (1957), to form what the author calls a 'catamegonic roof' (Fig. 6.1.4.2). The mirrors are then best made

**Figure 6.1.4.2**

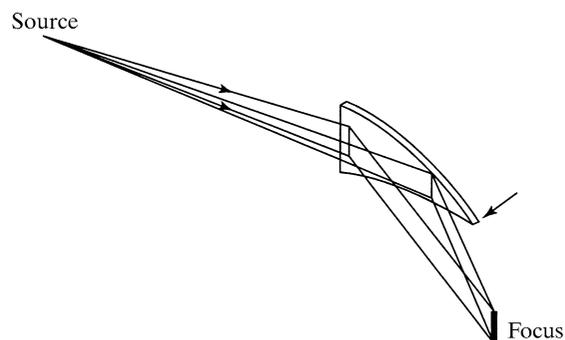
The 'catamegonic' arrangement of Montel (1957), in which two confocal mirrors with orthogonal curvatures lie side-by-side.

**Figure 6.1.4.3**

Mirror bender (after Franks, 1955). The force exerted by the screw produces two equal couples which bend the mirror into a circular arc. The slotted rods act as pivots and also as beam-defining slits.

from thicker material, and the reflecting surfaces are ground to the appropriate curvature. The same arrangement has been used by Osmic Inc. (1998) for their Confocal Max-Flux Optics, in which the curved surfaces are coated with graded-spacing multilayers.

Flat mirror plates can be bent elastically to a desired curvature by applying appropriate couples. Fig. 6.1.4.3 shows the bending method adopted by Franks (1955). A cylindrical curvature results from a symmetrical arrangement that produces equal couples at both ends. With appropriate unequal couples applied at the two ends of the plate, the curvature can be made parabolic or elliptical. Precision elliptical mirrors have been produced by Padmore *et al.* (1997); unequal couples are applied in this way. Cylindrically curved mirrors can be produced by applying a force at the tip of a triangular plate whose base is firmly anchored (Fig. 6.1.4.4). Lemonnier *et al.* (1978) first used this method for making curved-crystal monochromators. Milch (1983) described X-ray mirrors made in this way; the effect of the linear increase of the bending moment along the plate is compensated by the linear increase of the plate section so that the curvature is constant. An elliptical or a parabolic curvature results if either the width or the thickness of the plate is made to vary in an appropriate way along the length of the plate. Arndt, Long & Duncumb (1998) described a monolithic mirror-bending block in which the mirror plates are

**Figure 6.1.4.4**

Triangular mirror bender as described by Lemonnier *et al.* (1978) for crystal plates and by Milch (1983) for glass mirrors. The base of the triangular plate is clamped and the bending force is applied at the apex along the arrow.

6.1. X-RAY SOURCES

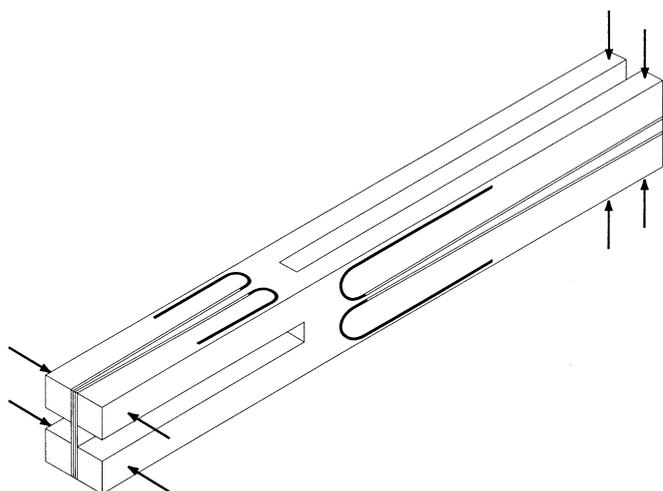


Figure 6.1.4.5
Mirror holder with machined slots for two orthogonal pairs of curved mirrors (after Arndt, Duncumb *et al.*, 1998).

inserted into slots cut to an elliptical curvature by ion-beam machining. The solid angle of collection is made four times larger than for a two-mirror arrangement by providing a pair of horizontal mirrors and a pair of vertical mirrors in tandem in one block (Fig. 6.1.4.5).

Mirror plates for these benders are usually made from highly polished glass, quartz, or silicon plates which are coated with nickel, gold, or iridium.

Mirrors for synchrotron beam lines that focus the radiation in the vertical plane are most often ground and polished to the correct shape, rather than bent elastically. Much longer mirrors can be made in this way.

The collecting efficiency of specularly reflecting mirrors depends on the reflectivity of the surface and on the solid angle of collection; this, in turn, is a function of the maximum glancing angle of incidence, which is the critical angle for total external reflection, θ_c . For X-rays of wavelength λ , measured in \AA ,

$$\theta_c \simeq 2.32 \times 10^{-3} (Z\rho/A)^{1/2} \lambda,$$

where Z is the atomic number, A is the atomic mass and ρ is the specific gravity of the reflecting surface.

Thus, for Cu $K\alpha$ radiation and a gold surface, $\theta_c \simeq 10$ mrad. The reflectivity of the mirror surface is strongly dependent on the surface roughness; for the reflectivity to be more than 50%, the r.m.s. roughness must not exceed 10 \AA .

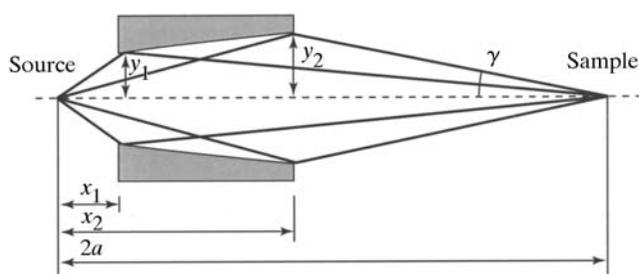


Figure 6.1.4.6
Ellipsoidal mirror for use with a microfocus X-ray tube, where x_1 is ~ 15 mm. The major axis, $2a$, may be up to 600 mm, whereas the exit aperture, $2y_2$, lies in the region 0.8–1.4 mm. The angle γ determines the cross fire on the sample and is less than 1 rad.

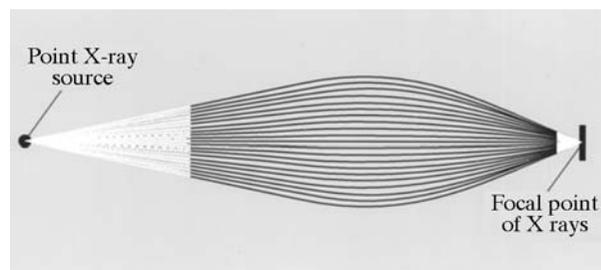


Figure 6.1.4.7
A polycapillary collimator (after Bly & Gibson, 1996).

It is not possible to design a reflecting collimator with a planar angle of collection greater than about $3\theta_c$. For the shorter wavelengths, in particular, variable-spacing multilayer mirrors (Schuster & Göbel, 1997) hold considerable promise. If the spacing at the upstream end of the mirror is 30 \AA , the largest angles of incidence will be 26 and 17 mrad for 1.54 and 1.0 \AA X-rays, respectively. By comparison, the critical angles at a gold surface for these radiations are 10 and 6.5 mrad, respectively.

6.1.4.2. Focusing collimators for microfocus sources

In most arrangements that include conventional X-ray tubes, the planar angle of collection is very small. A more efficient use is always made of the radiation from the target by a focusing collimator, which forms an image of the source on the sample (Fig. 6.1.4.6). The angle of collection should be as large as possible, while the cross fire, *i.e.* the angle of convergence, is kept small, say, at about 10^{-3} rad. It is possible to design focusing collimators based on gold-surfaced toroids of revolution (Elliott, 1965), which afford a planar angle of collection of about three times the critical angle for total external reflection, that is, about 30×10^{-3} rad.

Consequently, the mirror should *magnify* about 30 times, and if the image diameter, determined by a typical sample size, is to be $300 \mu\text{m}$, the size of the focus should be about $10 \mu\text{m}$. The solid angle of collection of such an imaging toroid is about 8×10^{-4} steradians, that is, more than 1000 times greater than the solid angle of a simple non-imaging collimator. The averaged mirror reflectivity achieved at present is about 0.3, so the microfocus tube and toroidal mirror combination produces a similar intensity at the sample as the conventional tube with a non-focusing collimator at about 300 times the power. Future increases of the reflectivity are likely as the surface roughness of the mirrors is improved.

A suitable microfocus tube has been described by Arndt, Long & Duncumb (1998); mirrors used with this tube were discussed by Arndt, Duncumb *et al.* (1998). The tube design allows the distance between the source and the mirror to be as little as 10 mm in order to achieve the necessary magnification without making the distance between the tube and the sample inconveniently long.

6.1.4.3. Other focusing collimators

There has been very active development in recent years of tapering capillaries for focusing X-rays, either as individual capillaries (see the review by Bilderback *et al.*, 1994), or in the form of multicapillary bundles. The latter were first described by Kumakhov & Komarov (1990); since then, they have undergone great improvements in the form of fused bundles (Bly & Gibson, 1996) (Fig. 6.1.4.7). Single capillaries have found the greatest use