So-called *insertion devices* with a zero magnetic field integral, *i.e. wigglers* and *undulators*, may be inserted in the straight sections (Fig. 4.2.1.7). A wiggler consists of one or more dipole magnets with alternating magnetic field directions aligned transverse to the orbit. The critical wavelength can thus be shifted towards shorter values because the bending radius can be made small over a short section, especially when superconducting magnets are used. Such a device is called a *wavelength shifter*. If it has N dipoles, the radiation from the different poles is added to give an N-fold increase in intensity. Wigglers can be horizontal or vertical.

In a wiggler, the maximum divergence 2α of the electron beam is much larger than ψ, the vertical aperture of the radiation cone in the spectral region of interest (Fig. 4.2.1.5). If $2\alpha \ll \psi$ and if, in addition, the magnet poles of a multipole device have a short period λ_0, the device becomes an undulator: interference will take place between the radiation emitted at two points λ_0 apart on the electron trajectory (Fig. 4.2.1.8). The spectrum at an angle φ to the axis observed through a pin-hole will consist of a single spectral line and its harmonics of wavelengths

$$\lambda_i = i^{-1}\lambda_0[(E/mc^2)^{-2} + \alpha^2/2 + \theta^2]/2 \qquad (4.2.1.21)$$

(Hofmann, 1978). Typically, the bandwidth of the lines, $\delta\lambda/\lambda$, will be ~ 0.01 to 0.1 and the photon flux per unit band width from the undulator will be many orders of magnitude greater than that from a bending magnet. Existing undulators have been designed for photon energies below 2 keV; higher energies, because of the relatively weak magnetic fields necessitated by the need to keep λ_0 small [equation (4.2.1.21)], require a high electron energy: undulators with a fundamental wavelength in the neighbourhood of 0.86 Å are planned for the European storage ring (Buras & Tazzari, 1984).

The wavelength spectra for a bending magnet, a wiggler and an undulator for the ESRF, are shown in Fig. 4.2.1.9. A comparison of the spectra from an existing storage ring with the spectrum of a rotating-anode tube is shown in Fig. 4.2.1.10.

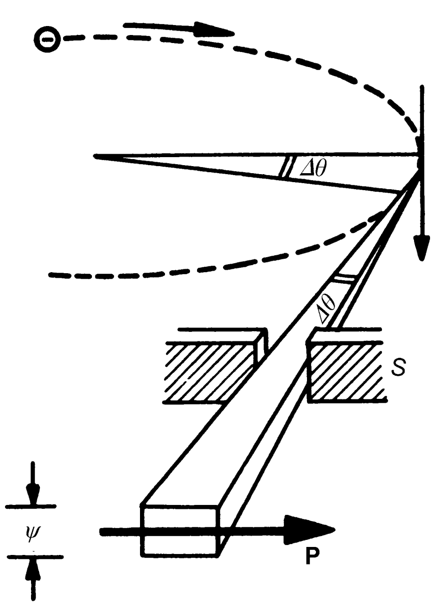

Fig. 4.2.1.5. Synchrotron radiation emitted by a relativistic electron travelling in a curved trajectory. B is the magnetic field perpendicular to the plane of the electron orbit; ψ is the natural opening angle in the vertical plane; P is the direction of polarization. The slit S defines the length of the arc of angle $\Delta\theta$ from which the radiation is taken. From Buras & Tazzari (1984); courtesy of ESRP.

The important properties of synchrotron-radiation sources are:
(1) high intensity;
(2) very broad continuous spectral range;
(3) narrow angular collimation;
(4) small source size;
(5) high degree of polarization;
(6) regularly pulsed time structure;
(7) computability of properties.

Table 4.2.1.6 (after Buras & Tazzari, 1984) compares the most important parameters of the European Synchrotron Radiation Facility (ESRF) with a number of other storage rings. In this table, BM and W signify bending-magnet and wiggler beam lines, respectively, σ_x and σ_z' is the source divergence; the flux is integrated in the vertical plane. The ESRF is seen to have a higher flux than other sources; even more impressive by virtue of the small dimensions of the source size and divergence are its improvements in spectral brightness (defined as the number of photons s^{-1} per unit solid angle per 0.1% bandwidth) and in spectral brilliance (defined as the number of photons s^{-1} per unit solid angle per unit area of the source per 0.1% bandwidth). In comparing different synchrotron-radiation sources with one another and with conventional sources (Fig. 4.2.1.10), the relative quantity for comparison may be flux, brightness or brilliance, depending on the type of diffraction experiment and the type of collimation adopted. Table 4.2.1.7 (due to Farge & Duke, 1979) attempts to compare intensity factors for a number of typical experiments. In general, a high brightness is important in experiments that do not embody focusing elements, such as mirrors or

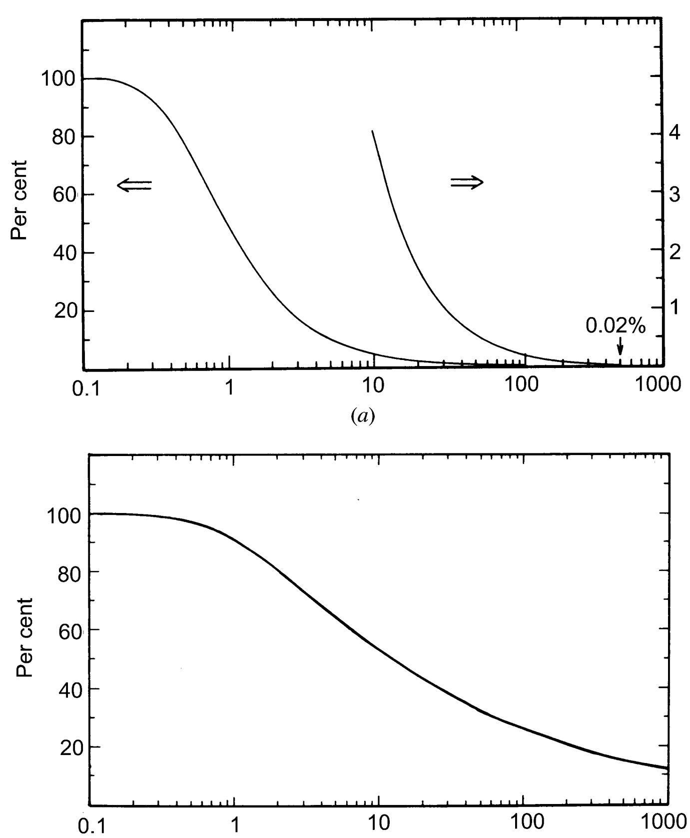

Fig. 4.2.1.6. Synchrotron-radiation spectrum: percentage per unit wavelength interval (a) of power of total power and (b) of number of photons of total number of photons at wavelengths greater than λ *versus* λ/λ_c. Note that half the power but only 9% of the photons are radiated at wavelengths less than λ_c; courtesy of H. Winick.

references