Synchrotron Radiation Primer

Charged particles do not radiate while in uniform motion, but during acceleration a rearrangement of its electric fields is required and this field perturbation, travelling away from the charge at the velocity of light, is what we observe as electromagnetic radiation. Such emission occurs, for example, in a radio or TV antenna where electric charges are periodically driven up and down the antenna at the carrier frequency specific for the station. Free accelerated electrons radiate similarly, although now the source (antenna) is moving. Radiation from a fast moving particle source appears to the observer in the laboratory as being all emitted in the general direction of motion of the particle. Think of tomatoes being thrown in all directions from a fast moving truck. This forward collimation is particularly effective for highly relativistic electrons where most of the radiation is concentrated in a small cone with an opening angle of $1/\gamma$ (some 0.1 to 1 mrad), where γ is the particle energy in units of its rest energy (typically 10^3 - 10^4). In synchrotron radiation sources (**storage rings**) highly relativistic electrons are stored to travel along a circular path for many hours. Radiation is caused by transverse acceleration due to magnetic forces in **bending magnets** (forming the circular path) or periodic acceleration in special **insertion device magnets** like undulators, wiggler magnets and wave length shifters**.** Radiation is **linearly polarized** in the plane of acceleration (in most cases the horizontal plane). **Elliptical** polarization occurs for bending magnet radiation observed from above or below the midplane. The radiation is emitted in pulses of 10 - 20 psec separated by some 2 nsec or longer separation if desired.

undulator: The electron beam is periodically deflected by weak magnetic fields. Similar to antenna radiation the particle emits radiation at the wavelength of its periodic motion in the undulator. To the particle this wavelength is the undulator period length (λ_p) divided by γ due to relativistic Lorentz contraction. In the laboratory system this wavelength appears to the observer further reduced by another factor γ due to the Doppler effect. The undulator period length of the order of cm's is thus reduced by a factor γ^2 (10^6 - 10^8) to yield short wavelength radiation in the VUV and x-ray regime. The spectral resolution of the radiation is proportional to the number of undulator periods and its wavelength can be shifted by variing the magnetic field. Most radiation is emitted within the small angle of $1/\gamma\sqrt{N_p}$.

wiggler magnet: Increasing the magnetic field strength causes the pure sinusoidal transverse motion of electrons in an undulator to become distorted due to relativistic effects generating higher harmonics of the single wavelength undulator radiation. The monochromatic undulator spectrum therefore changes into a line spectrum. For very strong fields many harmonics are generated which eventually merge into a continuous spectrum from IR to hard x-rays. The spectral intensity varies little over a broad wavelength range and drops off exponentially at photon energies higher than the **critical photon energy, $\varepsilon_{crit} \sim B\gamma^2$.** Compared to bending magnet radiation, wiggler radiation is enhanced by the number of magnet poles and is well collimated within an angle of K/γ, or a few mrad.

bending magnet: Radiation is emitted tangentially to the orbit similar to a search light while well collimated in the nondeflecting, or mostly vertical plane. the observer at the experimental stationsees radiation from only a small fraction of the circular path which can be described as a piece of a distorted sinusoidal motion. The radiation spectrum is therefore similar to that of a wiggler magnet while the intensity is due to only one pole. Because the geometry of the storage ring is determined by bending magnets, it is not possible to freely choose the field strength and the critical photon energy is therefore fixed.

wavelength shifter: This magnet consists of a high field central pole and two weaker outside poles to compensate the deflection by the central pole. The field strength can be chosen freely to adjust the critical photon energy and is used in conjunction with superconducting magnet technology particularly in low energy rings to extend the available photon energy to higher value.

storage ring

undulator

bending magnet

wiggler

time structure

~2nsec

time

micro bunch

20-100 psec

$I(1/\lambda_\gamma)$ undulator line spectrum

i=1   i=3 $1/\lambda_\gamma$ i=5

fundamental wavelength:

$\lambda_\gamma = \lambda_p(1+0.5K^2)/2i\gamma^2$,   i:harmonic

$K = 0.934\, B(T)\, \lambda_p(cm)$,

$2/\gamma\sqrt{N_p}$

continuous spectrum for wiggler, bending magnet and wave length shifter:

intensity

ε_{ph}

ε_{crit}

wiggler:

2K/γ