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India's first synchrotron Indus-1

The electromagnetic spectrum spanning a wide range of wavelengths [several km (radio waves) to femtometres (gamma rays)] has been in use for various research investigations and for a variety of other applications. X-ray diffraction to derive information on structures of solids on the atomic scale, infrared absorption and Raman effect to investigate dynamics of atoms and molecules in solids and liquids and gamma ray spectroscopy are some of the examples from research areas.

Beginning with the solar spectrum, followed later on by discharge tubes, X-ray tubes, klystrons, etc., a variety of sources of radiation spanning different wavelength regions of the electromagnetic spectrum have been in use. The development of circular accelerators resulted in a new and intense source of electromagnetic radiation and data of higher precision and better quality have become available.

Among the circular accelerators, there are three types, namely cyclotrons, synchrotrons and storage rings.

The cyclotron is a particle accelerator conceived by Ernest O. Lawrence in 1929, and developed at the University of California in the 1930s. It consists of two large dipole magnets designed to produce a semi-circular region of uniform magnetic field. Two D-shaped large dipole magnets provide a uniform magnetic field. Particles injected into the magnetic field region of a D trace out a semi-circular path until they reach the gap between the two D's. The electric field in the gap then accelerates the particles as they pass across it. Once the synchrotron principle was developed, it was found to be a much cheaper way to achieve high energy particles than the cyclotron.

A synchrotron (sometimes called a synchro-cyclotron) is a circular accelerator which has an electromagnetic resonant cavity (or perhaps a few placed at regular intervals around the ring) to accelerate the particles.

A storage ring is similar to a synchrotron, except that it is designed just to keep the particles circulating at a constant energy for as long as possible.

A synchrotron accelerates charged particles, such as electrons, to speeds close to that of light. A series of magnets is used to bend the path of the electrons into a circular shape. As they pass these 'bending' magnets, the path of the electrons is deflected and they emit intense beams of light, known as synchrotron radiation which is bright and fully tunable over a wide energy spectrum, is highly polarized, and has a time structure (pulses of width typically less than a nanosecond) useful for many types of dynamics experiments. The beam is in the form of a cone at a tangent to the orbit of the electron, rather like a searchlight.

The rapid increase in the brightness of X-ray beams available for research, since the introduction of synchrotron radiation in the 1960s is truly amazing. Compared to the X-ray tubes, the first, second and third generation synchrotrons have moved up in intensity by nearly 5 (in around the year 1975), 8 (1985) and 12 (2000) *orders*, respectively. First-generation synchrotron sources were high-energy physics accelerators, where the synchrotron radiation was an unwanted by-product. In the 1960s, physicists and chemists began to use the radiation from several of these accelerators in a 'parasitic mode'. The second generation of synchrotron radiation facilities, such as the Photon Factory in Japan, were constructed to provide synchrotron X-rays for research. They were designed to exploit the bending magnets. Recently, third-generation facilities were commissioned, for example, the 7 GeV Advanced Photon Source in USA, and provide even higher brightness X-ray beams. The storage rings of these machines are optimized for insertion devices, particularly the undulators. Advances in the creation, compression and transport of bright electron beams make it possible to base the next (fourth) generation of synchrotron radiation sources on linear accelerators rather than on storage rings. These sources are expected to produce radiation, orders of magnitude greater in peak power and peak brightness than the present third-generation sources. One should note that this categorization is not strictly demarcating but allows some blurring among these categories.

There are nearly 50 synchrotron facilities around the world, being used for a variety of research applications. The Synchrotron Radiation Source (SRS) at Daresbury was the world's first machine dedicated to the production and use of synchrotron radiation and the first user experiments were conducted in the early 1980s. Currently, worldwide a large number of particle accelerators/storage rings are dedicated to basic and applied research using synchrotron X-rays. Some of them are: LURE (Orsay), BESSY (Berlin), HASYLAB (Hamburg), SRS (Daresbury), Elettra (Trieste), SLS (PSI, Villigen, Switzerland), ALS (Berkeley, CA), APS (Argonne, IL), NSLS (Upton, NY), Photon Factory (Tsukuba) and SPring-8 (Nishi Harima).

Synchrotron radiation allows one to study the material properties using diffraction, spectroscopic and imaging techniques. The structure of powders, single crystals, surfaces, and various synthetic multilayers are determined using X-ray diffraction. Chemical and near-neighbour information is obtained from X-ray absorption spectroscopy, and the electronic structure is probed using angle-resolved and spin-polarized photoemission and various core-level spectroscopies. Imaging techniques include X-ray topography, X-ray microtomography, scanning X-ray microscopy and infrared spectromicroscopy. There are a number of other applications related to medicine, geology, industry, etc.

The special section 'Indus-1 Synchrotron' deals with the design, development, operation and utilization of India's first synchrotron at Indore. The prefatory article by D. D. Bhawalkar (**page 279**) provides a historical perspective of development of accelerators in India. Indus-1 synchrotron became operational in early 1999 and is currently being used by several user groups. Indus-2, the second synchrotron to provide radiation in the hard X-ray region is expected to begin operation by late 2003. The article by D. Angal-Kalinin *et al.* (**page 283**) deals with details of the accelerator and its subsystems. In addition, it goes into the commissioning exercise. R. V. Nandedkar (**page 291**) gives a 'brief description of characteristics of Indus-1 source and the description of the various beamlines and their status'. The first results in the reflectometry beamline on Indus-1 are reported in the article (**page 298**) by R. V. Nandedkar *et al.* S. M. Chaudhari *et al.* (**page 305**) describe the photoelectron spectroscopy beamline and the results of measurements on a series of standard samples are presented.

As Bhawalkar has stated, '(in Western countries) many manufacturers of integrated circuits or MEMS have their own synchrotron radiation sources, either for production line use or for development of new products or for research'. He has also noted: 'For effective use of Indus-1 and Indus-2, the number of scientists using them has to increase greatly. This can happen only when scientists become aware of the enormous potential of Indus-1 and Indus-2. The series of articles . . . is a beginning in this direction.'

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