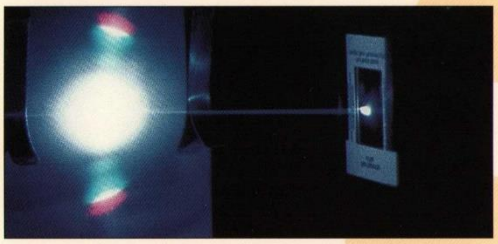
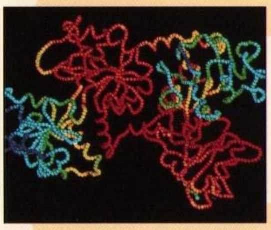
THE Brilliance OF X-RAYS

ATOMS

What is Synchrotron Light?

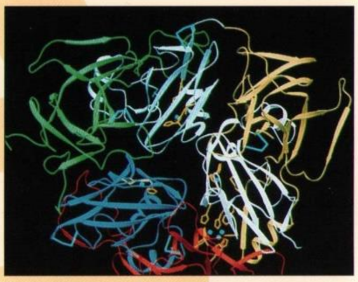


Synchrotron light is produced at the Synchrotron Radiation Source when an electron beam travelling close to the speed of light is accelerated in a magnetic field. The light covers a broad area of the electromagnetic spectrum, from infrared through to hard X-rays. Synchrotron X-rays are much more intense than those from a conventional laboratory source, enabling researchers to carry out experiments in a very short time – perhaps on samples which are rapidly changing, such as vigorous chemical reactions. Very dilute samples can also be studied easily. The light from the SRS has other important properties making it different to ordinary light; it comes in regular pulses, allowing data to be collected like a movie on samples which vary with time. The light is also very highly polarised, linearly in the centre of the beam and circularly above and below centre.



Crystallising proteins

Techniques based on synchrotron light are used to study a wide range of biological specimens. Many proteins, enzymes and viruses can be crystallised; diffraction of X-rays by the regular crystal structure allows the atomic structure to be solved in great detail. One of the biggest virus structures solved to date, known as SV40, was determined at the SRS using these techniques. More recently researchers have solved the structure of a light harvesting complex from a photosynthetic bacteria, helping explain the mechanisms of photosynthesis. The structures of a number of important bodily proteins have also been determined in this way, including human cerulo-plasmin – a blue coloured protein thought to be involved in the release of iron from cells – and F1-ATPase – an enzyme essential to cellular energy conversion.



Non-crystalline materials

Many biological materials are non-crystalline and different techniques are used to study them. Research on the SRS is helping scientists understand how muscle works at the atomic level and how changes in the molecular

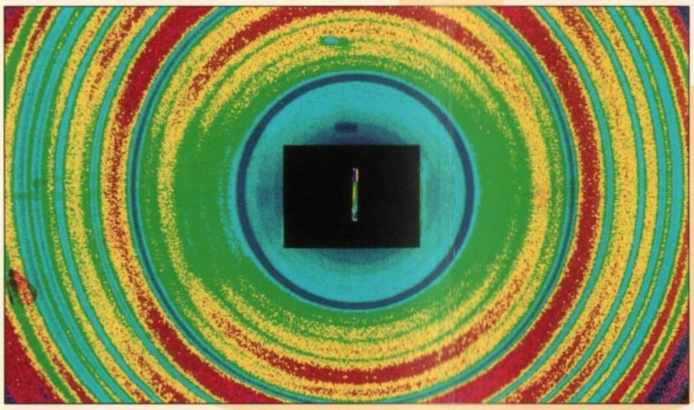
arrangement of optical tissues – lenses and corneas – leads to cataracts and other visual impairments. X-ray absorption techniques have recently confirmed the way in which iron is stored in the brain. This research may throw a new light onto Parkinson's and other degenerative diseases, as Parkinson's sufferers are known to have an increased iron content in the brain tissue. Common materials like polymers and foodstuffs can also be studied in detail, helping us understand how manufacturing processes can influence the properties or texture of the final product.

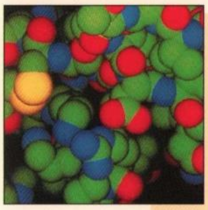
Catalysts and Chemistry

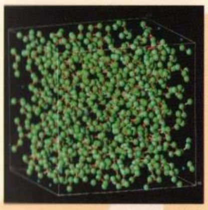
Researchers use the SRS to look at important chemical reactions at the atomic level. Many industrial chemical processes rely heavily on

catalysts. By understanding how these catalysts work, scientists can design new, more effective compounds that will be of great benefit to industry. The first ever measurements of a solid catalysing a liquid reaction were made at the SRS. These studies of a complex hollow centred or 'mesoporous' catalyst used in the epoxidation of cyclohexane are helping to explain reactions which are of vital importance to the petrochemical and pharmaceutical industries.

The SRS is an intense source of ultraviolet light, making it a perfect tool for the study of many processes in the upper atmosphere which are affected by UV from the sun. For instance, pollutant molecules can break down forming chlorine atoms which in turn react with, and destroy,





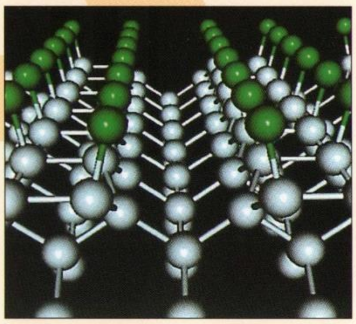


ozone. Work at the SRS is helping scientists understand the atomic processes involved in these reactions.

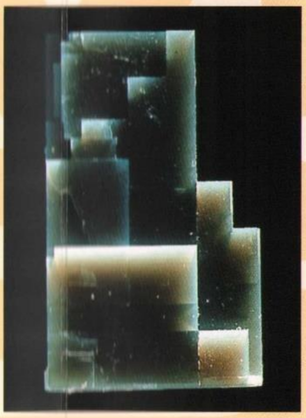
Studying Surfaces

Many important processes and reactions occur at the surfaces of materials and researchers use the SRS to study many different types of surface phenomena. Catalytic converters work because the special surface of the material inside the converter 'cleans up' the exhaust fumes, turning toxic carbon monoxide and oxides of nitrogen into harmless, naturally occurring water, nitrogen and carbon dioxide.

Inside every television set, microwave oven and radar set is a device called a thermionic cathode.



This gives off a beam of electrons which can be focused or steered helping to give, for example, the picture on a TV screen. Most cathodes are made from tungsten, coated in barium and oxygen, and the efficiency of their electron emission is highly dependent on the barium and oxygen coating. Experiments at the SRS have shown that the best arrangement is when barium atoms are on top of oxygen atoms, which themselves are in hollows on the tungsten surface. These results help explain why some cathodes work better than others and point the way toward making better devices in the future.



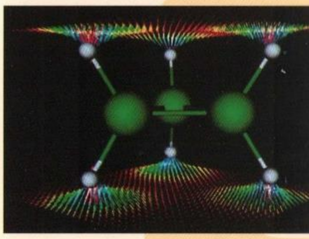
Looking at Materials

Our modern lifestyles depend very much on the huge variety of materials at our disposal. To understand the behaviour of these materials we need to examine them at the atomic level, using advanced experimental facilities. Everyday materials like polymers, cements, glasses and even chocolate have been under scrutiny at the SRS. The best results are often gained by studying materials under conditions that are similar to their 'real life'. To help do this special equipment is often installed on the SRS, such as a miniature injection moulding device for the study of plastics, and a giant press which will simulate conditions of

temperature and pressure many miles below the Earth's surface, helping us understand how atoms bind together when minerals are formed deep underground.

Magnetic Materials

With the advent of personal computers, high density data storage is becoming more and more important. Magnetic recording media have been used for many years but the amount of data that can be stored in this way is rapidly reaching its upper limit. Magneto-optic films offer an alternative type of data storage. Researchers on the SRS are investigating the properties of these materials using circularly polarised X-rays. Their findings may help us reach the data storage goal of 10 megabytes per square inch of film.

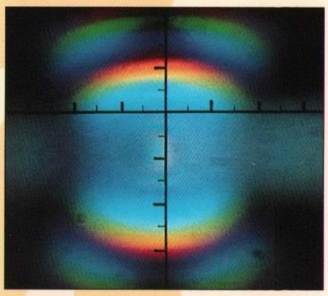


Sources of Synchrotron Light

Dipoles and Undulators

There are several different types of synchrotron light source at the SRS. The sixteen dipole magnets keeping the electron beam on its circular path all produce a broad spectrum of wavelengths, with the most intense output in the soft X-ray region – a wavelength of about 4×10^{-10}m.

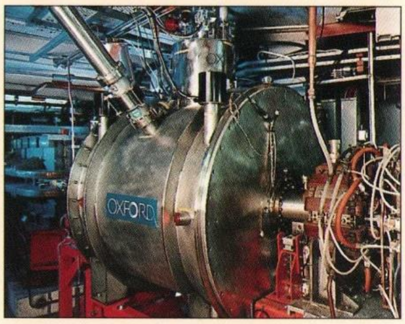
There are also two special types of magnets, the so-called 'insertion devices' placed between the dipoles. The first of these is known as an 'undulator' magnet. The undulator is formed from a periodic array of permanent magnets, that are arranged to gently wave the electron beam in a sine-like path through the magnet's length. Synchrotron light results from each undulation, and constructive interference between these emissions gives a very bright and narrow light beam.



Sources of Synchrotron Light

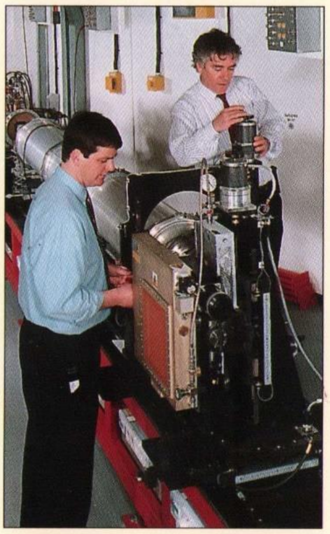
Superconducting Magnets

The second type of insertion device is a 'wiggler' magnet or 'wavelength shifter', so called because it shifts the most intense output further into the shorter or 'hard' X-ray region. There are two such magnets in the SRS. The wigglers are superconducting magnets; electromagnets formed from coils having no electrical resistance, and therefore generating extremely high magnetic fields. The high fields cause the stored electron beam to effectively take a 'hairpin bend', a huge acceleration generating very short wavelength light. The magnets are bathed in liquid helium at a temperature of -269°C to keep them superconducting.

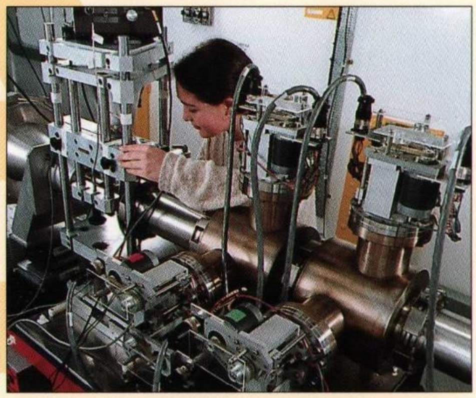


On the Beamlines

Synchrotron light is carried from its source in the storage ring to the experimental areas through high vacuum beam lines. Most of the X-ray beamlines contain focusing optics to concentrate the synchrotron light at the sample – mirrors are used to do this, as X-rays will pass straight through conventional lenses. Often the optics are cooled internally, enabling them to cope with the enormous heat loading of the bright light source without

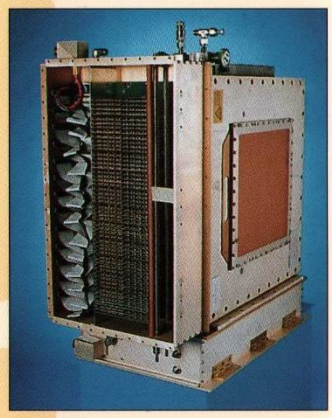


distorting. Some of the experiments use so-called 'white' beam – a broad spectrum of wavelengths – whereas others require single wavelength or 'monochromatic' beam which is isolated by a device known as a monochromator. The beam lines are kept under high vacuum so that the highly polished surfaces of the mirrors inside are not contaminated.



Collecting the Data

The interaction of the synchrotron light beam with an experimental sample must be recorded in some way so it can be fully analysed, giving information about the innermost structure of the sample. Many sorts of specially built detectors are used to measure the results of the experiments, be it X-



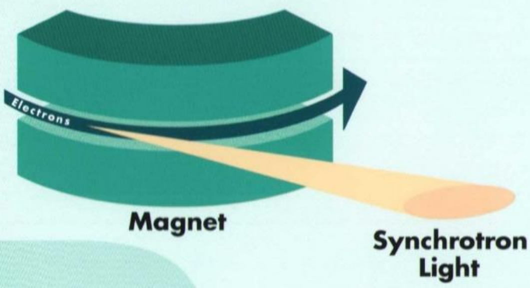
ray scattering, diffraction, absorption and fluorescence or reflection. Data collection can often be carried out remotely for many hours at a time through fast computerised detectors. Advanced computing facilities also help in the analysis of measurements and, using databases of known materials, researchers can compare their results with proteins or molecules whose detailed structures have already been solved.

The Synchrotron Radiation Source

The Synchrotron Radiation Source (SRS) at Daresbury Laboratory was the world's first dedicated source of synchrotron light. It runs 24 hours a day, providing intense beams of light spanning infrared through to hard X-rays. Over 2000 researchers use the SRS every year, performing experiments that increase our understanding in many areas of materials science, biology, chemistry and physics.

How is Synchrotron Light Produced?

When a charged particle travelling close to the speed of light is accelerated, it emits the broad spectrum of photons known as synchrotron light. At the SRS a beam of electrons is accelerated when it passes through a magnetic field, changing its path. The field is produced by sixteen huge



'dipole' electromagnets which constrain the beam to a roughly circular path 96 m around. Synchrotron light is emitted from all of these magnets and collected from 12 of them to feed experiments and test facilities. The light emerges like a searchlight in front of the emitting particle so it appears at a tangent to the bend. Three special magnets known as 'insertion devices' also produce light at the SRS.

The type of light produced at sources like the SRS depends on both the energy of the electron beam and the magnetic fields used to bend the beam. The higher the beam energy, the shorter the wavelength of the light produced. Strong magnetic fields will bend the beam more sharply – a greater acceleration which also gives shorter wavelength light.

The electron beam loses a great deal of energy emitting synchrotron light. To replace this energy, the electron beam bunches are 'pushed along' by radio frequency or 'RF' waves, like children on a roundabout kept turning by an adult. The RF is fed into the electron beam in four places as the beam travels around the SRS. This way the same electron beam can emit synchrotron light continuously for many hours.

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