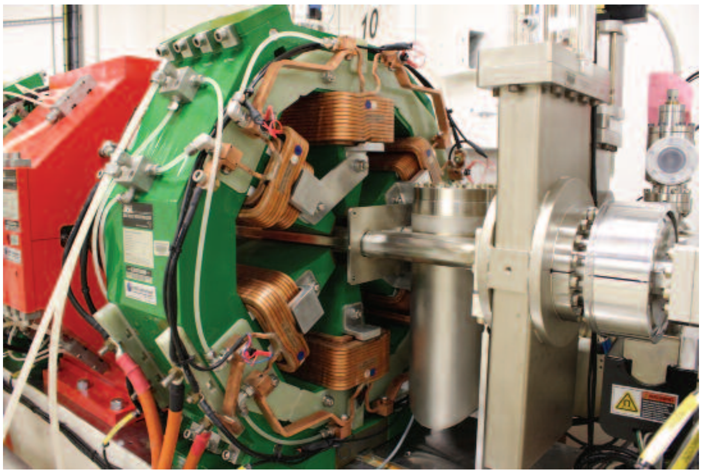
Looking on the Bright Side

Once an unwanted by-product of particle accelerators, synchrotron light now underpins many cutting-edge analytical techniques in scientific research. How is it actually produced?



The Australian Synchrotron uses powerful magnets and an electron beam the width of a human hair to create highly intense light for scientific research.

If you take a bunch of high-speed electrons and apply a powerful magnetic field to make them move in a curve rather than a straight line, they will give off extremely intense light known as synchrotron light. It's a natural phenomenon we can observe in interstellar space, but this bright light can also be made on Earth.

The kind of light produced depends on how fast the electrons are travelling. Electrons going around a bend at half the speed of light might produce visible light; at closer to the speed of light they might produce X-rays. Visible light and X-rays are both electromagnetic radiation, but X-rays have much higher energy levels.

In a particle accelerator, subatomic particles such as electrons and protons are accelerated to very high speeds, enabling physicists to probe the small-scale nature of matter and its interactions. As the early linear accelerators gradually gave way to more efficient circular accelerators where particles could be 'stored', the accelerators began to produce noticeable quantities of synchrotron radiation. Initially this was a nuisance, because electrons lose energy when they emit synchrotron light, but eventually researchers realised the potential value of this brilliant light source, which is now used for a multitude of scientific research purposes.

Like its counterparts around the world, the Australian Synchrotron is specifically designed to generate synchrotron light of high brilliance. Electrons are fired from an electron gun, fed through a linear accelerator and coaxed into a circular path. They are then injected into a ring-shaped vacuum chamber called a storage ring, where each bunch of approximately 10 billion electrons will travel the equivalent of 26 billion kilometres in 24 hours while the light they produce is siphoned off for experiments.

A complication is the need to allow for the effects of relativity: electrons become heavier as they approach the speed of light and require stronger magnetic fields to maintain their path.

In addition to carrying out the essential tasks involved in generating synchrotron light for use in a wide variety of experiments, the Australian Synchrotron's physicists have their own research programs.

Accelerator physicist Eugene Tan is reducing the length of the electron bunches that circulate in the storage ring about 60 cm apart. His aim is to produce coherent light in the far-infrared region, expanding the range of infrared frequencies available for analysis of gas-phase materials such as greenhouse-active gases.

To make coherent light, the length of the electron bunches must be comparable to the wavelength of the light that is required, in this case a few millimetres or one-tenth of the synchrotron's nominal bunch length. Bunch length depends on the individual energy spread of electrons in the bunch and the settings of the storage ring magnets.

Tan's colleague, Rohan Dowd, is using special "skew" magnets to shrink the electron beam, currently around 140 µm wide (slightly thicker than a human hair) and 10 µm high. Preliminary results indicate that the precise alignment of magnets in the Australian Synchrotron, and the physicists' fine control of the relationship between the vertical and horizontal motion of the electron beam, have created one of the world's smallest electron beams – just 1 µm high.

Narrow electron beams like this are required for the next generation of particle colliders being developed around the world. Dowd's work has also made it possible to extend the life of the stored electron beam and thus improve the stability of the synchrotron light generated at the Australian Synchrotron.

The design and development of the next generation of light sources is well underway internationally. The latest hot topic is free electron lasers – linear accelerators that send the electron beam down specialised arrays of magnets to produce coherent light ranging from infrared to hard X-rays. X-ray-free electron lasers could potentially yield three-dimensional "snapshot" images of single molecules without the need to fix them into a crystalline structure, a revolutionary advance in structure determination.

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