Diamond light, brighter than the sun

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The Diamond Light source building at dusk. Credit: Diamond Light Source.

It's the size of five football pitches and generates light 10 billion times brighter than the sun. As the Diamond Light Source celebrates its tenth anniversary this year, Penny Bailey visits one of the UK's biggest scientific investments to see how it works.

Imagine that the only thing limiting you is your imagination - that the physical means of achieving what you see in your mind's eye is right in front of you. That, according to Professor Mark Hodson, is how it is for scientists at the Diamond synchrotron in Oxfordshire. With its curving walls, lined with walkways, pipes and colourful, clunky-looking machines and gadgets, it's a sight that wouldn't seem out of place in an early episode of 'Doctor Who'.

From a birds-eye view, Diamond looks like a massive ring doughnut or a spaceship half a kilometre in circumference (roughly the size of five football pitches). In fact, it's a polygon of 24 straight sides, and its size and shape are dictated by its purpose.

As the name suggests, Diamond is a source of intensely bright light, which can be up to 10 billion times brighter than the sun. And it's not just visible light - Diamond is optimised to produce light with much shorter wavelengths in the form of X-rays and also generates infrared and ultraviolet light invisible to the naked human eye.

Researchers go to the synchrotron to use that brilliantly intense light in much the same way as they use visible light in a microscope or X-rays: to reveal things we can't see. Microscopes work by passing visible (optical) light through an object. The refracted light passes through two lenses that focus it to create an image of the object's microscopic structures, then magnify the image so we can see it. An X-ray machine passes X-rays through an object and captures the image created of its internal tissues on negative film. X-rays reveal the internal composition (tissues) of large objects such as people, and microscopes reveal the innards of tiny objects such as cells that are only a few microns (0.001 mm) in size, too small to be visible to the naked human eye.

The Diamond synchrotron is millions of times bigger than an X-ray machine or a microscope, yet the light it generates enables scientists to see the internal structures of things that are infinitely smaller, such as atoms. Atoms are measured in angstroms: one angstrom (1 Å) is 0.1 of a nanometre (nm), which in turn is one-billionth of a metre. To give you some context, a human hair is 100 000 nm wide and an ant is approximately 5 million nm long.

In trying to look inside an atom, scientists are trying to visualize something that is only 0.1 billionth of a metre big. To distinguish two objects (atoms) that are only 1 Å apart, researchers need to pass a much more intense light through them. They need to use light with far shorter wavelengths than the visible light used in microscopes - either ultraviolet light or X-rays. It's the job of Diamond to produce that light and send it to the 'cabins', the laboratories surrounding the storage ring where the experiments are actually carried out.

Acceleration

How does Diamond create those intense, invisible forms of light? Like CERN in Switzerland, Diamond is a particle accelerator, and it uses very similar technology. Both, as the term suggests, are designed to get particles zipping along at great speed. CERN sends neutrons and protons smashing into each other at speeds approaching the speed of light to understand what particles - and the universe - are made of. Diamond, by contrast, accelerates electrons. It also doesn't smash them into each other, and scientists don't actually do any experiments with the electrons themselves; instead, they use the high speed of the electrons to create intense light to use in their experiments.

The way the electrons are produced in the first place will be familiar to anyone who's ever owned a big, old-fashioned TV. The cathode ray tube in the back of the TV heats up an alloy, causing it to release electrons and fire them at the TV screen, which fluoresces, producing images. Diamond works on a similar principle, although on a much vaster scale.

The bridge over the storage ring of the facility. Credit: Diamond Light Source.

Rather than a screen, the electrons generated by heating an alloy in an electron gun are fired into a sequence of three accelerators. The first is the 30-m long Linac, which increases the speed of electrons from almost no miles per hour to something approaching the speed of light. They then pass into the booster, where they gain energy until they have enough to produce light of the kind and quantity needed to illuminate the atoms the scientists are looking at.

They then pass into the storage ring - the vast 560 m2 tube that gives Diamond its shape and size. It is here that the electron bundles (beams), which travel around the ring roughly half a million times every second, generate synchrotron light and send it into the beamlines leading to the experimental stations (laboratories) surrounding the storage ring.

Magnets at the point of entry to the beamlines bend the speeding electrons around the corners of the polygonal storage ring, which causes them to release energy in the form of light (photons). This light spans the electromagnetic spectrum from infrared to visible and ultraviolet light and X-rays.

Diamond is a 'third-generation' synchrotron, which broadly means that it uses more sophisticated magnets to create more intense light. At the beamline point of entry, 'insertion devices' cause the electron beam to wiggle backwards and forwards between the opposite magnetic poles. This 'constructive interference' produces very bright, very intense beams of X-rays - so intense that safety procedures are stringent. People cannot enter the lead-lined hutches in which the experiments take place when the machine is operating, so experiments are controlled remotely from a separate control cabin.

The power of these X-rays can help reveal the atomic structure of proteins and inorganic elements like metals. Mirrors and crystals help focus the beams down to the wavelength required for each station, which then passes into the experimental hutch where it interacts with the substance the scientists want to 'see', the interaction revealing what it is made of at the atomic level.

Around 2000 research groups a year come to do experiments at Diamond that they could not do anywhere else. Research ranges from solving protein structures to designing drug targets.

Scientists have used the synchrotron's light to look at the nutritional quality of wheat, assess the success of attempts to increase levels of zinc and iron in food, and work out which form of phosphate is best at locking up metal contaminants in soil. iPod and iPad users might be interested to know that the technology on which they are based - giant magneto resistance - wouldn't exist without synchrotrons. With new beamlines coming online in the forthcoming third phase of Diamond's development, new possibilities for research abound to push the limits of scientists' imaginations.

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