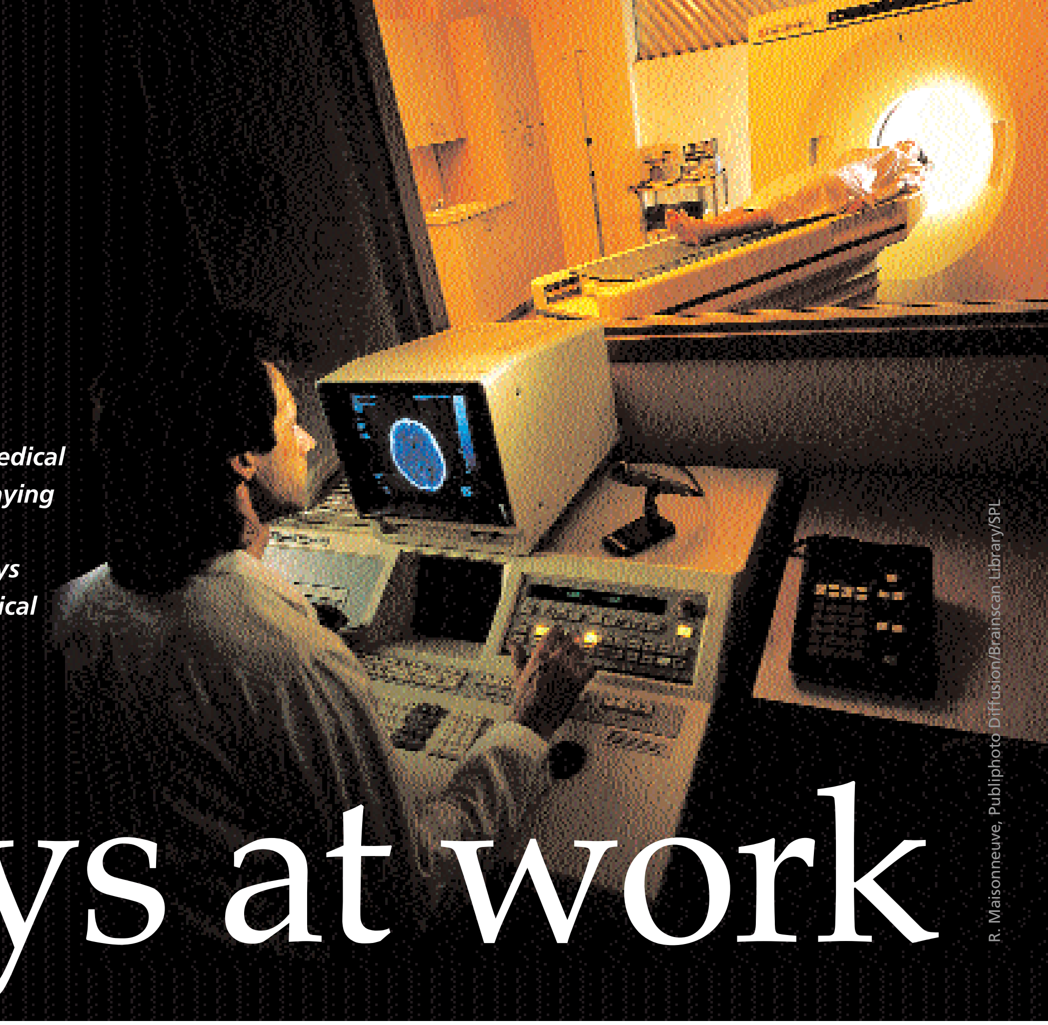
DAVID SANG

Have you ever been X-rayed? The medical profession does its best to avoid X-raying young people, but sometimes the benefits outweigh the hazards. X-rays have many uses other than this medical one, and they played a major part in discovering the structure of DNA.

X-rays at work



R. Maisonneuve, Publiphoto Diffusion/Brainscan Library/SPL

Above: *A CT scanner is a sophisticated X-ray machine. The source travels round the patient, producing images from different angles which are combined to form a three-dimensional view. CT stands for computed tomography ('slice-drawing'). Magnetic resonance imaging (MRI) uses radio waves instead of X-rays*

X-rays were discovered over 100 years ago by Wilhelm Röntgen. German-born, he was a professor of physics at the University of Würzburg, and that's where he made his big discovery. He was carrying out experiments using a cathode ray tube — an evacuated glass tube, rather like a television tube. It contains two metal electrodes which are connected to the positive and negative terminals of a high-voltage supply.

Switch on the supply, and a small current flows between the electrodes. Electrons escape from the cathode and are attracted to the anode. The space between the electrodes glows with light. This is because the vacuum in the tube is not perfect; it contains air at low pressure. Put a different gas in the tube and it glows a different colour.

STRANGE RAYS

On 8 November 1895, Röntgen was working with a cathode ray tube covered in light-tight black paper when he noticed something strange. Nearby was a screen coated with fluorescent paint, the sort of screen that is used for showing up invisible ultraviolet radiation. When Röntgen switched on his vacuum tube, the screen glowed. Some rays — some type of radiation — must be passing through the black paper and reaching the screen.

Röntgen soon established that the rays from his tube could pass through a wooden plank and even through metal sheets. And when he put his hand in the path of the rays, he noted that, 'flesh is very transparent, while bones are fairly opaque.' Röntgen could scarcely believe his results, but after weeks of concentrated work, he was able to publish three

BOX 1 MAKING X-RAYS

In any X-ray tube (Figure 1) there are two electrodes. A beam of electrons is produced by the **cathode**; the electrons crash into the metal **anode**, and their kinetic energy is transformed into X-rays.

The bigger the voltage between the two electrodes, the more the electrons are accelerated and the faster they are moving when they hit the cathode. High voltages produce high-energy, short-wavelength X-rays.

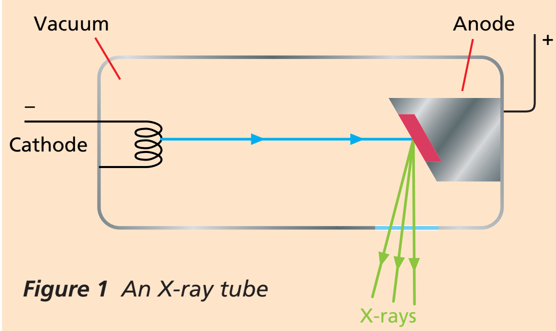
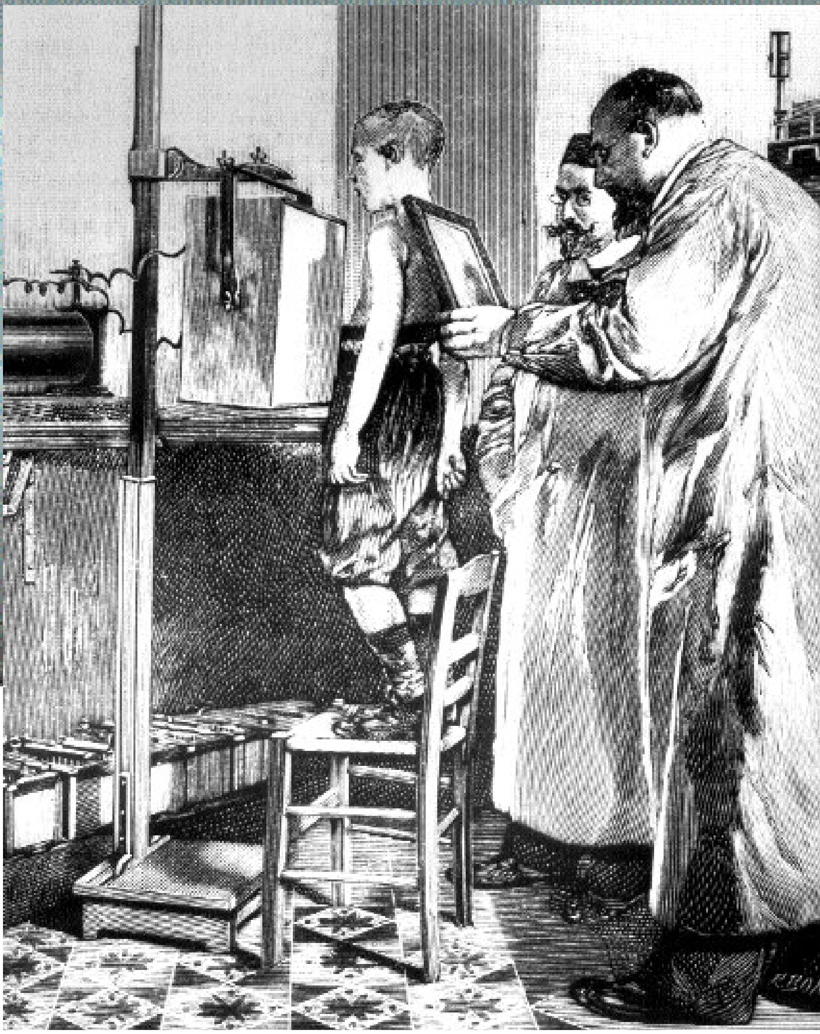


Figure 1 *An X-ray tube*

GCSE key words
X-ray
DNA
Ionising radiation
Electromagnetic spectrum



Topham/Keystone

Above: *Few safety precautions were taken by early users of X-rays*

So that he could devote more time to his studies, Röntgen had his bed moved into the laboratory, and his wife Bertha brought him his meals there.

papers outlining his discovery. He called his invisible radiation X-rays, because X stands for the unknown.

GOING PUBLIC

Wilhelm Röntgen's discovery caused a sensation. X-ray tubes were manufactured in large quantities, and many were sold to 'hobby scientists' to use at home. Public lectures and demonstrations were widely performed, and members of the public could volunteer to have themselves X-rayed in front of an audience. Röntgen himself shied away from this type of activity and gave only one public lecture.

X-rays found an immediate use in medicine, for examining fractured bones before operations. The rays pass through some materials more readily than others. We say that flesh transmits X-rays more readily than bone; bone is an absorber of X-rays. The thicker the bone, the more the X-rays are absorbed.

Wilhelm Röntgen

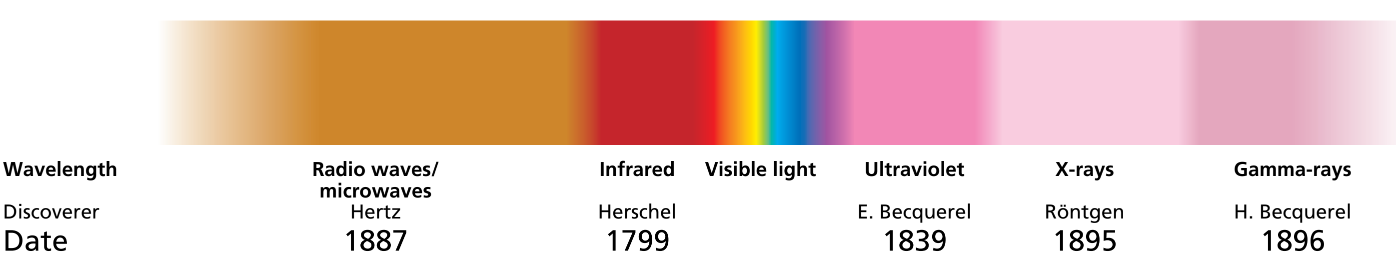
SPL

BOX 2 EXTENDING THE SPECTRUM

By the middle of the nineteenth century, scientists knew that the spectrum of light could be extended at either end to include two other radiations invisible to our eyes: infrared, which can be detected by its heating effect, and ultraviolet, detected using photographic film or a fluorescent screen (Figure 2). Wilhelm Röntgen's discovery of X-rays extended the spectrum further still.

Light, infrared, ultraviolet and X-rays are all types of electromagnetic radiation, and they all travel at the same speed through empty space. Beyond the ultraviolet region of the spectrum lie X-rays and gamma rays. X-rays travel as waves with a shorter wavelength than ultraviolet, while gamma rays (from radioactive substances) have even shorter wavelengths.

Figure 2 *Extending the electromagnetic spectrum*



BOX 3 INSIDE CRYSTALS

In the early 1950s, Rosalind Franklin used X-rays to try to discover the structure of DNA. We can think of X-rays as waves with wavelengths similar to the size of atoms. This means that a beam of X-rays will be diffracted (spread out) a lot when it passes between atoms.

In a crystal, atoms or molecules are regularly spaced. They make an excellent arrangement for diffracting X-rays. What happens is this: a narrow beam of X-rays is directed at a crystal. As the rays pass between pairs of atoms, they spread out — that's **diffraction** (Figure 3). In certain directions, neighbouring waves are in step and reinforce each other (constructive interference). In other directions, they are out of step and cancel each other out (destructive interference). Strong beams of X-rays emerge in particular directions, and are detected, appearing as spots on a photographic film.

This is the basis of **X-ray crystallography**. If the atoms are close together, the spots on the film are further apart, so the spacing of the atoms can be found (Figure 4). In addition, different arrangements of atoms give different patterns of spots.

Rosalind Franklin was lucky. DNA molecules are large and difficult to crystallise, and they tend to break up when exposed to energetic X-rays. She was able to make fibres of DNA which proved to be robust enough to give clear X-ray photographs. She showed that DNA had a spiral structure and she was able to work out the length of each turn of the helix.

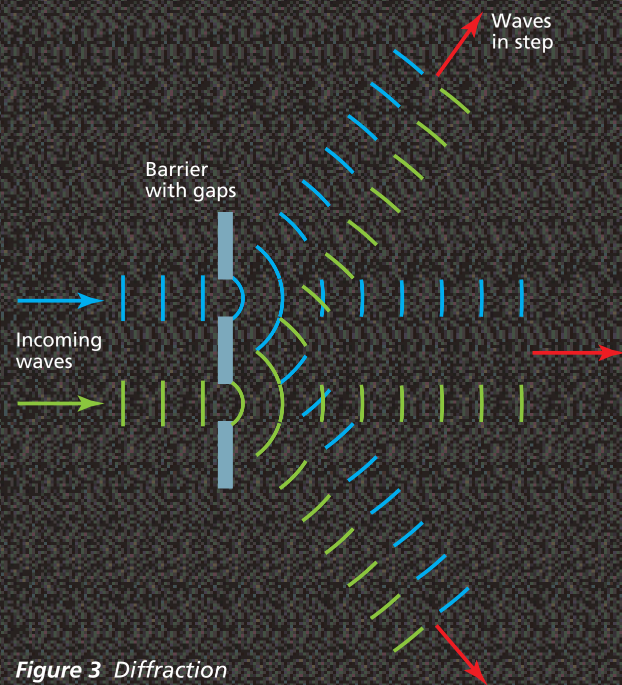
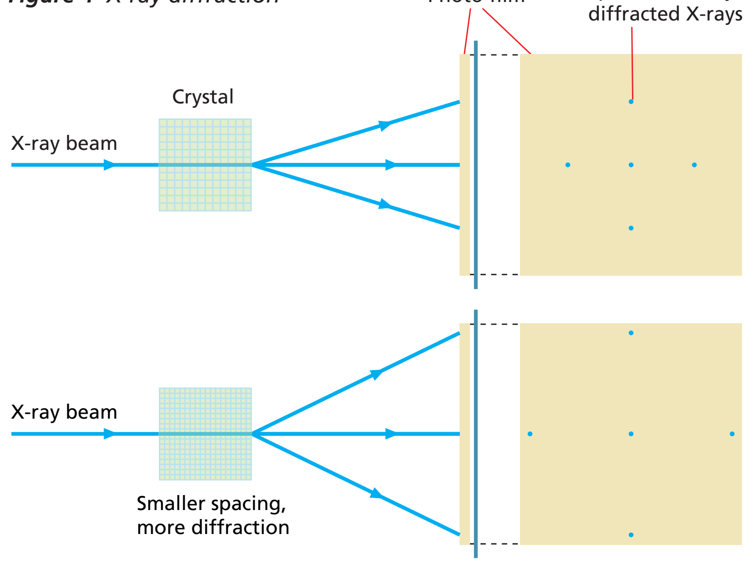


Figure 3 *Diffraction*

Figure 4 *X-ray diffraction*



X-RAY HAZARDS

The hazards of X-rays were not recognised soon enough. Medical staff regularly exposed their own hands to X-rays, to judge the length of time needed to get a good image. They often suffered reddening and even burns, but they never imagined the further harm they might be doing themselves.

X-rays (like gamma and ultraviolet rays) are a type of ionising radiation; that is, a ray may strike a molecule and cause it to become ionised. An electron may be knocked from the molecule, so that it becomes a positive ion; or the molecule may be split into two parts, one positive and the other negative. This can cause a **mutation**, a change in the inherited material, DNA.

If DNA is mutated, it may code for faulty proteins, including faulty enzymes. The mechanisms controlling a cell's normal development and division may be damaged and the result can be cancer. Early radiologists had an increased risk of leukaemia and skin cancer; many had to have fingers amputated.

Today, conditions for the use of X-rays are much more controlled. The dentist retreats to a safe distance when X-raying your teeth. In hospitals, technicians work behind lead-lined screens. The use of intensifying screens and electronic detectors also means that much lower doses of X-rays can be used.

Doctors try to avoid X-raying young people whose cells are developing and more vulnerable to damage. For elderly people, the situation is different. An X-ray may quickly reveal a problem without the need for invasive surgery. The risk to an older person is smaller, as they are less likely to live long enough for a cancer to develop. This is an interesting example of how benefits and costs can be balanced. It can be done only because we know about the possible consequences of exposing different tissues to different doses of X-rays.

David Sang writes textbooks and is an editor of CATALYST.

Röntgen was lucky. He avoided the hazards of X-rays. He designed a metal darkroom in which he worked; his X-ray tube was outside, and the X-rays entered through a small hole. The metal walls protected him. He died aged 78 in 1923.