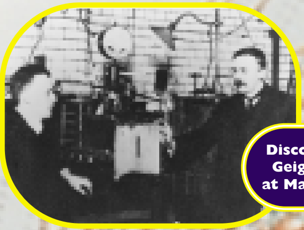
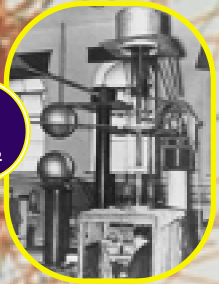
what is a particle accelerator?



Discovering the nucleus: Geiger and Rutherford at Manchester University



The Cockcroft-Walton machine produced the first artificial nuclear disintegrations in 1932

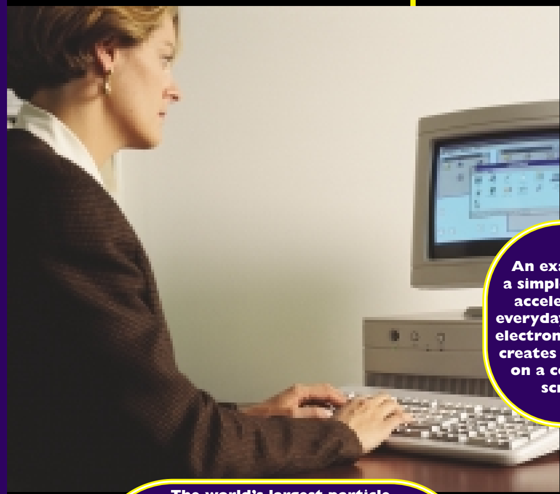
The first circular accelerator, built at Berkeley, California, in 1930 by Ernest Lawrence and Stanley Livingstone

Particle accelerators are machines that produce high-energy beams of subatomic particles for many purposes – from medical diagnosis and industrial processing, to research about the origins of the Universe. They come in many shapes and sizes, from less than a metre to many kilometres in length. You may not realise it, but you probably have a particle accelerator in your home! Televisions and computer monitors are all small accelerators.

The first accelerators were cathode-ray tubes. These are glass tubes with most of the air pumped out and fitted with a negative electrode (cathode) at one end and a positive electrode (anode) at the other. When a few hundred volts are applied between the electrodes, energetic rays cause a glowing spot to appear where they strike the glass vessel. In 1897, J J Thomson, in Cambridge, discovered that the rays consist of electrons – tiny particles of matter. Today, cathode-ray tubes form the basis of televisions and computer monitors, as well as screens for radar, cash dispensers and other applications.

A decade after Thomson, Ernest Rutherford, in Manchester, fired naturally occurring particles at materials to investigate the nature of their atoms. Using alpha particles emitted by the radioactive element radium he discovered the atomic nucleus – a tiny concentration of positive charge at the heart of the atom. He realised that to probe further, to penetrate inside the nucleus, he needed higher energy particles than radioactive materials can supply. His call for higher energies inspired the invention of the first high-energy particle accelerators.

how do particle accelerators work?



An example of a simple particle accelerator in everyday use – the electron tube that creates the image on a computer screen.

The world's largest particle accelerator was LEP in CERN, the European Laboratory for Particle Physics, near Geneva, beneath the border between France and Switzerland. British scientists were members of many of the teams that used this accelerator between 1989 and 2000 to explore the nature and origins of matter.

Modern particle accelerators work with a variety of particle beams. By far the most common, however, are those that work with electrons or protons (the positively charged particles in atomic nuclei).

To accelerate a subatomic particle you need to give it energy. This is easiest with an electrically charged particle, because you can use an electric field to give it energy. In a cathode-ray tube the voltage between the cathode and the anode sets up an electric field. Electrons, which are negatively charged, 'boil off' the cathode and are attracted to the positive anode. The attractive force they feel accelerates them as they travel towards the anode. The higher the voltage, the more energy the electrons gain.

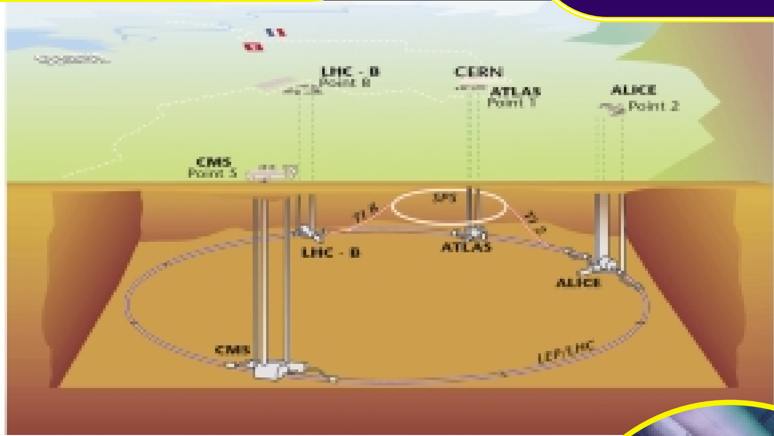
The energy an electron gains from 1 volt is called an 'electron volt' (eV). This is a very small amount of energy. In a television, the electrons gain an energy of about 10,000 eV, or 10 keV (kilo-electron volts) – a small amount of energy in everyday terms, but enough for the electrons to make bright spots when they hit the screen.

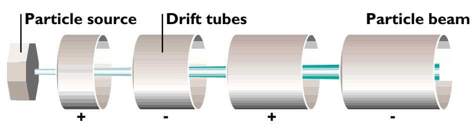
It might seem that to reach higher energies you need higher voltages, but this becomes difficult because high voltages like to make sparks! Instead, the accelerator pioneers discovered ways to reach a high energy by using a relatively low voltage again and again.

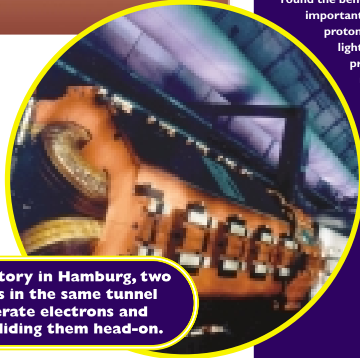
One way to do this is to repeat the voltage many times in a line, so that as the particle beam moves down the line its energy becomes higher and higher. This is the basis of the linear accelerator or 'linac'. Another technique is to use a magnetic field to bend the particle beam in a circle, so that it passes many times through the same electric field. The energy of the beam then increases on each circuit of the machine. This is the basis of the accelerators known as cyclotrons and synchrotrons.

One problem with circular accelerators is that the particles radiate energy as they travel round the bends. This effect is much more important with electrons than with protons (because electrons are much lighter than protons). The radiation produced is called synchrotron radiation. The energy lost this way is greater for higher energy particles and for sharper curves. Some electron accelerators are designed with sharp bends to produce synchrotron radiation deliberately, as an intense source of X-rays for research and industry.

In the Large Hadron Collider (LHC) at CERN, two proton beams will collide head-on inside one of the four giant detectors – each the size of a house – around the accelerator ring. The detectors are complex electronic instruments that record the movements of the particle fragments produced in the impact. Supercomputers then use the data to generate a picture of the collision, which is then interpreted by a physicist.







At the DESY laboratory in Hamburg, two different machines in the same tunnel seperately accelerate electrons and protons before colliding them head-on.

more

Further Information

If you would like to know more about particle accelerators, the following resources may help.

World Wide Web sites
How accelerators work
http://durpdg.dur.ac.uk/lbl/particleadventure/index.html
http://www2.slac.stanford.edu/vvc/accelerator.html
http://www.fnal.gov/pub/inquiring/physics/accelerators/

Accelerators as synchrotron radiation or neutron sources
http://www.cclrc.ac.uk/activity/brilliance
http://www.esrf.fr/
http://www.isis.rl.ac.uk/

Books
Gordon Fraser
The Quark Machines
Institute of Physics Publishing 1997

Jonathan Allday IOPP
Quarks, Leptons and the Big Bang
2002

Close, Sutton and Marten (OUP)
The Particle Odyssey
2002

PPARC also publishes information on a variety of topics related to physics and astronomy, to help increase public awareness of the UK's achievements in science and technology. Find out more by visiting the PPARC World Wide Web site:
www.pparc.ac.uk

Particle Physics and Astronomy Research Council

The Particle Physics and Astronomy Research Council (PPARC) is the UK Government-funded body that exists to support research in basic science:

- Particle Physics
- Astronomy
- Space Science

This support is provided by funding UK researchers and by ensuring that they have access to world-class facilities in the UK and overseas. The Council pays the UK's subscription to the science programmes of the European Laboratory for Particle Physics (CERN) and the European Space Agency (ESA).

PPARC recognises the importance of its science in assisting wealth creation; in post-graduate training; and in motivating young people towards an interest and career in science generally.

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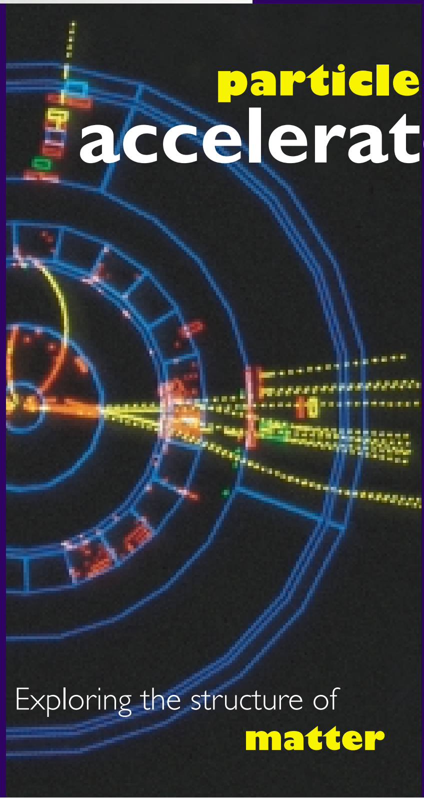
particle accelerators



Exploring the structure of **matter**

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who uses particle accelerators?

There are around 10,000 particle accelerators in the world today (discounting the millions of cathode-ray tubes). About half of these are used in medicine or biological research, and most of the remainder are in industry. Only 100 or so are used as high energy 'atom-smashers'. Here are just a few examples of the many applications.

Medicine

Most of the accelerators used in medicine are for radiotherapy, to treat cancers. They are usually linear electron accelerators, producing electron beams with energies of around 10 million electron volts (10 MeV). When the electrons strike a metal target in the machine, they create an intense beam of X-rays, which can be used to destroy tumours. Beams of other kinds of particles, such as protons and neutrons are also used in cancer therapy, and for making radioisotopes – radioactive forms of ordinary atomic nuclei used in medical diagnosis. (Neutron beams are made indirectly when beams of protons collide.)

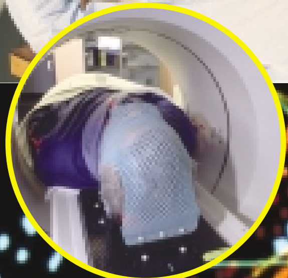
Industry

Accelerators have been used for many years in the electronics industry to create beams of ions – atoms with electrons removed – to modify materials used, for example, in the microchips for computer processors and memory. Electron beams, by contrast, are used, amongst other things, for welding and drilling metals.

Analysis

Particle beams, particularly electrons, protons and neutrons, are used to analyse materials in research and industry. For example, a proton 'microscope' can focus down to less than a millionth of a metre to analyse samples ranging from diseased brain tissue to paintings by 'old masters'. Carbon dating of very small samples, for instance from the Turin Shroud, is also possible using accelerator techniques.

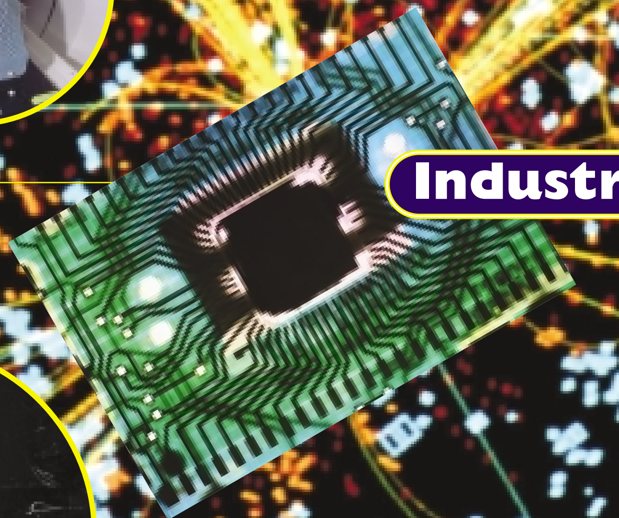
Medicine



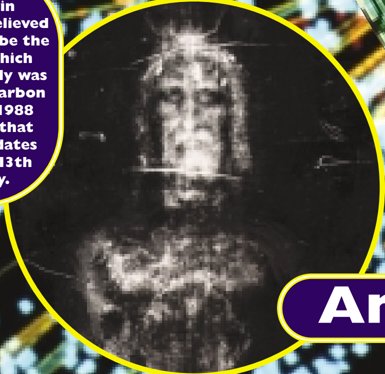
Entertainment

We can all experience the effects of high-energy particles! Many of our favourite electronic games rely on our skill at manipulating beams of electrons striking a television screen.

Industry

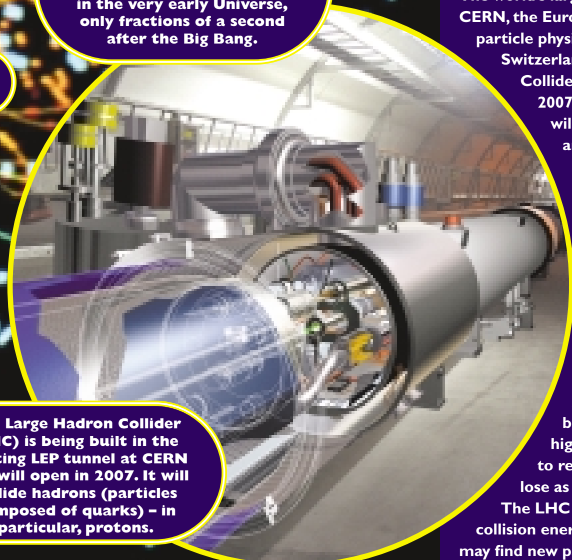


Analysis



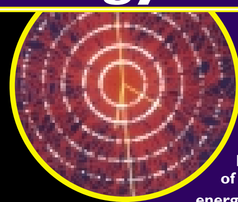
The Turin Shroud is believed by many to be the cloth in which Christ's body was wrapped. Carbon dating in 1988 indicated that the cloth dates from the 13th century.

By colliding high-energy particle beams together, researchers create conditions similar to those that existed in the very early Universe, only fractions of a second after the Big Bang.



The Large Hadron Collider (LHC) is being built in the existing LEP tunnel at CERN and will open in 2007. It will collide hadrons (particles composed of quarks) – in particular, protons.

The high-energy frontier



The most exotic, and perhaps best known, use of accelerators is as high-energy 'atom-smashers'. These machines allow physicists to probe the fundamental nature of matter.

Particles can behave like waves, where the higher the particle energy, the shorter the wavelength; the shorter the wavelength, the smaller the object that will scatter the wave. To probe matter on an ultra-small scale, therefore, we need high-energy particles.

Experiments at the Stanford Linear Accelerator Center in California began probing inside the proton in 1969 using electrons at 20 GeV (20 giga-electron volts, or 20,000 MeV) from a 3-kilometre linac. The results showed that the proton consists of smaller particles, which we call quarks. More recent experiments, at the DESY laboratory in Hamburg, force electrons to collide head on with protons at much higher energies. The scientists are probing details as small as a million million millionth of a metre (10^{-18}m), one thousand times smaller than the proton.

The world's largest accelerator is at CERN, the European laboratory for particle physics near Geneva, in Switzerland. In the Large Hadron Collider (LHC), due to open in 2007 two beams of protons will collide head on and annihilate each other in bursts of energy up to 14 TeV (14 billion billion volts!). The LHC will use the 27km long tunnel built for the Large Electron Position Collider (LEP) which ceased operating, after a hugely successful 11 year run, in November 2000. It is this big because it has to bend the high energy protons gently to reduce the energy they lose as synchrotron radiation. The LHC will provide the highest collision energies ever produced. It may find new particles, such as the Higgs Boson, and will certainly help to improve our understanding of the basic building blocks of nature.

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