Accelerator Tour

Overview

Welcome to the ISIS Virtual Tour!

Beams of neutrons and muons are used at ISIS to probe the structure and dynamics of condensed matter at microscopic scales ranging from the subatomic to the macromolecular.

There are only two practical methods of generating neutrons in large enough quantities to be useful for experiments: nuclear reactors or big accelerators.

ISIS uses the most efficient accelerator method of neutron production, which is to impact high-energy protons on a heavy metal target – a process known as spallation.

At ISIS, around 2×10^{16} neutrons are created each second using a 200 μA pulsed beam of 800 MeV protons colliding with a tungsten target.

Accelerating particles becomes progressively more difficult with increasing energy. A sequence of four different accelerators is required to produce protons with 800 MeV of energy.

Ion source and pre-injector

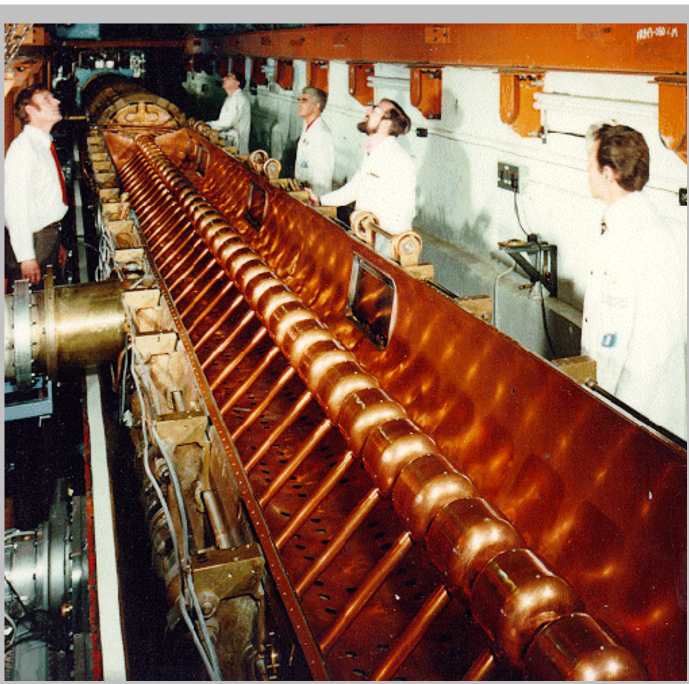
Stage 1: H^- ions (1 proton + 2 electrons) are produced in an ion source by a 50 A electrical discharge through a mixture of hydrogen gas and hot caesium vapour to create a plasma. Caesium ions are introduced into the plasma to encourage the hydrogen atoms to collect electrons from the cathode.

H^- ions are extracted from the ion source by a 17 kV positive extraction pulse. Typically 30–35 mA of H^- ions are extracted in pulses 200–250 μs long at 50 pulses per second.

Stage 2: The H^- ions are accelerated by a Cockcroft–Walton accelerator and injected into the linac. The Cockcroft–Walton is a giant 10-stage voltage multiplier that raises the ion source to 665 kV with respect to the earthed entrance wall of the linac. 2/3 Mv is a high voltage! Consequently large insulation spacings of around 2 m are required to prevent arcing to nearby surfaces.

Linac

Stage 3: The hydrogen ions are accelerated inside the drift tube linear accelerator (linac) to an energy of 70 MeV for injection into the synchrotron. 70 MV is difficult to reach with DC acceleration and alternating currents are needed to produce the accelerating voltages. The frequencies used are similar to those of radio waves – 202.5 MHz.
The ISIS linac has four cavities that progressively raise the energy of the ions as they pass through. The ions are hidden inside copper drift tubes when the oscillating accelerating field is in the wrong direction. Each cavity is 10 m long, has a diameter of 1 m and adds around 400 kW of radio frequency (RF) power to the beam.



The ISIS Linac

Synchrotron – Injection

Stage 4: To accelerate protons to 800 MeV is very difficult and a circular synchrotron accelerator must be used. By repeatedly passing the protons through the same acceleration devices, their energies can be built up rapidly in a compact space. The beam can also be shaped into a specific number of high intensity bunches of protons.

On entering the synchrotron, the H^- ions from the linac pass through a very thin (0.3 μm) aluminium oxide foil that strips the electrons from the ions and leaves only bare protons.

The stripping foil is very efficient, converting 98% of H^- ions into protons. By bending the proton beam through a sequence of magnets during injection, ions that have not been converted to protons are separated out, and the stream of protons can be efficiently merged with those already circulating in the synchrotron.

Synchrotron – Acceleration

The proton beam is guided around the ring by curved dipole magnets, focused by quadrupole magnets, and accelerated by RF electric fields applied across six double-gap cavities in the ring.

The basic operation of the synchrotron is to keep the orbit radius constant as the protons are accelerated and their velocity increases. This means that the acceleration must occur in a very specific way.

As the protons are accelerated and their kinetic energy (velocity) increases, the magnetic field is increased, and the voltage of the accelerating cavities must also be increased at the same rate. That is, the electric field, magnetic field and proton velocity are all increased in ‘synchronism’ with each other.

The proton beam is accelerated to 800 MeV in 10 ms and makes approximately 10 000 revolutions of the synchrotron before being extracted. During this time the magnetic and electric fields rise from their minimum to their maximum values.

At 800 MeV, the circulating protons have reached 84% of the speed of light and relativity effects become important. The beam current provides a good measure of the proton velocity.

On the south side of the synchrotron, the extracted proton beam line passes over the synchrotron on its way to the neutron and muon targets.

Synchrotron – Extraction

Once the proton beam has been accelerated to 800 MeV in the synchrotron, it is deflected out of the synchrotron ring by three fast kicker magnets for transport to the neutron and muon targets.

The injection and extraction process is repeated 50 times a second, and the current in the kicker magnets rises from 0 to 5000 amps in 100 nanoseconds! The proton beam has two bunches separated in time by 200 ns.

The ISIS Synchrotron

Extracted Proton Beam Tunnel

Stretching away into the distance, 13 dipole and 49 quadrupole magnets keep the proton beam tightly focused as it passes through the intermediate graphite muon production target before hitting the neutron target inside the target station.

The beam is focused to a 70 mm diameter spot at the neutron target, and delivers 200 µA of 800 MeV protons, or around 2.5×10^{13} protons per pulse (4 µC) at 50 pulses per second.

The beam has a power of 160 kW and generates around 2×10^{16} neutrons/second.

Target Station

Neutrons are created in the centre of the target station when the beam of high-energy protons collides with the nuclei of tantalum atoms within the target.

The energised nucleus of each atom releases energy by evaporating nuclear particles, mainly neutrons, in all directions. Each proton produces between 15 and 20 neutrons mainly with high kinetic energies of several MeV.

Cooling water is continuously pumped through the target to remove the large quantity of heat generated by the proton beam and spallation process. The kilowatts of heat generated is much less than the heat found in the core of a nuclear reactor, which typically generates megawatts of heat.

Moderating Neutrons

Neutrons emerging from the target must be slowed down to energies that are useful for condensed matter experiments.

Hydrogen-containing materials are very effective at slowing down neutrons by elastic nuclear scattering. The process is known as moderation, and there are three moderators close to the ISIS target that produce neutrons with complementary energy ranges.

The target is surrounded by neutron-reflecting material to ensure the maximum number of neutrons pass through the moderators.

The 20 K liquid hydrogen and 100 K methane moderators produce a large number of low-energy, long wavelength neutrons, whereas the 43 °C water moderator is optimised for higher energy, shorter wavelength neutrons. Each neutron instrument is built to view the moderator which produces neutrons that best match the instrument's applications.

Instruments

Data is collected on the neutron instruments by measuring the time it takes for a neutron to leave the moderator and reach the detectors. The start time is given when a proton bunch strikes the target and the end time is given when each neutron is detected. Knowing the distance the neutron has travelled and the time it has taken allows the neutron velocity, energy and wavelength to be easily calculated.

There are currently 21 instruments grouped around the neutron target and 6 muon instruments grouped around the muon target midway along the experimental hall. Nevertheless, ISIS is now full and a second target station is needed to allow more instruments to be built so that even more experiments can take place!

ISIS is used by a wide range of international scientists, including physicists, chemists, materials scientists, engineers and biologists. Find out more about their experiments in the Research section!