ISIS FACTS AND FIGURES

WHAT IS ISIS?

The ISIS Neutron and Muon Source is a world-leading research centre in the physical and life sciences. ISIS produces beams of neutrons and muons that allow scientists to study materials at the atomic level using a suite of advanced scientific instruments often described as ‘super-microscopes’.

Neutrons and muons show us where atoms are and what they are doing. By understanding the behaviour of atoms inside materials, we can better understand why these materials have the properties they do – and investigate ways to improve these properties and design new materials.

HOW DOES ISIS WORK?

ISIS makes neutrons by firing beams of high-energy protons into a tungsten target. To get the protons into a high-energy beam, we use a synchrotron accelerator with a circumference of 163 metres.

After being hit by the protons, the target releases neutrons, which are channelled along beamlines to the neutron instruments surrounding the targets. This is where the samples of materials being investigated are placed. The atoms inside the materials scatter the neutrons in all directions, and can absorb some energy from them. After passing through the sample, the direction and energy of the neutrons is recorded by detectors surrounding the sample material.

MUONS

ISIS produces muons as well as neutrons. Muons are heavy versions of electrons, and they only live for two-millionths of a second. At ISIS, muons are produced from a carbon target 20 metres upstream of the main neutron target in TS-1. Muon spectroscopy provides an alternative and complimentary technique to neutron scattering. They are very useful for studying magnetic materials and superconductors and can also be used to study how charges move inside materials – for example; charge carrier motion in conducting polymer materials or battery materials.

ISIS INSTRUMENTS

- There are 32 different neutron instruments at ISIS, and 7 muon experimental areas. ISIS produces both positive and negative muons.
- The unique instruments are designed to study specific properties of materials – which instrument you choose depends on what it is that you want to know.

ISIS HISTORY

ISIS has been operating for more than 30 years. The source was approved in 1977, the first neutrons were produced in late 1984, and the then Prime Minister Margaret Thatcher officially inaugurated ISIS in October 1985.

Funding for the ISIS Second Target Station project was announced by Lord Sainsbury (then Science Minister) in spring 2003 to increase capacity and scientific capabilities. The Second Target Station produced first neutrons in Aug 2008.

ISIS operates alongside other facilities such as synchrotron light sources (e.g. Diamond) and lasers. Scientists use neutron scattering and muon spectroscopy as part of wider research programmes providing unique and complementary information.

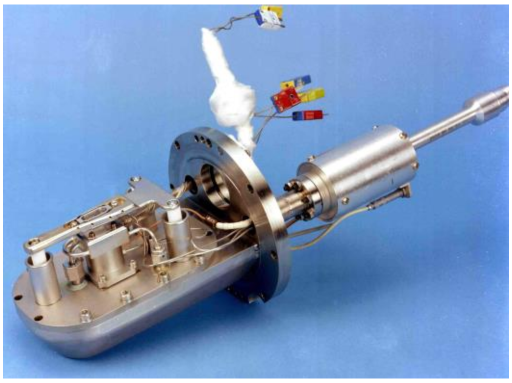
GENERAL ISIS FACTS AND FIGURES

- Almost 3500 visits by scientific users each year from over 30 different countries.
- About 75% of ISIS users are from the UK. ISIS has international partnerships with a range of countries, including Japan, Italy, the Netherlands and Sweden.
- Over 600 publications resulted from ISIS work in 2018; over 11,000 have been published overall to-date.
- Over 1100 experiments are carried out at ISIS each year, where their length varies from 1 day to 2 weeks.
- ISIS runs for around 190 days per year, in four or five run cycles of 30-45 days each.
- During a run cycle, ISIS operates 24 hours per day, 7 days per week.
- ISIS employs around 400 staff.
- ISIS is free to use for academic researchers, providing that the results are published in the public domain. If users do not want to publish their results, then beam time can be purchased.
- All experiment proposals to ISIS are peer-reviewed to ensure that the scientific quality is high.
- We also have over 3500 non-users visit, including 2000 school students, teachers and members of the public.

A BIT MORE DETAIL: THE NEUTRON PRODUCTION PROCESS

- Negative hydrogen ions are produced in the ion source, accelerated to 665 keV (4% light speed) and bunched using the Radio Frequency Quadrupole (RFQ).
- These negative hydrogen ions are then accelerated in the linear accelerator to 70 MeV (37% light speed).
- On entry into the synchrotron accelerator, the negative hydrogen ions are stripped of electrons by a 200μg/cm^2 carbon stripping foil, leaving just protons.
- The proton beam is injected over more than 130 turns of the synchrotron, accumulating 2.8×10^{13} protons.
- The proton beam makes approximately 10,000 revolutions of the synchrotron as it is accelerated to 800 MeV (84% light speed).
- The proton beam is extracted from the synchrotron using three fast kicker magnets in which the current rises from zero to 5000 A in 100 ns.
- Four in five proton pulses from the synchrotron are sent to the first target station. The fifth pulse is sent to the second target station.
- The proton pulses sent to the first target station first pass through the muon production target – a one cm thick piece of carbon. This takes 2-3% of the proton beam.
- 20 m after the muon production target, the proton beam hits the tantalum-clad tungsten neutron target.
- The proton beam energy deposited in the target on the first target station is 160 kW, and on the second target station 40 kW.
- Each proton produces 15-20 neutrons; ISIS produces around 2×10^{16} neutrons per second.
- Moderators slow the neutrons down to useable energies. On the first target station, these are water at 316K, liquid methane at 100K and liquid hydrogen at 20K.
- ISIS works 50 times every second; the process described above happens within 1/50th of a second . . . and then starts all over again.

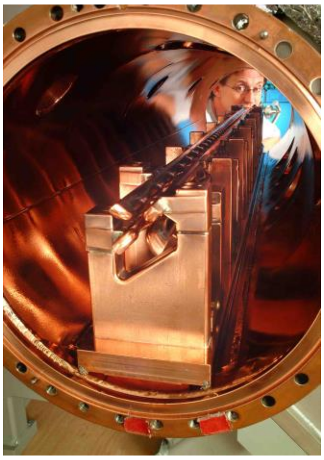
ISIS ACCELERATOR



THE ION SOURCE

It all starts at the Ion Source. Hydrogen gas and caesium vapour are fed into a space the size of a peanut and, after the application of a 50 amp electric discharge, H^- ions (a proton with two electrons) are produced.

INSIDE THE RFQ



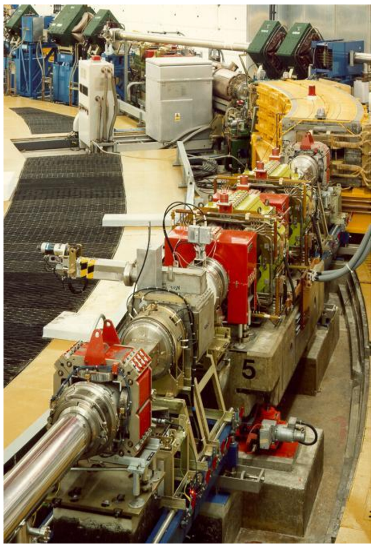
After being focused in the Low Energy Beam Transport, LEBT, the H^- ions enter a Radio Frequency Quadruple (RFQ) that uses complex, intense radio frequency electric fields to focus, bunch and accelerate particles. It is particularly well suited for use with low velocity ions.

The ISIS RFQ accelerates the beam to 665 keV (4% of the speed of light) using a frequency of 202.5 MHz. Inside the RFQ, there are four specially shaped electrodes to produce the required alternating gradient quadrupole electric field. Bunches of H^- ions roughly the size of a string of cocktail sausages are produced 4.94 ns apart from one another.

INSIDE THE LINAC

Next, the bunched beam enters the 40-metre long Linear Accelerator (Linac) which consists of many tube-shaped electrodes inside electrical resonator tanks. The linac accelerates the beam up to 37% of the speed of light.

When they exit the linac, the proton bunches are still 4.94 ns apart but are now about the size of frankfurters. A peak RF power of 7 MW (150 kW average) is needed to accelerate the beam in the linac. Of this, 1.5 MW (20 kW average) ends up in the beam; the rest is lost as heat in the tank.



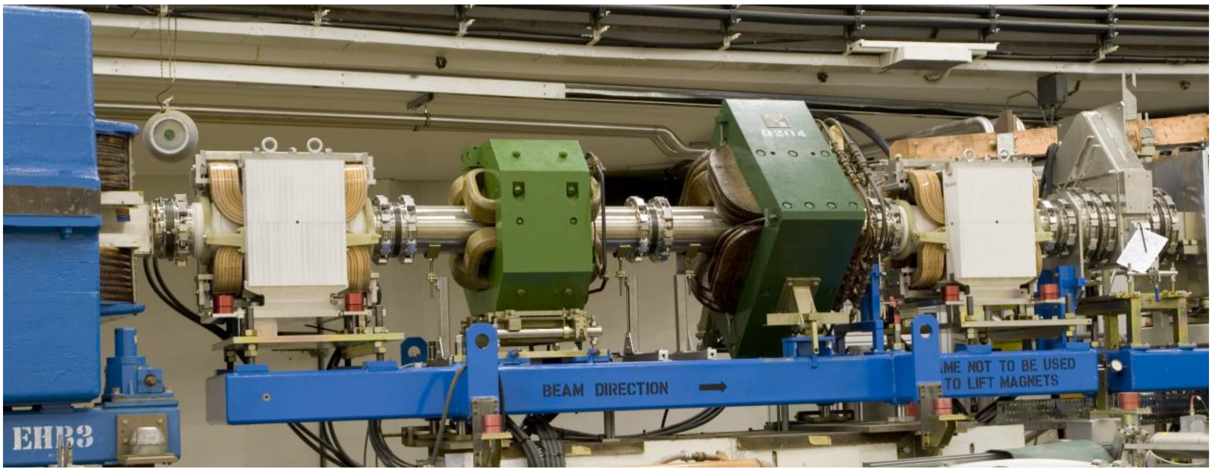
THE SYNCHROTRON

Before entering the synchrotron, the H^- beam is converted into a proton beam by passing it through a very thin foil made of carbon that strips off the electrons.

The proton beam then enters the synchrotron: a ring of drainpipe-sized tube, 163 m in circumference under vacuum. The beam travels around the synchrotron about 130 times until enough protons have been injected. Electric fields then accelerate the beam, forming it into two proton bunches, shaped like long salamis, on opposite sides of the ring. After about 10,000 revolutions the two bunches are travelling at 84% of the speed of light (800 MeV). Powerful electromagnets keep the beam in the pipe as, if the beam were to hit the pipe wall, it could melt it in seconds.

EXTRACTED PROTON BEAM LINE

Finally, the two proton bunches are kicked out of the synchrotron by very fast magnets and directed down 150 metres of beam-pipe towards the targets. Neutrons and muons are produced for use by scientists in their experiments when the proton beam collides with the targets. The muon target is a one cm thick sheet of graphite through which the beam passes, and the neutron targets are house brick-sized blocks of tantalum-clad tungsten.



The whole acceleration process repeats itself 50 times every second!

NEUTRON AND MUON TECHNIQUES

NEUTRON DIFFRACTION

Neutron diffraction experiments determine the atomic and/or magnetic structure of a material. This technique is used to study crystalline solids, gases, liquids or amorphous materials.

Neutron diffraction is a form of elastic scattering; the neutrons exiting the experiment have more or less the same energy as the incident neutrons. The technique is similar to X-ray diffraction, but the different type of radiation gives complementary information. The sample is placed in a beam of thermal or cold neutrons and the intensity pattern around the sample gives information on the structure of the material.

Nuclear scattering
Neutrons interact with matter differently to X-rays. X-rays interact primarily with the electron cloud surrounding each atom. The contribution to the diffracted X-ray intensity is therefore larger for atoms with a large atomic number than it is for atoms with a small atomic number. On the other hand, neutrons interact directly with the NUCLEUS of the atom, and the contribution to the diffracted intensity is different for each isotope; for example, regular hydrogen and deuterium contribute differently. Non-magnetic neutron diffraction is therefore directly sensitive to the positions of the nuclei of the atoms inside the sample.

Light atoms can also contribute strongly to the diffracted intensity, even in the presence of atoms with large atomic number as the scattering length varies from isotope to isotope rather than linearly with the atomic number. For example, Vanadium is a strong scatterer of X-rays, but its nuclei hardly scatter neutrons, so it is often used as a container material.

Magnetic scattering
Although neutrons are uncharged, they carry a spin, and therefore interact with magnetic moments, including those arising from the electron cloud around an atom. Neutron diffraction can therefore reveal the microscopic magnetic structure of a material.

SMALL ANGLE NEUTRON SCATTERING

Small angle neutron scattering (SANS) is a neutron technique able to probe structures at length scales from around 1 nanometre to more than 100 nanometres. It has a wide range of applications including studies of polymers, biological molecules, nanoparticles, microemulsions and liposomes used for cosmetics and drug delivery.

The instrument Sans2d can be used to examine size, shape, internal structure and spatial arrangement in nanomaterials, ‘soft matter’, and colloidal systems, including those of biological origin. SANS does not locate individual atoms but rather looks at the larger structures they form. This gives important insights into many everyday materials and biological systems.

REFLECTOMETRY

Neutron reflectometry is a technique for measuring the structure of thin films. It has applications from materials science through to soft matter and bioscience.

The technique provides valuable information over various scientific and technological applications including chemical aggregation, polymer and surfactant adsorption, structure of thin film magnetic systems and biological membranes.

The technique involves shining a highly collimated beam of neutrons onto an extremely flat surface and measuring the intensity of reflected radiation as a function of angle or neutron wavelength. The exact shape of the reflectivity profile provides detailed information about the structure of the surface, including the thickness, density, and roughness of any thin films layered on the substrate.

NEUTRON SPECTROSCOPY

Neutron spectroscopy measures the atomic and magnetic motions of atoms.

Inelastic neutron scattering measures the change in the energy of the neutron as it scatters from a sample. This can be used to probe a wide variety of different physical phenomenon: diffusional or hopping motions of atoms, the rotational modes of molecules, sound modes and molecular vibrations, recoil in quantum fluids, magnetic and quantum excitations or even electronic transitions.

Often knowing the atomic structure of a material will be sufficient to understand its nature. However, to gain a deeper insight into the underlying physics of, for example, a phase change, it is also necessary to understand the atomic dynamics. The vibrational motion of atoms is, entirely or in part, responsible for a large number of the characteristic properties of a material, such as the specific heat, thermal conductivity, optical and dielectric properties and electrical resistance, and a direct way of understanding the nature of atomic bonding. With the current interest in smart or functional materials whose properties are often determined by a complex balance or strong coupling between competing phenomena, understanding the atomic and magnetic dynamics is essential.

MUON SPIN ROTATION

µSR stands for *muon spin rotation, relaxation, or resonance*, or just *muon spin research.* The µSR technique is a method for investigating the structure and dynamics of matter on the atomic scale by implanting muons into a sample and observing the effects of the local environment on the muon behaviour.

Muons act as sensitive magnetometers, sensing the presence of local magnetic and hyperfine fields, and the resonance and precession signals allow these fields to be measured. Subsequent measurement of the time evolution of the polarisation enables the spatial and temporal variations of the internal fields to be followed. Implanted muons can also mimic the behaviour of hydrogen in materials: a muon has the same charge as a proton and one ninth of its mass, so acts like a light proton isotope.