Neutron scattering **Materials research for modern life**

Science & Technology Facilities Council

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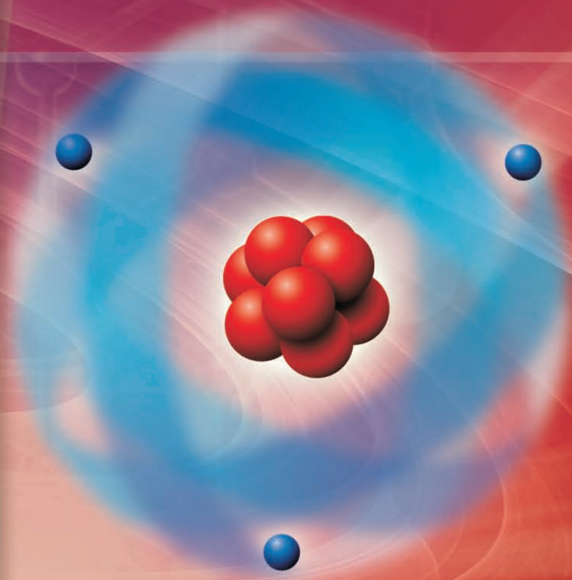

Almost all of the major changes in our society, the dramatic revolutions in transport and manufacturing, the growth of computing and the internet and the steady increase in average life span, have their origin in understanding and exploiting the physics and chemistry of materials.

The goal of modern materials science is to understand the properties of matter on the atomic scale, and to use this knowledge to optimise the properties or develop new materials.

In neutron scattering experiments, materials are exposed to intense beams of neutrons inside specialised instruments at large research centres. The images that are made are used to reveal the molecular structure inside the material which can be directly linked to the physical and chemical properties experienced in the everyday world. From this knowledge emerges fascinating new science or an understanding of current problems in industry.

The information in this brochure is just a sample of the significant social and economic impact that neutron scattering science contributes to our lives. Because of the collaborative nature of modern research, many of the experiments, research and development programmes are joint efforts between UK Research Councils, academia and industry.

The Science and Technology Facilities Council (STFC) ensures that research using neutron scattering continues to make a valuable contribution to society through its ongoing funding and development of the ISIS Neutron and Muon Source in the UK and the Institut Laue-Langevin in France.

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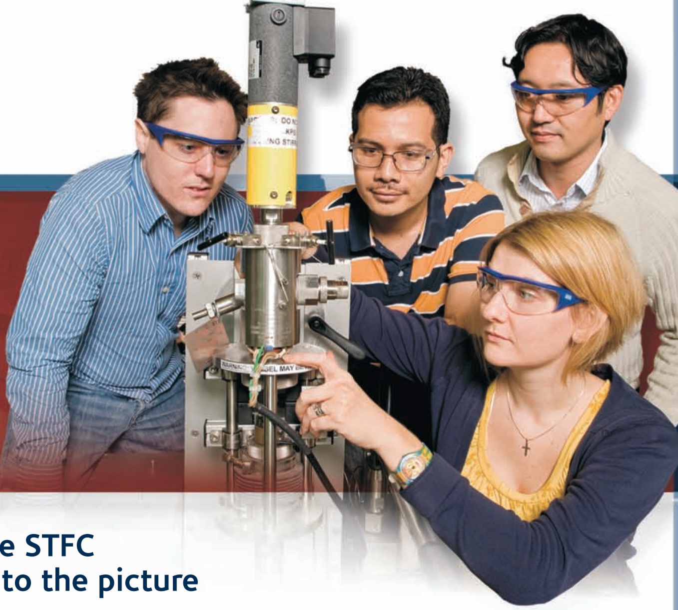
Introduction

What is neutron scattering?



A brief history

In 1932, in Cambridge, James Chadwick discovered the neutron, the missing part of the nucleus of Rutherford's atom. Understanding of the use and usefulness of neutrons progressed rapidly.

The development of the nuclear reactor allowed beams of neutrons for materials research to become routinely available, culminating with the construction in 1972 of the world's most powerful research reactor at the Institut Laue-Langevin in Grenoble, France.

Since the 1980s, accelerator-based neutron sources have become the global technology of choice for new investment. The UK's ISIS spallation neutron source near Oxford is the world's most successful neutron source of this type, and new spallation neutron sources in Japan, America and China are founded on ISIS instrumentation and technology.

With the availability of intense neutron beams over the past 40 years, the unique interaction of neutrons with matter has been used for materials research to understand the physical and chemical properties of matter at the atomic scale. From the early days as a technique rooted in physics, the science now making use of neutron scattering has grown to cover everything from engineering to medicine, archaeology to zoology.

Where STFC fits into the picture

The UK has the largest community of neutron scattering researchers in the world and STFC enables them to have access to the two best neutron sources in the world – ISIS in Oxfordshire and the Institut Laue-Langevin (ILL) in France. UK researchers working closely with their European colleagues over the past 40 years have ensured that, through continued innovation in neutron source and instrument design, Europe continues to be the most productive region in the world using neutron scattering for materials science research, whether that is materials design and discovery or solving immediate problems encountered in industry and society.

Every year over 1500 experiments are completed at the ILL and ISIS, covering a wide variety of research ranging from clean energy and the environment, pharmaceuticals and health care, through to nanotechnology, materials engineering and IT.

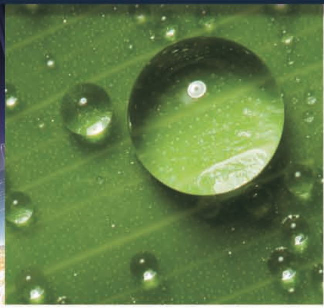
These research centres serve an international community of some 5000 scientists and each centre produces over 500 research publications each year. This brochure demonstrates the wide impact of neutron scattering research on everyday life.

What is a neutron?

Neutrons are abundant throughout nature. Along with protons and electrons, they form the basic building blocks of the material world. Neutrons are tightly bound together with protons in the nucleus at the centre of an atom. The most common methods of making neutron beams for materials research are nuclear fission using uranium fuel in a reactor, or spallation, where a high-power particle accelerator fires a particle beam into a metal target to release neutrons.

A world of **knowledge**

Neutron scattering research impacts on much of modern life…



… from clean energy and the environment, pharmaceuticals and health care, through to nanotechnology, materials engineering and IT.

The unique information that the technique provides is essential in making progress in contemporary materials science and in trying to solve some of the major global challenges of our time.

Energy

Energy created from burning fossil fuels has underpinned the major industrialisation of the modern world over the last 200 years. As we become more concerned with climate change and the security of our energy supply, the desire to harness other forms of energy from solar, wind, wave, hydrogen and nuclear becomes more pressing.

Hydrogen is one of the most promising fuels for the future. Research programmes to discover lightweight materials that can efficiently and safely store and transport hydrogen rely heavily on neutron scattering.

Flexible solar cells based on plastics instead of silicon offer the potential to cheaply cover wide areas of land and harness the abundant energy from the sun.

Engineering studies of components from nuclear power stations allow operating lifetimes to be confidently extended.

SEE PAGE 4

Environment and climate

In recent times, we have become acutely aware of the value of a clean and safe environment for healthy living, and the sensitivity of the climate to activity on Earth.

Neutron scattering is being used to help scientists understand the impact of pollution, work towards solutions for reducing or removing carbon dioxide from the atmosphere and industrial processes, and make more efficient use of natural resources.

Taking a molecular view of the world allows the motor industry to design lubricants and fuel additives that are kinder to the environment and to use lightweight alloys to improve fuel efficiency.

SEE PAGE 6

Medicine and health

Bioactive glass, artificial hips and gels for use in cleft palate surgery have all benefited from knowledge gained from neutron scattering. Multi-disciplinary teams of medics, physicists, materials scientists, chemists and engineers come together at research centres like ISIS and the ILL to make key breakthroughs in using materials in medicine.

The ability of neutron scattering to accurately determine molecular structures allows the behaviour of proteins, enzymes and cell membranes to be understood. Interactions of pharmaceuticals with biological molecules can be studied and compared with computer simulations, improving the chances of finding drugs to treat life-changing conditions such as Alzheimer's.

SEE PAGE 8

A world of knowledge





Electronics and IT

Over the past 50 years, the amount of information stored and processed has witnessed explosive growth, allowing hundreds of gigabytes of songs, pictures and words to be recorded onto devices which are continually shrinking in size.

The unique ability of neutron scattering to map out magnetism at the atomic scale is being used to pack more gigabytes into smaller areas, create ultra-sensitive sensors to read back the data, and develop new types of computer memory.

Studies of ceramic processing have improved the performance of mobile phone components, and testing semiconductor chips to determine the effects of cosmic ray neutrons is allowing companies to confirm the performance of their electronic systems.

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Manufacturing and industry

Millions of tonnes of materials are processed every day across the planet to manufacture the huge range of products that we need for daily life, from soaps, cosmetics and drugs through to cars, planes and industrial solvents. A small amount of molecular knowledge from neutron scattering experiments can go a long way in improving the efficiency, quality and price of industrial products.

Unique information from experiments at the ILL and ISIS is used daily in the manufacture of products used to keep people and their homes clean and fresh. Energy efficient mass production of key industrial chemicals is founded on basic knowledge of molecular interactions. Quality assurance of components in the aerospace and motor industries relies on long-term research programmes confirming the best conditions for making precision components.

➜ *SEE PAGE 12*

Natural world

Our world and universe continue to fascinate, intrigue and surprise. We can learn many lessons from plants and animals on how to solve common problems and gain deeper understanding of our place in the universe by studying the geology and natural processes of the planets.

Neutron scattering is being used to tease the secrets of spinning silk from spiders and how lizards avoid freezing in winter. Understanding how plants can defend themselves against disease offers new potential for crop breeding and medicines.

Replicating the extreme conditions found in the deep earth or the planets of the Solar System is bringing new insight to planetary science. Neutron beams can penetrate through the heavy engineering equipment used to generate high pressures to measure the properties of rocks and fluids needed for computer modelling.

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Heritage science

The origins and history of objects from museums and archaeological sites can be safely investigated using neutron scattering without damaging them or affecting their value.

Civil engineering projects rely on archaeologists to assess the significance of ancient remains that will be disturbed. Neutron scattering has been used to examine Roman objects found under the A2 in Kent which have similarities to those found at Pompeii.

Museums across Europe are using neutron techniques to understand how ancient Japanese swords were made during the 14th to 17th centuries.

Fresh thinking about the Battle of Towton is coming from neutron scattering experiments of battlefield weapons. Fought near Tadcaster in Yorkshire in 1461, it was the most dramatic battle of the Wars of the Roses.

➜ *SEE PAGE 16*

Energy

Hydrogen-fuelled society

New materials that can efficiently and safely store hydrogen have been discovered using neutron scattering, promising a greener future for transport.

Petrol and diesel are the lifeblood of transport, fuelling family school runs and holidays and keeping supermarkets stocked with food. But emissions into the atmosphere and a dwindling supply of fossil fuels are causing greater and greater concern. Clean-burning hydrogen offers a way to dramatically reduce carbon emissions.

Hydrogen is the most abundant element in the universe and is a perfect fuel. It has three times more energy than petrol per unit of weight, and when it burns it produces nothing but water.

Today's technology is capable of powering a car using hydrogen, but making and storing hydrogen safely is a challenge. The automotive industry is working to find safe, efficient and low-cost ways to store and transport hydrogen.

Scientists using neutron scattering have designed inexpensive hydrogen-rich solids to store and release hydrogen that can be safely used in cars and homes.

With neutrons we are on the road to making hydrogen fuel a reality.

> *"Our new hydrogen storage materials offer real potential for running cars, planes and other vehicles with little extra cost and no extra inconvenience to the driver."*
> **Professor Stephen Bennington,** chief scientist, Cella Energy

Extending the lifetime of nuclear power stations

The lifetimes of two UK nuclear power stations have been extended allowing them to continue to supply electricity to the national grid.

Nuclear power stations contain thousands of welded joints which over time become vulnerable to material ageing. EDF Energy worked with the Open University Materials Engineering group studying critical welded components using the powerful Engin-X instrument at ISIS to satisfy safety regulators of the integrity of repair welds in four Advanced Gas Cooled Reactors.

This study helped demonstrate that the welds retained their structural integrity, and supported 5 year life-extensions to be made for these power plants, deferring the need for decommissioning and replacement of two nuclear power stations at a cost of around £1.5 billion each.

> *"Neutron scattering studies of welding procedures have enabled uninterrupted electricity generation and allowed 5-year life extensions to be made for four Advanced Gas Cooled Reactors"*
> **EDF Energy**

Flexible plastic solar cells

Plastic solar cells are much cheaper to produce than conventional silicon solar cells and have the potential to be produced in large quantities.

In one hour, enough energy from sunlight falls on the Earth to satisfy the energy needs of the planet for a year, but large-scale harvesting of this enormous energy supply is only just starting.

Plastic polymer solar cells are much cheaper to produce than conventional silicon solar panels. Neutron scattering experiments have shown that efficient solar cells can be made from very thin films, with a flexibility like cling-film. These can be manufactured using very simple and inexpensive methods, by spreading a mix of polymers thinly over huge areas.

High-volume manufacturing could produce films of solar cells that are over a thousand times thinner than the width of a human hair. These films could be used to make light and easily transportable solar cell devices.

"Ultra-cheap and efficient polymer solar cells that can cover huge areas could help move us into a new age of renewable energy"
Professor Richard Jones, University of Sheffield

Super superconductors

Striking images collected in neutron scattering experiments may be the clue to understanding how advanced ceramics can transmit electricity without losing energy.

The ceramics, known as high-temperature superconductors, lose all resistance to the flow of electricity when cooled below -150ºC. Wires made from the ceramics can conduct up to 140 times more power than conventional copper wires of the same dimension, carrying electricity with 100% efficiency.

Yet despite their growing use in applications ranging from medical imaging scanners to revolutionary propulsion systems, exactly how they work remains a mystery.

Uniquely sensitive neutron instruments available at ISIS and the ILL are giving an unmatched clarity of vision into the interior world of superconductors. The unique results are guiding the search for new materials in the quest to make superconductivity take place at room temperature.

"We are finding that electric current is carried most efficiently in these materials when very weak atomic-scale magnetic interactions permeate the structure of the ceramics."
Professor Stephen Hayden, University of Bristol

Environment and climate

Enhanced oil recovery

A harmless soap-like additive turns carbon dioxide into a viable commercial solvent to increase the amount of crude oil that can be extracted from oil fields.

More than 40,000 oil fields are scattered around the world with the largest individual fields in the Middle East estimated to each hold more than 60 billion barrels of oil. Only a fraction of this oil can be brought to the surface because of reservoir characteristics and limitations in petroleum extraction technologies. Enhanced oil recovery techniques such as water-flooding or gas-injection are frequently used to improve the yield and economic return from a field.

High pressure carbon dioxide can be used in enhanced oil recovery as it is able to flow through the pores in the rock much more easily than water. Additives can thicken the carbon dioxide allowing it to flow through the rock more efficiently and push oil out of very small rock pores, increasing the oil field yield by up to 30%.

Previous advances in using carbon dioxide for oil recovery have used additives containing environmentally damaging fluorine. A new, safe additive developed using the unique molecular information coming from neutron scattering experiments contains no fluorine at all and is a harmless hydrocarbon.

Getting longer life out of existing oil reserves will also give more time for research into non-carbon energy sources such as solar or hydrogen.

"The discovery of a chemical capable of modifying the properties of carbon dioxide to make it suitable for widespread use as a solvent in enhanced oil recovery has been recognised as a game-changing technology."

Professor Bob Enick, University of Pittsburgh

Antarctic fossils

Leafy branches of 50 million-year-old conifers locked in rocks indicate a very different climate in Antarctica to the ice and snow found today.

Although Antarctica is now a land of ice and snow, for most of its history it was covered with lush forests. The remains of the forests are now preserved in the rock record as fossil wood, leaves, flowers and pollen.

Neutron imaging allows the three-dimensional structure of conifer branches to be seen for the first time since they were encased in sediment 50 million years ago, without breaking open the rock and destroying the fragile structures.

Alongside other studies, it has been established that conifers were an important component of forests that grew on Antarctica millions of years ago. This new knowledge is being used to understand climate systems in a former warm greenhouse world, and plant evolution and survival under the harsh polar light conditions.

"We take it for granted that Antarctica has always been a frozen wilderness, but the ice caps only appeared relatively recently in geological history. I find the idea that Antarctica was once forested absolutely mind-boggling."

Professor Jane Francis, University of Leeds

Cloudy skies

Air pollution fundamentally changes the way clouds form by destroying the oily layers coating water droplets.

Clouds are made up of droplets that form when water vapour condenses on tiny particles (aerosols) suspended in the air. Aerosols can come from many places: sea salt from the ocean, plants, or the burning of fossil fuels and vegetation.

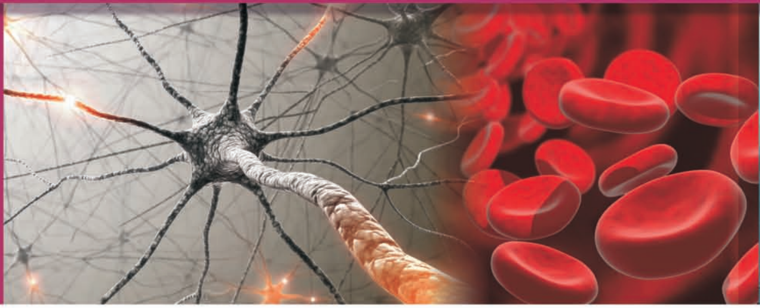
The more aerosols there are, the easier it is for clouds to form. The droplets grow in size until they are large enough to fall as rain.

Modelling cloud formation is one of hardest jobs in forecasting climate change. The potential for aerosols to form clouds and raindrops is dictated by little-known chemical reactions within the atmosphere.

Neutron scattering experiments have demonstrated that ozone created in the lower atmosphere from vehicle pollution can attack the oily films coating water droplets in the air and reduce the speed at which they can grow.

This newly-discovered mechanism is being used to update models of organic aerosols in the atmosphere and their impact on cloud reflectivity and drizzle potential, rainfall patterns and the water cycle.

Medicine and health



Tracking cholesterol

Precise measurements of cholesterol transport rates are giving new hope for treating Alzheimer's, a disease that affects around half a million people every year in the UK.

Cholesterol forms part of the outer membrane that surrounds every cell. It plays a vital role, carrying chemical and nerve signals around the body by insulating nerve fibres, and aids the production of important hormones.

Problems in cholesterol production and transport in the brain can lead to build-ups of the chemicals causing Alzheimer's disease. As well as Alzheimer's, abnormalities in cholesterol transport can lead to several other fatal diseases, such as narrowing of the arteries and heart disorders.

Neutron scattering experiments demonstrated that the movement of cholesterol between cells takes several hours longer than previously thought, and also showed how the errors in previous results had arisen.

The results are changing opinion on how disorders linked to abnormal cholesterol transport should be treated and how the neurochemistry throughout the central nervous system is affected.

"Neutrons revealed the true rate of cholesterol transport in cells. Inaccurate rates from previous studies have hampered our understanding of how healthy concentrations of cholesterol within cells are maintained."

Dr Lionel Porcar, Institut Laue-Langevin

Cleft palate

A new hydrogel material can make cleft palate surgery easier and less painful for the patient.

Cleft palates are the most common birth defect in Britain, with one in every 700 babies affected. Babies born with cleft palates usually have problems feeding, and may have speech difficulties in later life, as well as issues with their hearing, teeth and facial growth. In severe cases radical surgery is required to correct the problem and complications can occur as the child grows into an adult.

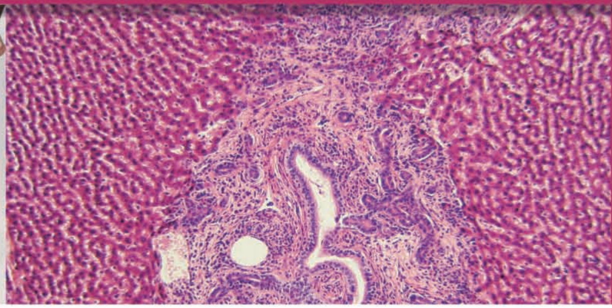
A new hydrogel material similar to that used in contact lenses has been developed by a team of surgeons and materials scientists in Oxford. They used neutron scattering to confirm the performance of the gel at the molecular level.

A small plate of the hydrogel material is inserted into the roof of the patient's mouth. The gel absorbs fluid and gradually expands over several weeks, encouraging new skin to grow. When enough skin has been generated, the plate is removed and the cleft is repaired using the new tissue. The new materials will improve the patient experience by reducing the number of hospital visits and simplifying surgical procedures.

A spin-out company from the University of Oxford has been formed to commercialise the materials.

"ISIS is an incredible facility and we are very fortunate to have it on our doorstep. It allowed us to show that the molecules in our hydrogel are aligned in the right way."

Marc Swan, surgeon, John Radcliffe Hospital, Oxford



Strength of hip replacements

Neutron stress measurements of artificial hip coatings will help to reduce failures.

Over 50,000 hip replacements are performed in Britain each year, and the number is expected to double by 2030.

Implants are commonly made using titanium coated with a thin layer of hydroxyapatite, which is the main constituent of human bone. The coating, which is around the thickness of a sheet of paper, encourages bone to bond to the implant and hold it in place.

Small changes to the coating procedure can cause the implant to fail in under six months leading to further painful operations for patients when the implant is replaced.

Differences in the thermal and mechanical properties of titanium and hydroxyapatite at the interface between the two materials cause residual stresses to form in the coating after spraying. Neutron scattering is being used to investigate hip implant coatings, collecting vital stress measurements to determine how this relates to implant failure.

With a clearer understanding of the microscopic structure, researchers are optimistic that the number of failed implants can be significantly reduced.

"Using neutron scattering, we are collecting vital stress measurements to investigate hip implant coatings. Combined with computer modelling we are optimistic that the number of failed implants can be reduced."

Dr Rehan Ahmed, Heriot-Watt University

Antibody armour

A combination of neutron and X-ray scattering has determined the structure of the most abundant human antibody for the first time in 40 years.

The most abundant human antibody is called secretory immunoglobulin A (SIgA). It acts as the immune system's first line of defence when the body comes into contact with the outside world. It is secreted in the lungs, genital system, saliva and gut to deal with bacteria, viruses and other microorganisms that cause diseases such as pneumonia and diarrhoea.

The antibody is so big, complex and fragile that it has proved extremely difficult to study, and despite its importance and prevalence, no new information has been available since the early 1970s.

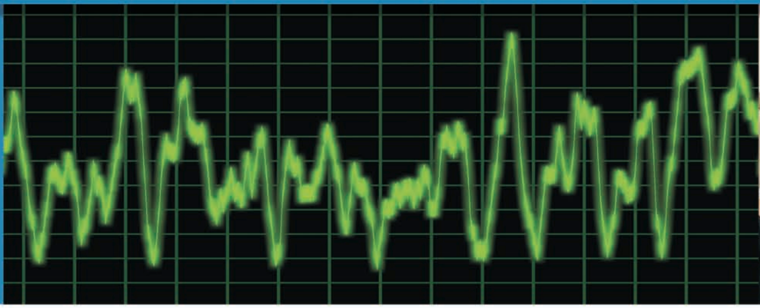
A combination of neutron scattering and X-ray experiments have now successfully revealed how the antibody is secreted and how its structure affects how it works.

For the very young, the elderly and others whose immune system is less efficient, the ability to make efficient vaccines or artificial versions of these antibodies will become increasingly important in defending their health from new types of infection.

"By mapping together data from neutron scattering and X-ray experiments we uncovered the molecular structure of secretory immunoglobulin. By combining both techniques we got the complete picture. Using only one technique alone there would have been gaps."

Professor Steve Perkins, UCL Structural Immunology Group

Electronics and IT



Mobile phone ceramics

The performance of components inside mobile phones is closely related to material properties. Neutron scattering can help manufacturers get the right specification.

Mobile phones use small ceramic antennas to give each one a dedicated operating frequency. They are used in base stations and handsets to carry the correct communication signals.

Consumer demand and evolving design of mobile phones has created a need to improve performance and lower the costs of these ceramic components. This includes reducing their power loss, which makes quality assurance essential during manufacture.

Device performance is closely related to material properties. Wireless solutions company Powerwave UK has re-created a critical manufacturing stage, inside a neutron scattering facility where the ceramic components are heated to over 1000°C.

The research was able to identify atomic-scale differences between materials processed under identical conditions, but having different electrical properties. This testing was significantly more efficient than previous trial-and-error methods, and has aided the manufacture of these components to the right specification.

"Neutron scattering experiments generated the data necessary to understand the structure of these complex ceramic materials."
David Iddles, development manager, Powerwave UK

Infection sensors

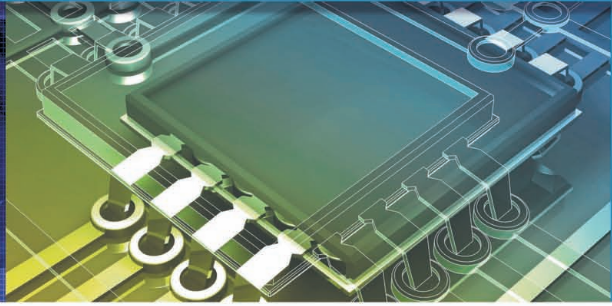
Biosensor quality control gets green light from neutron scattering experiments.

Sensors to monitor living systems are made up of a mix of biological elements and electronics. When diagnosing infectious diseases, these biosensors must be sensitive and quick enough to distinguish between a virus and a bacterial infection. For example meningitis comes in bacterial or viral forms and can be fatal if diagnosed incorrectly.

Orla Protein Technologies, a spin-out from Newcastle University, makes bespoke protein surfaces for large companies developing the next generation of biosensors. Neutron scattering is the only technique that enables Orla to test the quality of its bio-engineered surfaces at scales 10,000 times smaller than a human hair.

Orla's biosensors have a high performance protein surface, an invisible engineered biological film that detects the tell-tale molecules in a sample. This engineered biological film is so thin that a stack of 30,000 would only be as thick as a sheet of paper. Neutron scattering gives the information necessary to ensure that the protein surfaces are reliable for manufacturing.

"With neutron scattering we can introduce label molecules in reactions to help us tell where each component part is. These results reassure our customers and are essential for the success of our business."
Professor Jeremy Lakey, Orla ProteinTechnologies



Magnetic electronics

Creating a powerful new breed of electronics by controlling the magnetic properties of electrons flowing around silicon chips.

Conventional electronics relies on electrical currents caused by moving electrons around minute circuits etched on silicon. An emerging technology called 'spintronics' uses the magnetic properties of electrons at the same time to create a powerful new class of components. This technology has potential for a variety of applications in IT, motoring and healthcare.

The most widely used spintronic device is found in the read-head of magnetic hard-disk drives used inside desktop and laptop computers.

The spintronic read-head senses changes in the magnetism of layers only a few atoms thick allowing it to read smaller data bits than older technology. This has given a 40-fold increase in data-storage density in the last five years.

But many of the most promising materials, which industry hopes to deploy in future devices, only work under extreme conditions such as very low temperatures or large magnetic fields. The aim is to understand the complex physics of these new materials to get them to work at room temperature.

A number of UK universities and companies are attacking the problem to get a layer-by-layer understanding of the chemical and magnetic structure to connect the fundamental physics of spintronic materials with their actual behaviour. Neutron scattering is critical in exploiting spintronics for a powerful new generation of applications.

"Our aim is to understand the complex physics of these new materials to get them to work at room temperature. Neutron scattering is critical in exploiting spintronics for a powerful new generation of applications."
Professor Sean Langridge, STFC ISIS

Neutron rain

ISIS is helping aerospace companies to manage the effects of cosmic radiation on microchips flown in aircraft.

Cosmic rays hitting the earth's atmosphere generate showers of high energy neutrons that rain down on earth.

At normal aircraft flying altitudes of 30,000 to 35,000 feet, a silicon chip can be struck by a neutron every few seconds disrupting aircraft electronics which can cause problems ranging from wiping a device's memory to damaging the electronics.

Using neutrons, leading aerospace companies such as BAE, Aero Engine Controls, QinetiQ and MBDA are able to test components and manage the effects of cosmic radiation.

Dedicated testing facilities at ISIS can replicate hundreds of years of flying time in one hour of testing.

As the dimensions of electronic chip components continue to shrink, neutron effects are also being seen at ground-level in other areas such as transport, communications, medicine, and computing systems.

"ISIS is one of few facilities in the world capable of producing enough very high energy neutrons to perform accelerated testing. The new Chipir instrument at ISIS will be the best screening facility in the world."
Andrew Chugg, MBDA

Manufacturing and industry

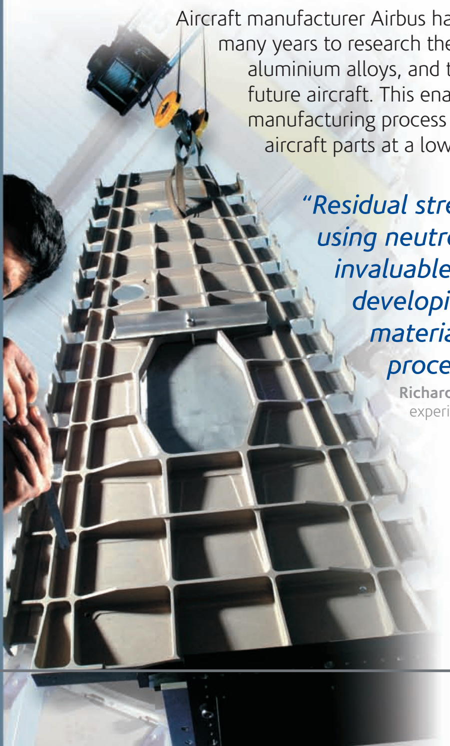
Stress relief in the air

Neutron scattering helps major aerospace companies assure the quality of engineering components.

Understanding stress distributions in aircraft parts after manufacturing is particularly important for the aircraft industry.

Neutron scattering can be used to map internal stresses giving information about the effectiveness of different manufacturing and processing techniques. The technique is well-suited for these studies as it is non-destructive and can look deep inside components.

Aircraft manufacturer Airbus has used neutron scattering for many years to research the integrity of welds in aluminium alloys, and to assess their suitability for future aircraft. This enables engineers to adjust the manufacturing process and make lighter and safer aircraft parts at a lower cost.



"Residual stress measurements using neutron scattering are invaluable for researching and developing existing and novel material manufacturing and processing techniques."

Richard Burguete,
experimental mechanics specialist, Airbus

Molecular makeover

Energy savings and cleaner manufacturing follow a molecular makeover.

Ineos ChlorVinyls is Europe's largest PVC manufacturer. More than 100,000 tonnes of methyl chloride are synthesised at its Runcorn site every year to make a wide range of everyday materials from plastics to pharmaceuticals.

Methyl chloride is made by passing methanol and hydrogen chloride over a catalyst that accelerates the chemical reaction. But Ineos ChlorVinyls found that a side product was also produced wasting energy and which was expensive to recycle back to methanol.

A collaboration between the University of Glasgow and Ineos ChlorVinyls used neutron scattering to understand what was happening at a molecular scale on the surface of the catalyst.

With this new insight, the catalyst surface was modified, significantly reducing the cost of the manufacturing process by almost completely eliminating the unwanted side product and avoiding construction of a new waste handling plant.

The new catalyst has now been operating continuously on both of the Runcorn methyl chloride reactors for several years.

Tackling chemical waste in the pharmaceutical industry

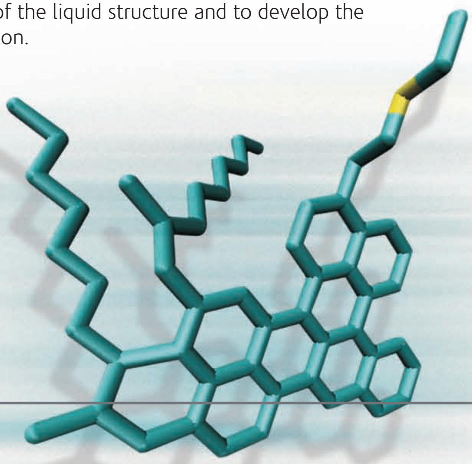
Ionic liquids have the potential to revolutionise the pharmaceutical industry.

Chemical waste is an expensive problem for the pharmaceutical industry, but researchers have used neutron scattering to develop a new approach that makes many chemicals easier to work with and helps reduce waste.

The vast majority of processes for making pharmaceutical ingredients are carried out in some form of organic solvent. However, organic solvents vapourise easily and can catch fire, making process safety an issue. Pharmaceutical ingredients also have to be free from all traces of solvent to make sure the drugs are safe.

Professor Chris Hardacre at Queen's University Belfast has developed a new approach using ionic liquids. Ionic liquids are highly stable, non-flammable solvents that don't emit dangerous volatile organic components, and don't get caught up in the final product.

Neutron scattering data was essential in obtaining a molecular view of the liquid structure and to develop the correct formulation.



Molecular insight gives industry a competitive edge

State-of-the art neutron experiments unlock the secret of a major industrial process.

The Lindlar catalyst is used in the commercial manufacture of vitamins and a range of other applications. Evonik Industries, a manufacturer of Lindlar and many other catalysts, wanted to acquire a competitive edge by developing a unique understanding of the Lindlar catalyst.

The catalyst incorporates the metals palladium and lead. Both the palladium and the lead play key roles. The palladium splits molecules in hydrogen gas into separate hydrogen atoms needed for chemical production, while the lead enables the catalyst to stop the reaction at the required point.

Neutron scattering provided the missing piece of the jigsaw by shedding light on what exactly happens on the surface of the catalyst during a chemical reaction. Evonik now know precisely how the Lindlar catalyst behaves and why it is so effective.

"Applying new analytical methods is one key step to understanding the critical parameters that control the performance of a catalyst. This will help us to improve further our industrial catalysts for the benefit of our customers."

Dr Konrad Möbus, Evonik Industries

Natural **world**

Spinning yarns

Neutron scattering is playing a key role in discovering how silk can be made artificially.

Spider-silk is five times as strong as steel and absorbs three times more energy than the material used in bullet-proof vests. The strength and elasticity of silk could be harnessed for new plastics and biomedical implants if it could be made artificially.

Spiders spin silk from a mix of water and proteins stored as a gel in specialised silk glands inside their bodies. As the gel is pulled through their spinning glands it becomes a very resilient solid that could have many potential uses in the industrial world.

Research teams are using neutron beams tuned for studying biological materials to shine a light on the atomic scale structural changes as the gel transforms into solid fibre. Experiments have unlocked some answers, and continue to reveal more of nature's secrets.

"We are asking how nature makes such amazing materials. Neutron scattering is an excellent technique for understanding the spider's magic tricks."

Dr Chris Holland, Oxford University Silk Group

Sub-zero survival

Food storage, fertility treatment and transporting medicines could benefit from a new understanding of how lizards survive at low temperatures.

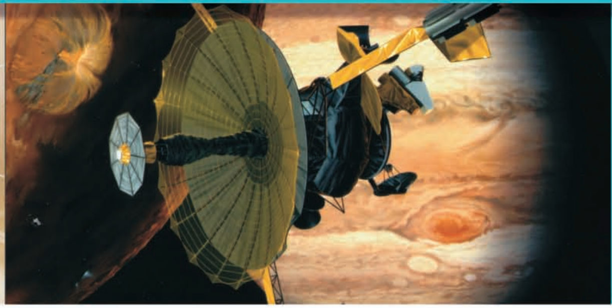
Cold-blooded lizards have only limited ability to regulate their own body temperature. When temperatures fall in winter, so does their body temperature, putting tissues and cells at risk of irreparable damage from internal ice.

To prevent lethal ice crystals forming in and between cells in their body, lizards use chemical compounds such as glycerol to reduce the freezing temperature of water. During prolonged exposure to sub-zero temperatures, cell activity is paused until temperatures rise again and normal activity can safely resume.

Molecular structure data collected with neutron scattering shows how mixing glycerol with water prevents rigid ice networks from forming. This new fundamental understanding of the role of glycerol will be helpful in a range of applications.

"Improving our fundamental knowledge of lizard cryopreservation may lead to improved storage and recovery of tissue for fertility treatment, better storage of drugs in the pharmaceutical industry and transport of organs for surgery, and better storage of food in the agricultural industry."

Dr Lorna Dougan, University of Leeds



Disease resistant crops

Anti-microbial plant defence proteins could be used in transgenic crop species to increase disease resistance and food yield.

Food security is becoming a major concern in the UK and across the world, as harvest yields are challenged by climate change, pests, diseases and the demands of a rising world population.

A quarter of the world's crops are lost to pests and disease. Understanding how plants defend themselves could be one way to reduce losses.

Common crops like rye, barley, oats, and wheat make antimicrobial proteins to defend themselves against disease, fungi and bacteria. In wheat, the defence proteins play an additional role in giving the endosperm texture, an economically important quality that determines the milling characteristics of the wheat.

Food scientists are using neutron scattering to learn about the molecular action of defence proteins and their interaction with the cell membranes of invaders. They can watch defence proteins punch their way through a cell membrane to kill hostile bacteria or strip vital components from its surface.

As regional climates change, this knowledge will also help farmers and breeders to adapt plants to counteract shifting weather patterns.

Planetary science

Geologists have developed novel high-pressure neutron scattering experiments to model the Earth's interior or predict the geology of the icy moons of the Solar System.

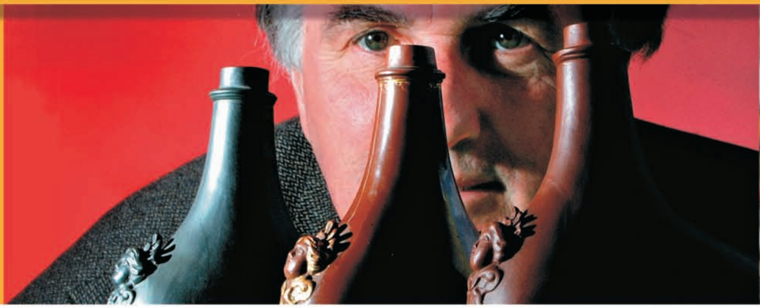
Satellite missions to the giant gas planets Jupiter and Saturn have revealed that our Solar System displays a rich variety of bodies, each with a complex and diverse evolutionary history.

Understanding the evolution of the planets and moons presents one of the major challenges in Earth and planetary sciences

Unique equipment developed by university groups in the UK and France for neutron scattering instruments can squeeze rocks and other materials to very high pressures. These high pressures reproduce the conditions found inside Titan, Saturn's largest moon, or inside the mantle of the Earth at depths of up to 700 km.

The precise data derived from neutron scattering experiments allows planetary scientists to better interpret the geology seen in surface images taken from spacecraft, or create robust interpretations of seismic data recorded on Earth.

Heritage **science**



Origins of Pompeii-style artefacts from Kent

Neutron scattering offers a non-destructive way to analyse rare Roman objects.

Road and civil engineering projects rely on archaeologists to assess the significance of ancient remains that may be disturbed and plan how to protect them.

During work to widen the A2 in Kent, two high status Roman pit-burials were discovered containing 2,000-year-old bronze artefacts. The wine-mixing vessel, jugs and ceremonial pan-shaped objects are among the best examples ever seen in Britain.

These 1st century AD artefacts are similar to ancient remains found at Pompeii so the excavators wanted to know if they were imported from Italy or manufactured locally using similar techniques.

Using neutron scattering, the items found in Kent are being compared at a molecular level with similar items from Pompeii. The technique allows detailed analysis of rare objects without cutting out a sample of the material for testing. The measurements are extremely delicate and non-destructive, so the objects are unharmed by the analysis.

"Neutron scattering experiments have helped us to characterise different Roman metalworking practices. They have allowed us to distinguish between goods imported from southern Italy and copies produced in the UK by skilled local craftsmen."

Dana Goodburn-Brown, ancient metals specialist, Oxford Archaeology

The finest steel

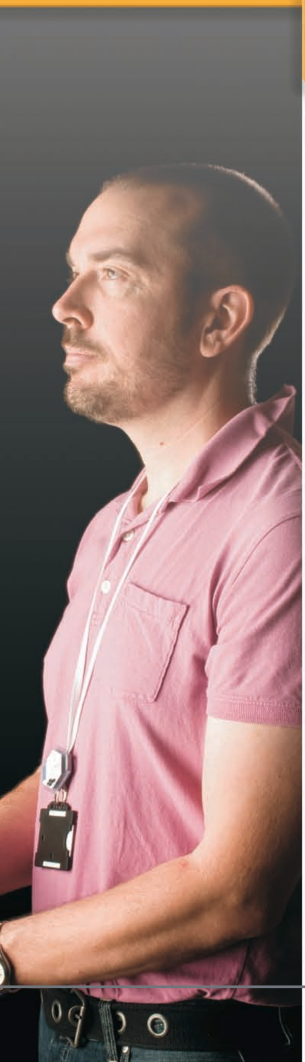
Museums across Europe are using neutron techniques to understand how Japanese swords in their collections were made during the 14th to 17th centuries.

Japanese swords are made from some of the finest steels known. Skilled craftsmen used the best available materials in order to provide the correct mechanical characteristics for every part of the blade according to its function. These ancient weapons were hand-made without any of the scientific processes used in modern steel manufacturing.

Non-destructive neutron scattering measurements map the distribution and chemical composition of hard and soft steel through the blades. With many swords not carrying identification of the sword-maker, neutron measurements reveal characteristics of the sword-making traditions and the steel-making process.

"The sword blades are of incredibly high quality comparable to those that are made today. In Japan in the 14th century, they were making them by instinct, and we're very interested in how they were making such high quality steel without modern control processes in place."

Jeremy Uden, senior conservator, Pitt Rivers Museum, Oxford



Britain's bloodiest battlefield

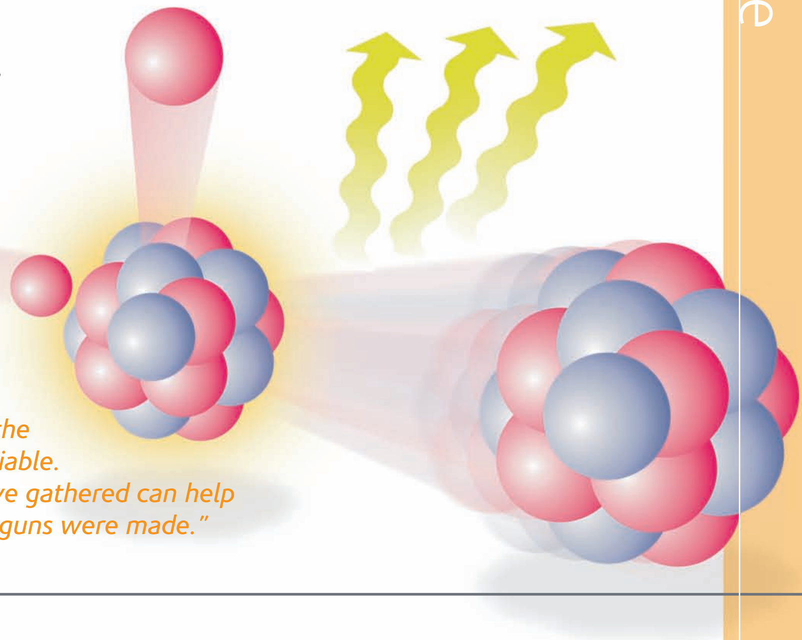
Fresh thinking about key events in the Wars of the Roses is coming from neutron scattering measurements of battlefield weapons.

The Battle of Towton, fought near Tadcaster in Yorkshire in 1461, saw up to 28,000 soldiers killed on a single day and was the bloodiest conflict of the Wars of the Roses.

Archaeologists are using neutron scattering to analyse bronze cannon fragments and lead shot found during a field survey at the North Yorkshire battlefield.

The fragments and the shot fired from them contain large amounts of lead, which absorbs X-rays very strongly. Neutron scattering techniques are the best-suited method for looking at these samples since they can see through lead.

Structure analysis has revealed that the cannon fragments were made of two different alloys and were from two different guns. The guns were probably not found intact because it was common for guns at the time to explode in the users' hands because of metal casting faults. The neutron scattering experiments are helping to piece together the history of the battles, giving clues to how and where the weapons were made.

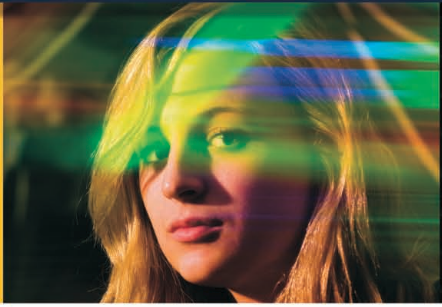


"The manufacturing of firearms in the 15th century was notoriously unreliable. The neutron scattering data we have gathered can help us to establish how and where the guns were made."

Tim Sutherland, archaeologist, University of York

Skills and careers

Working at large, multidisciplinary research centres like ISIS and the ILL gives students valuable technical and personal skills which are an advantage in any workplace



Science and technology programmes using neutron scattering deliver knowledge and results having long-lasting impact. But researching and improving the modern world can only be a success if there is a continual flow of experienced scientists who can effectively use these facilities. Training the next generation of scientists and engineers is absolutely crucial.

Training tomorrow's scientists

40% of scientists using neutron scattering at ISIS and the ILL are PhD students, and 20% are post-doctoral researchers. The tight working schedules and team environment provide real-world training in scientific and personal skills.

Training schools are run regularly by both research centres for UK and EU students teaching practical techniques and data analysis skills.

Early-career researchers using these large research facilities gain valuable confidence in pursuing ambitious new research programmes at the start of their professional careers.

"It's a high-pressure environment with other people depending on the quality of your work. Beam time is a precious resource. Rapid problem solving, team working and good communication are essential. It forces you to stop and think about your priorities and think clearly as a chemist."

Craig, PhD student, University of Bristol

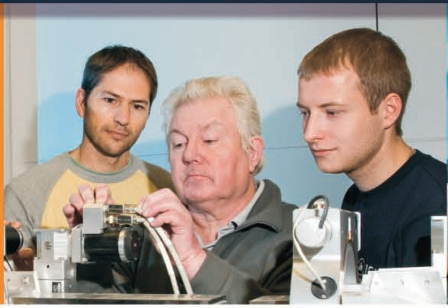
Engineering the future

As part of STFC's training programme, a graduate position in neutron scattering offers exceptional opportunities and training and is a great place to start a career in science, technology, engineering or mathematics.

We want the very best people to help us deliver the very best science and engineering. Graduates with good degrees in mechanical, electrical and electronic engineering are eligible for our graduate training schemes involving a mix of formal and tailored training, placements and project work working on real projects for real customers from day one.

"As a graduate mechanical engineer in ISIS, I enjoyed the diverse range of projects, and ISIS provided the necessary training for me to achieve chartered status with the Institute of Mechanical Engineers. It is very supportive in developing the careers of its staff."

Steph, mechanical engineer, STFC ISIS



A year in industry

Undergraduate students can spend from 6 months to a year at ISIS and the ILL as part of their university courses. Taking time out from studying to work at the forefront of science and technology builds skills, confidence and experience and gives students the space and time to work out the best path for their future careers.

"Working at ISIS helped me to realise that science was definitely the one for me. I got my honours degree in Environmental Science and now I'm starting a PhD."

Beth, PhD student, Centre for Ecology and Hydrology, NERC

Apprentices

Not everyone wants to be a scientist, but working in science, engineering and technology is perfectly possible without having a PhD or other university qualifications.

School-leavers and others with the right school-level qualifications can apply for an apprenticeship in electrical, electronic or mechanical engineering. A mix of college study and on-the-job training teaches innovative techniques needed not only within ISIS and the ILL but also in high-tech industry.

"I thought 'what could I do where I'm out and earning money?' I left school at 16, started my apprenticeship. It took me 3 years and from then on I've worked in ISIS doing electronic engineering. I really like the environment and the challenges that go with it."

Steve, electronics engineer, STFC ISIS

Inspiring young people

Inspiring young people in school to follow careers in science, engineering and technology is essential for the future well-being of the UK and Europe. Work experience placements for school students offer a unique view into the working world of science.

"It's been a great eight days in the big wide world. The things I most like about this kind of job, is that you're not repeating the same actions all day long like in a shop check-out. It's different. Everything is new territory and everything builds towards something bigger and better."

David, STFC ISIS work experience student

80 years of neutrons timeline

1932

James Chadwick discovers the neutron in Cambridge. He receives the Nobel Prize in Physics in 1935 for discovering this missing part of the atom.

1938

Enrico Fermi receives the Nobel Prize in Physics for his work investigating the atomic scattering and absorption cross-sections of slow and thermal neutrons.

1946

Ernest Wollan and Clifford Shull, using the Graphite Reactor at Oak Ridge National Laboratory, USA, establish the basic principles of the neutron diffraction technique. They prove the existence of antiferromagnetism, as predicted by Louis Néel who won the Nobel Prize in Physics in 1970.

1955

The first measurements of phonons from a prototype triple-axis spectrometer built by Bertram N Brockhouse confirm the quantum theory of solids.

1956

The Dido research reactor comes online at the Harwell Laboratory. This helped the UK to develop neutron scattering techniques for materials research.

Neutron facility

Nobel prize related to neutron scattering

1972

ZING-P and ZING-P' pulsed spallation neutron source concepts demonstrated by Jack Carpenter at Argonne National Laboratory.

1972

The Institut Laue-Langevin (ILL) in Grenoble, one of the most intense thermal neutron sources in the world, comes into operation. It exploits the use of neutron optics (guides) to substantially increase the experimental capacity of a neutron source.

1974

Small angle neutron scattering shows that polymer chains in the liquid state have a random coil conformation, as predicted by Paul J Flory who wins the Nobel Prize for Chemistry for his fundamental achievements in understanding macromolecules.

1984

The ISIS pulsed spallation neutron source opens at the Rutherford Appleton Laboratory. It is the first major neutron user facility based on a high-energy proton accelerator.

1987

J. Georg Bednorz and K. Alexander Müller receive the Nobel Prize in Physics for discovery of high temperature superconductors. Later, neutron spectroscopy shows that magnetic interactions are crucial to this phenomenon.

1991

Pierre-Gilles de Gennes receives the Nobel Prize in Physics for his work on liquid crystals and polymers. Neutron spin-echo spectroscopy was used to validate his models of the snake-like polymer reptation dynamics of polymers.

1994

Clifford Shull and Bertram Brockhouse receive the Nobel Prize in Physics for pioneering the development of neutron scattering techniques that can show "where atoms are" and "what atoms do".

2001

ILL Millennium upgrade begins with over a 20-fold increase in detection rate within a decade.

2009

Next-generation accelerator-based pulsed neutron sources come online in the UK (ISIS Target Station 2), Japan (J-PARC) and, USA (SNS) opening up new areas of science.

2010

Lund, Sweden, is chosen as the site for the European Spallation Source. Construction is planned to be completed by the end of the decade.

The information in this brochure is just a sample of the significant social and economic impact that neutron scattering science contributes to our lives. Because of the collaborative nature of modern research, many of the experiments, research and development programmes are joint efforts between UK Research Councils, academia and industry.

The Science and Technology Facilities Council (STFC) ensures that research using neutron scattering continues to make a valuable contribution to society through its ongoing funding and development of the ISIS Neutron and Muon Source in the UK and the Institut Laue-Langevin in France.

BBSRC · EPSRC Pioneering research and skills · Arts & Humanities Research Council · MRC Medical Research Council · Research Councils UK · Natural Environment Research Council · wellcome trust · Science & Technology Facilities Council

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Science & Technology Facilities Council