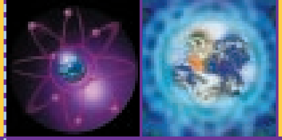


Probing the microscopic structure of condensed matter with neutrons

An application using Oxford Instruments Superconductivity's combined cryogenic and magnetic environments

Ian Bailey and the Sample Environment Team at the ISIS facility, Rutherford Appleton Laboratory, Oxfordshire, UK, support an international community of around 1600 scientists carrying out neutron scattering research in physics, chemistry, materials, geology, engineering and biology.

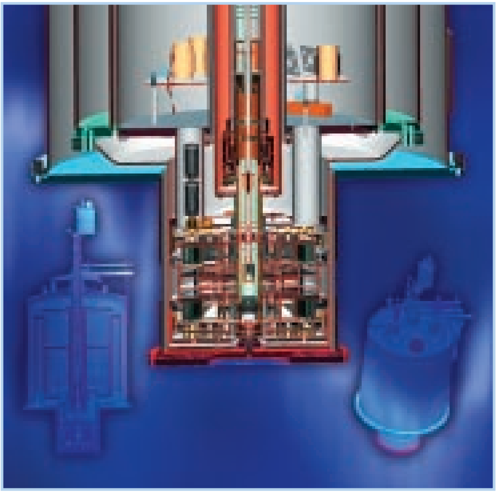
Oxford Instruments Superconductivity's combined cryogenic and magnetic environments, together with the ISIS spallation method of generating neutrons, provide new opportunities for exploring the microscopic structure of condensed matter.

The neutron is an ideal probe for studying both the arrangement and dynamics of atoms, or molecules, in materials. The interaction of neutrons with a nucleus is known exactly, facilitating the direct, unambiguous theoretical interpretation of experimental data. Neutrons also easily penetrate thick materials offering unique possibilities for materials testing and for observing materials under extreme conditions of temperature, pressure and/or magnetism. Neutrons, in addition, interact strongly with magnetic atoms making neutrons central to the study of magnetism.

At ISIS, neutrons are generated through the spallation process where a heavy metal target is bombarded with pulses of highly energetic protons from a powerful accelerator, driving neutrons from the nuclei of the target atoms. This results in an extremely intense neutron pulse with neutron brightness that exceeds most advanced steady state sources.

The advantage of high fields

High field magnets greatly enhance neutron scattering research opportunities at the ISIS facility. They can be used to directly, and cleanly, manipulate quantum states and induce new physical phenomena in quantum magnets, novel superconductors and other correlated-electron systems. Recently the condensed-matter research community has focused on strongly correlated electron systems, such as high temperature superconductors (HTSC), quantum magnets, colossal-magnetoresistive manganites, spin-frustrated systems and heavy fermion (HF) materials. These are characterised by a complex phase diagram where small changes in a given parameter can drive the system into a rich variety of exotic phases. Magnetic field is a particularly useful parameter in exploring competing phases through bulk measurements. When combined with ultra-low temperatures, such as with a Kelvinox™ ^{3}He/^{4}He Dilution refrigerator, a wealth of additional magnetic and electronic phases can be explored.



Schematic of cryo-magnet system

... in a variety of applications

High field neutron scattering is particularly useful for the study of HTSCs, heavy fermion superconductors and organic superconductors. Greater field strength enables a larger number of superconductors to be studied above their upper critical fields where superconductivity is suppressed. Neutron scattering, for example, has contributed to knowledge of anti-ferromagnetism and observations of spin fluctuations in HTSCs[1]. High fields are also essential in studying the process involved in colossal magnetoresistance in manganites, which have potential applications as transducers and field sensors. In materials such as $La_{2-2x}Sr_{1+2x}Mn_2O_7$ and $La_{1-x}Ca_xMnO_3$, for example, the paramagnetic insulator to ferromagnetic conductor transition is increased in high magnetic fields and is accompanied by a large magnetostriction.

The ISIS system recently supplied by Oxford Instruments Superconductivity consists of a 10 Tesla superconducting magnet, a cryostat with a tail section to house a split pair magnet, and an enhanced variable temperature insert (VTI). The VTI is integral to the cryostat, consisting of heat exchanger, feed capillary, external pump and a sample chamber mounted in the central vacuum bore of the cryostat. An intermediate radiation shield separates the VTI and main bath facilitating temperatures as high as 300 K without any impact on helium boil-off in the main bath.

The system has been especially designed to allow the passage of a beam of neutrons through the magnet to the sample chamber, which is free of liquid cryogens. “The 10 Tesla magnet is, so far, demonstrating better performance than our older 7.5 Tesla magnet,” says Ian Bailey. “The system is far easier to control and has a quicker response time – a function of the variable temperature insert, which provides a better temperature gradient over the samples being studied. Most of the magnetic transitions that researchers are interested in occur at very low temperatures and the combination of high magnetic fields and low temperatures is helping to study these fascinating phenomena in more detail.”

The 10T cryo-magnet exposed

Specifications

Cryogenic	
Basic temperature range	1.5 K to 300K
Temperature stability	better than ± 0.05K throughout the temperature range
Automatic temperature control	3K to 300K
Large sample space diameters	49 mm
Very low helium gas pressures in the sample region	15 mbar at 300K
Helium consumption (Helium volume 55 L)	350 cc/hr
Nitrogen consumption (Nitrogen volume 60 L)	500 cc/hr
Split Pair Magnet	
Maximum central magnetic field at 4.2 K	13.5 Tesla
Maximum central magnetic field at 2.2 K	15 Tesla
Homogeneity (over 10 mm diameter spherical volume)	5 parts in 1000
Current decay in persistent mode	1 part in 104 per hour
Split	15 mm
Split angles	± 2 degrees
Neutron access	330 degrees
Ultra Low Temperature Options	
Heliox VT	Base temperature up to 0.3 K
Kelvinox VT	Base Temperatures up to 25 mK

References: S.C.Zhang, Science 275,1089 (1997)

THE QUEEN'S AWARDS FOR ENTERPRISE: INNOVATION 2003

Reference No: DFC OI641/0903

UK sites of Oxford Instruments Superconductivity Limited, operate a Quality Management System approved to the requirements of BS EN ISO 9001.

Certificate No Q4118

Oxford Instruments Superconductivity

UK
Tubney Woods, Abingdon
Oxfordshire OX13 5QX
Tel: +44 (0)1865 393 200
Fax: +44 (0)1865 393 333

China
Rm. 14-F, No.1 Plaza
No.800 Nanjing East Road
Shanghai 200001
Tel: +86 21 63608530/1/2/3
Fax: +86 21 63608535

Germany
Otto-von Guericke Ring 10
D-65205 Wiesbaden
Tel: +49 6122 937 171
Fax: +49 6122 937 175

Italy
Via Leone Tolstoi 86
20098 San Giuliano
Milanese
Milan
Tel: +39 02 98 2215
Fax: +39 02 98 2414

Japan
Haseman Building
2-11-6 Tomioka, Koto-ku
Tokyo 135-0047
Tel: +81 03 5245 3261
Fax: +81 03 5245 4472

Spain
Avda Mata Piñonera, 2
28700 San Sebastian de los Reyes
Madrid
Tel: +34 91 659 0740
Fax: +34 91 654 6794

U.S.A.
130A Baker Ave. Ext.
Concord, MA 01742-2121
Tel: +1 978 369 9933
Fax: +1 978 369 6616

E-mail:
superconductivity@oxinst.co.uk

Visit our web site at
www.oxford-instruments.com

OXFORD INSTRUMENTS