RAL DESIGN & DISCOVERY
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SCIENCE AND ENGINEERING RESEARCH COUNCIL

SCIENTIFIC SCOPE OF THE MUON FACILITY

The positive muon provides a universal probe for materials research in that there are very few restrictions on the suitability of the host for implanted muon spectroscopy. The muon acts primarily as a 'microscopic Gaussmeter', the μSR frequencies displaying the local bipolar or hyperfine fields at particular sites within the lattice. Magnetic structures may therefore be determined, but because in contrast to magnetic resonance or Mossbauer methods, the muon generally occupies an interstitial site, μSR provides information from a new vantage point, providing an ideal complimentary tool to other techniques.

By virtue of the muon lifetime (2.2 μs), μSR also allows dynamical phenomena to be followed on a new timescale which is inaccessible to magnetic resonance and which conveniently bridges the gap to that accessible by neutron scattering.

Other experiments exploit the fact that the muon, whilst having the same charge and spin as the proton has only one ninth of its mass. From the point of view of solid state physics and chemistry, the positive muon can be considered as a light isotope of hydrogen. It provides severe tests of theoretical models for example the behaviour of hydrogen in metals. Neither NMR or neutron scattering is capable of observing proton behaviour in metals to low temperature or extreme dilution accessible to muon studies.

μSR has revealed information on the interplay of magnetic ordering and superconductivity in the new high Tc superconductors. It has proven to be the most appropriate probe of such low magnetic moment systems. In high Tc superconducting states, implanted muons sample the internal fields randomly on the scale of the characteristic length for flux penetration and the vortex lattice parameters.

In molecular materials, μSR has revealed the importance of zero point motion and dynamic effects in determining molecular structures. Many interesting scientific studies can also be carried out using negative muons which are also available from the ISIS source. Wide spread interest in muon catalysed nuclear fusion of DT mixtures has led to an experimental program benefiting from the advantages of the pulsed nature of the source.

Atomic physics studies underway include the measurement of the 1S-2S transition frequency in muonium μ^+e^- in vacuum to a precision of 1 part in 10^9. Such a measurement provides a stringent test of quantum electrodynamics and incorporating a pulsed laser system as it does, can only be carried out on a pulsed muon source.

The ISIS muon source has attracted such international interest since it was commissioned in 1987 that major expansion plans have now been funded by the EC and Japan. These will realise a major world class facility unrivalled well into the next decade.

THE ISIS PULSED MUON FACILITY

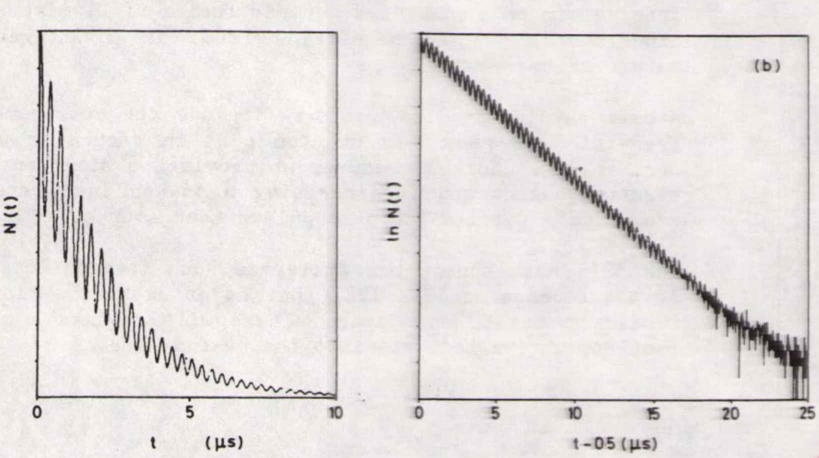
The ISIS Muon Facility is the world's most powerful pulsed muon source. The present beam-line and instrumentation is the product of international collaboration, having been funded by the European Community, France, Germany, Italy, Sweden and the UK with significant contributions from Japan. The pulsed nature and high intensity of the source present unique opportunities for researchers to use the muon as a universal probe in Atomic, solid state and chemical physics. The principal technique used for these studies is Muon Spin Rotation or Relaxation.

THE μSR TECHNIQUES

Spin polarised positive muons are implanted in a sample or 'target' at the focus of the beamline. They decay inside the sample with $\tau_\mu = 2.2$ μs, emitting positrons preferentially along their spin direction. This is the basis of the three μSR techniques, muon spin rotation, relaxation and resonance. In Muon Spin Rotation experiments, signals are obtained of the form

$$A(t) = A_o G(t) \cos \omega_\mu t$$

Here A_o characterises the asymmetry in positron emission (0.15-0.3 depending on geometry). The Larmor precession frequency, $\omega_\mu = \gamma B_\mu$ ($\gamma = 2\pi.135$ kHz/mT), gives the field acting on the muon directly, whether this is a spontaneous internal field in ordered magnets, or close to the externally applied field as in paramagnetic studies. G(t) is a damping or depolarisation function which reflects the distribution or fluctuation of the local fields or motional effects. This function is the primary source of information in the magnetic and diffusion studies summarised below. μSR is in fact unique in its ability to determine G(t) even in the limit of zero frequency, ie when the average field at the muon site is zero. This is the basis of Muon Spin Relaxation. The characteristic frequencies ω_μ may also be accessed by inducing transitions of the muon spin with an RF field, or via cross-relaxation to another spin species. This is the basis of Muon Spin Resonance.



Test μSR spectrum accumulated from 8 million muon decays recorded in an aluminium sample (room temperature, 20 mT applied field). The effective positron count-rate versus time is displayed on linear scales in (a) and the same data, revealing the behaviour at long elapsed time, on log-linear scales in (b). The muon radioactive lifetime is 2.2 μs.