TRIUMF

Canada's national laboratory for particle and nuclear physics and related sciences is operated through a contribution from the National Research Council of Canada.

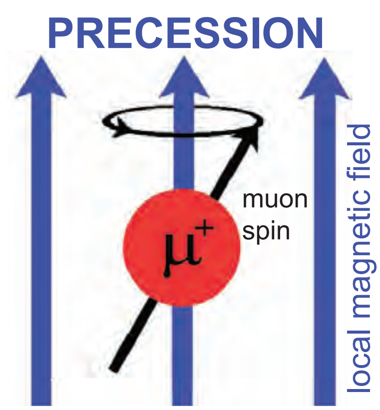
μSR: Muon Spin Resonance

Using muons to probe other kinds of matter

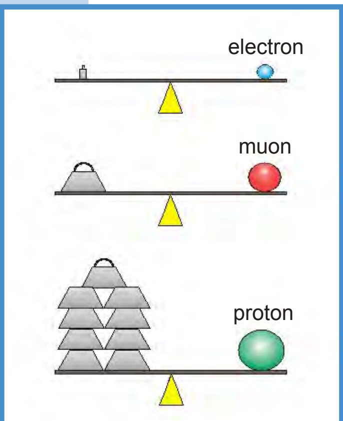
Ever since the invention of the microscope, scientists have been peering deeper and deeper into the world around us. During the past century, new and better techniques for looking inside materials have been found, including X-ray diffraction, electron microscopes and neutron scattering. Scientists at TRIUMF are using another technique to examine materials, called μSR (pronounced "mew-ess-are"), which has become a unique and powerful probe to peer into and gain a deeper understanding of what goes on inside materials like semiconductors, magnets and superconductors.

In the acronym μSR, the "μ" stands for "muon" (μ is the greek letter "mu"), "S" is for "spin", and "R" can stand for a number of words, including but not limited to rotation, relaxation, resonance or research. The acronym is meant to draw attention to the analogy between μSR and the more commonly know techniques of NMR (nuclear magnetic resonance) and ESR (electron spin resonance). Whereas NMR utilizes the spins of ordinary atomic nuclei, μSR is a collection of methods that use the muon's spin to examine structural and dynamical processes in bulk materials on an atomic scale.

The broadest application of the μSR technique is as a magnetic probe. Beams of positive muons are created with their spins lined up in the same direction. When these beams are shot into a material, the muons' spins precess (wobble like a top) around the local magnetic fields in the material (see image, right). The unstable muons soon decay into positrons; since these anti-electrons tend to be emitted in the direction of the muons' spin, μSR scientists can examine how the internal magnetic fields of different materials have affected the muons' spins by observing the directions in which the positrons are emitted.

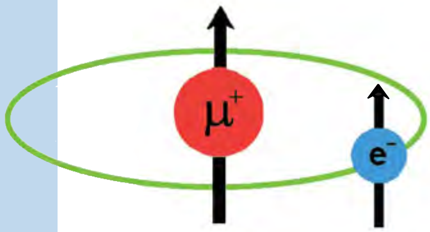


Another application of the μSR technique is to examine the properties of hydrogen inside different materials. Muonium is very



Did you know?

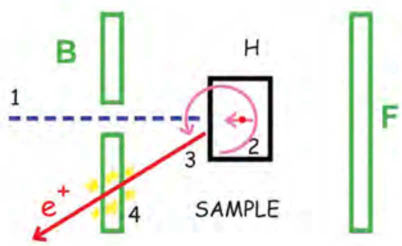
Scientists consider negative muons to be heavy electrons, but positive muons act more like light protons. Muons are unstable particles 200 times heavier than electrons. Negatively charged muons are so much like electrons that they are rarely used in μSR because they get trapped in atoms. Instead, μSR usually uses positively charged muons, which solid state physicists and chemists generally think of as light protons, as they have only one-ninth the mass of normal protons.



much like hydrogen, except that the electron orbits around a muon instead of a proton. By looking at the chemical reactions of muonium atoms, μSR scientists can examine how hydrogen atoms would react in various materials. This research is especially important in semiconductors since hydrogen influences their conductive behaviour.

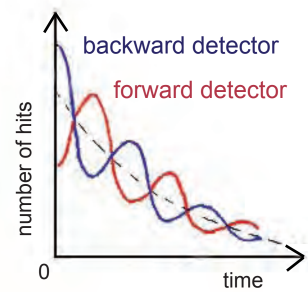
Generally, researchers use the μSR technique to tackle fundamental problems in condensed matter physics and chemistry that they cannot investigate through other means. One advantage of μSR is that muons can be implanted into virtually any material. This makes it especially good for probing inside superconductors, since many other probes cannot penetrate them without disturbing their properties.

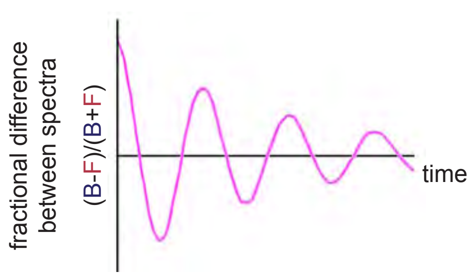
TRIUMF's μSR facility is the only one in the Western Hemisphere. The μSR community is the largest at TRIUMF and contributes important research to materials science and condensed matter physics. For more detailed, technical information about μSR, visit http://musr.org/intro/musr.



A beam of muons (1) enters the sample and stops. The muon spins precess about the local magnetic field, H (2). When a muon decays, it emits a positron (3) in the direction of its spin. This positron is detected as it goes through either the (F)orward or (B)ackward counters (4).

The number of hits at different times is plotted for each detector (F and B). Superimposed upon the exponential decay of the muon is an oscillation showing extra counts as the muons' spins sweep past the detector like a precessing lighthouse beam.





By taking the difference between the two detector signals divided by their sum, one can measure the frequency of the muons' spin precession. When different muons precess at different frequencies, the amplitude of the precession signal decays (spin relaxation). The frequency and relaxation rate tell μSR scientists about the local magnetic fields inside the sample.

ENDURING VANCOUVER FOUNDATION

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