Bilby getting into “hard” physics

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“Bilby”, the time-of-flight, small-angle neutron scattering (SANS) instrument, at the Australian Centre for Neutron Scattering is the machine to investigate structures at the nanoscale. These studies are often in soft condensed matter or biologically relevant materials like proteins, self-organised lipid assemblies and biological macromolecules. However, the SANS instrument also plays a vital role in solid-state physics and materials science including studying additives in modern materials, ferromagnetic correlations and the formation of large topological objects in correlated electron systems like skyrmions or artificially structured materials.

For over 20 years, physicists have been using SANS to study how magnetic fields penetrate through superconductors. As magnetic flux penetrates a type-II superconductor a sublattice of Abrikosov vortices (also called flux lines, flux tubes, or fluxons) develops, and each flux line carries a quantum of magnetic flux. These tiny vortices of supercurrent tend to arrange themselves in a triangular flux-line lattice (FLL). Many properties of the FLL are well described by the phenomenological Ginzburg-Landau theory or by the electromagnetic London theory, which treats the vortex core as a singularity.

Studying the geometry and the dimensionality of the FLL, and the properties of individual Bragg-like peaks allows researchers to investigate critical properties of superconductors such as the magnetic penetration depth, the shear and tilt modulus of the FLL and the importance of pinning centres as a function of temperature and or applied field. These results help distinguish between models and help researcher develop better materials for technologists in the future.

Flux line lattice measurements

In August 2017, researchers from the Australian Centre for Neutron Scattering, Australia and the National Synchrotron Radiation Research Centre, Taiwan measured the first FFL on BILBY opening up the way for studies of other superconductors and magnetic systems.

Nb is a well characterised material (for example, “Vortex Lattices in Superconducting Niobium and Skyrmion Lattices in Chiral MnSi: An Investigation by Neutron Scattering” by Sebastian C. Mühlbauer from the Technische Universität München [1]), and therefore has been chosen for the test.

Figure 1 shows in details the experimental set-up and the typical SANS image from the vortex lattices.

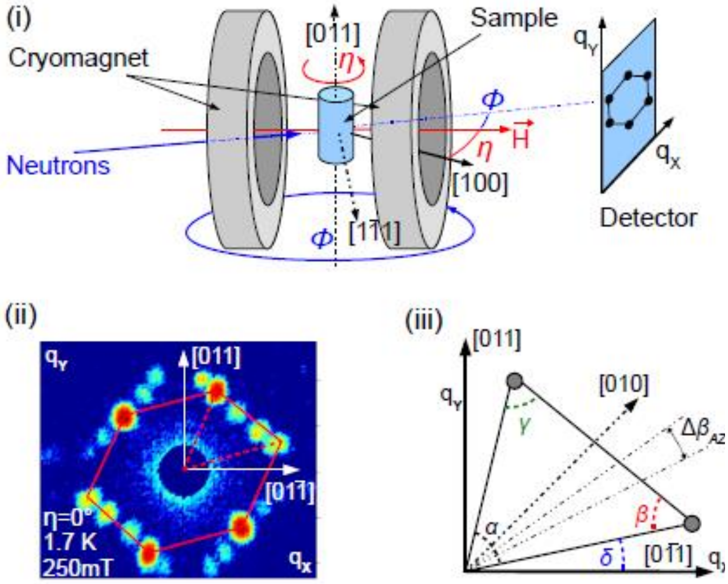

Figure 1. SANS set-up and a typical pattern from vortex lattices in Nb

Panel (1): S mall angle neutron scattering set up. Φ denotes the angle between the incoming neutron beam and the magnetic field, while η denotes the angle between magnetic field and the crystallographic [100] direction. Panel (ii): Typical detector image in the scalene vortex lattice phase,. For clarity just one domain is marked in red. Panel (iii): the nomenclature describing the vortex lattice: α, β and γ represent the internal angles of the half vortex lattice unit cell, δ represents the tilting angle of the vortex lattice unit cell, with respect to the horizontal $[00\bar{1}]$ axis. The azimuthal instrumental resolution is denoted $\Delta\beta_{AZ}$.

To observe the vortex lattice scattering, BILBY has been set in time-of-flight mode, ~9.2% Δλ/λ on the rear detector. Sample-detector distances for the rear detector, top and bottom, and left and right curtains were set to 16m, 5.2m and 4.2m, respectively. The smallest, 2.5mm diameter, sample aperture, has been used.

By default, in ToF mode BILBY is collecting data on the wide wavelength range, from 2 to 20Å. Though during the data reduction, the wavelength range is being adjusted taking into account some specific features of the collected data. For the large Nb crystal mounted on a thick Al stick inside the magnet, there are two issues appeared. One is been caused by so called Bragg edge scattering by Al stick. The Bragg edge is clearly visible on the transmission plot, see figure 2. The second issue has been caused by multiple scattering of Nb itself. As a result, the range of the wavelengths between 5Å and 9 Å has been used in data reduction.

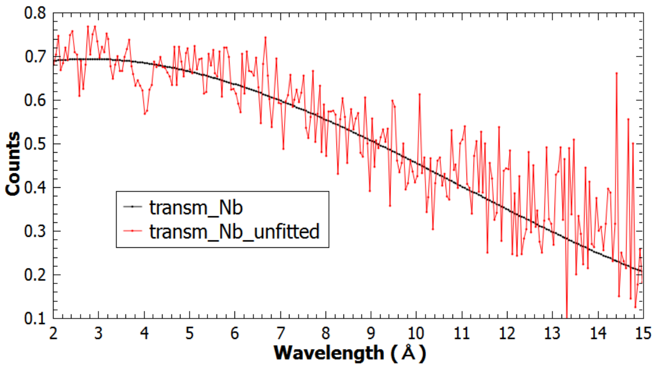

Figure 2. Nb transmission. Red line: calculated. Black line: fitted with the third order polynomial function.

Accessible *q*-range covers angles from 0.002Å^{-1} to 0.164Å^{-1}, which is wide enough to observe scattering from the flux lattices.

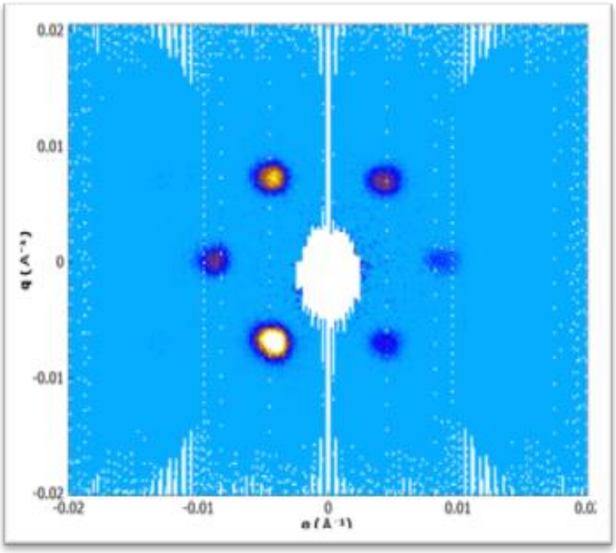

Figure 3 presents two 2D scattering patterns recorded from Nb crystal at two conditions: 1.6K and 0.33T, and 1.6K and 0.1T.

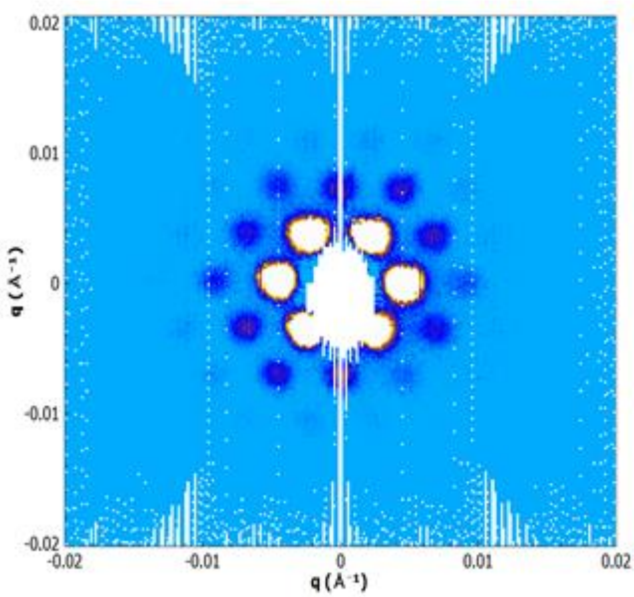

Figure 3. 2D I(q) reduced data from Nb crystal at 1.6K temperature in (top) 0.33T and (bottom) 0.1T magnetic field, at the same crystal orientation.