BIR
The British Institute of **Radiology**

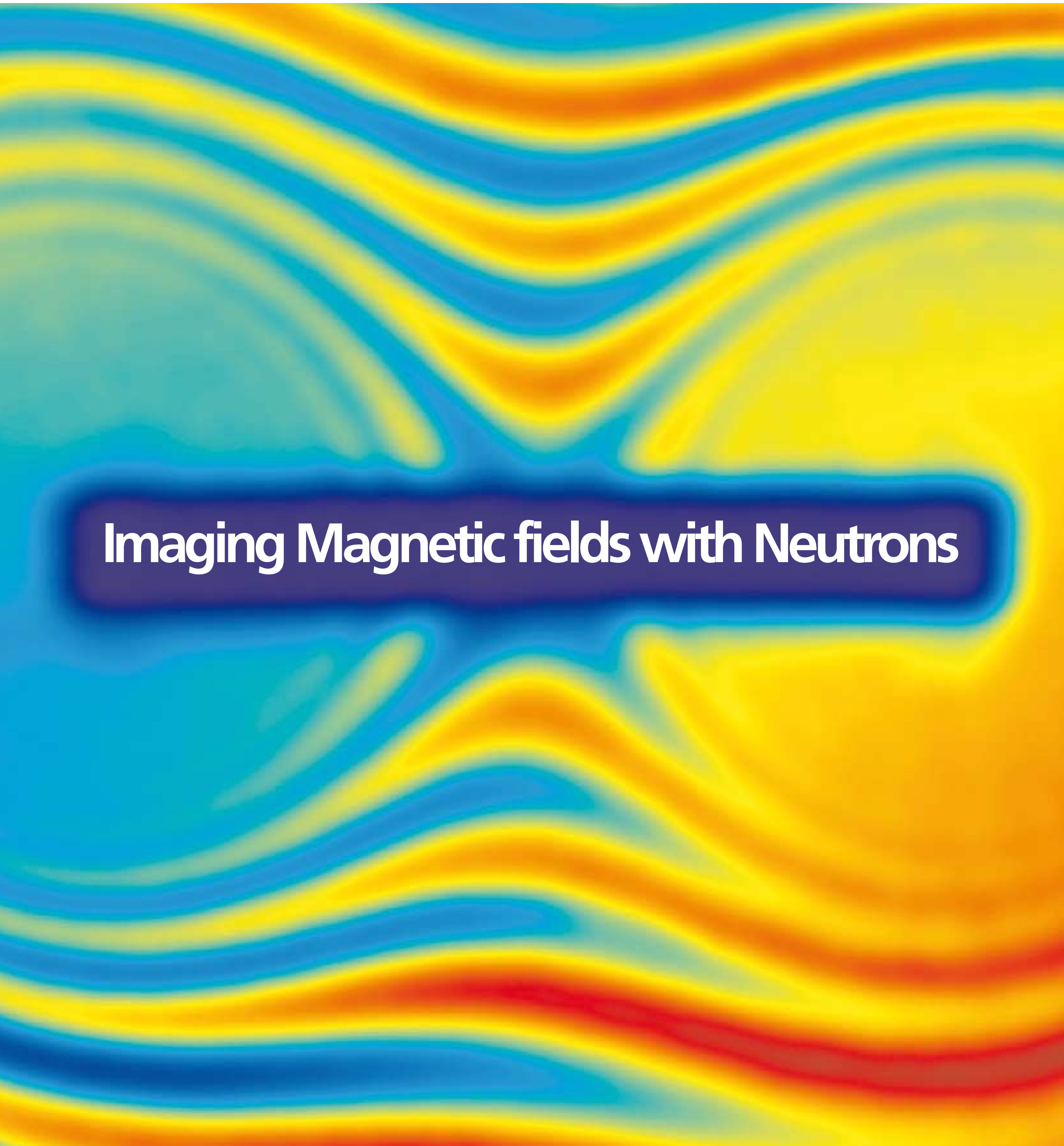
Autumn 2008

News

News and information for members

ISSN 1751-6994

Honorary Editors: Sue Marchant and Simon Blease



Imaging Magnetic fields with Neutrons

Imaging magnetic fields with neutrons

Neutron imaging dates back to shortly after the discovery of the neutron by Chadwick in 1932, and often provides important complementary information to that yielded by X-rays. Neutrons, however, also have a permanent magnetic dipole moment, making them highly sensitive to magnetic fields – a property that can be combined with standard radiographic and tomographic imaging approaches to reveal macroscopic magnetic properties. This technique has recently been developed at the Helmholtz Centre Berlin (HZB, formerly the Hahn-Meitner Institute) for the visualization of magnetic fields both within and around matter, information that is inaccessible using other methods.

Neutrons and magnetism

The principle of magnetic imaging rests upon two influences felt by neutrons in the presence of an applied magnetic field. First, the internal quantum-mechanical angular momentum, or spin (which is always aligned anti-parallel to the magnetic moment), will orient either parallel (spin up) or anti-parallel (spin down) to the field. Second, the magnetic moment will begin to undergo Larmor precession around the field in a predictable manner. For a neutron traversing a magnetic field, the rate of precession depends only on the local field strength. The total angle of precession is therefore dependent on the strength of the field and the time that the neutron spends within the field (i.e. on the neutron velocity and on the path length). For a mono-energetic beam variations in the precession angle for a given path through a magnetic field are thus indicative of the distribution of the field along that path.

If the field has a significant component perpendicular to the neutron magnetic moment then precession of the moments will cause the neutron spin-state to beat between spin-up and spin-down. Such variations can be measured using a spin-polarized beam, i.e. one in which all neutrons are in the same spin-state. The polarization may be considered as the average spin over the whole beam and the flipping of spin-states will therefore cause fluctuations in the polarization. By measuring these changes it is possible to "see" the magnetic fields within a sample.

Experiments on CONRAD at the Helmholtz Centre Berlin

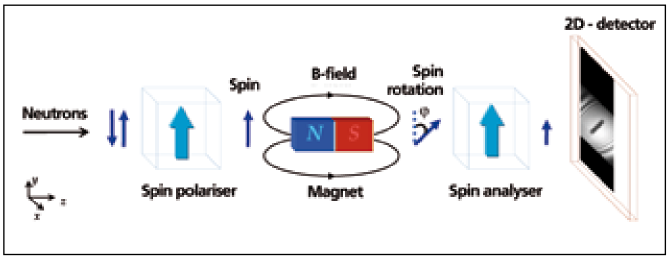


Figure 1: Schematic diagram of the set up used for imaging magnetic materials on CONRAD. The neutron beam is polarized, allowed to precess around a magnetic field, analysed, and then detected. Note how the intensity (dark blue arrow) behind the analyser is smaller than the intensity behind the polarizer.

Magnetic imaging experiments with polarized neutrons have recently been undertaken on the COld Neutron RADiography facility at the HZB. The setup used a spin-filter to polarize a neutron beam, which was then allowed to pass through a magnetic sample before being analysed (repolarized) with a second spin-filter and detected (Figure 1). The key to the image thus formed is that the analyser only transmits the component of the beam polarization that is parallel to its own polarization axis. As a

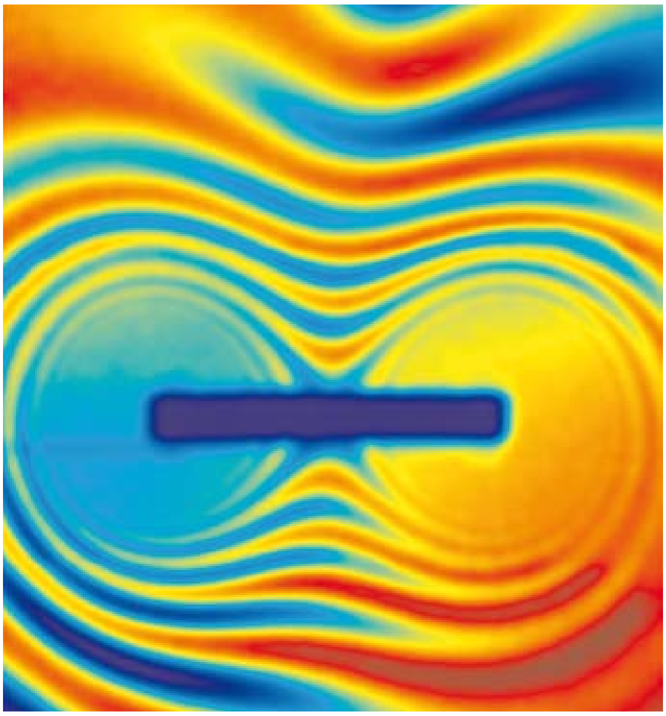


Figure 2: A radiograph showing the field lines surrounding a bar magnet. The magnetic field decreases in strength with distance from the magnet, resulting in a series of maxima and minima, where the beam polarization is sequentially parallel or anti-parallel, respectively, to the analyser. Very close to the magnets (where the field is strongest), the field lines are too close together to be resolved spatially.

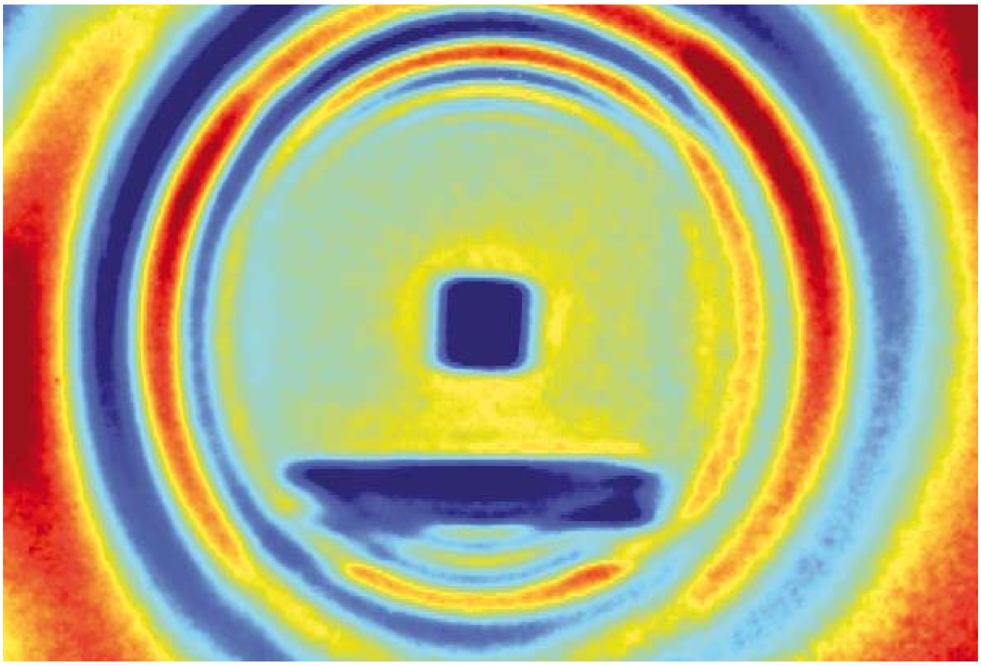


Figure 3: A radiograph showing the field lines around a bar magnet levitating over an yttrium-barium-copper-oxide (YBCO) superconductor, a result of the so-called Meissner effect. In its superconducting state the YBCO expels all magnetic fields and thus repels the permanent magnet.

result, the intensity measured behind the analyser is the initial beam intensity modulated both by conventional attenuation (the magnitude of which can be found from a standard radiograph) and by some sinusoidal function that is directly related to the angle by which the polarization has precessed. The maximum (minimum) intensity will be measured when the beam polarization and the analyser are aligned perfectly parallel (anti parallel).

This has been demonstrated with variety of magnetic systems. Figure 2 reveals the familiar pattern of field lines surrounding a simple dipole magnet, while Figure 3 shows the field around a magnet, levitating due to the Meissner effect. The technique can also be extended into three dimensions in some instances as indicated in Figure 4, which shows magnetic field trapped inside a superconductor.

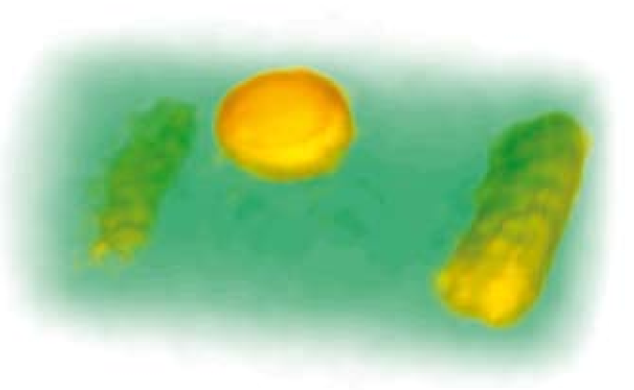


Figure 4: A three-dimensional reconstruction of trapped flux (yellow regions left and right) inside a polycrystalline cylinder of lead. When cooled to below its critical temperature in the presence of a weak magnetic field some flux is present inside due to defets and grain boundaries, and this remains trapped even after the field is switched off.

Outlook

Further investigations are already underway, which aim to optimize various parts of the experimental apparatus with a view to realizing the potential of this technique for imaging magnetic phenomena throughout science and technology. To understand high temperature superconductivity, for example, it is vital to understand how magnetic fields are established and distributed within materials.

M Dawson, N Kardjilov, I Manke, A Hilger & J Banhart, Helmholtz Centre Berlin, Germany

For further information

Please refer to Kardjilov N et al. Three-dimensional imaging of magnetic fields with polarized neutrons, Nature Physics. 2008;4:399–403. 4, pg. 399–403 (2008)