# Inside modern magnets

Neutron experiments combined with X-ray studies are leading to better permanent magnets

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IN8 – one of the instruments involved in the experiment, which has recently been rebuilt

Although iron is the most familiar magnetic material, many of today's practical magnetic devices are made from a combination of magnetic elements – so-called transition metals such as iron or cobalt, and rare-earth elements such as samarium or neodymium. Powerful permanent magnets made of samarium and cobalt ($SmCo_5$) or neodymium/iron/boron (Nd-Fe-B) compounds are in wide commercial use. The magnetic moments of the different types of atoms in these materials interact in complex ways and we still do not fully understand how. To find out more about their magnetic structure, and thus improve their performance, we need to look at 'model' systems and measure the fundamental interactions.

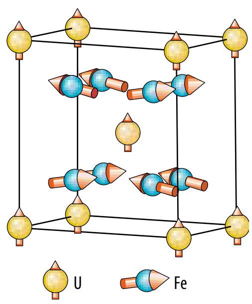
One such magnetic material is a compound containing iron, aluminium, and a rare earth (M) such as dysprosium (Dy) or holmium (Ho), or an actinide such as uranium (U). The formula is $MFe_4Al_8$, where M = Dy, Ho or U. The electrons responsible for iron's magnetism sit in the so-called 3*d* electronic shell in the atom, while in dysprosium or holmium, which are heavier elements with more electrons, they sit in the 4*f* shell. In uranium, the heaviest element, they sit in an outer 5*f* shell.

## A complex structure

We have been studying in considerable detail how the various electronic shells (3*d*, 4*f* and 5*f*) develop their ordered magnetic moments as the temperature is lowered. This has been the subject of considerable controversy in the past. Using polarised neutrons (p.6), we could obtain information about the orientation of magnetic moments. From these results, coupled with magnetic X-ray measurements made at the neighbouring European Synchrotron Radiation Facility, emerges a unified picture of the magnetic ordering process.

As we expected, the magnetic ordering is dominated by the 3*d* electrons of iron, although the type of ordering is influenced by the M atom. Surprisingly, in the rare-earth based materials the initial magnetic ordering occurs only in the array of iron atoms, whereas the rare-earth magnetic moments remains disordered. In contrast, in the uranium compound, the iron 3*d* and uranium 5*f* electron shells interact enough to cause the two sets of atoms to order at the same temperature.

The X-ray studies show that ordering in the 4*f* electrons is more complicated and involves the information being transmitted to the 4*f* shells via the intermediary 5*d* electrons of the rare-earth element, but they do order when the temperature is low enough. Through polarised neutron measurements, we showed that the 4*f* magnetic moments dance along with the (dominant) iron 3*d* moments, but with their spins oriented at an angle to those of the 3*d* moments depending on temperature. This phase angle is different for each element, and its origin is not understood. At the lowest temperatures, the rare earth moments try and align themselves ferromagnetically (all in the same direction), but the iron prevents them from doing so, and the subsequent competition gives rise to unusual behaviour in a magnetic field. These experiments are good examples of how neutron and X-ray studies together can analyse the complex magnetic structure of strategically important materials. ■




The unusual magnetic configuration of the uranium iron aluminium ($UFe_4Al_8$) compound

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