

fact, at the critical temperature (7.6 K) for bulk ferrimagnetic order, the spin-correlation length extends to about 200 Mn-radical pairs. The short-range order effects observed in these materials are unique.

[Mn(hfac)₂(NITet)], where the radical Et is an ethyl group, has a zig-zag chain structure and as a consequence a less ideal one-dimensional behaviour, as again evidenced by EPR and NMR spectra. [Mn(hfac)₂(NITPhOMe)], where PhOMe denotes a para-methoxy-phenyl group, has an interesting helical structure: it crystallizes in the P3₁ space group which means that a centre of symmetry is lacking. As such it can be expected to give rise to non-linear optical properties. There is in fact a sizeable second harmonic generation coefficient. This property is associated with the organic moiety, the metal ions being there to ensure asymmetric ordering of the radicals in the crystals. Another interesting property of [Mn(hfac)₂(NITPhOMe)] is optical activity in the paramagnetic phase. Since there must be Faraday rotation in the ordered phase it would be interesting to investigate the interplay of the two properties, which are present together in the same compound for the first time. This is a clear example of the coexistence of different properties in molecular organic magnets which is not found in the classic inorganic magnets.

The three [Mn(hfac)₂(NITR)] compounds order magnetically at 7.6 K (R = iPr), 8.4 K (R = Et), and 4.8 K (R = PhOMe). The variation in the critical temperature is associated with the structural variation, which affects the magneto-crystalline anisotropy. As the variation is brought about by changing the peripheral R group, this suggests that it may be possible to fine-tune the magnetic properties of organic magnets by controlling the chemistry [9].

Nitronyl nitroxides and rare-earth ions

Several surprises are encountered with building block **12**. From the structural point of view its derivatives form columnar compounds similar to those of the transition-metal ions, with the rare-earth ions and the organic radicals alternating in a regular way in space. The first surprise was found with [Gd(hfac)₃(NITet)]. Assuming nearest-neighbour interactions along the chains, the compound might behave either as an one-dimensional ferromagnet (for parallel alignment of the spins) or as a ferrimagnet (for antiparallel alignment of the spins) since the individual magnetic moments are compensated. However, experiments have shown that the compound behaves as an *antiferromagnet*. This can be rationalized by introducing antiferromagnetic next nearest-neighbour interactions between both pairs of radicals and pairs of rare-earth ions. In this way, a given spin is under the conflicting influence of opposing interactions, and is strongly frustrated. This situation has long been theoretically predicted, but very few compounds exhibiting frustration have been identified. Since Gd(III) is an isotropic ion with $S = 7/2$, [Gd(hfac)₃(NITet)] is an excellent example of a one-dimensional Heisenberg magnet with conflicting interactions. For the moment only the simplified Ising model has been worked out for the case of

different spins interacting also with next nearest-neighbour ones. It has been found that the ground state can be described by a configuration with two neighbouring spins in the up direction, and the two following spins in the down direction. It is also likely that for the Heisenberg case, a helical configuration will have the lowest energy.

The energy of the metal-radical interaction is ferromagnetic, with an energy of about 5 K, while the radical-radical and the metal-metal interactions are antiferromagnetic. The energy of the first is approximately 15 K while the metal-metal exchange interaction mediated by the radical is of the order of 10 K, a value which is surprisingly high for rare-earth ions where the inner 4f magnetic orbitals are well shielded from the interactions with the ligands.

The materials obtained by substituting the isotropic Gd(III) ions with, for instance, anisotropic rare-earth ions such as Dy(III) also behave as antiferromagnets. Perhaps more surprising than the observation of confusion is that [Dy(hfac)₃(NITet)] orders as a weak ferromagnet at 4.2 K. Compare this with the behaviour of simple dysprosium salts such as Dy(OH)₃ which order due to dipolar interactions as ferro- or antiferromagnets at temperatures which do not exceed 5.2 K. The Dy-Dy distances in these hydroxides are fairly small (in the range of 3 Å) while in [Dy(hfac)₃(NITet)] the shortest intra-chain Dy-Dy distances are much larger (8.74 Å) and the inter-chain ones are 10.76 Å. It seems that the weak dipolar interactions in [Dy(hfac)₃(NITet)] are enhanced by the strong magneto-crystalline anisotropy but also by correlation between the spins of the metal ions within the chains [10].

The investigation of organic ferromagnets is just beginning and the concerted efforts of

chemists and physicists are needed to fully appreciate the enormous potential arising from the impact of molecular chemistry on the solid-state physics of these novel materials. We expect that the principal lines of research in the next few years will involve attempts to increase the critical temperatures below which they become magnetic (by making more efficient three-dimensional structures) as well as more accurate investigations of material properties. It is especially in the field of the optical properties that major breakthroughs are expected.

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FURTHER READING

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LHC Endorsement Provides Backing

Eighteen of CERN's nineteen Member States meeting in an extraordinary Council on 15 April endorsed a resolution envisaging participation by non-member states and the creation of a special statute that gives them voting rights. Also endorsed were financing options proposed by C. Llewellyn Smith, CERN's Director-General. If non-member state participation materialises, CERN's next large accelerator — the LHC — could begin operating in 2002. The safety net is financing from CERN's ordinary budget with operation starting two years later (the four-year shutdown of LEP is the price one pays for LHC). A decision on financing can wait until 1997 when major investments begin.

The Member States clearly appreciated that there needed to be a firm statement of support for the LHC to back up the Director-General otherwise he would have a difficult time in negotiations with Japan and the USA. It is anticipated that formal voting on the LHC proposal will start at the next Council in June, shortly before proposals on LHC collaboration go to the US Congress in July. A High-Energy Advisory Sub-panel on the Future Vision of the US Program in Particle Physics, which reports to the US Department of Energy's High-Energy and Particle Physics Advisory Panel, has already announced the

preliminary conclusions of its report which will be released in May. Agreement has been reached on two points following discussions with the particle physics community:

- Collaboration in LHC "would provide important opportunities... valuable use of technical progress achieved by the Superconducting Super Collider ... and the basis for further international collaboration".
- US vitality in the field will be assured by adequate funding to support effective running of existing and upgraded facilities.

The ordering is important because the US particle physics budget has been stripped bare following wholehearted commitment to the SSC before the project's termination.

Conjecture that Germany would not support the LHC at this stage turned out to be true, although it hopes to know fairly soon the extra contributions the host countries will make. Spain did not endorse the resolution as it owes CERN some 150 MSFR, equivalent to two annual contributions, having contested the industrial returns. Council offered a 20% reduction in its contributions over the next 5 years provided the arrears are settled by June and the savings spent on building up the country's high-energy physics community, which Spain says is too small in relation to the CERN contribution.