The use of nanoscale magnets for technological applications such as information storage or quantum computing requires monodisperse magnets that can be addressed individually. A major step towards achieving this goal came recently with the discovery of molecules that function as identical magnets, and the ability to deposit a monolayer of these molecules on a suitable substrate. At low temperatures these single molecule magnets (SMMs) exhibit fascinating quantum mechanical behaviour that dramatically effects macroscopic properties such as magnetization. These include the observation of quantum tunnelling of the magnetization (QTM), topological quantum phase interference, and quantum coherence. However, the small quantity of magnetic material present in a monolayer (or sub-monolayer) implies that it is virtually impossible to accurately determine their magnetic properties with conventional bulk techniques. However, depth-resolved $\beta$-detected NMR ($\beta$-NMR), which has $\approx 10^{13}$ orders of magnitude higher sensitivity compared to conventional techniques. However, depth-resolved $\beta$-NMR spectra were measured by implanting the $^8$Li nuclei into sample 1 at two different energies and in the Si substrate below the Mn$_{12}$ monolayer. An example of the stopping profile of the implanted $^8$Li at two different energies is shown in Fig. 1(a). At $E = 1$ keV, where most of the $^8$Li stop within 10 nm of the surface of Si, the dipolar field from the Mn$_{12}$ moments is large. However, at $E = 28$ keV the average $^8$Li implantation depth is $\sim 250$ nm, and the dipolar field at this depth is negligible; hence, the local field experienced by the $^8$Li is simply the applied uniform field $H_0$. As a result the measured resonance line at 1 keV is significantly broadened compared to that measured at 28 keV, as clearly seen in Fig. 1(b) at $T = 3.2$ K. Furthermore, the resonance measured in sample 2 at $E = 28$ keV and $T = 3.2$ K is identical to that measured in sample 1 under the same conditions, and the broadening observed in sample 2 is much smaller at $E = 1$ keV. This demonstrates that low energy $\beta$-NMR spectroscopy is sensitive to the magnetization of the Mn$_{12}$ monolayer. In particular, the $^8$Li nuclei implanted into sample 1 at low $E$, and hence stop close to the Mn$_{12}$ molecules, experience a large distribution of magnetic fields, which are attributed to the dipolar fields from the Mn$_{12}$ monolayer.

The observed broadening of the resonance line at low implantation energies, compared to high implantation energy, enables the determination of functional form of the dipolar magnetic field from the Mn$_{12}$ moments experienced by the $^8$Li. This is found to follow a power law decaying function with power $\sim -3$ as expected from its dipolar nature. It also provides a measure of the size of the magnetic moment of individual Mn$_{12}$ molecules. The main finding of our study is that the temperature dependence of the size of magnetic moment on a Mn$_{12}$ molecules is dramatically different from bulk. In particular, at low temperatures ($\sim 3.2$ K) the magnetic moment in the monolayer is estimated to be $5 - 12 \mu_B$ compared to $20 \mu_B$ in bulk.

Publications:

Conferences and Seminars: