Making molecular magnets

These days, magnetic memory is everywhere. Hidden inside your smartphone, your laptop and even your credit card, billions of tiny magnetic stripes store information in the form of 1's and 0's; the language of our digital age. But recent research from Professor Sally Brooker's team at the University of Otago is looking at magnets in a new way. They have developed and immobilised magnets each made from a single molecule that could open up a world of high-density data storage, and futuristic computers.

Short on storage

Typically, magnets are made up of regions called domains, which, in reality, are clustered groups of atoms or molecules that are aligned with one another. Because these regions are separated by domain walls, each one can store a single 'bit' of information; so to store lots of data, we need lots of domains. But in this era of miniaturisation, size is everything, and the only way to squeeze more data in, is by making the domains themselves smaller. This is exactly where the Otago team's work comes in – instead of relying on groups of molecules, their single molecule magnets, or SMMs for short, could store information on just one.

So, what do they look like? "Our SMMs are macrocycles – large rings of organic fluff – that surround three transition metal ions and one lanthanide ion," said Professor Brooker, "and it's this structure that allows us to control their chemistry." 'Large' is very much a relative term here – the ring measures just 1.3nm across, equivalent to one-millionth of a millimetre. The big ring structure developed by Professor Brooker and her co-worker, Dr Humphrey Feltham, makes these SMMs very robust. Unlike many other molecular magnets in development, theirs retains its structure when dissolved – vital for processing into practical, scalable SMM devices.

Collaboration is key

Professor Brooker and Dr Feltham have worked on SMMs for a number of years, collaborating with Professor Annie Powell (Germany), Professor Rodolphe Clérac (France) and Professor Chibotaru (Belgium). Their first paper was featured on the cover of the Chemistry a European Journal, and has been highly cited (111 times since 2011). But it was during Dr Feltham's first post-doc, funded by the MacDiarmid Institute, that they had their latest breakthrough. Working with Professor Brooker's colleague Dr Carla Meledandri, they successfully attached their magnetic molecules to the surface of gold nanoparticles. The design of the connection between them ensured each nanoparticle was covered by a single layer of SMM. Then, using the Institute's SQUID magnetometer in Lower Hutt, they demonstrated that their molecule retained its unique magnetic behaviour once immobilised on the nanoparticle. A very exciting day at the lab!

Professor Brooker visited the world's leading SMM researcher, Professor Roberta Sessoli (Florence), and this result really caught the Italian team's attention. "This is the team that discovered the very first single molecule magnets in 1993," recalls Professor Brooker. "They can choose to work with any group they want, so we are very excited to be now collaborating with them in order to characterise our new material in more depth."

Sally Brooker and her research group

Cool customers

For most practical applications, magnetic storage materials need to retain their magnetisation for 10 years – right now, single molecule magnets are some way from that. Even at the incredibly low temperature of 1.5K (-271.65°C), the best lifetimes are only a couple of years, so they are not economically viable at present.

"It's important to remember that back in the day, it was thought computers could never be smaller than a room, or weigh less than several tonnes," Professor Brooker said. "Due to the low temperatures required, superconductors weren't considered practical at first either, and now they're vital to countless technologies… so don't write these magnets off!"

Data-mine

There is plenty of reason for her optimism – the payoff of the success of this technology could be huge. Because every molecule behaves like a separate magnetic domain, SMMs have the potential to store unimagined quantities of data in fantastically small volumes. In fact, one paper suggests that while every cm² of today's best memory devices can store 200GB (enough to store more than 80,000 books), single molecule magnets could manage more than 3TB per cm²… that's at least 150 times more information stored in the same space.

Looking even further ahead, SMMs could also have a role to play in the next generation of quantum computers. Because of their small size, these molecules can make use of a weird effect called 'quantum tunneling of magnetisation', whereby, instead of each domain storing either a 1 or a 0, it could store both at the same time. This seemingly small change could have massive implications – it would be as if, using the same 26 letters of the alphabet, we could suddenly spell billions of words instead of a few hundred thousand. To put it simply, this could change the world.

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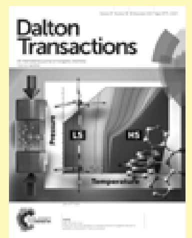

S. Brooker, J. L. Tallon and co-workers

Dalton Transactions
Pressure induced separation of phase-transition-triggered-abrupt vs gradual components of spin crossover, Dalton Transactions, 2015