Johanna Galloway

Magnificent magnetic bacteria

The magnetic disc of a computer hard drive

Key words

magnet

bacteria

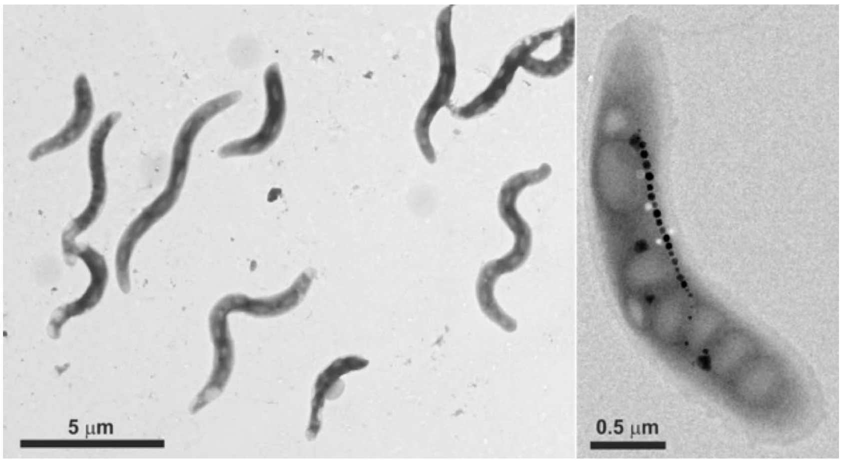
biomineral

computer memory

It takes a lot of rare natural resources and energy to make a mobile phone, laptop or computer, the modern technology we use every day. That is why many scientists would like to take inspiration from Mother Nature to help us to make more environmentally-friendly machines in the future. Johanna Galloway is one of them.

We've all heard of viruses in computing, but few people know that real microbes (specifically magnetic bacteria) may actually be useful in computers.

The storage of data in smartphones, laptops or computers uses magnets to record the information in binary code. Making the magnetic materials that are used to store this code usually needs expensive specialised equipment, high-temperature processing and scarce (often poisonous) minerals, which is not very environmentally-friendly. That is why we want to use magnetic bacteria to help us make magnets for computer memories.



Electron microscope images of magnetic bacteria; we can see magnetic particles that are too small to see with a light microscope (5 µm = 5 × 10^{-6} m). Images from Dr Sarah Staniland (University of Leeds) and Dr Masayoshi Tanaka (Tokyo University of Agriculture and Technology, Japan.)

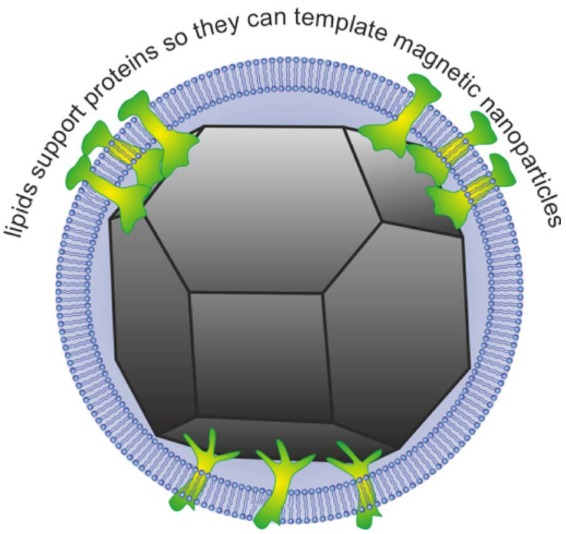
Magnetic bacteria are able to make their uniform magnets whilst happily swimming around in their natural habitat, so they could be a much greener way of making high quality magnetic components for modern technology. In my work, I study how magnetic bacteria make such good magnets, and think about how we can use them for inspiration to make computer memories of the future.

An electron microscope image of a magnetic bacterium shows magnetic field lines within the bacterium.

[From R. E. Dunin-Borkowski, M. R. McCartney, R. B. Frankel, D. A. Bazylinski, M. Pósfai, P. R. Buseck (1998). Science, vol. 282, page 1868. Reprinted with permission from AAAS.]

Why do some bacteria make magnets?

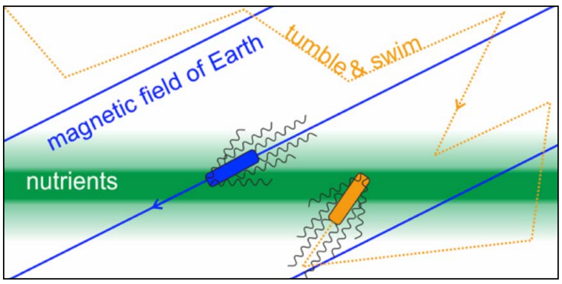
Magnetic bacteria are anaerobic – they inhabit areas that do not contain oxygen, like in deep ocean waters or in water-logged soils, because oxygen is poisonous to them. In these areas, different nutrients become concentrated at different levels, and bacteria must move around to find their optimal living conditions. Normal, non-magnetic bacteria are able to sense the presence of chemicals in their surrounding environment, a bit like our sense of smell. They move along the concentration gradients around them by randomly tumbling and swimming to try to find high concentrations of nutrients; this is called chemotaxis.



Structure of a magnetosome, showing the lipid membrane supporting proteins that template the magnetic nanoparticle inside the compartment

However, some bacteria have evolved a trick to help them navigate the layers of nutrients to find their niche – they synthesise tiny magnets so they can line up with the Earth's magnetic field. This is an example of biomineralisation. Magnetic bacteria biomineralise magnetic particles within compartments called magnetosomes that are usually about 50 nm (50 × 10^{-9} m) across. A magnetosome compartment consists of a layer of lipid fat molecules and proteins. The proteins have evolved to form a template on which the magnetic nanoparticles form; these are usually made of the magnetic mineral magnetite (Fe_3O_4). The particles are large enough to maintain their magnetism at room temperature and above, so are permanent magnets.

The size, shape and material of a magnet are all important for determining its properties. The proteins in the magnetosome work together so that the nanomagnets inside are all the made from the correct mineral (e.g. magnetite, rather than other non-magnetic iron oxides) and that they are of the same size and shape. This means they have very uniform magnetic properties.



Non-magnetic bacteria (orange) tumble and swim to find nutrients, but magnetic bacteria (blue) can align with the magnetic field of the Earth so their search is more efficient.

Other proteins organise the magnetosomes into a chain inside the bacterium so that the poles of the permanent nanomagnets are aligned. This helps the magnetic bacteria to align with the magnetic field of the Earth, just as a compass needle points north. Magnetic bacteria combine chemotaxis with this magnetic alignment to follow a concentration gradient of nutrients along the Earth's magnetic field lines which they use like paths, speeding up the process of finding nutrients. This is far more efficient than the 'tumble and swim' method used by most other bacteria, as it reduces a three dimensional search to just one dimension, a straight line.

Using magnetosomes in technology

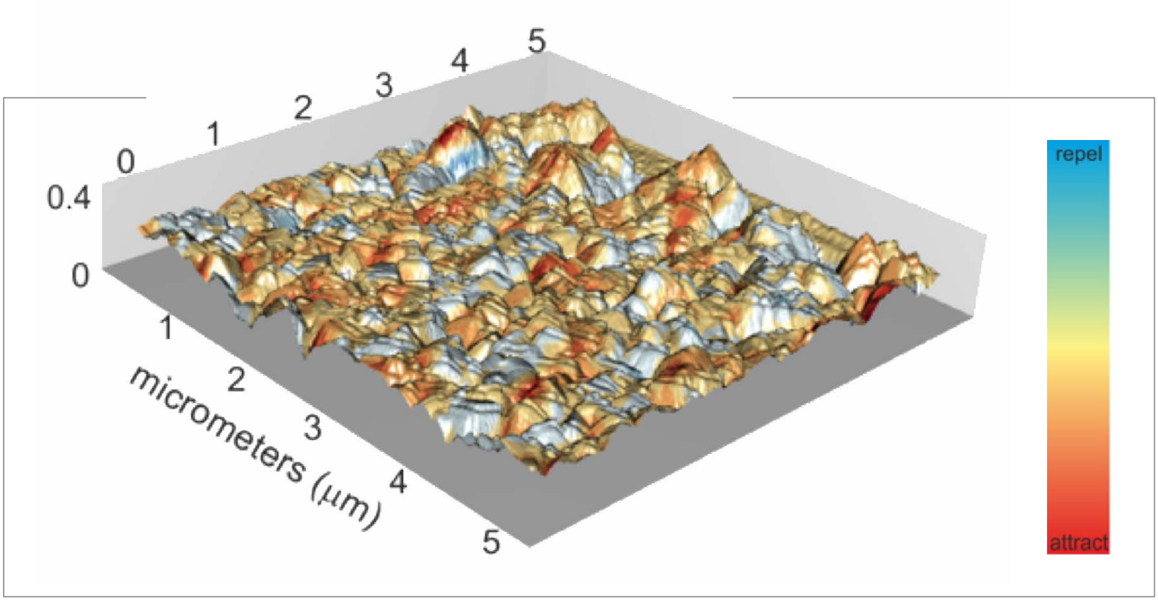
Magnetic nanoparticles are really important for many modern gadgets and technologies. For example, they can be used in medicine to treat cancer and they are used to store data in devices like computers. By studying magnetic bacteria, we hope to find greener methods of making magnetic nanoparticles for use in modern technology.

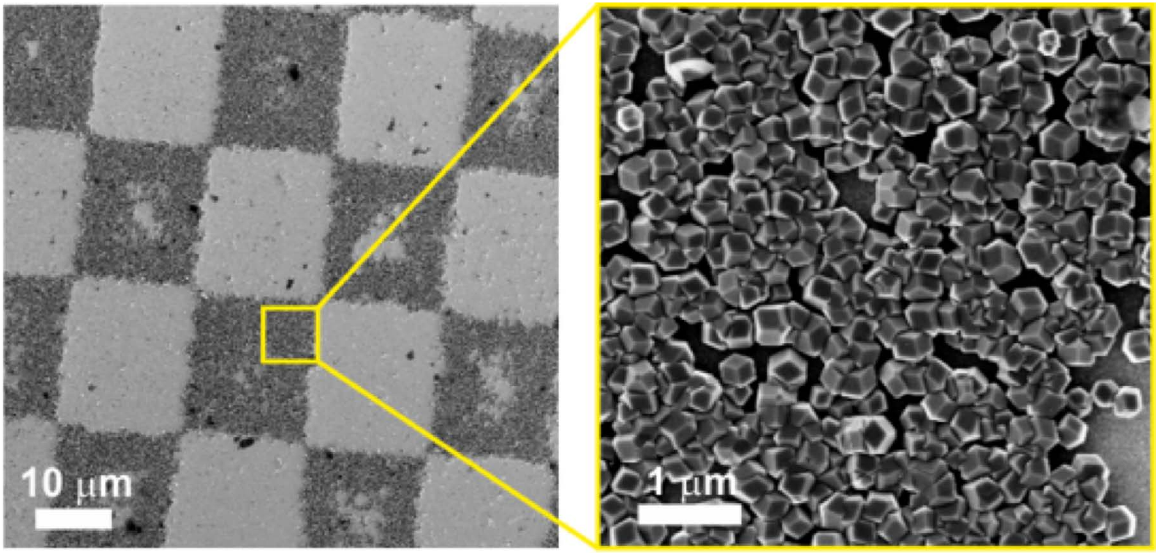
Researchers at the Université Pierre et Marie Curie in Paris, France, have shown that the magnetosomes from magnetic bacteria can be used to heat cancer cells when an alternating magnetic field is applied. The magnetosome chains were extracted from lab-grown magnetic bacteria and injected into tumours. A rapidly alternating magnetic field causes the magnetic particles in the magnetosomes to flip back and forth, so that they heat up. The heat generated can kill tumours more effectively than 'normal' synthetic magnetic nanoparticles without being toxic to the other non-cancerous cells.

Unfortunately, magnetic bacteria can be quite difficult to keep happy and grow in the laboratory because of the low oxygen levels that they like to live in. This is why our research group in the School of Physics and Astronomy at the University of Leeds is very interested in studying the biomineralisation proteins from the magnetosomes of magnetic bacteria. We are trying to find out how they work, so that we can use them to make uniform magnets; it is much easier to make a protein than to grow lots of magnetic bacteria.

Can we just use the proteins to make magnets?

In 2003, a group at the Tokyo University of Agriculture and Technology in Japan isolated proteins from the magnetosome of a magnetic bacterium. One of these proteins, called Mms6, was added to a test-tube of iron salts and alkali at room temperature. The protein controlled the size and shape of magnetic nanoparticles formed from the solution, without the need of the magnetic bacteria.





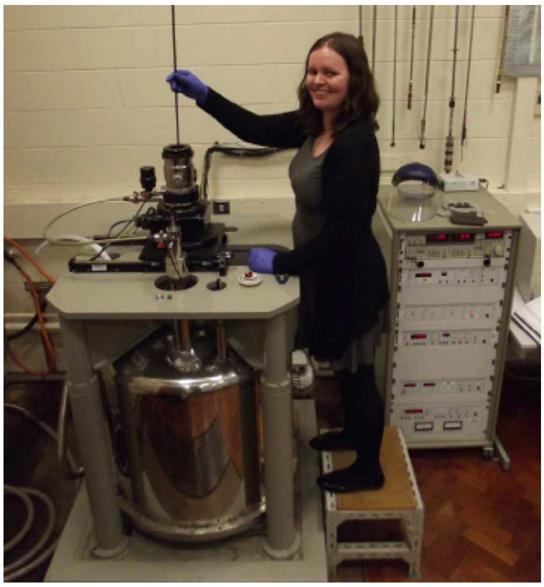
The Mms6 protein is attached to a chessboard pattern where it forms magnetic nanoparticles from a solution of iron and alkali (1 μm = 1×10^{-6} m). A very sharp magnetic probe was used to map the surface using magnetic force microscopy (MFM). This technique is able to image the height of features on the surface as well as any magnetic attraction (red) and repulsion (blue) of the particles.

Unfortunately, the magnetite nanomagnets templated by the Mms6 protein are magnetically soft – it is really easy to reverse their magnetism with an external magnetic field. The magnetic materials used in data storage must be magnetically hard to make sure that saved information stays on the magnetic recording layer. Therefore, we are working on making magnetically hard biotemplated nanomagnets on surfaces that are more suited for use in data storage.

We have shown that Mms6 can make uniform magnetic particles with increased magnetic hardness by adding elements like cobalt to the solution it is incubated with. We have also patterned the Mms6 protein on to a surface where it was able to biotemplate patterns of nanomagnets. Images of these patterned magnets show that the magnetic nanoparticles interact with each other on the surface in a similar way to magnetic particles used for recording data.

We are now trying to combine these techniques to increase the magnetic hardness of our biotemplated magnetic patterns for use in technology. One great advantage of using biomolecules like proteins to make materials is that they can assemble and heal themselves. This is very exciting, because these biomolecules could be designed to assemble themselves into the patterns we need to make the components for our future products. This means that instead of being broken by viruses or worms, green computers of the future could be able to build and fix themselves, all thanks to inspiration from these magnificent magnetic bacteria.

Johanna Galloway is in the Department of Physics and Astronomy at Leeds University.



Johanna loads a sample into a magnetometer to measure its magnetic properties.