appeared on 1st May 2013

Sparklers point the way

The lustre in the diamond is helping trace nano-magnets in bacteria, says S.Ananthanarayanan.

The diamond has a very high index for dispersing light, which makes it glint in different colours and is celebrated as a gemstone. And it has unparalleled hardness, which makes it valuable in industry and research. And it is a form of everyday carbon, so removed from charcoal at one end, or all things living, at the other, that it is a marvel to study, just for itself. Among other things, it has a face centred cubic crystal structure and is the best conductor of heat among bulk materials.

D. Le Sage, K. Arai, D. R. Glenn1, S. J. DeVience, L. M. Pham, L. Rahn-Lee, M. D. Lukin, A. Yacoby, A. Komeili and L. Walsworth, of institutes in Massachusetts and in California report in the journal, ***Nature***, an application of using the diamond crystal to detect magnetic effects within living tissue – with good resolution of detail and while the tissue is still alive - qualities that existing method do not have.

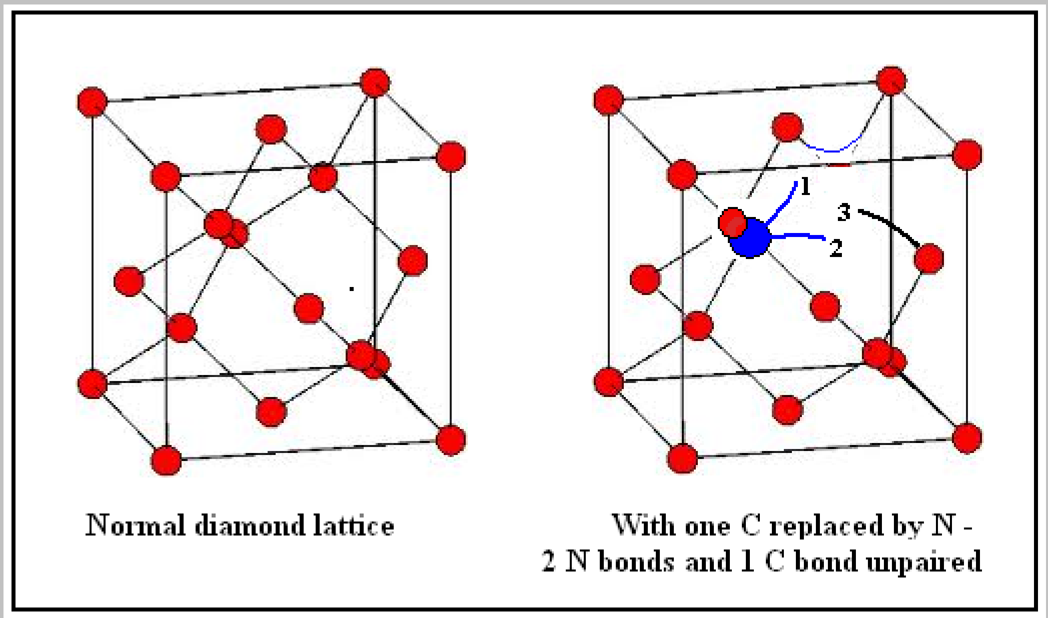
Magnetotaxis

Living things are known to mineralize and create minute magnetic particles within themselves. It is thought that these help some animals ‘sense’ the direction of a magnetic field, like the earth’s field, and navigate or orient themselves. A simpler instance is of bacteria that form magnetic bodies within themselves, whose effect is to turn the bacteria along an applied magnetic axis. These bacteria develop bodies called ***magnetosomes***, which contain nanoparticles, or chains of ***iron oxide*** or ***iron sulphide***. These bacteria can survive only in near-total lack of oxygen and it is thought that the magnetic guidance system has evolved to help them simplify navigation while trying to reach favourable conditions.

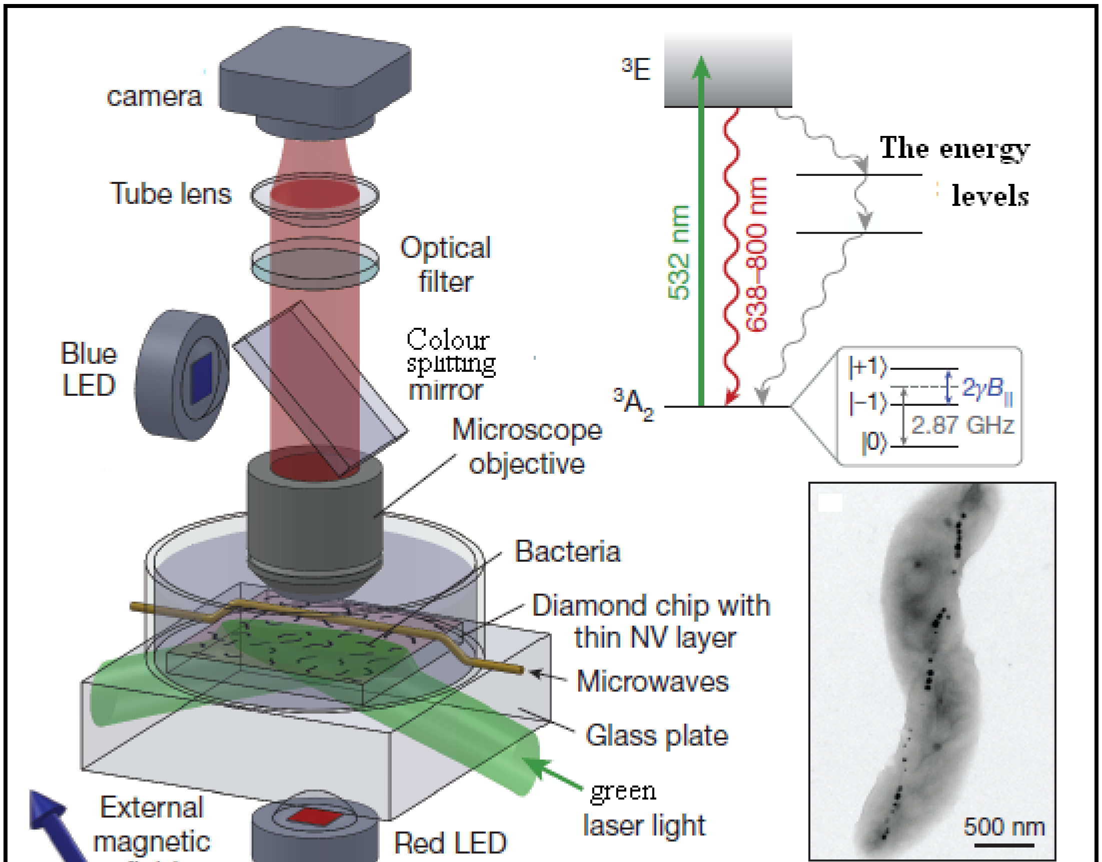
The work of Le Sage and others, of imaging magnetic structures within cells, would also enable investigation of similar formations in more complex organisms. The technique developed to spot magnetic cells in different kinds of tissue could be useful in biology and medicine. The genetics of magnetic cells, how non-magnetic, mutant cells could arise and how nano-particles are shared during cell division could be studied. The presence of magnetic nano-particles in cells could also lead to clearer imaging of organs, in methods like MRI, and such presence has also been linked with diseases of degeneration of nerve tissue.

Diamond detector

Diamond has a rigid crystal structure and does not allow any contaminants in its composition, except atoms of boron and nitrogen. This makes for diamonds, which are transparent, to appear clear and colourless. Small quantities, one part in a million, of boron impurity give diamonds a blue tinge and nitrogen impurities lead to yellow diamonds. Nitrogen atoms in the lattice create a change in the otherwise uniform crystal structure. The diamond atom, being carbon, has four electrons in its outer shell. Each atom can hence share its outer shell electron with a neighbouring carbon atom, to form a stable framework of fully balanced carbon atoms. The nitrogen atom, however, has five outer shell electrons. In the condition called the ***Nitrogen-Vacancy (NV)*** – where one carbon atom is replaced by a nitrogen atom, three of the five outer shell electrons form bonds with carbon atoms, leaving two unpaired electrons, called a ***lone pair***. The electrons from three neigbouring carbon atoms are also unpaired. Two of these get together to form a bond and that leaves one unpaired electron, in addition to the pair from the nitrogen atom.



The energy levels of the three electrons at a place where there is an NV, which are called ***NV colour centres***, are easily excited by visible light and the centres emit a bright red light. The nature of this luminescence is again sensitive to magnetic fields, as such fields affect the splitting of energy levels at the NV. This effect, which allows very fine resolution detection of magnetic fields, hence promises a means to detect the magnetic effects of intracellular magnetic material. The technique has already been applied to measure things of very fine detail, as fine as the spin of a single electron, but these results were within a neighbouring diamond crystal. Imaging of nano-particles outside the crystal is a different question, which Le Sage and colleagues addressed.



The apparatus

Electron photo of the nano-particles

Le Sage and Co used a pure diamond chip doped with a 10 nano meter (100 millionths of a millimeter) deep surface layer of NV centres. The NV energy levels were made uniform with the help of a green laser light and then manipulated using microwaves and detected with the help of the fluorescent light emitted. The frequencies of fluorescence get affected by external magnetic fields, and this was the property used for detecting the magnetic field of the bacteria. And for each imaging NV spot (pixel), imaging was done with four orientations of the fields, so that the exact orientation of the magnetic organelles could be found out.

The experiment was done with two kinds of samples, dried bacteria placed directly on the diamond chip and also with live samples in a liquid medium, with suitable changes in the way the beams were shone. The magnetic scan provided a picture of the magnetic fields created by the nano-particldes, down to sub-cellular resolution. The same apparatus also created optical images of the bacteria, Electron microscope pictures then proved that the magnetic imaging correctly localized the ***magnetosomes*** in the bacteria.

"Our results provide a new capability for imaging bio-magnetic structures in living cells under ambient conditions with high spatial resolution, and will enable the mapping of a wide range of magnetic signals within cells and cellular networks," say the authors in their paper.