Research Matters SPRING 2004

The science of levitation

Magnetic levitation occurs when the force on a diamagnetic object, due to an inhomogeneous magnetic field, is strong enough to balance the body's weight resulting from the effect of the Earth's gravity[1]. The effect is not noticeable, however, in a homogeneous magnetic field; the atoms also need to be within a magnetic field gradient. If the product of the field strength and the field gradient is large enough, then the force exerted on the atoms is sufficient to counteract the effects of gravity.

When a team of scientists at Nottingham approached Oxford Instruments Superconductivity to supply a superconducting magnet for their research, they requested several features to enable effective levitation experiments. The magnet had to be capable of producing a large field gradient, running in persistent mode and was to be used by a large, multidisciplinary group of scientists. The equipment, therefore, preferably needed to be easy to use and relatively low maintenance.

To meet these needs, Oxford Instruments Superconductivity produced a system that uses Minimum Condensed Volume (MCV™) technology. Unlike conventional superconducting magnets, this only uses a few litres of liquid helium and does not loose any cryogen to evaporation. This keeps maintenance to a minimum, removes the need for helium refills and keeps the system compact. Additionally, the range of experiments that can be carried out is increased by the fact that the 50 mm diameter bore access is at room temperature and can therefore be used with living systems. Despite its small size, the magnet is capable of field strengths of up to 17 Tesla at the centre of the bore (the earth's magnetic field is typically 0.07 mT) and, vitally for levitation, can produce a (field gradient x field) product of up to 1,470 T^2/m. Although this is sufficient to levitate water/oil-based substances and plastics, the Nottingham team wanted to levitate denser materials and tried augmenting the effect.

Dense objects floating in liquid oxygen in a glass Dewar vessel positioned just above the top of the magnet bore. Image courtesy of Nottingham University.

Enhancing levitation with oxygen

One means of achieving this enhancement, oxygen gas, had already been demonstrated by Ikezoe *et al* [2]. Oxygen molecules (O_2) are paramagnetic, and so are attracted to magnetic fields. The resultant enhanced buoyancy, when a diamagnetic object is placed in oxygen gas, is named the magneto-Archimedes effect. In an ingenious development of this experiment, reported in Nature earlier this year, the Nottingham magnetic levitation team exploited Charles' law and Curie's law in order to levitate a much wider range of materials[3]. A combination of these two effects gives x10 enhancement of the magneto-Archimedes effect near the boiling point of liquid oxygen. As the cold oxygen gas is at ordinary atmospheric pressure, it is very easy and quick to manipulate the samples and to put them into the levitation system. The Nottingham group was able to levitate natural diamonds (which have a density of 3.51 g ml^{-1}) in cold oxygen gas. Liquid oxygen is even more paramagnetic, and therefore provides still greater buoyancy. This enhancement allowed the researchers to float silicon, a £1 coin, a piece of lead and even gold and platinum in liquid oxygen3.

These studies also revealed that whilst inside the magnet, the liquid oxygen adopts surface corrugations, similar to the strange instabilities displayed by ferrofluids in a high magnetic field[4]. This may provide a useful system for theoretical models of crystal formation and dynamics.

Future applications

Using the new magnet, the Nottingham group aim to study granular dynamics and how shaken particles behave within fluids in the presence of a strong magnetic field. The ability to effectively vary gravity could be an important tool to investigate these systems and may have future applications in mineral separation. Together with Dr Ken Lowe in the Biology department, the team are also working to identify and develop plants that will thrive in the low gravity conditions experienced in space travel.

Future applications of magnetic levitation will, of course, be partly dictated by the design of the magnet. It may prove valuable to increase the magnetic field gradient that can be achieved, to allow, for example, a wider range of crystals to be grown under low gravity conditions. Despite the fact that scientists are always looking for ways to improve their methodology, existing developments may still help to expand the applications of this technique. Thanks the MCV™ closed system and the enhancement provided by liquid oxygen, magnetic levitation is likely to become much more accessible and hopefully, in future will be carried out on a much larger scale.

References:

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