Ferrofluids

Magnetism Review

Common magnets are typically described as having a north and south pole. Similar poles (north-north or south-south) repel one another, while opposite poles attract one another (north-south or south-north). Unpaired electrons within a magnetic material are responsible for magnetic interactions. Electrons can provide contributions to magnetism through their spin angular momentum (rotation about their axes) and their orbital angular momentum. Some materials are permanent magnets and, through contact, can impart magnetic behavior to other materials.

Ferrofluids and Their Characteristics

In the 1960's, scientists from the NASA Research Center were investigating methods for controlling liquids in space. They developed ferrofluids, which are colloidal suspensions of magnetic nanoparticles, such as Fe_3O_4, in a liquid; the nanoparticles typically have sizes of about 100 angstroms, or 10 nm. Ferrofluids respond to an external magnetic field. This enables the fluid's location to be controlled through the application of a magnetic field. Ferrofluids can also be prepared using metals like cobalt and iron as well as magnetic compounds such as manganese zinc ferrite ($Zn_xMn_{1-x}Fe_2O_4$, $0 \leq x \leq 1$). Much research has been centered around ferrofluids that contain small particles of magnetite, Fe_3O_4. Magnetite can be produced by mixing Fe(II) and Fe(III) salts together in a basic solution. The particles must remain small and separated from one another in order to remain suspended in the liquid medium. Magnetic and van der Waals interactions must be overcome to prevent the particles from agglomerating into larger particles. Thermal motion of magnetite particles that are smaller than ~100 angstroms in size is sufficient to prevent agglomeration due to magnetic interactions. Surfactants prevent the nanoparticles from approaching one another too closely.

Surfactants and How They Work

Surfactants are added during the synthesis of ferrofluids to surround the small particles and overcome their attractive tendencies. For example, oleic acid can be added to oil-based ferrofluids. This surfactant is a long-chain hydrocarbon with a polar head that attaches itself to the surface of the magnetite particle. The long chains comprising the tails act as a repellent cushion and prevent the close approach of another particle. For this aqueous-based synthesis of ferrofluids using magnetite, Fe_3O_4, the surfactant, tetramethylammonium hydroxide, $[N(CH_3)_4][OH]$, is used. The nanoparticles created by the synthesis are thought to be coated with hydroxide ions from the surfactant, which themselves attract a sheath of largely positive tetramethylammonium cations. This structure creates electrostatic interparticle repulsion that can overcome the van der Waals forces that would otherwise cause the particles to agglomerate.

Picture from JCE articles—also on website from lecture notes

Spikes

When a strong magnet is placed near the ferrofluid, spikes are observed. The spikes arise from the tendency of the particles to line up along the magnetic field lines to lower their energy. Surface tension of the fluid, however, limits the extent to which the particles can align themselves with the field.

Possibly the diagram & explanation from ferrofluid paper-website
http://ice.chem.wisc.edu/materials/ferrofluids.html

Uses and Capabilities

Ferrofluids have a wide range of applications. They have been used in rotating shaft seals, where they behave as a liquid O-ring. The ferrofluid is held in place by permanent magnets and forms a tight seal, reducing friction relative to that produced in a typical mechanical seal. These rotating shaft seals are found in rotating anode x-ray generators and in vacuum chambers used in the semiconductor industry. Ferrofluids are also used in high-speed computer disk drives to eliminate harmful dust particles or other impurities that can cause the data-reading heads to crash into the disks. Another application of ferrofluids is in improving the performance of loudspeakers. In a loudspeaker electric energy is sent through a coil located in the center of a permanent magnet. Bathing the electric coil in ferrofluid dampens unwanted resonances and provides a way to dissipate heat from the excess energy supplied to the coil. This leads to better overall sound quality. Biologists such as Michael Walker, Carol Diebel, and Cordula Haugh of the Experimental Biology Group, have also been studying how ferrofluids aid in the migratory senses of animals. They have studied how trout respond to the magnetic field of the earth. Apparently a few small branches of the trigeminal nerve enter the nose of the trout. There the nerves seem to connect with some unusual cells that do not appear to be involved in the trout's sense of smell. The cells contain crystals of a mineral that have yet to be identified. It is suspected that the crystals are magnitite. When the magnetic field is steady, spikes or action potentials are produced. If the magnetic field changes so do the spikes. This signals when the migratory process should take place. Finally, ferrofluids may be used in future biomedical applications. Researchers are attempting to design ferrofluids that can carry medication to specific locations in the body through the use of applied magnetic fields. Ferrofluids may also be used as contrast agents for magnetic resonance imaging (MRI).