

Mesmerising Liquid Magnets

Radical new ferrofluid material could revolutionise technology

T.V. Venkateswaran



WHEN the Sun dawned, it was just another day. Unaware of the portent jolt awaiting, research scholar Xubo Liu unlocked the lab room to commence his days' work. Like any other day, lost in thoughts, he opened the door, switched on the lights, kept his bag aside and moved towards his workbench.

What he saw on the workbench shocked him. Stunned and surprised it took a moment to believe his eyes. Overwhelmed Liu summoned his supervisor Thomas Russell, a distinguished professor of polymer science and engineering at the University of Massachusetts Amherst.

Xubo Liu was a scholar from Beijing University of Chemical Technology, and they both were visiting the Lawrence Berkeley National Laboratory to perform joint experiments on ferrofluids.

They were experimenting with iron-oxide nanoparticles dispersed in an oily substance. The oil droplets hanging out from the end of the stirrer were spinning on their own, in unison like synchronised swimmers. What made the droplets

swirl? That was the mystery. That was the moment Liu knew something momentous was happening.

Ferrofluids

This story goes back to a bizarre discovery made by NASA engineers fifty years ago. They were trying to figure out the



Thomas Russell



Xubo Liu

solution to a vital space challenge. On Earth, the propellant from the fuel tank on its own flowed through the pipes to the combustion chamber pulled by gravity. In the freefall 'zero' gravity environment in space, the fuel will not flow as it does on Earth. How to move the fuel around? NASA engineers had to come up with a novel solution – ferrofluids. They demonstrated that if ferromagnetic particles were added in the fuel, then they could move it around the 'zero gravity' of space, without using pumps.

Paramagnetism

Of course, the idea was not used by NASA. Nevertheless, since then, ferrofluids have been an object of fascination. Essentially ferrofluids are a mixture of magnetic nanoparticles, like iron oxide, a special coating that helps it to disperse in the liquid medium, and a water-based or oil-based liquid.

As the ferrofluids contain materials like iron oxide typically, and they exhibit paramagnetism in the presence of an external magnetic field. Most magnets are made out of Iron oxide. Lodestone, a naturally occurring magnetic material, is incidentally made up of iron oxide.

However, magnetic properties are lost once the external induction is removed. Why? Although each of the iron oxide nanoparticles is akin to a tiny magnet, the ferrofluid *per se* does not exhibit ordinarily magnetic property. Impelled by the Brownian motion, a characteristic of liquids, the nanoparticles are in a state of constant motion. With no orderly arrangement, the magnetic pole of each particle pointed at a random direction. Pair of nanoparticles with opposite direction cancelled each other, resulting in zero magnetic moments.

Recipe for a Liquid Magnet

The team first prepared iron oxide nanoparticles 20 nanometers in diameter, treated with carboxyl, a chemical that readily bonds with water. They then dispersed these nanoparticles into millimetre size toluene droplets and suspended the droplets in water.

This was a ferrofluid. It has all the essential ingredients of ferrofluids. When they placed this suspension in a strong external magnetic field, like an iron nail placed inside a coil becomes a temporary magnet, as anticipated the droplets too showed magnetic properties. Induced by the external field, the Iron oxide particles in the droplets had aligned in an orderly fashion, exhibiting magnetic property. No surprises until now.

Perhaps it was the end of the day, or maybe they were exhausted from the days work. They switched off the external magnetic coil, closed the lab and went home. They returned the next day, yet the droplets hanging from the stirrer were spinning as if they were magnets. That was amazing. Like many discoveries in science, this too was serendipitous.

The Science behind the Magic

How come the droplets retained their magnetism, unlike other ferrofluids, even in the absence of an external magnetic field? Intrigued researchers examined what they had created. They used the sophisticated atomic force microscopy techniques and our knowledge of surface chemistry to come up with an answer. They showed that the nanoparticles formed a solid-like shell at

the interface between the two liquids through a phenomenon called 'interfacial jamming'.

They had placed drops of the Iron oxide solution into toluene, an oily substance. The polymers of toluene have a strange property like a surfactant. They loath water, technically called hydrophobic.

Once the toluene solution comes into contact with water, the water molecules are repulsed, whereas the Iron oxide nanoparticles are attracted by the hydrophobic polymer in the oil. As a result, the fine nano Iron oxide particles form a layer between the outer toluene and inner water iron oxide droplet. With just 20 nanometres in size, each oil drop contained about 70 billion iron-oxide nanoparticles floating around. About 1 billion nanoparticles from the droplet migrated to the surface to form a solid layer of the thin film around the droplet. Billions of nanoparticles on the surface film were jammed packed, with no elbow room to move. Russell remarked, "the particles get stuck in place, like a traffic jam at 5 o'clock".

When the droplets are placed in a powerful magnetic field, the nanoparticles on the surface film align in the same direction, making the droplet into a magnet. However, as the nanoparticles have no elbow room to move, once aligned, they stay the same way. As all the billions of tiny nanoparticle of Iron oxide permanently line up, the whole droplet becomes a permanent magnet.

Furthermore, the researchers found that the magnetised nanoparticles on the surface could transfer the orientation to the particles swimming around in the core. The entire droplet becomes permanently magnetic. Moreover, like each fragment of a broken magnet remains a magnet with north and south pole, when a droplet is split into two, each divided droplet retained the magnetic property.

Magical Potential

What startled Liu was that the ferrofluid droplets he and his colleagues had fabricated exhibited permanent magnetism. They had created a permanently magnetic liquid. Whatever be the shape – bar, horseshoe, ring – the magnets that we know until now are all solids. "We can morph the liquid magnets into various shapes and conform to various shapes," Russell exclaims enthusiastically. The researches have shown that the liquid drop could change from a sphere to a cylinder to a pancake shape. As the liquid takes the shape of the container, the possibilities are unlimited.

From a simple Lodestone magnetic needle showing direction, magnets have come a long way shaping our technology. From read and record data on magnetic tapes in memory devices to medical scan devices that use powerful magnets, magnets play a crucial role in our daily life.

Now, with the invention of the soft magnet whose shape and size can be manipulated, radically new possibilities emerge. From soft robots to targeted drug delivery is a tantalising journey. Who knows what is in store.

Dr T.V. Venkateswaran is a Scientist in Vigyan Prasara, C-24, Qutab Institutional Area, Behind Qutab Hotel, New Delhi-110016. Email: tvv123@gmail.com