3D printed nanomagnets unveil a world of patterns in the magnetic field

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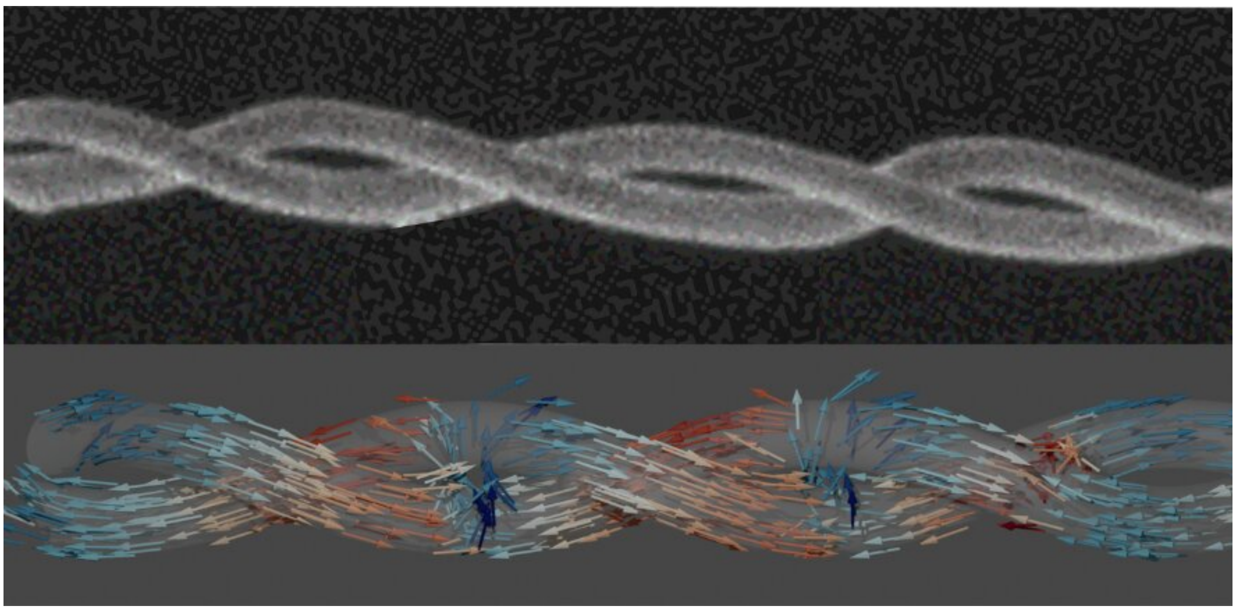

Nanoscale magnetic double helices (top) are found to host highly coupled textures, observed both experimentally and with simulations (bottom). Credit: Claire Donnelly

Scientists have used state-of-the-art 3D printing and microscopy to provide a new glimpse of what happens when taking magnets to three-dimensions on the nanoscale—1000 times smaller than a human hair.

The international team led by Cambridge University's Cavendish Laboratory used an advanced 3D printing technique they developed to create magnetic double helices—like the double helix of DNA—which twist around one another, combining curvature, chirality, and strong magnetic field interactions between the helices. Doing so, the scientists discovered that these magnetic double helices produce nanoscale topological textures in the magnetic field, something that had never been seen before, opening the door to the next generation of magnetic devices. The results are published in *Nature Nanotechnology*.

Magnetic devices impact many different parts of our societies, magnets are used for the generation of energy, for data storage and computing. But magnetic computing devices are fast approaching their shrinking limit in two-dimensional systems. For the next generation of computing, there is growing interest in moving to three dimensions, where not only can higher densities be achieved with 3D nanowire architectures, but three-dimensional geometries can change the magnetic properties and offer new functionalities.

"There has been a lot of work around a yet-to-be-established technology called racetrack memory, first proposed by Stuart Parkin. The idea is to store digital data in the magnetic domain walls of nanowires to produce information storage devices with high reliability, performance and capacity," said Claire Donnelly, the study's first author from Cambridge's Cavendish Laboratory, who has recently moved to the Max Planck Institute for Chemical Physics of Solids.

"But until now, this idea has always been very difficult to realize, because we need to be able to make three-dimensional magnetic systems and we also need to understand the effect of going to three dimensions on both the magnetisation and the magnetic field."

"So, over the last few years our research has focused on developing new methods to visualize three dimensional magnetic structures—think about a CT scan in a hospital, but for magnets. We also developed a 3D printing technique for magnetic materials."

The 3D measurements were performed at the PolLux beamline of the Swiss Light Source at the Paul Scherrer Institute, currently the only beamline able to offer soft X-ray laminography. Using these advanced X-ray imaging techniques, the researchers observed that the 3D DNA structure leads to a different texture in the magnetisation compared to what is seen in 2D. Pairs of walls between magnetic domains (regions where the magnetisation all points in the same direction) in neighboring helices are highly coupled—and as a result, deform. These walls attract one another and, because of the 3D structure, rotate, "locking" into place and forming strong, regular bonds, similar to the base pairs in DNA.

"Not only did we find that the 3D structure leads to interesting topological nanotextures in the magnetisation, where we are relatively used to seeing such textures, but also in the magnetic stray field, which revealed exciting new nanoscale field configurations!" said Donnelly.

"This new ability to pattern the magnetic field at this length scale allows us to define what forces will be applied to magnetic materials and to understand how far we can go with patterning these magnetic fields. If we can control those magnetic forces on the nanoscale, we get closer to reaching the same degree of control as we have in two dimensions."

"The result is fascinating—the textures in the DNA-like double helix form strong bonds between the helices, deforming their shape as a result," explained lead author Amalio Fernandez-Pacheco, former Cavendish Researcher, now working at the Institute of Nanoscience & Materials of Aragón. "But what is more exciting is that around these bonds form swirls in the magnetic field—topological textures!"

Having gone from two to three dimensions in terms of the magnetisation, now Donnelly and her collaborators from the Paul

Scherrer Institute and the Universities of Glasgow, Zaragoza, Oviedo, and Vienna will explore the full potential of going from two to three dimensions in terms of the magnetic field.

"The prospects of this work are manyfold: these strongly bonded textures in the magnetic helices promise highly robust motion and could be a potential carrier of information," said Fernandez-Pacheco. "Even more exciting is this new potential to pattern the magnetic field at the nanoscale, this could offer new possibilities for particle trapping, imaging techniques as well as smart materials."

More information: Claire Donnelly, Complex free-space magnetic field textures induced by three-dimensional magnetic nanostructures, *Nature Nanotechnology* (2021). DOI: 10.1038/s41565-021-01027-7. www.nature.com/articles/s41565-021-01027-7

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