An Invisible Cloak for Magnetism

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The subject of metamaterials is mad science at its finest – researchers trying to create materials with properties that don't exist in nature, and that cannot be made with ordinary atoms.

Metamaterials possess nano-scale structures and special effects that can only be created in the lab, which can lead to a variety of interesting applications. For example, some metamaterials have a negative refractive index, meaning they refract incoming light waves "through" themselves rather than back to the source of the light, and act as "invisible cloaks."

Now, researchers from Imperial College London are doing something a little different with metamaterials. In a recent study published in *Nature Materials*, Fridrik Magnus, et al., have fabricated the first non-resonant metamaterial that operates with light waves of zero frequency. This goal is somewhat different than most studies with metamaterials, which focus on higher frequencies like microwaves and visible light.

For one thing, the scientists could use the metamaterial as a building block for a magnetic invisibility cloak. Such a cloak could hide magnetism by guiding an applied magnetic field around a cloaked region.

"It is already possible to protect a region of space from magnetic fields; simply surrounding it with a strongly magnetic material will do the job," coauthor Ben Wood of Imperial College London told *PhysOrg.com*. "However, a magnetic cloak would go further – it would keep magnetic fields out of the inner region without disturbing the fields outside the cloak."

In the zero-frequency regime, the wavelength is very large, and magnetism and electricity become decoupled. This decoupling allows the researchers to concentrate on the magnetic properties without worrying about the electric ones when designing devices like the cloak.

"When we say that ours is a zero-frequency metamaterial, we mean that it behaves as intended only at very low or zero frequency," Wood explained. "It will interact with light at higher frequencies, but not in a useful way."

The new metamaterial consists of layers of stacked lattices, which themselves are composed of 10 x 10 arrays of thin lead plates. One of the defining properties of a metamaterial is that its lattice spacing must be smaller than the wavelength of light it interacts with. For light with zero frequency, the wavelength is large and diverges, so that this constraint is easily met. The individual lead plates in the design are 300 nanometers thick and 167 micrometers across, with the lattices spaced 100 micrometers apart.

The researchers then applied a magnetic field to the metamaterial, "pushing" the field through the gaps between the lead plates. The metamaterial showed a diamagnetic response – a weak magnetic repulsion. The strength of the repulsion depended on the ratio between the size of the lead plates and the lattice spacing. For the scientists, this connection was significant: it meant that they could tune the metamaterial's magnetic properties.

The researchers explain that the non-resonant metamaterial could have some advantages over those that consist of resonant structures and have a negative refractive index. The negative refractive index is one way to achieve optical invisibility, but it comes at the price of high loss and frequency dispersion.

The researchers plan to use non-resonant metamaterials for other purposes. For instance, a design paradigm called transformation optics tells scientists what properties are needed to achieve a certain effect. Because these properties always have non-negative refractive indices, non-resonant metamaterials can provide the required properties.

“Transformation optics is a way to design devices,” Wood explained. “It allows us to mimic transforming space for light, and gives us a prescription for the electromagnetic properties we need to achieve a given effect, like cloaking. However, these properties are not usually found in natural materials, and this is where metamaterials can help. They allow us to make the devices that we design using transformation optics.”

More information: Magnus, F.; Wood, B.; Moore, J.; Morrison, K.; Perkins, G.; Fyson, J.; Wiltshire, M. C. K.; Caplin, D.; Cohen, L. F.; and Pendry, J. B. “A d.c. magnetic metamaterial.” *Nature Materials*, Vol. 7, April 2008, pp. 295-297.