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Physicists Develop New Class of Composite Materials with 'Reversed' Physical Properties Never Before Seen

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Physicists at the University of California, San Diego have produced a new class of composite materials with unusual physical properties that scientists theorized might be possible, but have never before been able to produce in nature.

The remarkable achievement, detailed in a paper that will appear in a forthcoming issue of Physical Review Letters, was announced here today at a meeting of the American Physical Society. The UCSD physicists said they expect their discovery to open up a new subdiscipline within physics and produce an array of commercial applications for this material, on which the university has applied for a patent.

"Composite materials like this are built on a totally new concept," said the two co-leaders of the UCSD team, Sheldon Schultz and David R. Smith, who announced their discovery at a news conference. "While they obey the laws of physics, they are predicted to behave totally different from normal materials and should find interesting applications."

The unusual property of this new class of materials is essentially its ability to reverse many of the physical properties that govern the behavior of ordinary materials. One such property is the Doppler effect, which makes a train whistle sound higher in pitch as it approaches and lower in pitch as it recedes. According to Maxwell's equations, which describe the relationship between magnetic and electric fields, microwave radiation or light would show the opposite effect in this new class of materials, shifting to lower frequencies as a source approaches and to higher frequencies as it recedes.

Similarly, Maxwell's equations further suggest that lenses that would normally disperse electromagnetic radiation would instead focus it within this composite material. This is because Snell's law, which describes the angle of refraction caused by the change in velocity of light and other waves through lenses, water and other types of ordinary material, is expected to be exactly opposite within this composite.

"If these effects turn out to be possible at optical frequencies, this material would have the crazy property that a flashlight shining on a slab can focus the light at a point on the other side," said Schultz. "There's no way you can do that with just a sheet of ordinary material."

He notes that the development of this new class of materials, which was financed by the National Science Foundation and the Department of Energy, is entirely consistent with the laws of physics and was predicted as a possibility in 1968 by a Russian theorist, V.G. Veselago. "But until now," Schultz adds, "no one had the material, so it couldn't be verified."

Underlying the reversal of the Doppler effect, Snell's law, and Cerenkov radiation (radiation by charged particles moving through a medium) is that this new material exhibits a reversal of one of the "right-hand rules" of physics which describe a relationship between the electric and magnetic fields and the direction of their wave velocity.

The new materials are known by the UCSD team colloquially as "left-handed materials," after a term coined by Veselago, because they reverse this relationship. What that means is physically counterintuitive-pulses of electromagnetic radiation moving through the material in one direction are composed of constituent waves moving in the opposite direction.

The UCSD physicists emphasized that while they believe their new class of composites will be shown to reverse Snell's law, the specific composite they produced will not do so at visible-light frequencies. Instead, it is now limited to transmitting microwave radiation at frequencies of 4 to 7 Gigahertz-a range somewhere between the operation of household microwave ovens (3.3 Gigahertz) and military radars (10 Gigahertz).

However, Schultz said the UCSD team will soon be attempting to verify that a composite constructed on similar principles will be able to focus and disperse microwaves in exactly the opposite manner as normal lenses. "We did not do this experiment yet," he said. "But this is what the equations predict. Physicists will understand that if our data presented in our paper are correct, given Maxwell's equations, then this will be the result."

The composite constructed by the UCSD team-which also consisted of Willie J. Padilla, David C. Vier, and Syrus C. Nemat-Nasser-was produced from a series of thin copper rings and ordinary copper wire strung parallel to the rings. It is an example of a new class of materials scientists call "metamaterials." "Even though it is composed of only copper wires and copper rings, the arrangement has an effective magnetic response to microwaves that has never been demonstrated before," said Schultz.

The idea for the new composite came from Smith, building on the work of John Pendry of Imperial College, London. In 1996, Pendry described a way of using ordinary copper wires to create a material with the property physicists call "negative electric permittivity." Electric permittivity-often referred to as the "dielectric constant"-is the response of a material to electromagnetic radiation.

"When you take a material like plastic, glass or sapphire and you shine microwaves onto it, you can characterize how the microwaves going through it will behave by a parameter called electric permittivity," explained Schultz. Most known materials in nature have a positive electric permittivity.

Pendry also recently suggested a way of using copper rings to make a material with negative magnetic permeability at microwave frequencies. Just about all of the magnetic materials in nature, those that respond to magnetic rather than electric fields, have what physicists call a "positive magnetic permeability."

What's unusual about the new class of materials produced by the UCSD team is that it simultaneously has a negative electric permittivity and a negative magnetic permeability, a combination of properties never before seen in a natural or man-made material.

"And the interesting thing is that it's produced with no magnetic material," said Schultz. "It's all done with copper."

"The bottom line," said Smith, "is that this material-this metamaterial, at frequencies where both the permittivity and permeability are negative, behaves according to a left-handed rule, rather than a right-handed rule."

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