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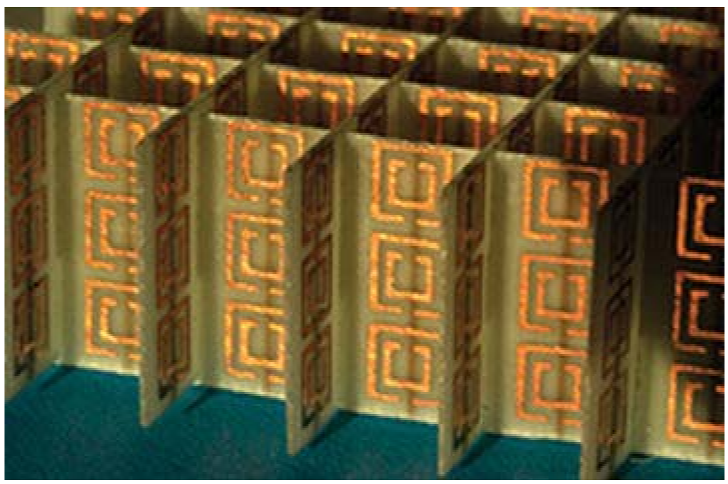
Out of Sight

Physicists get serious about invisibility shields

Peter Weiss

First, a disclaimer: Invisibility cloaks like Harry Potter's are nowhere near becoming reality. Nor has anyone unearthed proof that the infamous Philadelphia experiment—in which U.S. Navy scientists in 1943 supposedly made a destroyer and its crew vanish—really took place. Stygian crystals, said to confer invisibility in *Star Wars* films and books, remain figments of writers' imaginations. And not one invisibility shield yet exists, not even a mouse-size one, as best anyone can tell.



WEIRD WITH WAVES. Arrayed on fiberglass panels, this metamaterial's copper loops and wires manipulate microwaves in unnatural ways. This type of device might someday make objects invisible to the electromagnetic waves. The height of the structure is about that of a pea.
Pendry

The reality is this: Scientists have recently been doing some deep thinking about how light and matter interact. As a result, even some practical-minded physicists and engineers have embraced the notion that humankind's long-held desire to make a person or an object invisible may no longer be just the stuff of fantasy.

"In principle, it's possible to make cloaking devices," contends theoretical physicist Ulf Leonhardt of the University of St. Andrews in Scotland, speaking for a growing number of researchers. In recent studies, several teams have proposed rigid shells or walls—invisibility shields—that would interact with electromagnetic radiation in new ways. As a result, observers could, in essence, look right through those shields and the objects they enclose.

While none of the strategies has yet been tested experimentally, experimental physicist David Schurig of Duke University in Durham, N.C., predicts that he and his colleagues will demonstrate such a device that can render, say, a toaster-size object invisible to radar in less than 6 months.

"What differs from science fiction," says experimental physicist David R. Smith, who heads the Duke team, is that those authors "imagine a field in space that does this. We do it by creating a material that directs the light around the thing being cloaked."

The new strategies also differ from the military's current stealth technologies for planes, boats, and armored vehicles. Whereas those objects have equipment and surface coatings that absorb or deflect radar signals, the envisioned invisibility devices would cancel electromagnetic waves from the object or route radar or light signals around it.

Although some of the new schemes might apply only to objects already too small to be seen with the naked eye, others may be suitable for ordinary, human-scale items. However, no theorist has yet proposed a shield that drapes and folds like a cloak—à la Harry Potter.

The right stuff

The new invisibility proposals all stem from findings that some recently invented materials—and, under the right circumstances, some old favorites—can manipulate electromagnetic waves in extraordinary ways.

Dubbed negative-index materials, left-handed materials, or metamaterials, the new substances differ from natural materials by virtue of specific electromagnetic properties that not long ago were considered to be unrealistic. Researchers created the first electromagnetic metamaterial just 6 years ago (SN: 3/25/00, p. 198: Available to subscribers at http://www.sciencenews.org/articles/20000325/fob5.asp).

"It's really because of the development of metamaterials that the manufacturing of such cloaking devices could be possible," Leonhardt says.

Metamaterials consist of three-dimensional arrays of hoops, rods, or other shapes made of metal or other electrically conductive materials that are joined by electrical insulators, such as fiberglass.

Whereas lenses or other optical devices made of ordinary materials bend radiation one way, metamaterials bend it the other. Although not easily explained in everyday terms, the effect stems from electromagnetic waves traveling backward once they enter metamaterials, notes Schurig.

Electromagnetic radiation typically exerts a repulsive pressure on objects, so it should, in theory, attract metamaterials. Also, the well-known Doppler shift, in which the frequency of electromagnetic radiation from an object increases as the object approaches, is expected to reverse for metamaterials. Experiments have yet to confirm those two predictions.

The unique properties of metamaterials go beyond those offered in nature, says Nader Engheta, a theorist and electrical engineer at the University of Pennsylvania in Philadelphia. "If a [desired] property of a material is not available in nature, then metamaterials come into play. You can design the material to have that property."

It turns out that metamaterials aren't alone in producing odd effects. On small scales, some precious metals and other natural materials, such as silver, gold, and silicon carbide, act much as metamaterials do.

Scientists refer to such behavior in natural materials as plasmonic. That's because the effects result from the interplay between plasmons, which are waves of electrons, and the impinging electromagnetic radiation. Theorists say that both types of substances can be exploited to reduce the visibility of objects.

"Metamaterial or plasmonic engineering is the new way of looking at this," Engheta says.

Cover up

Engheta and his University of Pennsylvania colleague Andrea Alù have mathematically demonstrated the cloaking of microscopic, idealized spheres and cylinders by coatings made from metamaterials, or plasmonic materials.

Calculations published by the team in the July 2005 *Physical Review E* indicate that sometimes, the radiation-scattering pattern produced by such a coating will cancel the scattering pattern from the particle inside, rendering the coated particle invisible. For instance, Engheta says, silicon particles encased in gold or silver coatings might appear to vanish at specific infrared, visible, or ultraviolet wavelengths.

The effect was unexpected. "We stumbled into it," Engheta recalls.

The invisibility might extend to larger objects composed of many coated particles, Engheta says, though no one has thoroughly evaluated this possibility. Still, calculations for a metal wire and other structures made of these coated particles suggest that larger-scale invisibility is feasible by this strategy, he says.

Engheta's work was the first that "explicitly said you could use metamaterials to do cloaking," says Leonhardt. "It's a very valuable contribution."

Some aspects of the composite objects, however, could undermine their usefulness. For one, a coating of a specific material and thickness might render invisible no more than one type, size, and shape of particle.

Also, this version of invisibility would probably be complete at only one wavelength, Engheta says.

Cloak room

In another approach to rendering things invisible, a microscopically thin film of metamaterial or plasmonic material might create an invisibility zone. Anything placed close to either side of the film would disappear from view.

John B. Pendry of Imperial College London in England introduced the notion of such films, called superlenses, in 2000 and proposed using the unusual materials to build them. Scientists in California and New Zealand have subsequently showed that a plasmonic film of silver only a few nanometers thick can serve as a superlens.

Mathematicians Graeme W. Milton of the University of Utah in Salt Lake City and Nicolae-Alexandru P. Nicorovici of the University of Technology in Sydney, Australia, have made calculations showing that radiation scattered from an object would trigger a superlens to extend an electromagnetic field from its surface. This protruding field would interfere with any subsequent radiation from the object, canceling its electrical and magnetic fields.

"No light ends up being scattered back, so you end up not being able to see the object," Milton explains. He and Nicorovici present their analysis online and in an upcoming *Proceedings of the Royal Society A*.

The canceling effect would extend to a distance on each side of the lens equal to half the lens' thickness—in effect, causing that region of space to disappear. "It's really weird," says Milton.

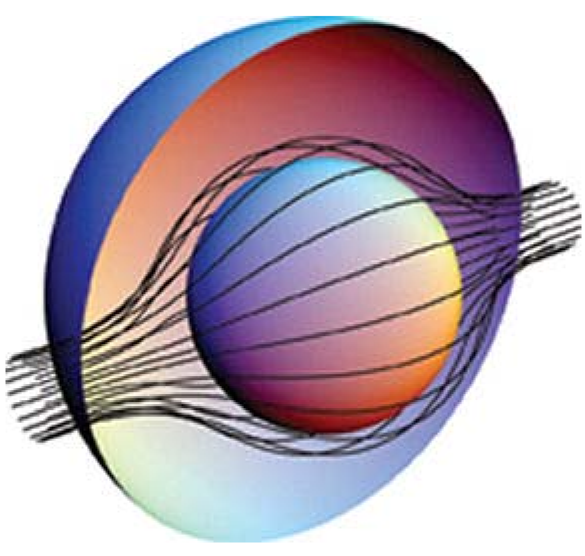
So far, the researchers have demonstrated mathematically that objects in the cloaking region whose electrical and magnetic fields align perfectly parallel to the superlens would vanish. However, the team has yet to fully analyze whether the effect applies to objects in other orientations.

Other restrictions apply to this type of cloaking. For instance, the invisibility would be preserved only if all the objects involved stayed still. What's more, a particular configuration of superlens and object would vanish only for radiation at one frequency. "At nearby frequencies, it would be partly visible," Milton says. Finally, the effect may require illumination with coherent light, such as that from a laser.

"Although the jury is still out for larger objects," notes Pendry, the superlens-cloaking scheme "is a very, very interesting one."

Around the bend

In two other independently derived but similar invisibility techniques, researchers propose using a shell of metamaterials to distort the ordinarily straight paths along which electromagnetic fields extend through space. Such distortion might carve out a space within the shell that would hide things.



SHELL GAME. A shell filled with a metamaterial (not shown in diagram) may render invisible a spherical region (inner ball)—and whatever's in that region. The hypothetical shell forces light rays (dark lines) to detour around the cloaking region, but they then resume their paths as though nothing had blocked them.
Pendry, Schurig, and Smith/*Science*

"We're taking rays that would hit this cloak volume and squishing them into a corridor that goes around that volume," Pendry explains.

In the June 23 *Science*, he, Smith, and Schurig describe their approach. In another report in the same journal issue, Leonhardt outlines a similar scheme he independently devised.

Because the rerouted electromagnetic waves would travel within the metamaterial shell and emerge from it on the same trajectories that they were on upon entering it, the cavity's contents would, in effect, be transparent. Because the shell would require electromagnetic waves to curve one way and then another in different places, the properties of its metamaterials would have to vary from place to place throughout the shell. Designers would need to create a three-dimensional mosaic from many physically different pieces of metamaterials, Leonhardt says.

In the two reports in *Science*, the inventors of the shielded-cavity schemes work out mathematical formulas for charting a desired distortion and then transforming that pattern of distortion into a map of how the shell's electromagnetic properties must vary throughout the structure.

Having carefully studied the proposal by Pendry's team, Milton says that he's "confident that it's correct."

Cloaking was actually an afterthought for Pendry's team. Having devised a scheme for controlling electromagnetic fields, "we thought, 'What could we do with it that would blow people's minds?'" Pendry recalls.

While the shielded-cavity proposals face obstacles, they seem the most versatile and unrestricted of the new invisibility schemes.

Potential spoilers for the approach take several forms. For the strategy to work for visible light, it would require metamaterials that don't yet exist. What's more, those materials might be difficult to create because they require nanoscale engineering in three dimensions, scientists say.

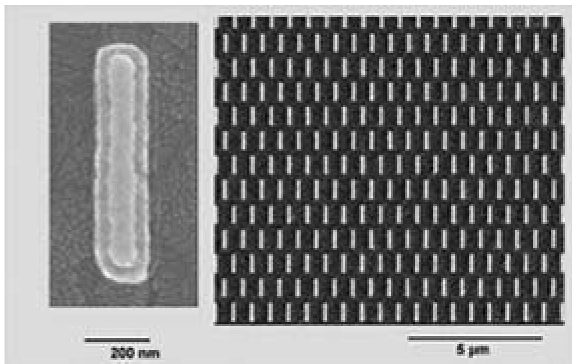
Like other invisibility approaches, the shielded-cavity technique is expected to work only within a narrow range of wavelengths. However, that range is likely to be broader than that for plasmonic coatings or superlens cloaking, says Pendry.

In a promising development, at least two research teams have recently reported making arrays of nanosize gold particles that exhibit electromagnetic behavior close to what's needed for visible-light cavity shielding.

Shielded cavities could theoretically be of any size and could enclose objects of any dimension, shape, or substance—even ones that live and move. Pendry points out, however, that a person concealed within an invisibility shell wouldn't be able to see out any more than someone outside it could see in.

Get real

Should some of these invisibility techniques ultimately succeed, even in a limited way, they're likely to have practical applications.



NO-SEE-UMS. A nanoscale bar of gold and glass (left) is the building block of a metamaterial (right) that manipulates infrared light just below the visible spectrum. The material bends the light in a direction opposite to what normal materials do.
V. Shalaev, *et al.*/Purdue Univ.

If they lead to invisibility across a broad band of visible wavelengths for substantial objects, such as people or vehicles, the consequences could be enormous. Humankind could realize dreams dating back millennia: the ultimate level of spying, hiding, invading, and so on. That's assuming that the rigid, metamaterial shells or other needed equipment aren't too cumbersome to tote around.

These dreams may, in part, explain the funding for Pendry's and Engheta's teams from the Defense Advanced Research Projects Agency, a part of the Defense Department that promotes research into cutting-edge technologies that sometimes prove to be more fiction than fact.

Also of considerable interest to the military—and much closer to fruition—are proposed invisibility shields against longer wavelengths, such as the microwaves used in radar. While the shield that Smith's group expects to construct within 6 months will hide only small objects, Pendry says that shields big enough to hide aircraft hangars from radar are possible.

Because of the greater challenges of rerouting visible light, however, Pendry cautions that shells for that portion of the electromagnetic spectrum are unlikely any sooner than 5 years from now.

The prospects for plasmonic coatings and superlens cloaking depend ultimately on whether the approaches will work for large objects. A use of superlens cloaking could be to reveal areas inside an object by putting part of it in an invisibility zone.

"Our [approach] presents the possibility that an object can be half cloaked," Milton says, although that wouldn't apply to living matter because its parts move.

Even if the techniques don't extend to large objects, plasmonic coatings might still have practical value in several areas. In near-field scanning optical microscopy, for instance, an observer views a detailed image of a nanoscale object by positioning a minuscule probe beside it. Plasmonic coatings might render the intrusive probe invisible, Engheta suggests.

Plasmonic particles might also serve as ingredients of antiglare coatings, he adds. Moreover, both those coatings and superlenses might offer new ways to shield electronic or optical devices from disruptive radiation or from eavesdropping.

Whether scientists have something to teach the Hogwarts School of Witchcraft remains to be seen.

However, there's little doubt, says Leonhardt, that the recent theorizing will open "a new box of tools for optical and electrical engineering."

"When you do that," he asserts, "it will have an impact."

References:

Alù, A., and N. Engheta. 2005. Achieving transparency with plasmonic and metamaterial coatings. *Physical Review E* 72(July):016623. Abstract available at http://dx.doi.org/10.1103/PhysRevE.72.016623.

Leonhardt, U. 2006. Optical conformal mapping. *Science* 312(June 23):1777-1780. Abstract available at http://www.sciencemag.org/cgi/content/abstract/312/5781/1777.

Milton, G.W., and N.-A.P. Nicorovici. In press. On the cloaking effects associated with anomalous localized resonance. *Proceedings of the Royal Society A*. Abstract available at http://dx.doi.org/10.1098/rspa.2006.1715.

Pendry, J.B., D. Schurig, and D.R. Smith. 2006. Controlling electromagnetic fields. *Science* 312(June 23):1780-1782. Abstract available at http://www.sciencemag.org/cgi/content/abstract/312/5781/1780.

Shalaev, V.M., *et al*. 2005. Negative index of refraction in optical metamaterials. *Optics Letters* 30(Dec. 15):3356-3358. Abstract available at http://www.opticsinfobase.org/abstract.cfm?URI=ol-30-24-3356.

Further Readings:

Pendry, J.B., and D.R. Smith. 2006. The quest for the superlens. *Scientific American* 295 (July):60.

______. 2004. Reversing light with negative refraction. *Physics Today* 57(June):37. Available at http://www.physicstoday.org/vol-57/iss-6/p37.html.

Weiss, P. 2001. Electromagnetism acts oddly in device. *Science News* 159(May 5):285. Available to subscribers at http://www.sciencenews.org/articles/20010505/note17.asp.

______. 2000. Coming soon: Knavish electromagnetic acts. *Science News* 157(March 25):198. Available to subscribers at http://www.sciencenews.org/articles/20000325/fob5.asp.

______. 2000. Black hole recipe: Slow light, swirl atoms. *Science News* 157(Feb. 5):86. Available at http://www.sciencenews.org/articles/20000205/fob4.asp.

For additional information about invisibility, go to http://www.st-andrews.ac.uk/~ulf/invisibility.html, http://www.ee.duke.edu/~drsmith/cloaking.html, and http://en.wikipedia.org/wiki/invisibility.

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http://www.sciencenews.org/articles/20060715/bob9.asp
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