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OPTICS

Watch your back

Kosmas L. Tsakmakidis and Ortwin Hess

A proposal for transporting photons invisibly between two unconnected points in space seems worthy of a *Star Trek* plot. But it is in principle wholly realizable, and could open up new vistas — literally.

Imagine walking down a footpath, staring unconcernedly at the clear track in front of you. Suddenly, you stumble over an object. You look down, but there is nothing to be seen on the ground. You step back and try a different angle of view, again without success. But you know something must be there, because you can feel it.

This situation is brought a step closer to reality with a device dreamt up by Greenleaf *et al.*[1] and described in *Physical Review Letters*. The authors propose a way of creating an 'invisible tunnel' through which photons, the elementary particles of light, can propagate between two seemingly unconnected points. To an observer standing where they emerge from their tunnel, the photons seem to come from nowhere. To an external viewer, they seem to be teleported from one place to the other. And anything within the tunnel cannot be seen by anyone. In analogy to the infamous 'wormholes' — a prediction in general relativity of tunnels through space-time that connect distant areas of the Universe — the authors call their brainchild an electromagnetic wormhole.

The wormhole works (in theory) by neatly combining concepts from differential geometry, general relativity, electromagnetism and the theory of 'metamaterials'[2]. Metamaterials are composite, nanostructured materials with specifically tuned electromagnetic properties. The authors construct the tunnel wall of their wormhole using a metamaterial layer that is designed to bend light waves around it without reflection, much as water waves bend around a tree branch or similar obstruction lying just below the surface of the water. This layer thus renders whatever is inside it invisible. The idea draws on techniques proposed[3,4] for the creation of an 'invisibility cloak' (Fig. 1a) — a device that has already been constructed and proved viable, at both microwave[5] and optical[6] wavelengths.

The advance in Greenleaf and colleagues' scheme[1] is that a cloaked object can 'see' into the outside world at the end of the tunnel, because photons are also free to propagate through it. The tunnel 'deceives' photons into thinking that remote regions are connected to each other so that they naturally follow the path inside the cylindrical channel. This cylinder is not part of conventional three-dimensional space, but is part of a higher-dimensional space outside it. Its topology is rather like the handle of a coffee cup connecting two areas of the cup's surface. If the handle is hollow and has two open ends, it presents an alternative route (other than staying on the surface of the cup) for getting from the one place to the other.

The key to the realization of this scheme is that this new photon-space does not naturally exist in real space. Rather, using suitable coordinate transformations, the authors tweak Maxwell's equations — the set of equations that describe the workings of electromagnetic waves — to simulate it. The equations retain their form on passing from the real to an artificial photon-space; the only thing that is required to complete the deception of the photons is to modify the values of the electric permittivity and magnetic permeability (numbers that codify the degree to which a material allows electric and magnetic fields to pass).

Such a concealed communication channel could be deployed for military purposes for the secret transmission of information or stealth technologies. But it might also find its way into civilian applications: rerouting mobile-phone signals around obstacles, for example, or shielding sensitive medical devices from interference by magnetic resonance imaging scanners. But the possibilities don't end there. Two of Greenleaf and colleagues' invisible electromagnetic tunnels, built into the frame of a pair of special half-moon spectacles, would effectively 'glue' the photon-space behind the head to the photon-space in front of the eyes, allowing one literally to watch one's back (Fig. 1b).

Currently, metamaterial technology allows the construction of invisibility cloaks that work well for only a limited range of frequencies. The electromagnetic wormhole in its present form can also be only short, otherwise the image of an object being transmitted through it becomes noticeably distorted. The true potential of such schemes will become clear in future experimental tests. What is plain now is that innovations are coming thick and fast in this burgeoning world of 'transformation optics'. ■

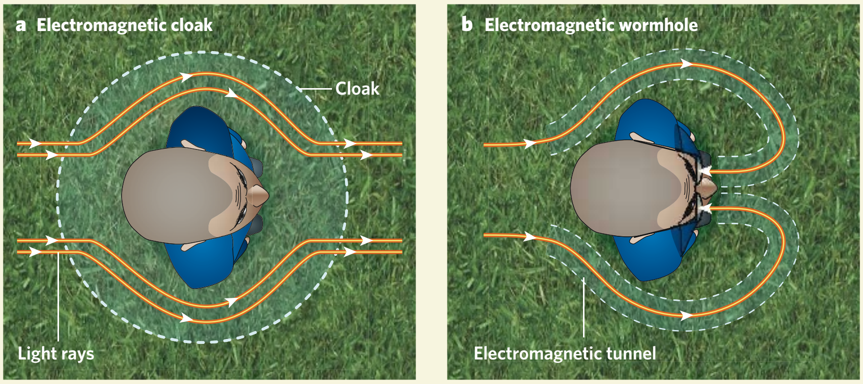

Figure 1 | It's behind you. a, The invisibility cloak devised by Pendry *et al.*[3] uses specially structured 'metamaterials' to open up a 'hole' in photon-space, inside which one can place an object. Photons are naturally redirected around the object, rendering it invisible, at least when viewed with photons at a certain wavelength. **b**, Greenleaf and colleagues' electromagnetic wormhole[1] is a natural extension of the invisibility idea, with exciting potential applications. For example, in principle two flexible wormholes attached to the frame of a specially designed pair of half-moon spectacles could project the photon-space behind the head to the half-moon area of the lenses, providing a seamless 360° view.

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