
100% META-MATERIAL
I GUESS THIS SOLVES THE UNSIGHTLY PANTY-LINES ISSUE.
THE ONLY PROBLEM IS MY DRY-CLEANER CAN NEVER FIND THEM...
INVISIBILITY CLOAK
(...DRESSES, PANTS, & CARDIGANS, TOO)
IF WE COULD CLOAK STAINS AND SMELLS, I'D NEVER HAVE TO DO LAUNDRY AGAIN!

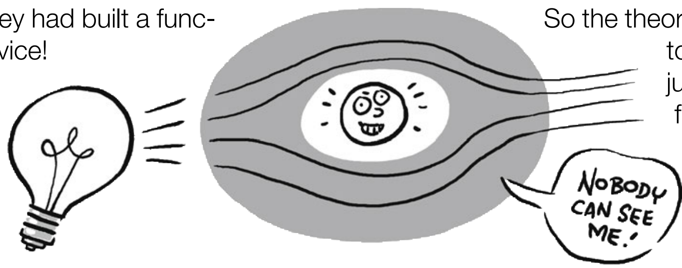
Invisibility Cloaks

Walk Like a Magician

It is an old dream: walking through the streets without being seen. Just put on a magic cape, and become invisible. One would be able to pull the best practical pranks ever! Although the most purposes this invisibility cape would be used for would quite probably not be very nice, probably everybody has thought about it at some time in their life.

Now You See Me – Now You Don't

This is why the world listened up, when researchers of Duke University in North Carolina announced 2006, that they had built a functioning cloaking device! The first enthusiasm was slightly curbed, however, when they added that it would only work for small objects, only for microwaves, and only when looking from a very specific direction. So, instead of turning an object invisible to the naked eye, it would allow for it to be placed in a running microwave oven without getting hot. Still, it is a good start. But how does the "invisibility cloak" work, precisely?



Bending Light – the First Step to Invisibility

Before we can understand how invisibility works, we need to be clear on what it is that makes us see things. The ancient Greeks assumed that our eyes worked like ray emitters, sending out some kind of sensory beam. Whenever that beam hit something, we would see it. Nowadays we know that it is pretty much the other way round: A light ray from the sun (or another source) hits an object. Of all of those rays hitting it, some are absorbed (heating it up), and some are reflected, depending on the wavelength of the light ray (↗[1]). The reflected light rays, whenever they hit our eye, give us the impression of a certain color (depending on the wave length) in that direction.

So the theory is easy: For an object to become invisible, we just need to prevent it from getting hit by light rays! So an invisibility cloak should simply guide the light around the object it envelops. Whenever a light ray hits the cloak, it should not reflect the beam into any direction, but should alter its path so that it can emerge on the other side, as if there had never been an obstacle at all.

Refraction – Can It Help?

All right, so for an invisibility cloak to function, one needs to be able to bend light. Materials can do this, it is called refraction! Refraction happens every time light passes from one medium to another – it slightly changes its direction. This is why it is so dif-

↗[1]: *"Kepler's Laws" on page 47*

B. Bahr, B. Lemmer, R. Piccolo, *Quirky Quarks*, DOI 10.1007/978-3-662-49509-4_3

ficult to catch a fish with your bare hands: the fish is not at the position where you see it, but slightly next to it. The reason is that the light gets refracted, when it passes from the fish, through the border between water and air, to your eyes. So can one use this to make the fish completely invisible?

Now here comes the big problem: The angle under which something is refracted depends on the so-called refractive index of the material it passes through. Vacuum has a refractive index of precisely 1, air has an index from ever so slightly larger than 1, water has one of 1.33, glass of about 1.5, and so on. Normal materials in the world all have a refractive index equal to or larger than 1! Because of this, light can only be bent towards the object, never away from it. For guiding a light ray around an object with refraction, one would need a material which at some points has a refractive index of smaller than 1, or even negative indices, which are less than zero!

The Refractive Index: the Crux of the Problem

Materials with these refractive indices would have very peculiar properties. If the index would be between 0 and 1, light would not only be bent away from the object, it would also travel faster than the speed of light. And in materials with negative refractive index, light would even travel backwards! Would that even make sense?

Metamaterials: Bending Light to Our Will

But this is precisely what the researchers at Duke University have achieved: to create a material which has, effectively, a refractive index smaller than one. How did they manage that? Well, the optical properties of the material do not come from the types of atoms it consisted of, but also from the way these atoms were arranged: They built a ring, made of arrays of lots of tiny copper structures, only micrometers wide. Whenever a light wave with a certain wavelength would hit these little structures, they would start to emit electromagnetic waves themselves, like thousands of little antennas. Because of constructive and destructive interference, these little waves would add up, and the resulting light wave would be traveling in a different direction than the initial one. The changed direction would be such that, effectively, the material behaved as if it had a refractive index of less than one.

Because the interference of electromagnetic waves is very dependent on the actual wavelength, it should be no surprise that it only works for waves with a very specific frequency – in this case, microwaves. But it did work: If the ring was hit by microwaves from a certain direction, the waves would be guided around the ring, and emerge on the other side, as if nothing had obstructed their path. Any object placed in the center of the ring was completely shielded from the microwave radiation.

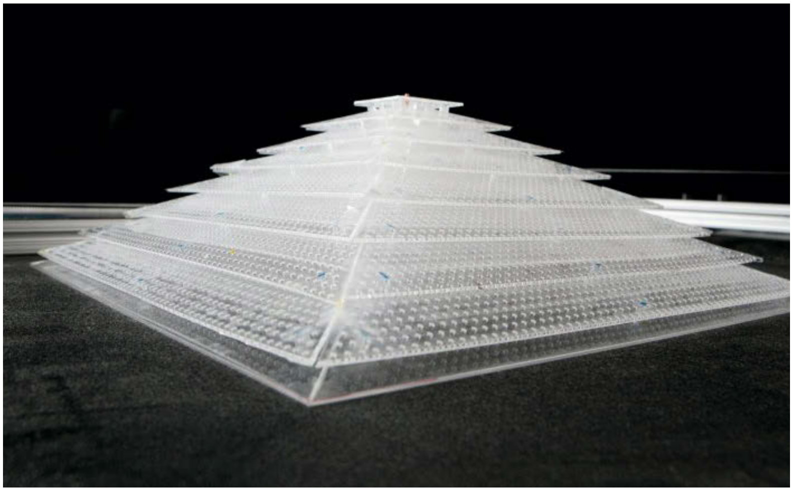
These materials, whose optical properties are specifically designed by their microscopic structure, are also called meta-materials, and research in these has exploded in the past decade. Soon, versions of the "invisibility cloak" were produced, which worked with larger objects, moving objects, sometimes even for some parts of the visible spectrum.

"Invisibility" Also for Other Types of Waves

Because what is used here is essentially the wave-like nature of light, one could ask oneself: does this also work for other types of waves? Of course it does! Just a few years ago, the researchers at Duke University presented a "silence cloak". This was constructed out of 3D-printed materials, and was able to shield an object completely from sound waves. You can see it in the picture on this page. A person covered with such a silence cloak would hear nothing from the outside: sound waves would be guided around it completely. Bats would fly right against them – they'd be completely "invisible" to their sonar.

One could easily think of other uses: By constructing the right kind of barriers, one might be able to guide water waves around small islands. Possibly quite useful for those little archipelagos which are frequently in danger of drowning in storms. Although sturdy houses and good raincoats might actually be cheaper…

However, after all is said and done, we have to conclude that, at the time this book is written, no cloak has been constructed which would make us actually feel like Harry Potter. Although there is a lot of research happening in this area at the moment, we are still some major steps away from being able to walk through the streets without anybody being able to see us. But who knows what the future will bring?



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