**METAMATERIAL MAGIC: THE FUTURE OF SCIENCE IS NOW!**

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Metamaterials are special materials, usually made from multiple materials, such as metals and plastics, which are arranged in repeating patterns. What is unusual is that the patterns are at very very small scales.

Metamaterials have a property that is rarely seen in naturally occurring materials: they are engineered to have a property that arises, not from the properties of the materials it is made from, but from their specially designed structures. Their precise shape, geometry, size, orientation, and arrangement , all go into giving them their smart properties. In particular, they can manipulate electromagnetic waves (that is light waves), acoustic (sound waves), or even seismic waves, by blocking, absorbing, enhancing, or bending them in a manner that normal materials cannot achieve.

Imagine a material that super bends light and makes the object invisible and revolutionizes technology. Yes, it seems fictional – remember Harry Potter’s invisible cloak. What if I tell you that cloak is true? These incredible materials are called **metamaterials**, and they’re not just the stuff of dreams – they’re the future of science. Ready to dive into the magical world of metamaterials and discover how they could change our lives? Buckle up, this journey will amaze you.

**What are metamaterials?**

The word meta in Greek means “Beyond”. So, when we talk about metamaterials, we’re essentially talking about materials that go beyond ordinary, with properties that are unimaginable. They are not our everyday materials. Imagine constructing LEGO blocks. These metamaterials are artificially engineered ones with ordered micro- and nano- structured patterns and 2 dimensional structures. See the picture for an AI-generated image of a metamaterial. These super materials can control and manipulate light. The thickness of the material must be of sub-wavelength of the incident light.

**Negative Refractive Index**

One of the coolest things about metamaterials is the *negative refractive index*. What if I tell you that it doesn’t obey Snell’s Law. Yes, in normal materials, light bends in predictable way, when passes from one material to another, like air to glass. This bending is described by Snell. But here the light bends in opposite direction, this leads to some strange and amazing effects – super lenses, that can focus light more precisely than conventional lenses. It’s like having a microscope with superhero vision. By bending light around the object, metamaterials can create the effect of invisibility. Light travels around the object and does not go through it, making us believe that the object isn’t there – like an *invisible cloak*.

Metamaterials are artificial materials which have the property to manipulate electromagnetic waves with its negative values of permittivity (response to electric fields), permeability (response to magnetic fields) and refractive index. Normal materials have positive values of both (so that light bends *towards* the normal when it travels from air to glass, etc). A negative value of these quantities means that they have unusual responses compared to normal materials. The property can be understood from the figure: the right hand side figure shows “normal” refraction from a rarer to denser medium. The light (red line) bends towards the normal (black line). The left hand figure shows light falling on a metamaterial. Instead of bending towards or away from the normal, the light bends the other side! This s what makes metamaterials so unique.

Now, let’s go back to 1968, when Victor Veselago, a Soviet Russian physicist first predicted materials with such *negative* permittivity and permeability. However it was difficult to find these materials in the lab. This is because the materials that had negative permittivity (response to electric fields) showed such behaviour for light at very high frequencies (we know that blue light has higher frequency than red light). But negative permeability materials (response to magnetic field) occurred at much lower frequencies.

In 2000 John B. Pendry, and his colleagues, proposed a variety of geometric structures that they thought could make artificial metamaterials. They gave a concept of a “perfect-lens” that could overcome diffraction limit from conventional lens to allow for imaging at much higher resolution than what could be achieved so far. Then David R. Smith, a physicist and electrical engineer at Duke University, United States, joined hands with him and created the first metamaterial by bending microwaves in ways that natural materials couldn’t. In 2006, they designed and built the invisible cloak which bend microwaves and effectively make the object invisible.

**Metamaterial Antennas**

Imagine antennas that are super tiny but really powerful. They can do incredible things which normal antennas can’t. They can pick up signals from different places and frequencies, making them super versatile. These antennas fit perfectly inside our smartphones, so that we can be connected all the time. For example, right now we have 5G communication. But the 6G antenna communication will be of metamaterials. They make GPS more accurate. Regular antennas are good, but when we add metamaterials, they have now superpowers!

**Other applications**

Some metamaterials can control sound waves too. They can block or absorb sounds, which could be majorly used for making quiet rooms or even helping with noise pollution. Another application is they can also affect heat. Metamaterials can help to make things cooler or warmer than they usually would be, and can be widely used in electronics to prevent the heating of devices.

As metamaterials evolved, their unique properties opened up incredible possibilities. One of the most exciting areas where they make significant impact is the realm of sensors. These sensors are crafted with precision, offer sensitivity and specificity, and are used to detect slight changes in the normal environment. Their periodic structure makes them perfect for medical diagnostics too. The non-invasive treatment is its super specialty. They can monitor blood glucose level for example.

Future potential metamaterials hold immense promise for the future, from revolutionizing quantum computing to creating advanced wearable technology. Let’s gear up to the new realms of innovation.

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*References: Wikipedia, Physics Today article at https://pubs.aip.org/physicstoday*