**Lecture 1**

# Metamaterials, transformation optics, and cloaks of invisibility

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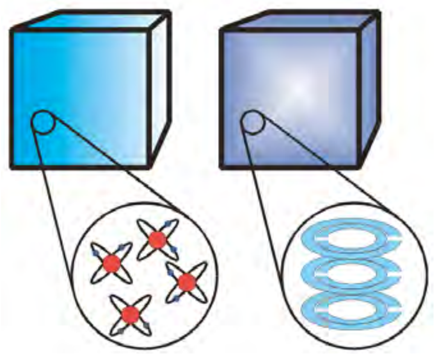
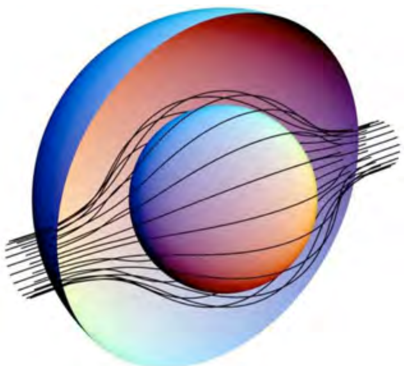
*Metamaterials:* we control electromagnetic radiation in general and light in particular by exploiting the properties of materials and their response to electric and magnetic fields. Glass refracts light because of its response to electric fields and can be used to focus light – hence much of the optics industry. However nature has provided us with a limited palette of properties, much more restricted than allowed in principle by the laws of physics. The response of conventional materials to electromagnetic fields is determined by their constituent molecules. In contrast metamaterials owe their properties to much larger units, though still less than the wavelength of radiation. These large structural units, or 'metamolecules' can be designed to give a much wider spectrum of properties. In fact almost any property allowed by physical laws can in principle be engineered in this way. The development of these new materials will be traced and examples given.



Far left: in conventional materials $\varepsilon,\mu$ derive from the constituent atoms. Right: in metamaterials $\varepsilon_{eff},\mu_{eff}$ derive from the sub-units which may contain many atoms

*Transformation optics:* our intuitive understanding of light has its foundation in the ray approximation and is intimately connected with our vision: as far as our eyes are concerned light behaves like a stream of particles. Here we look inside the wavelength and show how the new concept of transformation optics that manipulates electric and magnetic field lines rather than rays can provide an equally intuitive understanding of sub wavelength phenomena and at the same time be an exact description at the level of Maxwell's equations.

*Invisibility*: Hiding an object presents two challenges: the object must not be seen and surrounding objects must not be obscured. In other words the hidden object must not cast a shadow. This latter requirement presents a challenge because light incident on the cloak must be captured, preserved, and steered around the cloak to emerge on the same trajectory it had before it hit the cloak. Transformation optics is the ideal tool for this design challenge.



Left: rays of light care captured by a cloak and deviated around the hidden space, to emerge on the far side of the cloak