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Improving the maths behind the invisibility cloak

Cherry Canovan, 2nd year PhD (part-time), Physics Department. Supervisor: Professor Robin Tucker.

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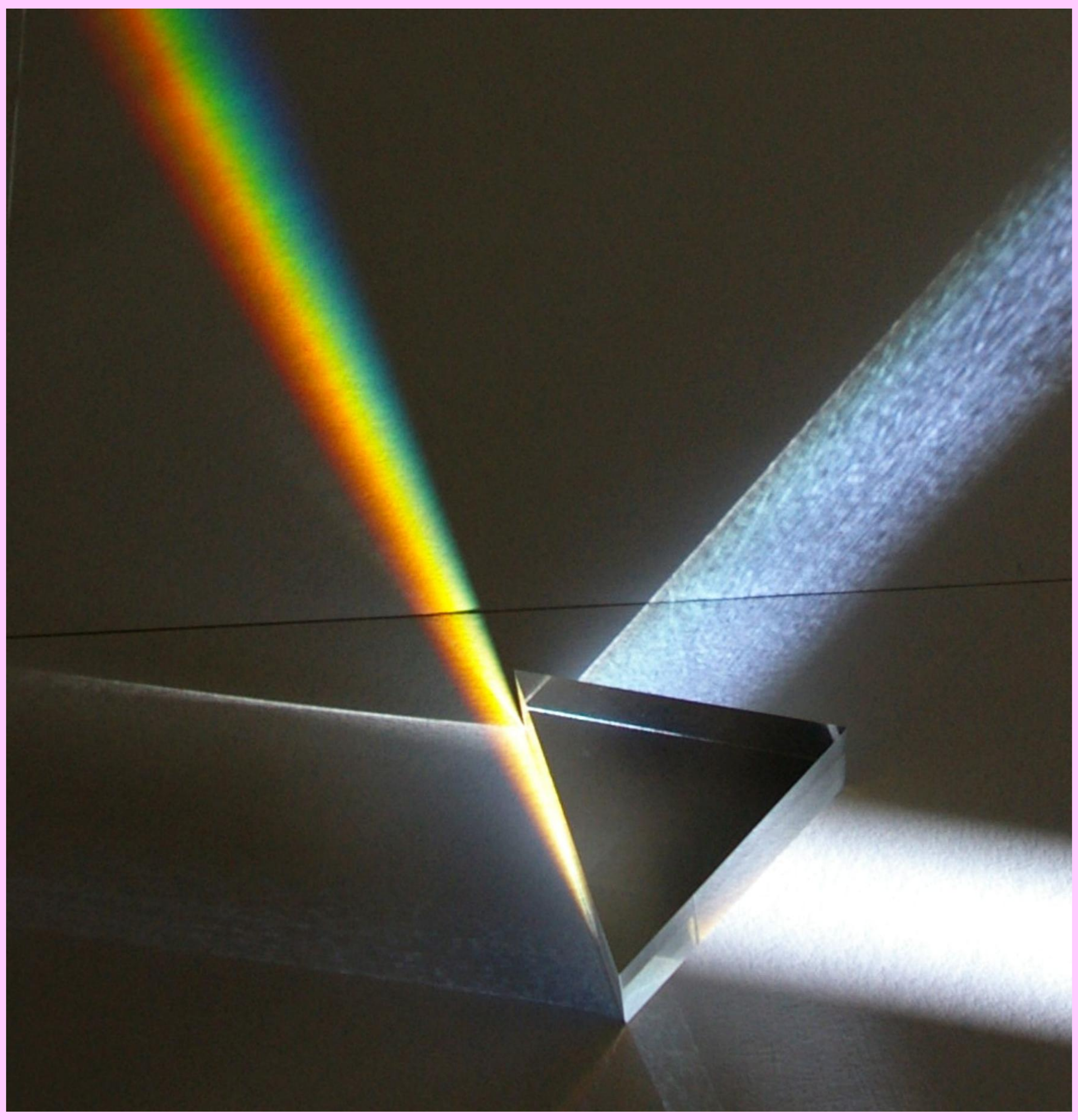
What happens to light when it hits an object?

When light enters any substance, it interacts with it on an atomic level. Some frequencies will have just the right amount of energy to 'excite' an atom – push an electron up to a different energy level, or make a molecule vibrate or rotate – while others will travel through virtually unchanged. This is the reason that white light can enter a prism and be split into a rainbow.

Light is made up of travelling electric and magnetic waves, and both these parts can exhibit 'dispersion' – a different physical reaction to different frequencies. The electric reaction, which dominates in 'normal' materials, is known as the permittivity, while the magnetic reaction is known as the permeability.

Substances can react to, and absorb, many different frequencies in light, and as a result the distributions of permittivity and permeability can show multiple peaks.



But why is this important?

One of the hottest topics in physics is the creation of metamaterials – materials which are specially engineered to have weird properties, such as 'cloaking', or the effect of invisibility. These effects are dependent on permittivity and permeability, so we need to know how they vary with frequency.

But creating these materials also relies on computers to model what their behaviour will be – and the models are very poor at dealing with dispersion. Even those which attempt to deal with these effects cannot model what happens when the medium moves – pretty essential for an invisibility cloak!

What progress have we made?

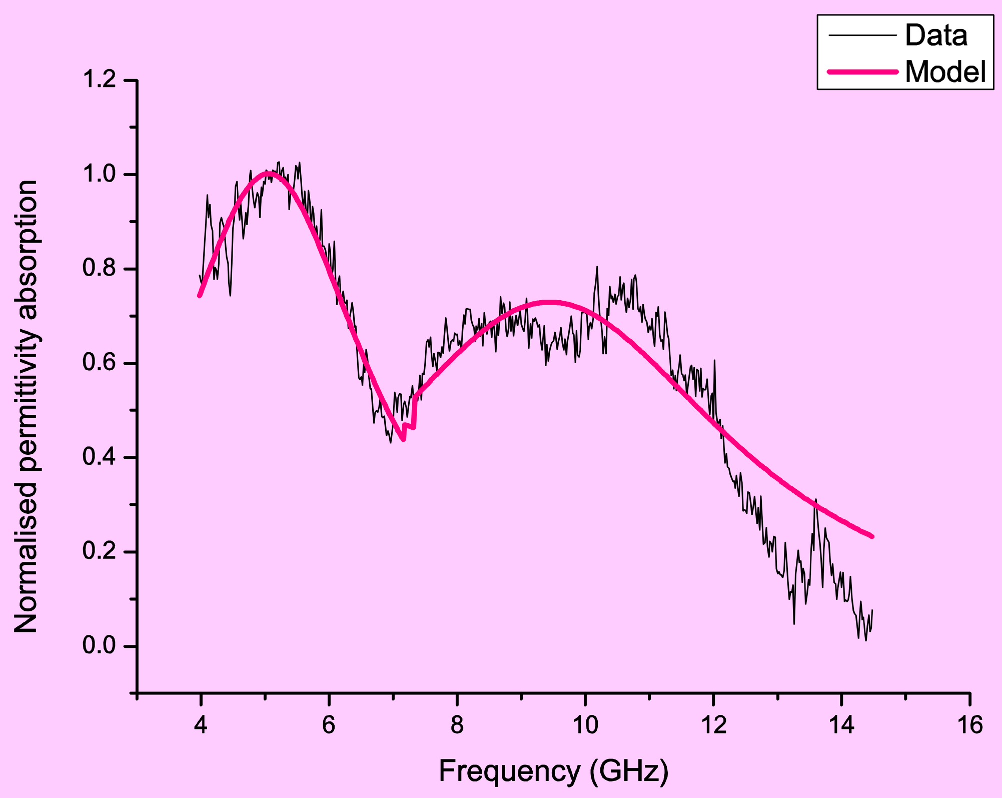
Lancaster's Mathematical Physics group uses a special maths called differential geometry. We hope to produce a model which can be used for real materials – those that move, have many different resonances and which exhibit dispersion in both electric and magnetic response.

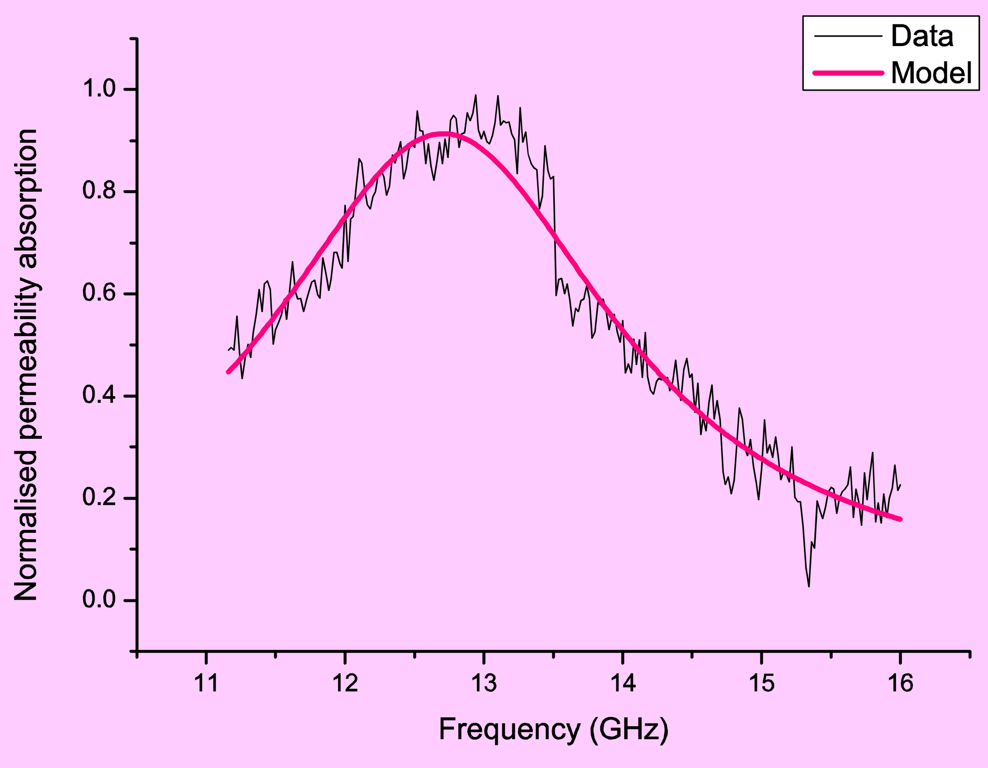
The results shown here are those of an early, simplistic model of permittivity and permeability compared with a data set for silicone rubber at microwave frequencies[1].

The top graph shows absorption in the permittivity – the peaks show frequencies at which the energy of the electric field is absorbed. This model deals naively with multi-peaked distributions, but we are considering ways to refine it.

The bottom graph shows absorption in the permeability. Many standard models do not allow for dispersion in the magnetic response.

The model will be refined to predict results for moving media, in which the group has a long-standing interest[2], as well as to include 'spatial dispersion' which takes into account near-neighbour effects.





1. Gama, A. M. & Rezende, M. C., "Complex permeability and permittivity variation of carbonyl iron rubber in the frequency range of 2 to 18 GHz." *Journal of Aerospace Technology and Management* **2** (2010): 59-62.
2. Canovan, C. E. S. & Tucker, R. W. T., "Maxwell's equations in a uniformly rotating dielectric medium and the Wilson–Wilson experiment." *American Journal of Physics* **78** (2010): 1181-1187