

Abraham vs. Minkowski 1-1

Does a photon *gain* or does it *lose* momentum when it enters a glass slab? *Both* may be the simple, yet ingenious answer to this centenary dilemma.

What happens to a photon when it enters a material? Does it *gain* momentum, as proposed by Minkowski? Or does it *lose* momentum, as argued by Abraham? Many great scientists have dwelt on the so-called *Abraham-Minkowski* dilemma over the past hundred years. Now, Stephen Barrett from the University of Strathclyde, Glasgow, UK, may have solved the puzzle in a brilliant, yet simple way: Abraham and Minkowski are both right!

The origin of the Abraham-Minkowski dilemma can be traced back to the beginnings of the XX century: in 1908 Minkowski suggested that a photon *gains* momentum when entering a medium; only a year later, in 1909, Abraham contended that, on the contrary, it actually *loses* momentum. Astonishingly, there are very good reasons to give credit to both viewpoints. Let us have a closer look at some of the most intuitive arguments in favor of each of the two theories.

If a photon traveling in vacuum enters a material, a slab of glass for example, its speed decreases by a factor, known as the *refractive index*. It follows rather logically that the photon's momentum, which is proportional to its speed, should also *decrease* in the glass. There, one might justifiably think, *Abraham* must be right!

However, a photon is a quantum entity with a wavelength and a momentum given by the Planck's constant divided by its wavelength. In the glass the wavelength decreases by a factor equal to the refractive index and, therefore, its momentum must *increase*. We would now seem to be justified in thinking that *Minkowski* must be right, after all.

Puzzling! Both arguments come across as sound and logical – yet they would also seem to lead to antithetical conclusions. Indeed, for over one hundred years, generations of great scientists racked their brains over this dilemma, unable to reach any sort of definitive resolution.

Since physics is an experimental science, it may be argued that it is for the experiments to decide on the issue. And there is, indeed, very good experimental evidence in favor of the theories – actually, in favor of *both* theories! Where, then, is the catch, if indeed there is one?

Some experimental evidence in favor of Minkowski comes from the cooling of atoms and from the optical stretcher. The latter, for example, is a device where a cell kept between two counter-propagating laser beams stretches along the axes of the beams. This appears to be consistent with the Minkowski momentum, since the stretching results from the decrease of the momentum when light crosses the boundary between the water and the cell. On the opposite side of the field, sympathetic to Abraham, we find a recent experiment that shows the recoiling of an optical fiber on the exit of a light pulse.

Barnett may well have found the answer. Surprisingly,

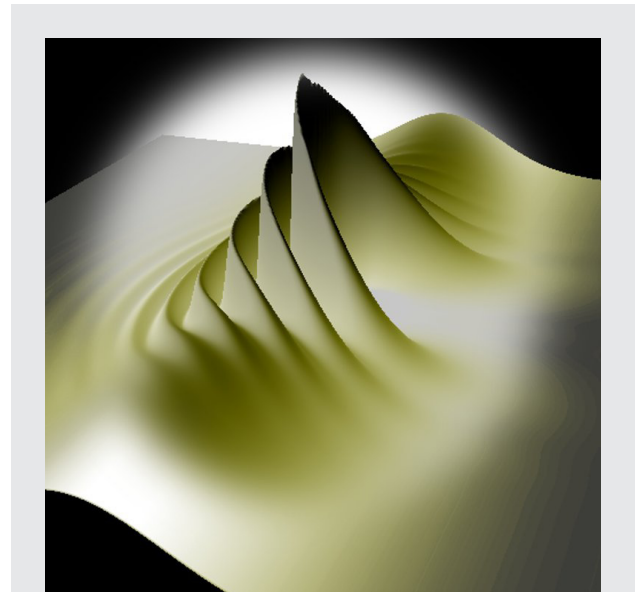


Figure 1: How does the momentum of a photon change when it interacts with matter? Does it increase or decrease? Both viewpoints are actually correct, depending on which momentum is being considered.

both arguments are reasonable and sound because they are both right – but they refer to two different momenta, namely the *kinetic momentum*, where Abraham's theory is concerned, and the *canonical momentum*, where Minkowski's theory is concerned.

The kinetic momentum of a body is simply the product of its mass multiplied by its speed. The kinetic momentum of a photon when it enters a medium decreases in accordance with Abraham's prediction, but such change is compensated by the recoiling of the medium, so that what is conserved is the total kinetic momentum of the photon and the medium.

The canonical momentum is a little subtler to grasp. It can be intimately related to the quantum nature of the photon. It appears in the interactions between single photons and single atoms, such as atom cooling. The canonical momentum of a photon increases when it interacts with an atom, and, as predicted by Minkowski once again what is conserved is the total canonical momentum of the photon and the atom.

"If light propagates in free space," explains Barnett, "there is no difference between the kinetic and the canonical momentum. However, such difference matters when

light propagates inside a medium.” This may go some way towards explaining why the fact that Abraham’s and Minkowski’s theories refer to two different momenta, went unnoticed before

Looking ahead, Barnett asks: “Might there be phenomena where both momenta show up at the same time?” Once the idea that both momenta are correct is accepted, it would make sense to plan experiments where both are present together. The focus on trying to prove/disprove Abraham or Minkowski may have prevented scientists from exploring

such possibilities in the past – the good news is that this may be about to change soon.

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