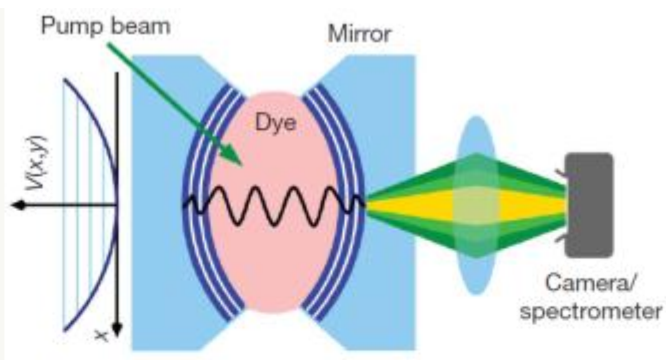
LIGHT DOES MATTER

Light is special. In our everyday experience it behaves like a wave, which gets reflected, refracted and shows interference with other light of the same wavelength. At the same time, light also consists of particles, so-called photons. This duality is quite fundamental: the Hanbury Brown and Twiss experiment for example only works because of the particle-like properties of light.

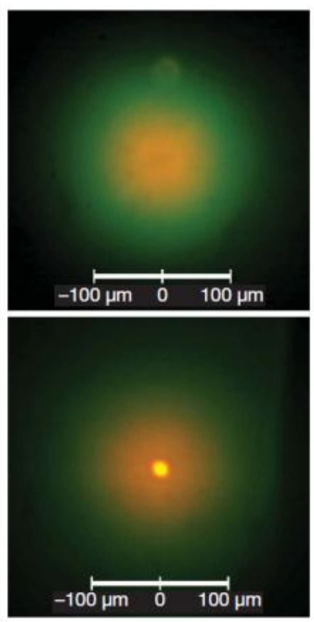


The experimental setup. A laser beam injects photons into a cavity filled with light, and a camera observes the photons coming out of the cavity. Reprinted by permission from Macmillan Publishers Ltd. Nature 468, 545-548 (2010).

This amazing and perhaps confusing duality, where light in one experiment appears to be a wave and in others it behaves like particles, is now laid bare in a paper published in *Nature*. There, Jan Klaers, Martin Weitz and colleagues from the University of Bonn in Germany take one of the classical properties of light waves and turn it upside down — by demonstrating a related effect that only works when considering the particle qualities of light!

The classical effect they use is that light waves can all oscillate synchronously. This is exactly what happens in a laser, and is typical behaviour for a class of particles to which photons belong to, the bosons. Bosons love to be all in the same state.

A similar synchronous behaviour can also occur for other bosons, including certain atoms, which then all assume the same quantum state. This state is called a Bose-Einstein condensate, after Satyendra Nath Bose (after whom bosons are named) and Albert Einstein, who described it first in 1924. It is a Bose-Einstein condensate of light that Weitz and colleagues have now demonstrated.



Bose-Einstein condensation of light, as observed by a camera looking at the photons from the cavity. The narrowing of the spatial distribution as the light intensity is increased (bottom image) is a tell-tale sign. Reprinted by permission from Macmillan Publishers Ltd. Nature 468, 545-548 (2010).

Well, so if photons are bosons anyway, what is the big deal, what is the difference? I have to confess this was my first thought when only reading the title of the paper. A Bose-Einstein condensate of light? Simply turn on any laser, and there you have something similar. But there is a subtle difference: in the Bose-Einstein condensate of atoms, the number of atoms is conserved — atoms may drift in and out of the experimental system, but they obviously are not artificially created on the spot. This is different to a laser, where new light is created all the time.

But how to get light behave like that, like discrete atomic particles? The trick is to confine the light between two mirrors that are very close together (Fig. 1). Light only fits between the mirrors if its wavelength is short enough. But a maximum wavelength of light also means that the light has a certain minimum energy (the energy of light is inverse to its wavelength).

The minimum energy of light between the mirrors is high enough to rule out the creation of new photons, because the thermal energy from the heat is too small, and other energy sources aren't available either. No new photons are created, and the system behaves more like a bunch of particles. Even so, at this stage we still haven't achieved a Bose-Einstein condensate, all we have is light bouncing back and forth between two mirrors.

As in the case of atoms, the photons need to be cooled down. The purpose is to bring them closer together in energy, and this can done by a cooled dye solution that is placed between the mirrors. The interaction of the photons with the dye molecules brings them in tune with the temperature of the solution, which again is very much like what would happen for regular particles.

As a last step, to get the Bose-Einstein condensate going we need a sufficient number of particles. The images taken of light passing through the cavity show this impressively (Fig. 2). Broadly speaking, at low light intensities there aren't enough photons to synchronise with each other to form a condensate. As a result, the light is broadly distributed. At high enough intensities, however, the Bose-Einstein condensate is clearly evident through the narrow distribution of light in a single beam. This is to some degree comparable to the narrow beam coming out of a laser, and shows the relationship between both effects.

Indeed, in many ways the properties of light in a laser and in this Bose-Einstein condensate are similar. But the similarity arises not from the wave-like property itself, but from the dual nature of light that can act as a wave as well as a particle. In that respect the demonstration of Bose-Einstein condensation of light makes a full circle: light that behaves like matter that behaves like light. Simply beautiful.

Source: http://allthatmatters.heber.org/2010/11/24/light-does-matter/