Measuring the Very Real Pressure of Virtual Photons

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Under some conditions, quantum fluctuations of light can put real, physical pressure on an object. In new research that came out just yesterday in the journal *Physical Review Letters*, a team of scientists from the RIKEN research institute in Japan show that it's theoretically possible to "see" and study the virtual photons that make up these quantum fluctuations.

Before we get into the details of this research, let's take a mental boat ride. There's nothing quite like sailing through the water, propelled by the wind into the openness of the sea. In this situation, the invisible wind that fills the sails seems to take on an almost magical power. In reality, this power comes from the collective force of countless air molecules all traveling in the same direction. Each air molecule carried by the wind that hits the sail gives it a small push forward before bouncing backward. Together, these pushes keep the boat in motion.

Sailing boat. Credit: Elisaboba (CC BY 2.0).

Just like the air molecules powering a sailboat, particles of light (photons) can form a "wind" that pushes on a mirror. In such a wind, each particle that hits the mirror gives it a small push before bouncing backward. Add up enough of these pushes and it's possible to propel a mirror forward, as in the proposed solar sail technology that would use photons from the sun to power spacecraft without propellants. This wind of photons is called radiation pressure.

In his 1798 poem *The Rime of the Ancient Mariner*, Samuel Taylor Coleridge describes an unnatural twist in the wind. It turns out that this twist parallels a seemingly unnatural twist in radiation pressure. Mauro Cirio, Neill Lambert, Kamanasish Debnath, and Franco Nori, the authors of this research, set the stage for the twist this way: "In an ocean without wind or waves, a boat stands completely motionless as disgrace fell upon its crew. However, another boat is approaching. This surprising sense of movement in this otherwise motionless scene comes as an odd omen to the crew, who wonder 'But why drives on that ship so fast, Without or wave or wind?'"

"Following this Romantic analogy," the authors say, "in the case when no 'wind of photons' is present, is it still possible to observe radiation pressure pushing on a mirror? The answer is actually yes."

It's not possible for a sailboat to sail without wind, but under the right conditions, it is possible for radiation pressure to exist without photons. This is because there is a quantum regime in which light and matter are so strongly intertwined that the line between them blurs. Scientists have only recently been able to probe this regime, called the ultra-strong coupling regime, with experiments.

In this regime, an atom placed between two mirrors will be surrounded by a cloud of quantum fluctuations of light—a cloud of virtual photons that flash in and out of existence. These virtual photons can exert radiation pressure on a mirror even though they aren't real photons. Although they lead to interesting physical processes, it's hard to study these virtual photons without destroying them.

Over drinks at the Half Yard, a British pub near RIKEN, Mauro Cirio and Neill Lambert came up with a new way to measure the force of these virtual photons in a nondestructive way. It took them nearly a year to work out the details, but this new paper describes their idea, demonstrates its feasibility based on theory, and outlines how to carry it out experimentally.

To get the basic idea of the process, imagine a mirror attached to a spring in such a way that when you push on the mirror the spring is compressed. Now, place another mirror facing the first mirror and an atom between them. In the ultra-strong coupling regime, radiation pressure from the virtual photons will give tiny pushes, or momentum kicks, to the moveable mirror. Each kick will move the mirror by a tiny amount.

Normally this movement would be too small to measure with current technology, but the system suggested by the researchers mechanically amplifies each kick. This means that the mirror moves a much greater distance under the radiation pressure—a distance that should be detectable with state-of-the-art technology. According to the analysis, this technique is very sensitive, doesn't destroy the virtual photons, and has a high signal-to-noise ratio.

With this work, the researchers have paved the for experiments that should, in principle, be capable of detecting these virtual photons in a new way. This is important because the more we know about the world, even in its strangest regimes, the better we can understand, appreciate, and harness its wonders—from the seas to quantum fluctuations of light.

—Kendra Redmond