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A vacuum can yield flashes of light

"Virtual particles" can become real photons under the right conditions.

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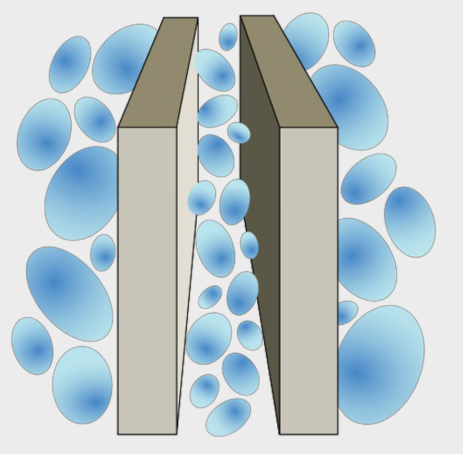

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'Virtual particles' can have real physical effects.

A vacuum might seem like empty space, but scientists have discovered a new way to seemingly get something from that nothingness, such as light. And the finding could ultimately help scientists build incredibly powerful quantum computers or shed light on the earliest moments in the universe's history.

Quantum physics explains that there are limits to how precisely one can know the properties of the most basic units of matter—for instance, one can never absolutely know a particle's position and momentum at the same time. One bizarre consequence of this uncertainty is that a vacuum is never completely empty, but instead buzzes with so-called “virtual particles” that constantly wink into and out of existence.

These virtual particles often appear in pairs that near-instantaneously cancel themselves out. Still, before they vanish, they can have very real effects on their surroundings. For instance, photons—packets of light—can pop in and out of a vacuum. When two mirrors are placed facing each other in a vacuum, more virtual photons can exist around the outside of the mirrors than between them, generating a seemingly mysterious force that pushes the mirrors together.

This phenomenon, predicted in 1948 by the Dutch physicist Hendrick Casimir and known as the Casimir effect, was first seen with mirrors held still . Researchers also predicted a dynamical Casimir effect that can result when mirrors are moved, or objects otherwise undergo change. Now quantum physicist Pasi Lähteenmäki at Aalto University in Finland and his colleagues reveal that by varying the speed at which light can travel, they can make light appear from nothing.

The speed of light in a vacuum is constant, according to Einstein's theory of relativity, but its speed passing through any given material depends on a property of that substance known as its index of refraction. By varying a material's index of refraction, researchers can influence the speed at which both real and virtual photons travel within it. Lähteenmäki says one can think of this system as being much like a mirror, and if its thickness changes fast enough, virtual photons reflecting off it can receive enough energy from the bounce to turn into real photons. "Imagine you stay in a very dark room and suddenly the index of refraction of light [of the room] changes," Lähteenmäki says. "The room will start to glow."

The researchers began with an array of 250 superconducting quantum-interference devices, or SQUIDs—circuits that are extraordinarily sensitive to magnetic fields. They inserted the array inside a refrigerator. By carefully exerting magnetic fields on this array, they could vary the speed at which microwave photons traveled through it by a few percent. The researchers then cooled this array to 50 thousandths of a degree Celsius above absolute zero. Because this environment is supercold, it should not emit any radiation, essentially behaving as a vacuum. "We were simply studying these circuits for the purpose of developing an amplifier, which we did," says researcher Sorin Paraoanu, a theoretical physicist at Aalto University. "But then we asked ourselves—what if there is no signal to amplify? What happens if the vacuum is the signal?"

The researchers detected photons that matched predictions from the dynamical Casimir effect. For instance, such photons should display the strange property of quantum entanglement—that is, by measuring the details of one, scientists could in principle know exactly what its counterpart is like, no matter where it is in the universe, a phenomenon Einstein referred to as "spooky action at a distance." The scientists detailed their findings online February 11 in Proceedings of the National Academy of Sciences.

"This work and a number of other recent works demonstrate that the vacuum is not empty but full of virtual photons," says theoretical physicist Steven Girvin at Yale University, who did not take part in the Aalto study.

Another study from physicist Christopher Wilson and his colleagues recently demonstrated the dynamical Casimir effect in a system mimicking a mirror moving at nearly 5 percent of the speed of light. "It's nice to see further confirmation of this effect and see this area of research continuing," says Wilson, now at the University of Waterloo in Ontario, who also did not participate in the Aalto study. "Only recently has technology advanced into a new technical regime of experiments where we can start to look at very fast changes that can have dramatic effects on electromagnetic fields," he adds.

The investigators caution that such experiments do not constitute a magical way to get more energy out of a system than what is input. For instance, it takes energy to change a material's index of refraction.

Instead, such research could help scientists learn more about the mysteries of quantum entanglement, which lies at the heart of quantum computers—advanced machines that could in principle run more calculations in an instant than there are atoms in the universe. The entangled microwave photons the experimental array generated "can be used for a form of quantum computation known as 'continuous variable' quantum information processing," Girvin says. “This is a direction which is just beginning to open up.”

Wilson adds that these systems “might be used to simulate some interesting scenarios. For instance, there are predictions that during cosmic inflation in the early universe, the boundaries of the universe were expanding nearly at light-speed or faster than the speed of light. We might predict there'd be some dynamical Casimir radiation produced then, and we can try and do tabletop simulations of this."

So the static Casimir effect involves mirrors held still; the dynamical Casimir effect can for instance involve mirrors that move.

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