Explained | Are phonons, particles of sound, quantum too?

Physicists have found that packets of vibrational energy behave like packets of light energy using a new kind of beam-splitter.

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An insect's motion on the surface of water creates two sets of ripples that interfere with each other, creating an interference pattern visible in the 11-12 o'clock region, New Mexico, May 29, 2019. | Photo Credit: Mike Lewinski/Unsplash

One of the two big news items these days from the realm of computing is quantum computers (the other is artificial intelligence). Recently, IBM published a paper in which it claimed to have demonstrated that a quantum computer could solve a *useful* problem that today's conventional computers can't, a result merited by concerns that their computations might become too unreliable when they also become complicated.

What are qubits?

Quantum computers use qubits as their basic units of information. A qubit can be a particle – like an electron; a collection of particles; or a quantum system engineered to behave like a particle. Particles can do funky things that large objects – like the semiconductors of classical computers – can't because they are guided by the rules of quantum physics. These rules allow each qubit to have the values 'on' and 'off' at the same time, for example.

The premise of quantum computing is that information can be 'encoded' in some property of the particle, like an electron's spin, and then processed using these peculiar abilities. As a result, quantum computers are expected to perform complicated calculations that are out of reach of the best supercomputers today.

Other forms of quantum computing use other units of information. For example, linear optical quantum computing (LOQC) uses photons, the particles of light, as qubits. Just like different pieces of information can be combined and processed by encoding them on electrons and then having the electrons interact in different ways, LOQC offers to use optical equipment – like mirrors, lenses, splitters, waveplates, etc. – with photons to process information.

In fact, any particle that can be controlled and manipulated using quantum-mechanical phenomena should, on paper, be usable as an information unit in a quantum computer.

What are phonons?

This is why physicists are wondering if they can use phonons as well. Photons are packets of light energy; similarly, phonons are packets of vibrational energy. So the question is: can we build a quantum computer whose information unit is, colloquially speaking, sound?

According to a paper published in *Science* this month, it should be possible.

The problem is that researchers can manipulate electrons using electric currents, magnetic fields, etc., and they can manipulate photons with mirrors, lenses, etc. – but what can they manipulate phonons with? To this end, in the new study, researchers from the University of Chicago have reported developing an acoustic beam-splitter.

What is a beam-splitter?

Beam-splitters are used widely in optics research. Imagine a torchlight shining light along a straight line. This is basically a stream of photons. When a beam-splitter is placed in the light's path, it will split the beam into two: i.e. it will reflect 50% of the photons to one side and let the other 50% pass straight through.

While it seems simple, the working of a beam-splitter actually draws on quantum physics. If you shine a million photons at it, it will create two beams, each of 500,000 photons. We can then reflect these two beams to intersect each other, creating an interference pattern (recall Young's double-slit experiment). But researchers have found that an interference pattern appears even when they shine photons at the beam-splitter one by one. What are the photons interfering with? The answer is *themselves*.

This is because a) particles can also behave like waves, and b) until an observation is made, a quantum system exists in a superposition of all its possible states (like a qubit being partly 'on' and partly 'off' at the same time). So when the single wave interacts with the beam-splitter, it enters a superposition of the two possible outcomes – reflected and transmitted. When these states recombine, an interference pattern shows up.

What did the new study do?

In the new study, the researchers developed an acoustic beam-splitter – a tiny device resembling a comb, with 16 metal bars jutting out of it. It was placed in the middle of a 2-mm-long channel of lithium niobate. Each end of the channel had a superconducting qubit – a qubit whose circuit components were superconducting – that could both emit and detect individual phonons. The whole setup was maintained at an ultra-low temperature.

If these phonons were converted to sound, their frequency would be too high for humans to hear. Each phonon in the study represented, according to the paper, the "collective" vibration of around one quadrillion atoms.

The team found that these phonons interacted with the comb just like photons interact with an optical beam-splitter. When a phonon was emitted from the left side of the channel, it was reflected half of the time and transmitted to the right side the other half. When phonons were emitted simultaneously from the left and the right sides, they both ended up on one side (as expected).

A phonon-based computer...?

"The basic science question is whether phonons ... actually behave the way quantum mechanics says they should," Andrew Cleland, a physicist at the Pritzker School of Molecular Engineering and a member of the study team, told *Physics* magazine. His team's tests proved that they do.

But it's still a long way from here to a functional quantum computer that uses phonons as units of information. As University of Nottingham physicist Andrew Armour put it more broadly to *Science News*: "What you're doing is extending the [quantum] toolbox... People will build on it, and it will keep going, and there's no sign of it stopping any time soon."

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