PHYSICS TODAY

DOI:10.1063/PT.6.1.20191217a

17 Dec 2019 in Research & Technology

Phonons leap a nanoscale gap

The Casimir effect mediates heat transfer across a vacuum without photons.

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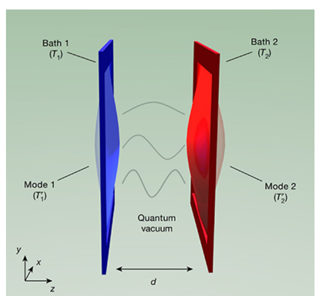
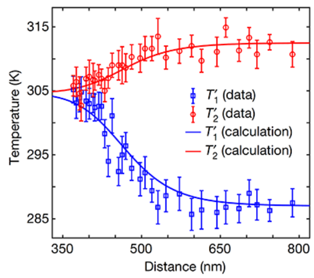


Credit: K. Y. Fong et al., *Nature* **576**, 243 (2019)

Phonons by definition require a material to propagate—lattice vibrations can't happen without a lattice. Yet for a decade theorists have suspected that a phonon could move across a vacuum gap between two materials with the help of a quantum effect known as the Casimir force. Now Xiang Zhang of the University of California, Berkeley, and his colleagues have observed for the first time a phonon moving between two materials spaced hundreds of nanometers apart. Because phonons are energy carriers, the result reveals a new nonradiative route for heat transfer in vacuum.

Unlike the classical conception, real vacuum is full of quantum fluctuations in the form of electromagnetic waves. In an infinite free space, those waves can take any wavelength. If two parallel conducting plates are introduced, they restrict the allowed wavelengths: The electric and magnetic fields must go to zero at the plates, so the longest possible wavelength (the top mode in the figure above) is twice as large as the distance *d* between the plates. For smaller *d* values, fewer wavelengths are allowed, and the energy in the system goes down. The system can reduce its energy by pulling the plates together with an attractive force, the Casimir force (see, for example, the article by Jeremy Munday, *Physics* [Loading [Contrib]/a11y/accessibility-menu.js]ctober 2019, page 74).

In their experiment, Zhang and his group replace the conducting plates with gold-coated silicon nitride membranes. One is kept cool at 287 K (T_1 in the figure above) and the other is heated to 312.5 K (T_2). In a membrane, a phonon takes the form of an oscillation of around 200 kHz in distance from the other membrane, which leads to a time-varying Casimir force. That time-varying force creates oscillations in the other membrane—that is, the phonon transfers from the hotter to the colder membrane with a maximum heat flux of 6.5 × 10^{-21} J/s.



Credit: K. Y. Fong et al., *Nature* **576**, 243 (2019)

Successful phonon transfer between the membranes reduces the temperature difference. The researchers monitored the temperature by way of the surface atoms' Brownian motion; they used the interference from a laser reflected off the back of the membranes. When the membranes are more than 600 nm apart, their temperatures don't change. As the membranes are brought closer together, phonon transfer is easier, and the two temperatures approach an equilibrium value (see the second figure).

Keeping the membranes close together is crucial because the Casimir force drops off quickly with distance. But they can't be too close or stronger heating mechanisms—such as near-field radiation—come into play. Zhang and colleagues picked membrane dimensions that amplified the Casimir effect; that amplification allowed them to keep the membranes far enough apart.

Phonon heat transfer through vacuum could have implications for managing heat in integrated circuits. The mechanism may provide a new way to intentionally dissipate heat in high-density transistor circuits, and it is an important consideration for keeping close elements thermally isolated in, for example, optical communication devices, which are sensitive to temperature cross talk. On a fundamental level, the conventional three methods of heat transfer—conduction, convection, and radiation—must now become four. (K. Y. Fong et al., *Nature* **576**, 243, 2019.)