


Non-sticky interactions

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Quantum mechanical fluctuations of the electromagnetic field in a vacuum between two close together objects result in an attractive force. Now, it has been experimentally shown that by exploiting a similar repulsive interaction, attraction between objects can be modulated simply by tuning temperature.

In the absence of electrical forces, two objects separated by nanometre-scale distances experience stiction: adhesion that prevents them from moving away from each other. Stiction leads to the irreversible breakdown of parts of nano- and microfabricated structures, such as nano- and microelectromechanical systems^{1,2}. Consequently, it also causes the failure of devices consisting of such systems, for example accelerometers. The underlying cause of stiction is the attractive interaction between bodies due to the confinement of quantum mechanical fluctuations of an electromagnetic field. This is known as the Casimir–Lifshitz force^{3–5}.

Now writing in *Nature Physics*, Falko Schmidt et al.⁶ have experimentally demonstrated that the unavoidable and – for practical reasons – undesirable attractive Casimir–Lifshitz force between two bodies can be counteracted with a repulsive force, called critical Casimir force. This result shows a new way to prevent the stiction between close objects, hindering the breakdown of devices.

In 1948, Hendrik Casimir theoretically showed that two ideal metallic plates, which create a cavity in vacuum (Fig. 1a), confine the quantum fluctuations of the electromagnetic field between them, leading to an effective attractive force stemming from the unbalanced radiation pressure inside and outside the cavity – this is the so-called Casimir effect³. Following an extension of the theory by Evgeny Lifshitz^{4,5} to account for realistic materials for the plates and for a non-empty space inside the cavity, for instance filled with liquid, the force has since been called the Casimir–Lifshitz force. Interestingly, Lifshitz realized that the interaction can also be repulsive, in particular for non-trivial combinations of materials. However, in nature, the observed force is typically attractive.

The analogous force for thermal fluctuations in statistical physics, known as the critical Casimir force, was first described for two plates confining a binary liquid mixture in 1978 by Michael Fisher and Pierre-Gilles de Gennes⁷. A commonly studied binary liquid mixture consists of water and 2,6-lutidine (an oily fluid), which can be either mixed or separated into two phases if the temperature is below or above a critical temperature ($T_c = 34^\circ\text{C}$) for a given mass fraction. Typically, fluctuations due to the thermal motion of atoms and molecules occur on a molecular scale. However, as the critical temperature of a second-order phase transition is approached, fluctuations in the density are correlated at longer length scales, forming regions in which one of the components becomes more concentrated than the other (illustrated by the blue and red regions in Fig. 1b). Within this context,

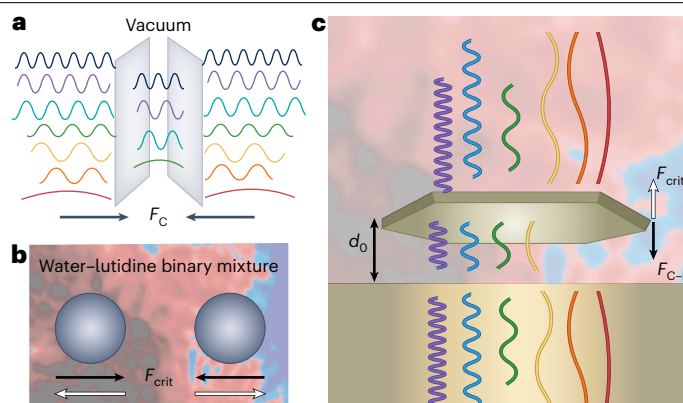


Fig. 1 | The Casimir effect and its extensions. **a**, Two ideal metallic plates in vacuum confine the quantum fluctuations of the electromagnetic field (coloured wavy lines), leading to an effective attractive force (F_C) between them (black arrows), a phenomenon known as the Casimir effect. The generalization of this force in the presence of non-ideal materials is called the Casimir–Lifshitz force. **b**, Two colloids act as boundaries confining thermal fluctuations, depicted as blue and red shaded regions, in a water–lutidine binary mixture near its critical point resulting in an attractive or a repulsive interaction (black and white arrows, respectively) depending on the surface treatment of the colloids. This is known as the critical Casimir force (F_{crit}). **c**, Schematic of the experimental setup of Schmidt et al. consisting of a gold flake immersed in a water–lutidine binary mixture near its critical point and facing a substrate. In this system, the repulsive critical Casimir force (F_{crit}) counteracts the attractive Casimir–Lifshitz force (F_{C-L}) between the flake and the substrate, avoiding the stiction between them and keeping the flake at a certain stable equilibrium distance d_0 from the substrate. Reproduced with permission from ref.¹⁴, European Physical Society, EDP Sciences, courtesy of Andrea Gambassi and Clemens Bechinger.

the presence of two objects, such as two colloidal particles (Fig. 1b), sets boundaries that confine the local density fluctuations, leading to an effective force between the objects. The force is repulsive if the objects' surfaces have opposite hydrophilic or hydrophobic character, and attractive if both have the same character. This implies that the sign of the critical Casimir force can be controlled through chemical surface treatment, whereas its intensity can be controlled through the temperature.

Although both the Casimir–Lifshitz force and the critical Casimir force were theoretically predicted several decades ago, accurate measurements proved challenging with the first demonstrations achieved only around the beginning of this century^{8–10}. For the Casimir–Lifshitz force, most of these experiments were performed using a spherical surface facing a plate because aligning two parallel planar surfaces, as in the ideal system proposed by Casimir (Fig. 1a), is difficult. Only recently, experiments with a gold flake immersed in a fluid facing a gold substrate in parallel plane geometry have been successfully carried out^{11,12}. These experiments have attracted the attention of scientists from diverse fields because they present a new experimental platform

for studying fundamental physics and have potential applications. A possible use of the phenomenon could be in photochemical reactions enabled by polaritons¹²: the strong coupling between light and matter, for example for the case of a molecule inside an optical cavity, gives rise to hybrid light–matter excited states, called polaritons, which can modify reaction rates.

The previous experiments in the parallel plane geometry^{11,12} used one of the following strategies to counteract the attractive Casimir–Lifshitz force between the flake and the substrate. In the first strategy, a coating of a low-refractive-index material with a thickness ranging from tens to hundreds of nanometres covers the gold substrate. This layer introduces a repulsive contribution to the Casimir–Lifshitz force, which balances the attractive Casimir–Lifshitz force between the flake and the substrate. In the second strategy, the repulsive interaction is caused by an electrostatic double layer force. In this case, the fluid mediating the interaction between the two bodies is a solution of ions in water, which allows the repulsive electrostatic force between both surfaces to be tuned as a function of the ion concentration. As a result, one can finely control the distances at which the flake hovers over the substrate at equilibrium.

In contrast to previous works, Schmidt et al. innovatively exploited as a counteracting force the repulsive critical Casimir interaction between the gold flake and the substrate (see Fig. 1c), which is similar in intensity to the Casimir–Lifshitz force and can be tuned simply by modifying the temperature of the system around the critical temperature. This way of modulating the balance between the forces acting on the flake is simpler, faster and less invasive in the system, making it possible to dynamically fine-tune the stable vertical position of a micro-object such as the flake.

Another highlight of Schmidt et al.'s experiment is the way in which they estimated the distance between the two interacting bodies. Rather than using optical spectroscopy, which leverages the high reflectivity of both the gold flake and the gold substrate surfaces (as was done in previous works^{11–13}) to determine the flake–substrate distance, they introduced a new and much more general approach, which uses the lateral diffusion coefficient of the flake along the substrate. The novelty of this approach is that it is not limited to bodies with highly reflective surfaces.

Schmidt et al. also demonstrated spatio-temporal control of the flake over a substrate consisting of alternating strips of hydrophobic

gold and hydrophilic glass. In addition to the vertical displacement of the flake controlled by the balance between the attractive Casimir–Lifshitz and the repulsive critical Casimir forces, the flake could be also displaced in two dimensions over the substrate surface. This displacement occurs because of Brownian motion, coupled with the repulsive and attractive critical Casimir forces introduced by the gold and glass strips, and the ability to fine-tune the repulsive critical Casimir force through the temperature. Although this displacement is not yet completely deterministic and local temperature must be controlled with high accuracy, it paves the way for controlled movement of nano- and microscopic objects at the nanoscale by acting on the system through temperature gradients and appropriate substrate design. This could be interesting in deterministic positioning of nano- and micro-objects, for instance portable nano- and microsensors.

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Competing interests

The author declares no competing interests.