Spinning around

In a series of calculations in the late 1940s, Dutch physicist Hendrik Casimir explored how the finite velocity of light should alter the van der Waals attraction between neutral, non-polarized molecules, especially over long distances. In a first calculation, he and colleague Dik Polder found that an atom far away from a perfectly conducting wall should feel an attraction toward the wall. In a second, they extended this to the interaction of two atoms, again finding an attraction, the associated energy decaying in proportion to the 7th power of the separation R. Finally, in 1948, Casimir also realized that there would be a force even between two perfectly conducting walls, as the walls' zero-field boundary conditions exclude long-wavelength modes of quantum vacuum fluctuations from inside the cavity. The vacuum, as a result, has a higher energy density outside the cavity than within, and the imbalance should tend to force the two walls together.

Thus was born the notion of the Casimir force, arising purely from the nature of the quantum vacuum. Such forces were eventually detected between parallel plates in experiments in 1958, and since then, many related effects have been explored, including the role of Casimir forces in gravity, and a similar phenomenon driven by thermal fluctuations (A. O. Sushkov et al., *Nat. Phys.* **7**, 230–233; 2011).

Less well known is that Casimir also predicted some rotational effects associated with the angular rather than linear momentum of virtual photons. In some settings, this might produce a torque on an object made of anisotropic material, while in others it may instead produce a quantum drag on rapidly rotating objects. In principle, even a completely neutral rotating object should radiate energy away. Until recently, the prospects for detecting such rotational influences were remote, but this has now changed with the increasingly delicate control over light–matter interactions made possible with lasers. Two independent research teams have recently reported new experiments that bring us several steps closer to seeing both the Casimir torque and quantum drag in action.

For 30 years now, researchers have used laser tweezers — a standing-wave field that confines a particle within a small region — to trap and experiment with atoms and other small particles. In recent experiments, physicist René Reimann and colleagues of the ETH in Zurich used this approach to levitate a small silica nanoparticle of diameter 100 nm (*Phys. Rev. Lett.* **121**, 033602). The pattern of laser intensity holds the particle in place, but its polarization allows other influences. By making the light circularly polarized, for example, Reimann and colleagues could make the light transfer angular momentum to the particle, driving it to spin.

The earlier experiments with nanoparticles trapped under vacuum, frictional drag associated with the few air molecules left in the chamber limited the spinning speeds achieved. By using a stronger vacuum, and avoiding laser heating that often ejected particles from the trap, Reimann and colleagues were able to reduce this frictional drag and make the particles spin as rapidly as 1 GHz. Giving confidence in the results, the achieved speed of rotation increased as they improved the vacuum in just the way predicted by simple theory.

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Further experimental advances should make it possible to observe quantum friction, which should slow the rotation of any particle. The magnitude of the effect depends on many things, and a particle with higher electrical conductivity or temperature should slow faster, especially if held nearby a surface. A close surface can amplify the rate of slowing — for a graphite nanoparticle and surface — by about 100 million times. Reimann suggested to me that significant slowing could be detectable over a few days for a particle at 1,000 K, although this will require a reduction of vacuum gas pressure by about five orders of magnitude beyond their current experiments. It will also require elimination of any rotational driving forces from the trap, and may well require experiments in zero gravity — challenging, to be sure, but perhaps feasible in the next few years.

In related work, a team led by physicist Tongcang Li of Purdue University in Indiana have managed spinning speeds about the same as Reimann et al., but using a non-spherical object — a nanodumbbell about 170 nm long (*Phys. Rev. Lett.* **121**, 033603). They manufactured these nanodumbbells by coaxing individual suspended colloidal particles to bond together, and then, like Reimann and colleagues, used laser tweezers and circularly polarized light to spin the dumbbells. By using non-spherical particles, however, Li and colleagues also made a very different kind of experiment possible.

In 1797, British scientist Henry Cavendish first managed to measure the strength of the weak gravitational attraction between two masses by using a torsion balance — a dumbbell made of two connected masses suspended at its mid-point from a fine wire. A third mass pulling on one of the dumbbell ends twisted the wire, allowing the detection of the extremely small force. Li and colleagues achieved a similar set-up by using the laser tweezers to trap the dumbbell, but using linearly polarized light. In this situation, the laser tended to force the dumbbell to line up with the direction of light polarization. In an experiment, the team was able to measure the small oscillations of the dumbbell about this position.

This kind of experiment has expanded the boundaries on the sensitivity of torque measurements. Indeed, a levitated nanodumbbell under high vacuum is already about five orders of magnitude more sensitive than the current state-of-the-art nanofabricated torsion balance. With further refinement, Li and colleagues believe, this set-up should be able to detect a small torque arising purely from quantum fluctuations, which will act on a nanodumbbell placed close to a birefringent plate. This demonstration may come fairly quickly, as the current set-up appears already to be three orders of magnitude more sensitive than required.

These experimental techniques also open up other possibilities, as rotations of GHz frequency are faster than anything seen in ordinary engineering, and should allow unprecedented tests of material properties at the nanoscale. As happens so often, experimental efforts to realize extreme conditions expand the possibilities for science and technology in many directions at once. In this case, it's in large part the outcome a quest kicked off 70 years ago by a few calculations of the curious properties of the quantum vacuum. ❐

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