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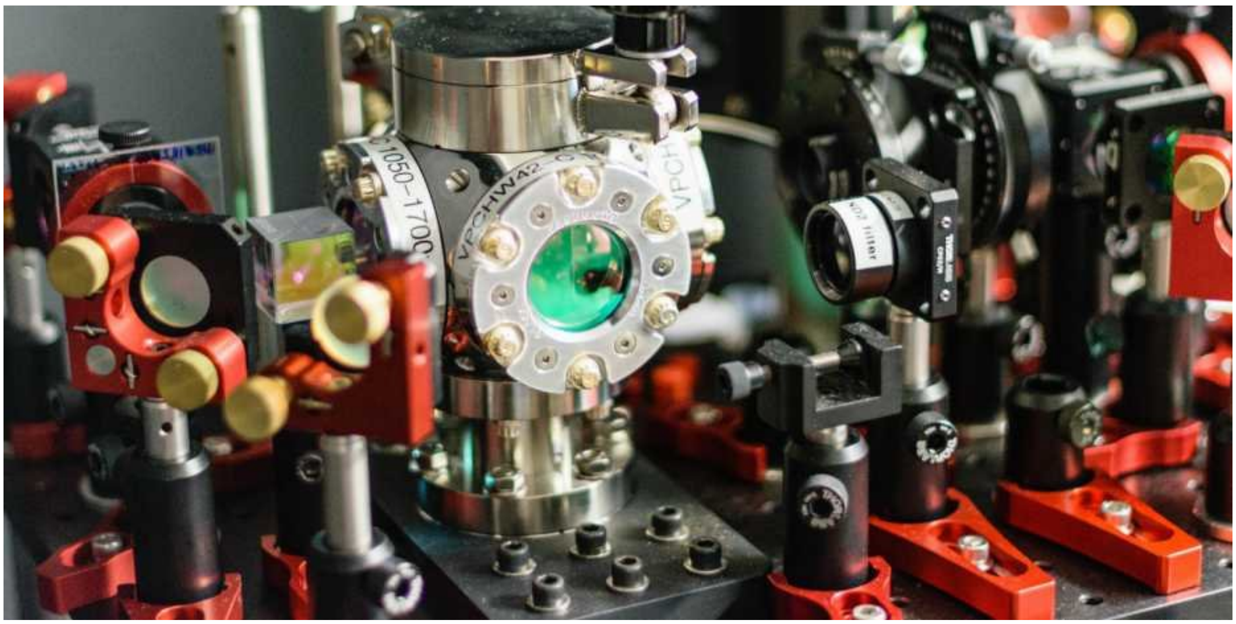
The world's fastest rotation

July 24 2018, by Oliver Morsch



The vacuum apparatus in the centre of the picture contains the world's fastest rotating object. Inside it, a tiny glass particle is levitated and made to rotate by a laser beam. Credit: ETH Zurich / Michael Doderer

Researchers at ETH have made a nanoparticle turn around its own axis a billion times per second. From such measurements of rotating particles, the scientists hope to obtain new insights into the behaviour of materials under extreme stress.

Nothing in the world rotates faster than a tiny particle in a laboratory at the Institute for Photonics in Zurich.There, ETH professor Lukas

Novotny and his collaborators have succeeded in manipulating a minuscule piece of glass only a hundred nanometres in size – a thousand times smaller than a hair – in such a way as to make it turn around its own axis more than a billion times a second. The scientists hope that their experiments will yield new insights into the stability of glass and other materials under extreme stress. The results of their research were recently published in the scientific journal *Physical Review Letters*.

It takes considerable technical effort to make on object rotate that fast. "To do so, we trap the glass particle in a vacuum apparatus using so-called optical tweezers," explains René Reimann, a post-doc in Novotny's laboratory. Optical tweezers are created by a strongly focused laser beam, where the glass particle is levitated by light forces at the focus of the beam. This allows the scientists to eliminate any direct mechanical contact with the outside world, which would lead to friction losses. Moreover, the pressure in the apparatus is a hundred million times lower than the normal air pressure at sea level. This means that only very rarely do single air molecules collide with the particle, slowing it down slightly in the process.

The researchers now adjust the polarisation of the laser beam to be circular. This means that the direction in which the electric field of the laser light oscillates is not constant, as it would be for linear polarization, but rather rotates continuously. That rotation, in turn, is partially taken over by the glass particle when the laser light passes through it. The torque thus transferred makes the nanoparticle turn faster and faster.

To measure the rotation frequency, the scientists analyse the laser light of the optical tweezer using a photodetector. The rotation of the glass particle creates a periodic variation in the intensity of the light that has passed through the particle. From this variation, Novotny and his colleagues calculated that its rotation frequency was higher than a gigahertz (a billion rotatations per second). "It probably turned even faster, but with our current photodetector we can't measure any higher frequencies," Reimann admits. Buying a faster detector is, therefore, one of the researchers' top priorities.

With that detector, they hope to be able to measure rotation frequencies up to 40 gigahertz. It is likely, however, that the nanoparticle will explode before turning that fast. At what frequency exactly that is supposed to happen is far from clear, as there are no reliably measurements for such small objects. From material research it is known that optical glass fibres that are only a few micrometres thick can withstand enormous tensile stress (several times that of steel cables). Nevertheless, nobody knows exactly how robust a glass particle measuring only a few nanometres is against the extreme centrifugal forces that arise at the high rotation frequencies now realized at ETH. Those centrifugal forces can be up to a hundred billion times larger than the gravitational force of the earth. "That's roughly equal to the force of gravity on the surface of a neutron star," Reimann says to give an idea of the order of magnitude.

For nanotechnology, such measurements are important because the properties of materials at the nanoscale can differ drastically from those of larger objects. That is partly due to the extreme purity of nanoparticles and the virtual absence of defects. Moreover, measurements at similarly high rotation frequencies would hardly be technically possible using larger objects. The challenge to make nanoparticles rotate ever faster, therefore, also has some practical relevance.

It is not just the rotations of the glass particle that are extremely fast, however, but also the progress in this field of research. As a few other groups were working on similar experiments, Novotny and his collaborators had to hurry quite a bit. "The data were finally taken in just two weeks. That was a strenuous finish, and the entire team worked together very hard to get it done," Reimann recalls. In the end, the researchers were rewarded with a new record.

More information: René Reimann et al. GHz Rotation of an Optically Trapped Nanoparticle in Vacuum, *Physical Review Letters* (2018). DOI: 10.1103/PhysRevLett.121.033602

Provided by ETH Zurich