Towards a quantum limited optical torque and force sensor

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Levitated Microspheres

Our spheres are levitated in a gravito-optical trap similar to the technique of optical tweezers used for precision \(10^{-12}\) N force sensing in biological applications. Our system improves that sensitivity to \(10^{-19}\) N force sensing by trapping in high vacuum.

Optical Trapping

Our technique is similar to the optical tweezers used in biology for pN force sensing, but we want to use it to measure short-range interactions. By trapping them in vacuum, microspheres are thermally isolated, allowing 1,000,000X better sensitivity.

Quantum Limited Sensitivity

At pressures < \(10^{-10}\) mbar, quantum mechanics sets a fundamental limit to the sensitivity with which the position of an object can be measured. At the 'standard quantum limit', laser shot noise and back-action will limit our force sensitivity for a 10 ng sphere to \(4 \times 10^{-20}\) N/√Hz, which corresponds to an acceleration sensitivity of \(4 \times 10^{-19} g/\sqrt{Hz}\) where \(g\) is the standard acceleration due to gravity.

Acceleration Sensing

The force and acceleration sensitivity is calibrated using an applied electric field as the charge of the sphere is varied by single electron steps. Below are (left) how we measure charge and (right) experimentally measured charge of a trapped sphere during the discharging process.

Our current acceleration sensitivity is 0.5 μg/√Hz, the world's best for an optically levitated ng-scale object.

Spheres can be stably trapped for > 1 month. Measurement sensitivity scales with the square root of the measurement time; nano-\(g\) acceleration sensitivity is reached in \(10^4\) s of integration time.

The measured rotational damping time of 16 hours corresponds to a torque sensitivity of \(3 \times 10^{-23}\) Nm/√Hz. Lower pressures lead to longer damping times, which give better torque sensitivity which makes an excellent microgyroscope.

Next-Generation Setup

A new setup is under construction, with the goal of further improving sensitivity towards the standard quantum limit.

Applications

- Dark matter search
- Charge neutrality measurement
- Millicharged particle detection
- Gravity at the microscale
- Coulomb’s law at the microscale

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