Detecting yocto(10^{-24})newton forces with trapped ions

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Abstract: We report a calibrated measurement of 174 yoctonewton (1×10^{-24} N = 1 yN), using a cloud of 60 $^9Be^+$ ion confined in a Penning ion trap. These measurements suggest that ion traps may form the basis of a new class of ultra-sensitive deployable force sensors.

1. Summary

Measurement of extremely small forces is of interest in a variety of fields ranging from atomic-force-microscopy, to electron spin resonance, to tests of fundamental principles. State-of-the-art small force detection relies on using thin cantilevers of which the resonant vibrational response is probed in reaction to an external force. Such systems have achieved force sensitivities on the order of attonewtons [1]. It has been suggested that single trapped ions could achieve force sensitivities on the order of ~ 1 yn and consequently be used as a new class of force sensor [2].

Here we demonstrate a calibrated, yoctonewton scale force measurement using 60 $^9Be^+$ ions confined in a Penning ion trap. The ions are subjected to a small oscillating electric field and their resonant response is probed using phase sensitive detection of modulations in the fluorescence intensity of a probe beam near-resonant with the $^2S_{1/2} \longrightarrow {}^2P_{3/2}$ transition. We detect forces as small as 174 yn corresponding to a force sensitivity of 390±150 yn/$\sqrt{\text{Hz}}$. Extrapolated sensitivities are consistent with ~ 1.7 yn/$\sqrt{\text{Hz}}$ in the single ion limit [3].

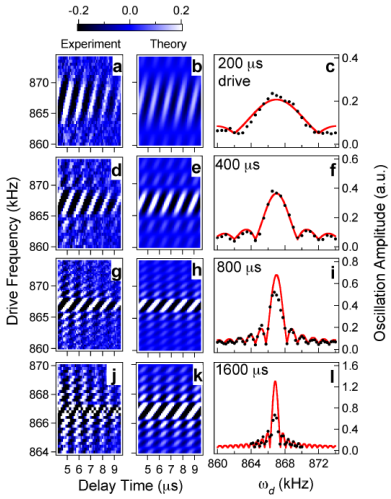

Figure 1: Resonant response of $^9Be^+$ ions under the influence of weak, oscillating electric fields. Left-most column - Experiment, modulations in fluorescence intensity as a function of driving force simulation for different drive times (indicated in right-most column). Central column - Theoretical simulation corresponding to left column. Right-most column - cross sections through data in left-most column with theoretical fits.

2. References

[1] D. Rugar, R. Budakian, H.J. Mamin, and B.W. Chui, Nature **430**, 329 (2004)

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