Optical ponderomotive force

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Ponderomotive force is defined as a nonlinear force that describing the motion of a charged particle in an inhomogeneous oscillating electromagnetic field.

$$F = -\frac{q^2}{4m\omega^2}\vec{\nabla}|\vec{E}(r,t)|^2 \tag{1}$$

To study the motion of the charged particle by ponderomotive force, instead of electron ponderomotive force, we build asystem with "optical ponderomotive" force by levitating a microsphere in a vacuum environment. As you can see in Fig1, particle is trapped by laser and gravity (here we assume the absorption coefficient of the particle is very low, so we only consider scattering force) [1]. Once the beam is modulated, we can investigate the motion of the particle in a time dependent oscillating system.

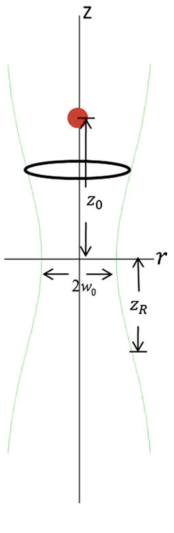

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Figure 1: Trapped particle balanced by scattering force and gravity

Mathematically, we can written the equation of motion

$$m\ddot{z} = F_{scattering} - mg \tag{2}$$

$F_{scattering}$ is the scattering force obtained by Mie theory [2]

$$F_{scattering} = \frac{I(z)\pi a^2}{c}Q \tag{3}$$

where $I(z)$ is the intensity of beam, a is the radius of the microsphere, Q is a dimensionless parameter calculated from Mie theory and c is the speed of light. With the time modulating, we will get

$$I(z,t) = I(z)(1 - 2\gamma\cos(2\omega t)) \tag{4}$$

where γ is defined as modulating depth. So our first step to study this system is figure out $I(z)$ by assuming the motion of particle is very small from origin. The trajectory of the particle will obey the mathieu equation. The motion of particle will be stable periodic, aperiodic or unstable periodic [1]. Then the next step is to do mathematical analysis of this equation and find the stable and unstable regions of this system. Further study, we can study this model as a time delay differential equation. At this time, I am still try to work out what it is. I think this is important to do this project, because we can experimentally build this and prove our results by measuring the displacement by changing the parameter.

The difficulty of this project is math analysis of the equation, the mathieu equation should be helpful. Then build the simulation of this system to find the stable and unstable region with given parameters. This may take two weeks. Then studying the time delay system, I think this is more related to what we are studying now. I am excited to see the application of information theory. I will use about two weeks(not sure) to do this, but I am pretty sure I can learn a lot from it. The last week, I will write down report and prepare my presentation.

Due to this specially time, it is impossible to do the experiment. If we have chance, we can experimentally build the system (which we have done this before) and track the particle.

References

[1] Wu, Binbin, and Gerald J. Diebold. "Mathieu Function Solutions for the Photoacoustic Effect in Two-and Three-Dimensional Structures and Optical Traps." International Journal of Thermophysics 33.10-11 (2012): 2185-2193.

[2] C.F. Bohren, D.R. Huffman, "Absorption and Scattering of Light by Small Particles" (Wiley- Interscience, New York, 1983)