Measurement of the Casimir-Polder Force

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About Steck Lab

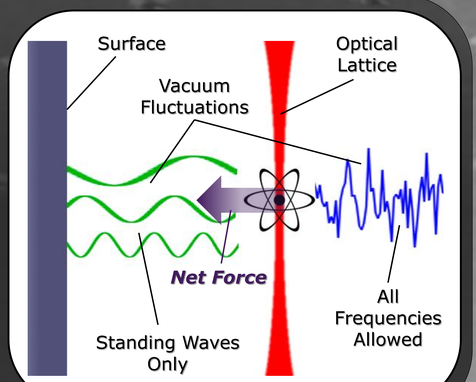
Abstract

Atom optics requires heavy use of lasers to trap, cool, and perform other precise operations on materials with widely varying optical properties. Diode lasers have come into favor due to their low cost and small size, but they are difficult to control and require complex electronic equipment to produce a useful laser beam. Once a laser is locked to a desired frequency, it can be used to perform experiments on atoms on a quantum scale. Steck Lab, which has been working with Rubidium atoms for several years, has recently begun work on Strontium atoms as well since they can be used to precisely measure quantum effects like the Casimir-Polder force. However, the precision of Strontium reflects the necessary precision of the equipment needed to manipulate it, so the lab has had to redesign their experimentation to better accommodate its use. This research has applications in Quantum Information Processing, Nanotechnology, and the improvement of Atomic Clocks.

The Casimir-Polder Force

I. The Casimir Effect
   a. Vacuum Fluctuations (VFs) exist in electromagnetic fields due to the Heisenberg Uncertainty Principle.
   b. VFs interact with matter and can have any frequency.
   c. Only VFs that create a standing wave may exist between objects due to surface boundary conditions.
   d. There is greater pressure on the outside of objects so they experience a force that pushes them together.

II. Measurement of the Casimir-Polder Force
   a. As an atom is brought close to a surface, there is a shift in its energy and resultant absorption spectrum.
   b. Change in the Strontium spectrum is used to determine magnitude of the Casimir-Polder force.



Methods

1. Contain Strontium atoms in a Magneto-Optical Trap (MOT) and load them into an Optical Lattice.
   - MOT uses light and magnetism to trap and cool groups of atoms.
   - Optical Lattice uses light interference patterns to hold atoms individually in tiny potential wells.
2. Place the atoms near a surface by displacing the optical lattice.
   - Here the surface is a dielectric material or metallic plate.
3. Observe changes in atom energy levels associated with the Casimir-Polder force.

MOT Diagram

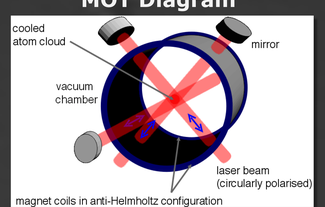


Image Source: http://en.wikipedia.org/wiki/Magneto-optical_trap

Optical Lattice

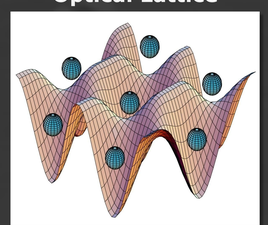
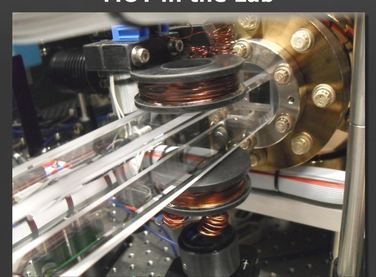


Image Source: http://www.physics.umd.edu/rgroups/amo/rolstonwebsite/bec.htm

MOT in the Lab



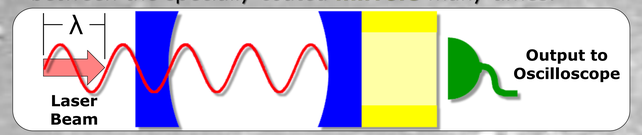
UCORE Fellow Contribution

Steck Lab is on the cutting edge of physics and quantum mechanics research, but there is always room for help from undergraduate students. UCORE Fellows and other undergrads posted in the lab were tasked with building and troubleshooting several key systems designed to control diode lasers to be used in future Strontium based experiments.

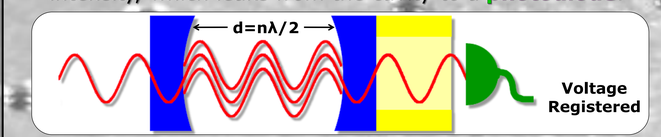
Fabry-Perot Cavity

Lasers should emit a single, narrow-band frequency range of light, but poorly tuned diode lasers can lase irregularly over a broad spectrum (multimode lasing), rendering them useless to precision experiments. An FPC is used to identify improperly tuned laser output.

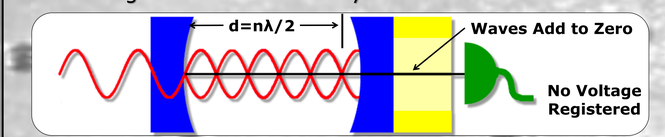
1. An incident **light wave** enters the cavity and reflects between the specially coated **mirrors** many times.



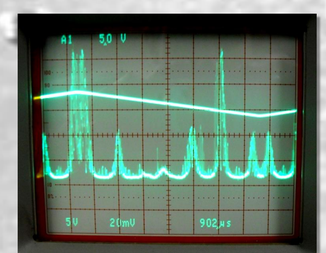
2. If cavity length is a half-integer wavelength of the incident light, the waves will constructively interfere and reach high intensity, which leaks from the cavity to a **photodiode**.



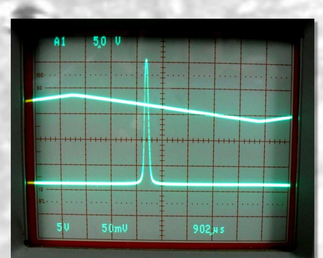
3. If cavity length does not satisfy d=nλ/2, reflected waves will eventually destructively interfere with incoming waves, resulting in near zero intensity.



4. By scanning one of the mirrors back and forth with a piezomechanical ring **actuator**, we can detect the optical modes comprising a laser beam and correct the output.



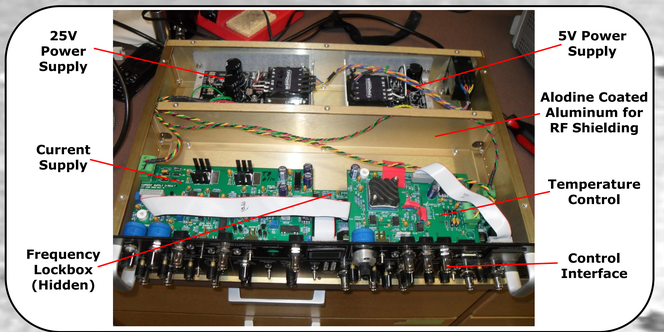
Multimode Output



Proper Output

Master Laser Driver

This is the main control board responsible for locking a diode laser to a precise frequency. This equipment has high cost and low availability commercially so Steck Lab chooses to design and assemble their own custom drivers. This also allows for greater control over specialized experiments.



Driver Sections:
I. Temperature Control
   a. Prolongs life of laser diode.
   b. Maintains stable and adjustable frequency output.
II. Current Supply
   a. Precisely controls voltage and current draw.
   b. Fast modulation of current for frequency correction.
III. Frequency Lockbox
   a. Complex P-I-D feedback circuit.
   b. Allows frequency locking by analyzing detector inputs and modulating signals to the Current Supply, Fabry-Perot Cavity, and other equipment.

Next Steps

1. Lock a laser to a sample of Rubidium atoms to test full functionality of the master laser driver.
2. Interface driver with newly designed lasers and other equipment specific to Strontium experiments.
3. Perform final calibrations to Frequency Lockbox and lock the laser to a Strontium sample.

Acknowledgements

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