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14. ABSTRACT

This grant was used to support graduate students in training. It was used primarily to support a student, Joel Hensley, who was working on an experiment effort to measure the recoil momentum of an atom when it absorbs a photon.

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July 27, 2001

Final Report of Assert Supplement to the Grant "Applications of laser Cooling and Trapping" F49620-98-1-0423

Granting period: 04/01/98 to 03/31/2001

This grant was used to support graduate students in training. It was used primarily to support a student, Joel Hensley, who was working on an experimental effort to measure the recoil momentum of an atom when it absorbs a photon, which translates into a measurement of $\hbar/M_{atom}$. A measurement of $\hbar/M$ can lead to an improved value of the fine structure constant, α, the dimensionless number that sets the scale of the strength of all electromagnetic interactions. The fine structure constant can be written as $\alpha^2 = (2R_\infty/c)(M_{Cs}/m_e)(\hbar/M_{Cs})$, and all the quantities in this expression except $\hbar/M_{Cs}$ have been measured with an uncertainty of 2 parts in a billion or less. The measurement of the mass ratios were stimulated by the prospect of our measurement.

The value of the fine structure constant is determined in a number of methods: the most accurate techniques are the quantum Hall effect (24 ppb), the ac Josephson effect (39 ppb) and neutron interferometry (34 ppb). If one assumes the QED calculation of g-2 and the experimental measurement of g-2 are correct, then a value of α can be determined to a precision of 3.8 ppb. On the other hand, one can take the alternate point of view that a comparison of the best predicted quantity in all of science with one of the best experimental measurements is frustrated by the lack of knowledge of α.

In 1992, we showed that an atom interferometer based on optical Raman pulses was well suited for this measurement since it converts the measurement of a velocity change into a interferometer phase shift measurement. Since our measurement is a measurement of the phase difference between two atom interferometers, many systematic effects common to both interferometers subtract out of the final value. Added precision was obtained by adding a large number of photon impulses separating the two interferometers, thus improving the precision of the technique. In a second generation experiment, we developed an interferometer based on adiabatic transfer in order to increase the number of optical pulses we could use and to decrease a number of systematic effects. Currently, our best data is taken with a momentum separation of over 120 photon momenta.

Joel began working on the project with Brent Young, whose thesis developed the adiabatic transfer method of atom interferometry. During this time, Joel developed a state-of-the-art actively-stabilized vibration isolation system that was crucial for this experiment. Brent left before an exhaustive list of systematic checks were done and work of finishing the measurement became Joel's responsibility.

Since then, Joel, working with a postdoc, has analyzed and eliminated many systematic effects that could give spurious phase shifts. Precision measurements require a deep understanding of many aspects of physics, and is usually far more challenging than the observation of a new effect. This is especially true with an apparatus constructed in stages by three graduate students and consisting of two actively stabilized Ti:sapphire lasers, over a half a dozen actively-stabilized diode lasers, a state-of-the-art actively stabilized vibration isolation system, well over a dozen electro-optic and acousto-optic modulators, hundreds of optical components, and so on. To make matters more challenging, many of the lasers and components were state-of-the-art and home-made.

We have completed our search for systematic effects. These effects can be quite subtle. s an example, the number and density of cold atoms was varied to look for a change in the asured phase shift due to dispersive effects (so-called "electromagnetically induced nsparency" effects), or the fact that the momentum of the photon in a dilute, dispersive edium would be changed. We will also do a complete theoretical analysis of the problem where a numerical integration of the full density matrix description of the multi-level cesium atom describing the laser fields, the coherences, and the forces that arises from this complex energy level structure.

We are hoping to come in with an uncertainty of ~ 4 ppb in α. We have already shown that the all of the other known systematic effects (such as phase front distortions, beam pointing accuracy and stability, ac Stark shifts, errors in frequency locks, phase shifts due to imperfect microwave electronics, thermal loading of acoustical optic modulators, missed photon kicks, etc.) have been controlled to better than 1-2 few parts per billion uncertainty. We feel that this measurement will be a landmark experiment. Joel will be graduating with his Ph.D. by the end of this summer quarter.

In addition to training Joel, the ASSERT supplement was used to support two beginning graduate students for part of one year: Adam Black and Hilton Chang. They are currently working with Vladan Vuletic, a former postdoc of mine who has become an assistant professor at Stanford. They are working on a new idea to laser cool atoms (and molecules) in an optical cavity with off-resonant light (patent is pending) and waveguide atom interferometers.