

## Atom Interferometers

Dallin S. Durfee, Johnny Lumpkins, Billy Bud Smith

We will be writing our paper on atom interferometers. Atom interferometers are similar to optical interferometers. In an optical interferometer a beam of light is split in half. The two halves of the beam travel different paths and then are directed back toward each other. They are then recombined. Because light is a wave, when the light beams are recombined they can add constructively or destructively. Whether they add constructively or not depends on the difference in the phase of the two beams. This phase is determined by things such as the relative lengths of the two paths and the index of refraction of the media that the beams travel through. By detecting the intensity of light exiting the interferometer in a certain direction you can obtain information about the relative phase of the two beams.

An atom interferometer takes advantage of the fact that atoms are also waves. But because atoms can have extremely small wavelengths they can potentially be more sensitive than optical interferometers. And since atoms have properties such as mass and electrical polarizability, they can measure things which cannot be detected with an optical interferometer. Some of the applications we plan to discuss include rotation sensing and inter-atomic collisional properties. We also plan to discuss atomic clocks, which are really a special type of atom interferometer.

To make an interferometer you need a source of atoms, a way to split the atomic wave function, a way to direct the two halves of the wave function, a way to recombine the two halves of the wave, and a way to detect the wave coming out of the interferometer. The atomic sources used include thermal atomic beams, laser cooled clouds of atoms, and Bose-Einstein condensates. The atom waves can be split and recombined using either laser beams or physical diffraction gratings. The beams can be directed using either laser beams, diffraction gratings, or atomic wave guides. In different experiments we have read about, the atoms are detected either by shining resonant laser light on the atoms and detecting fluorescence or with a device called a hot wire detector.

### Sources

- P. R. Berman, ed., *Atom Interferometry*, Academic Press, 1997.

This book contains a large number of articles on various aspects of atom interferometry.

- C. W. Oates, F. Bondu, R. W. Fox, and L. Hollberg, "A diode-laser optical frequency standard based on laser-cooled Ca atoms: Sub-kilohertz spectroscopy by optical shelving detection," *The European Physical Journal D* **7**, pp. 449-460, 1999, <http://www.edpsciences.org/articles/epjd/abs/1990/10/d8271/d8271.html>.

This article contains a long and detailed description of an atomic clock based on a Ramsey-Bordé interferometer scheme.

- M. Kasevich and S. Chu, "Atomic interferometry using stimulated Raman transitions," *Physical Review Letters* **67**, pp. 181-184, 1991, <http://prl.aps.org>.

This article describes an interferometer in which laser beams are used to split, direct, and recombine the two halves of the atomic wave function.

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## I. Introduction

1. How an optical interferometer works
  - a. Splitting and recombining the beam
  - b. Constructive and destructive interference
2. Example: Detecting mirror movement with a laser interferometer
  - a. How does output relate to mirror position
  - b. Why is the measurement so sensitive?
3. Atom interferometry
  - a. Atoms are also waves
  - b. Planck's relation
  - c. Compare wavelength of thermal atoms to visible light
  - d. Compare properties of atoms to properties of light

## II. Making an atom interferometer

1. Sources of atoms
  - a. Incoherent atoms
    - i. Compare to optical interferometry with a light bulb
    - ii. Thermal beams
    - iii. Advantages and disadvantages of thermal beams
    - iv. Laser-cooled atoms
    - v. Advantages and disadvantages of laser-cooled atoms
  - b. Coherent atoms
    - i. Compare to laser interferometry
    - ii. Bose-Einstein condensates (BEC)
    - iii. Advantages and disadvantages of BEC
2. Splitting, directing, and recombining the beams
  - a. Laser beams
  - b. Gratings
  - c. Waveguides
  - d. Comparison of advantages and disadvantages
3. Detecting the output
  - a. Fluorescence detection
  - b. Hot-wire detectors
  - c. Absorption imaging

## III. Uses of atom interferometers

1. Atomic clocks
  - a. Microwave clocks
  - b. The "Bloch sphere"
  - c. Optical frequency clocks
2. Rotation sensing

- a. Sagnac effect
  - b. Comparison with optical gyroscopes
3. Acceleration sensing

#### IV. Conclusions

1. Sensitive measurements due to short de Broglie wavelength
2. Many ways to create one
3. Many uses

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- P. R. Berman, ed., *Atom Interferometry*, Academic Press, 1997.

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This article describes an interferometer in which laser beams are used to split, direct, and recombine the two halves of the atomic wave function.

- T. L. Gustavson, P. Bouyer, and M. A. Kasevich, "Precision rotation measurements with an atom interferometer gyroscope," *Physical Review Letters* **78**, pp. 2046-2049, 1997, <http://prl.aps.org>.

This article describes a device which measures rotation using an atom interferometer. This device uses a thermal effusive oven and lasers to split and recombine the waves.

- J. F. Clauser, "Ultra-high sensitivity accelerometers and gyroscopes using neutral atom matter-wave interferometry," *Physica B+C* **151**, p. 262, 1988.

This early article explores the possibility of making accelerometers and gyroscopes with atom interferometers.

- A. Lenef, T. D. Hammond, E. T. Smith, M. S. Chapman, R. A. Rubenstein, and D. E. Pritchard, "Rotation sensing with an atom interferometer," *Physical Review Letters* **78**, p. 760, 1997, <http://prl.aps.org>.

This paper describes an atom interferometer which measures rotation. This interferometer uses a supersonic thermally generated beam and diffraction gratings.

- A. Peters, K. Y. Chung, and S. Chu, "High-precision gravity measurements using atom interferometry," *Metrologia* **38**, p. 25, 2001. <http://www.iop.org/EJ/abstract/0026-1394/31/1/4>.

This article describes the measurement of gravity and acceleration with atom interferometers. The device uses lasers to split and recombine the wave.

- Y. Shin, M. Saba, T. A. Pasquini, W. Ketterle, D. E. Pritchard, and A. E. Leanhardt, "Atom interferometry with Bose-Einstein condensates in a double-well potential," *Physical Review Letters* **92**, p. 050405, 2004, <http://prl.aps.org>.

This article describes the interference of two Bose condensates held in the focus of two overlapping laser beam and then split in half by moving the two beams. They induced a phase shift by applying AC Stark shifts.

- D. S. Durfee, Y. K. Shaham, M. A. Kasevich, "Long-term stability of an area-reversible atom-interferometer Sagnac gyroscope," *arXiv:quant-ph/0510215*, 2005.

This paper by a particularly handsome group of experimenters describes an interferometer based on a thermal beam split and recombined using lasers. The paper discusses some of the limits and difficulties of atom interferometers.