

Atom Interferometers

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We will be writing our paper on atom interferometers. Atom interferometers utilize the wave properties of atoms to make precision measurements. They are very similar to optical interferometers like the one that Michelson and Morley used to search for the ether wind, but utilize the mass and internal structure of the atom as well as the extremely short de Broglie wavelengths possible with atoms to make more precise measurements or types of measurements not possible with optical interferometers.

In an atom interferometer each atom's quantum wave is split in half. The two halves of the wave travel different paths and then are directed back toward each other and are recombined. When the waves 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, the gravitational potential of the two paths, etc. By detecting the interference pattern you can obtain information about the relative phase of the two beams.

We will discuss the basics of how atom interferometers are made as well as applications of atom interferometers. We will consider the source of atoms (including coherent, laser-cooled, and thermal sources), how the atoms waves are split and recombined (including laser manipulation techniques and the use of physical gratings).

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. Use of atom interferometers

1. Overview
2. Atom interferometer rotation sensors
 - a. Uses of a super-precise gyro
 - b. Sagnac effect
 - c. Sensitivity and stability limits

d. Comparison with other sensors

IV. Conclusions

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

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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.