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## ATOM WAVE INTERFEROMETER

Chris R. Ekstrom, David Keith, Bruce G. Oldaker,  
 Quentin Turchette and Professor David E. Pritchard

Office of Naval Research Contract No. N00014-89-J-1207  
 December 1, 1989 - November 30, 1990

Using fabricated transmission gratings as optical elements for the matter waves, we are constructing an atom interferometer which will physically separate atom waves before recombining them. Atom interferometers will be useful in studies of atomic properties, tests of basic quantum physics, for metrology, as a rotation sensor, and perhaps ultimately as devices to make ultra-small structures using atom holograms.

During 1990 our atom interferometer evolved from a rough and ready state to an essentially complete device. Major effort was spent on a new detector and on developing procedures to increase detector sensitivity, source modifications which give about ten times the previous signal with more reliability, a computer data acquisition and analysis system and appropriate software, rebuilding components to reduce the vibrational noise level, and a simulation program to calculate the expected interference pattern and signal. We also worked in collaboration with the MIT Submicron Structures Laboratory to produce atom gratings with higher transmission, better dimensional stability, and less distortion. We tried several times to observe atom fringes, but were frustrated by grating problems each time. The improvements in signal to noise and grating transmission resulted in much better atom diffraction patterns, see Fig. 1.

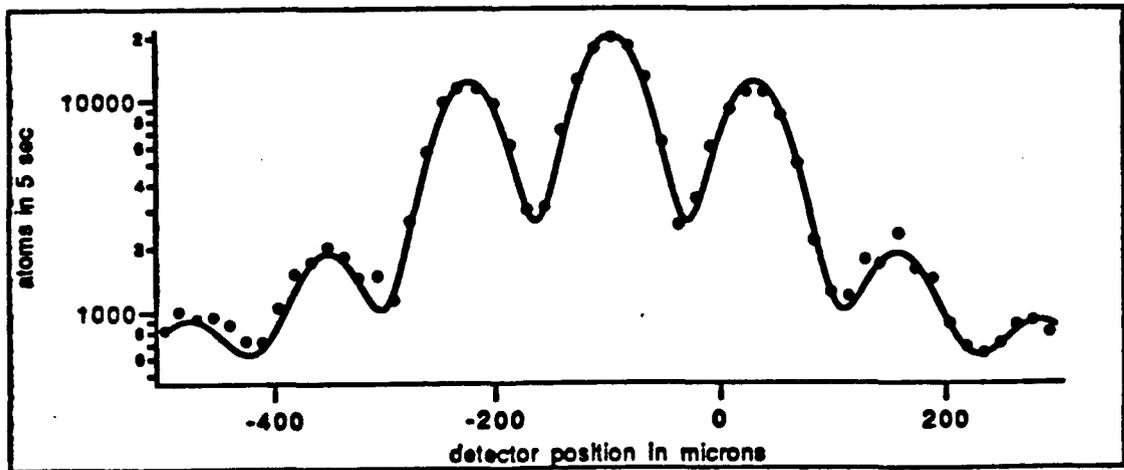


Figure 1: Diffraction of Atoms from Fabricated Grating.

Our interferometer consists of three  $0.2 \mu\text{m}$  - period diffraction gratings equally spaced  $\sim 0.65 \text{ m}$  apart in our atomic beam machine. The maximum separation of the atom waves will be  $\sim 60 \mu\text{m}$ . The first two gratings separate and redirect the atomic beam forming a standing wave interference pattern in the atomic flux at the third grating, which acts like a mask to sample this pattern. Figure-1 shows the design of the interferometer.

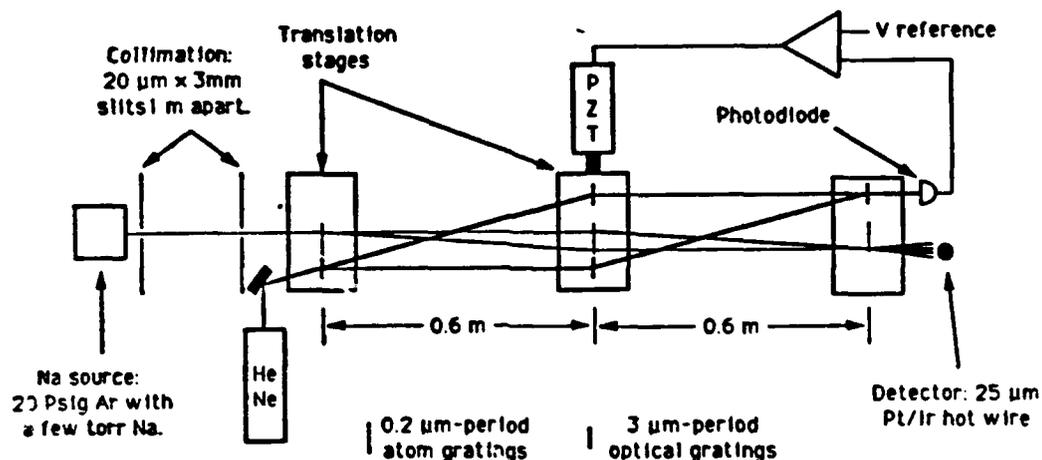


Figure 2: Our current atom interferometer with laser interferometer stabilization system (Not to scale.)

The mechanical vibrations of our machine are a principal technical obstacle because they could blur the interference pattern. There are two types of required limits on vibrations. First, the three gratings must move relative to each other by less than  $\sim 1/4$  period ( $50 \text{ nm}$ ) during the time the final grating samples the intensity at a given position. Thus, the rms amplitude of relative vibrations integrated over all frequencies greater than the reciprocal of the detector integration time must be less than  $\sim 50 \text{ nm}$ . The second requirement is related to the motion of the gratings due to acceleration of, or rotation about, the center of mass of the grating system during the  $1.3 \text{ ms}$  it takes for the atoms to traverse the interferometer. This means that below  $\sim 900 \text{ Hz}$  the rms acceleration must be less than  $10^{-2} \text{ ms}^{-2}$ , and the rms angular velocity must be held below  $10^{-4}$  radians per second.

Because each grating/slit assembly in the interferometer is in neither the near nor far field of the others, it is not possible to produce an analytic expression for the interference signal. We have advanced the state of the art of interferometer calculations by devising a way to cast the multiple grating problem as a convolution problem, enabling us to use Fast Fourier Transforms. A ten minute run on a CRAY can simulate the interferometer with an incoherent source possessing the actual velocity

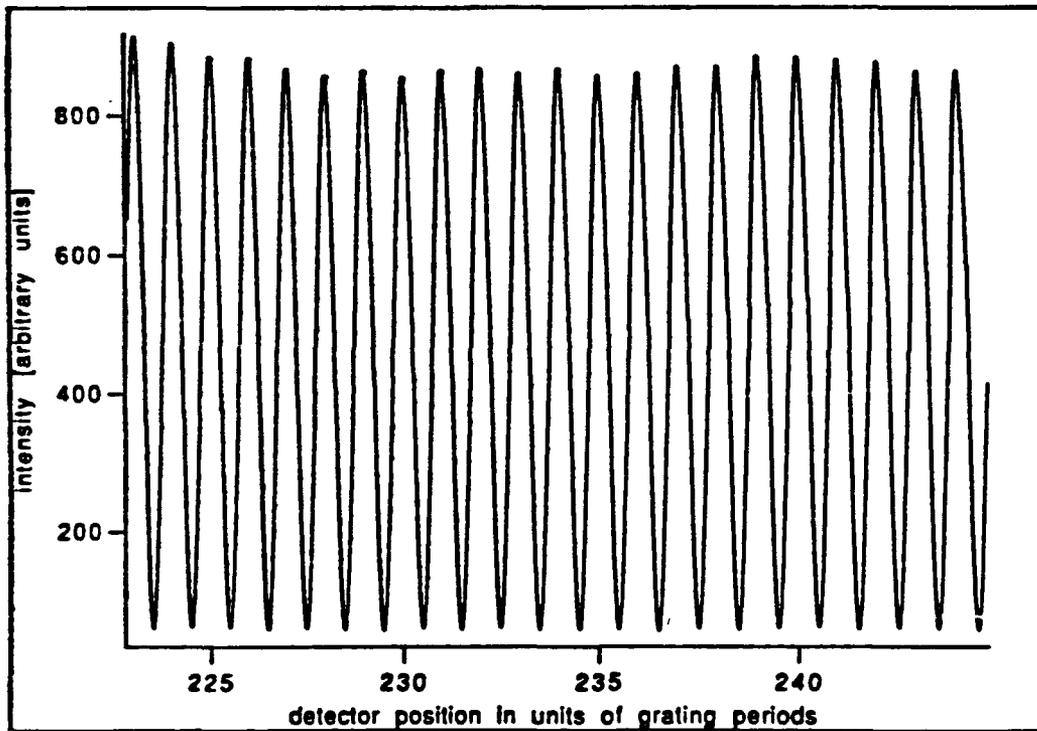
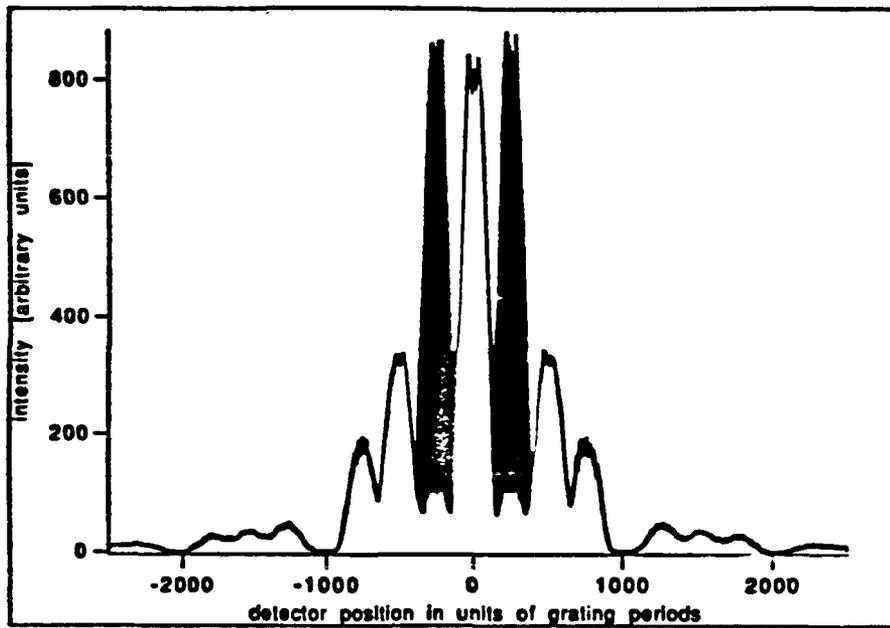


Figure 3: (a) Predicted intensity distribution at position of third grating. Atoms diffracted by different routes wind up in the major bumps shown. When different routes diffract into the same bumps, interference results, which appears as solid black. (b) Detail of intensity on right side of first order bump (the one used in our interferometer). The interference pattern has the period of one grating period — hence the total transmitted intensity is a periodic function of the third grating's position.

profile. Figure 3 shows the results of a typical calculation.

These numerical simulations have allowed us to investigate several important issues in interferometer design. We have investigated the rate at which fringe contrast degrades with mis-spacing of the three gratings and due to the spread of initial velocities (and corresponding change of deBroglie wavelengths) in the source beam. We have also examined the possibilities of constructing interferometers with varying degrees of beam collimation, and we plan to study the effects of source coherence (the collimator does not really have a blackbody source behind it).

When we have successfully demonstrated this interferometer, our first experimental objectives will be to make improved measurements of the polarizability of sodium and the Aharonov-Casher effect.

#### RECENT PUBLICATIONS

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#### THESIS (Graduate)

Bruce Gordon Oldaker, *Multi-Photon Momentum Transfer from Light to Atoms*, Ph.D. thesis, Department of Physics, MIT 1990.

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