Simulating an antimatter gravity interferometer

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Introduction

How to make a direct measurement of the gravitational acceleration of antimatter?

- Precision, 3-grating muonium atom-beam (Mach-Zehnder) interferometer
- As beam diffracts, an interference pattern forms
- Atoms “fall” under influence of gravity
- Interference pattern is shifted down or up
- This phase shift can be measured

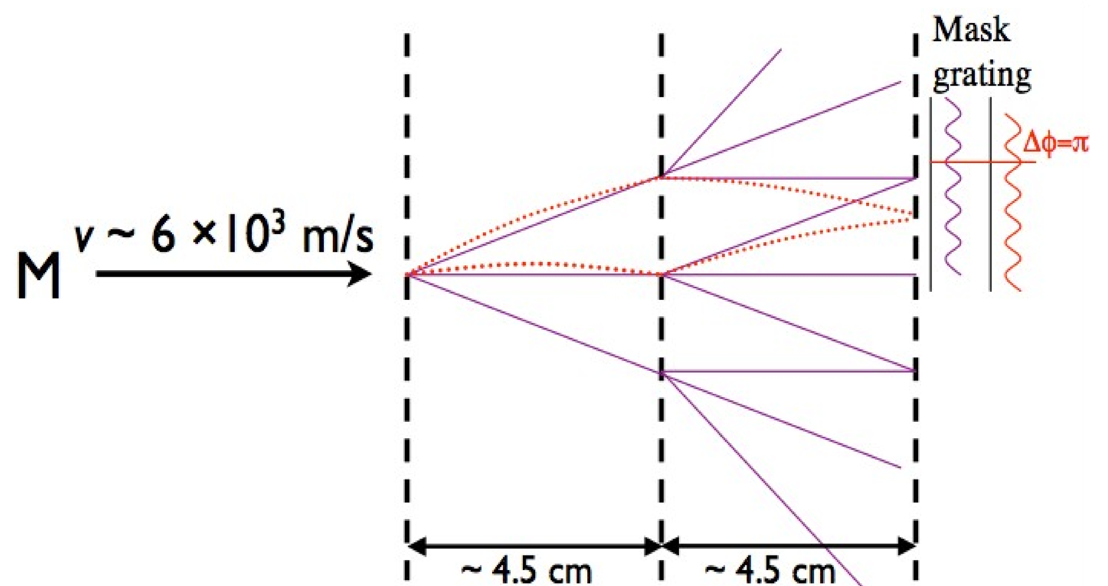

Figure 1

What is an interferometer? What is diffraction?

- A device that uses wave interference to perform a measurement. Types:
  - Optical: two rays of light follow different paths
  - Atomic: an atom beam takes the place of light behaving as a matter wave (quantum mechanics)

In a Mach-Zehnder interferometer, a single beam is split and interferes with itself

- Diffraction: when waves pass through small openings (slits) they bend and spread out in different directions

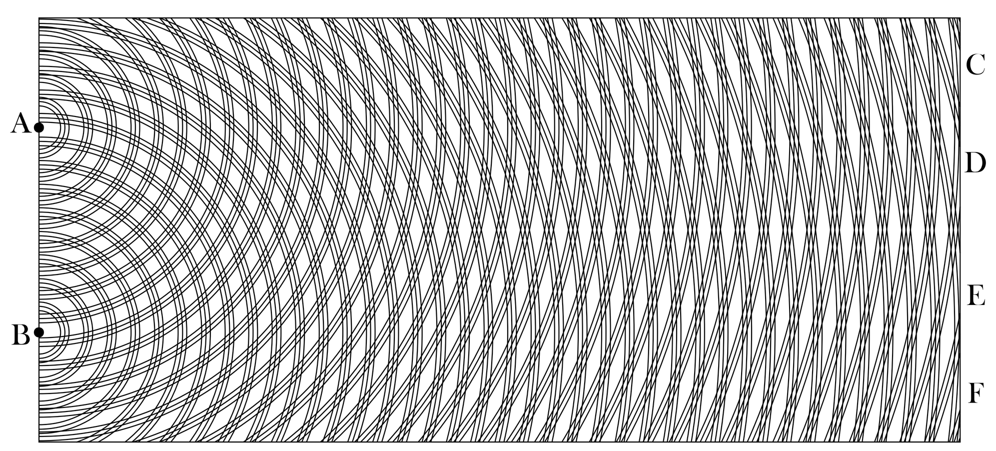

Figure 2

Simulation

What are we simulating?

- Beam propagation, with successive diffractions
- Shape of interference pattern at the end

The simulation is programmed in C (and some C++). It is based on Dr. McMorran's work on electron diffraction at the Univ. of Arizona.

The Gaussian Schell Model (GSM) is used to model the muonium matter wave:

$$w = w_o\sqrt{\left(1+\frac{z}{r_o}\right)^2+\left(\frac{\lambda z}{w_o l_o}\right)^2} \qquad r = z\frac{\left(1+z/r_0\right)^2+\left(\lambda z/w_o l_o\right)^2}{\left(z/r_o\right)\left(1+z/r_o\right)+\left(\lambda z/w_o l_o\right)^2}$$

It is expected that the interference pattern will be shifted due to gravity. That phase shift is given by:

$$\varphi = \frac{2\pi g t^2}{d}$$

Other sources of phase shifts considered: Van der Waals effect, grating not perfectly aligned and image charge.

Results

Purpose of the simulation: predict how the geometry and imperfections of the device will affect the measurement. We can then find the optimal parameters to ease the execution of the experiment.

One of the outputs of the simulation is an image of the diffraction pattern produced by the beam.

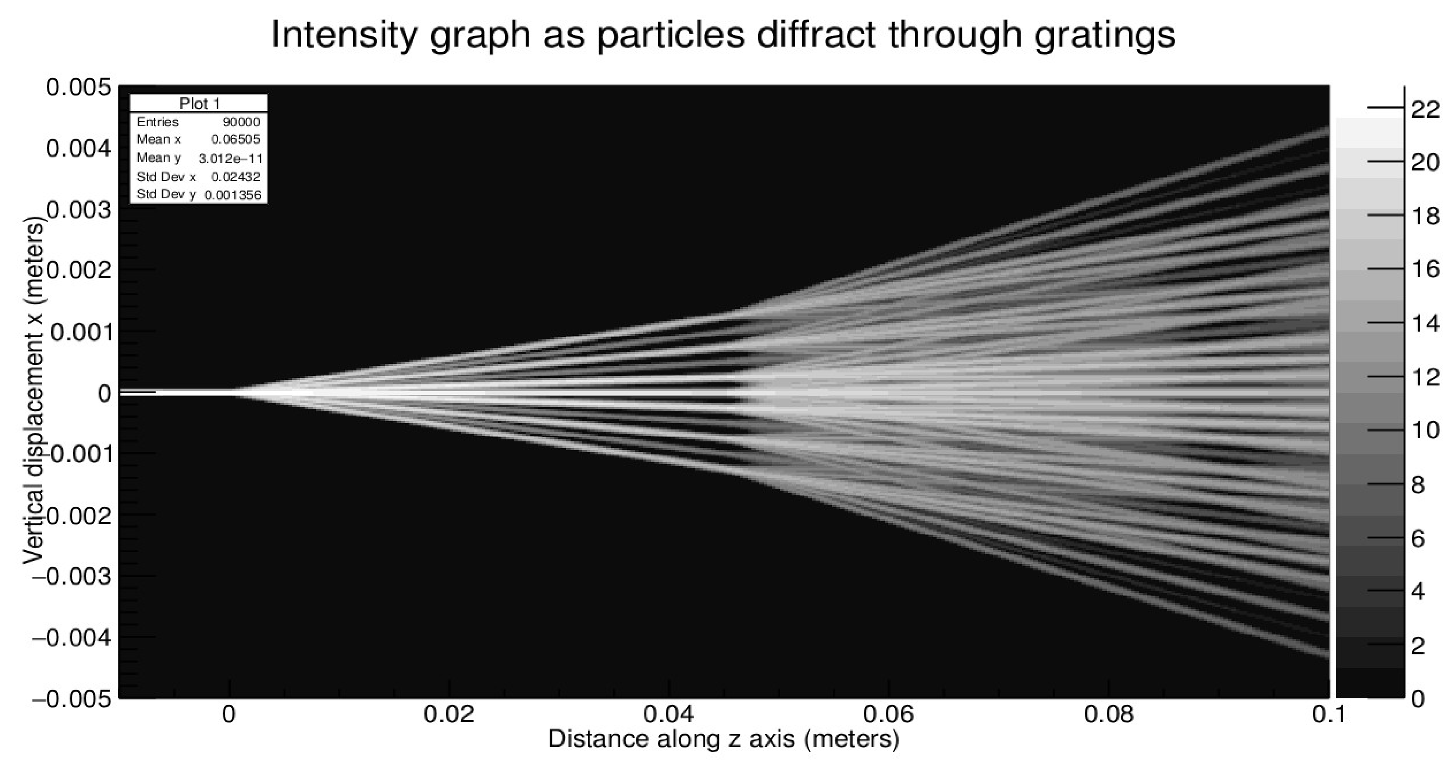

Figure 3

The second output is the intensity profile at the third grating. This will be compared to that for x rays, which are not affected by gravity.

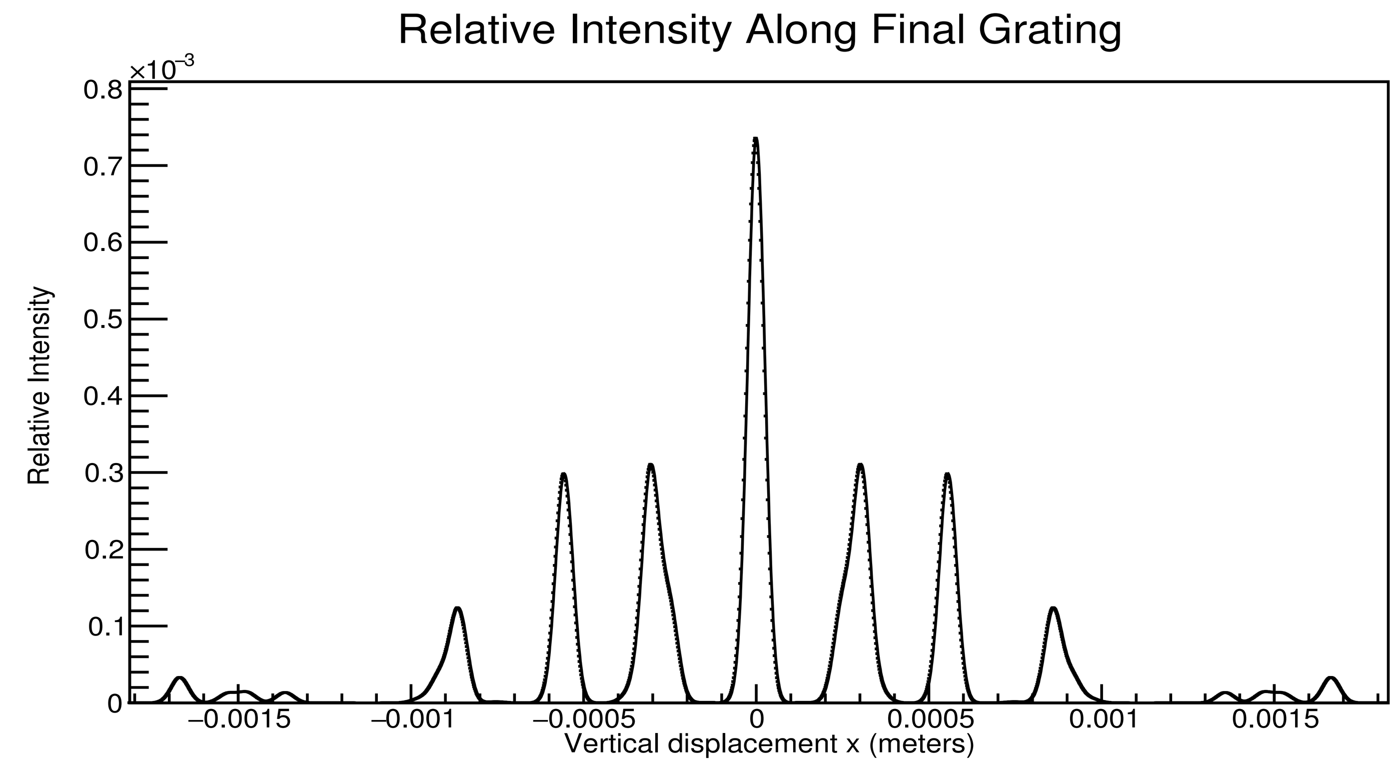

Figure 4

Present and future work

Main goals for the semester:

- Clean cluttered parts of code and make it readable
- Have it conform to the C standard as much as possible
- Improve accuracy of GSM implementation
- Improve accuracy of Van der Waals implementation
- Document theoretical basis and code structure

Possible goals for future work:

- Improve computational time-efficiency using process parallelization
- Reduce memory usage
- Implement any phase-shifting interactions that might be relevant
- Generalize simulation so it can work with other kinds of beams and other interferometer designs

References

[1] B. McMorran, “Electron diffraction and interferometry using nanostructures” (PhD thesis). The University of Arizona, 2009. Available at: <http://goo.gl/0UcqNr>
[2] D. M. Kaplan et al., “Antimatter gravity with muonium”, arXiv:1601.07222v2

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