BEC’s and Me

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Final REU Presentation
Bose-Einstein Condensates

- State of Matter

- Very near absolute zero (few billionths of a degree above absolute zero)
  - Coldest place in the universe!

- Wave-functions begin to overlap and particles become indistinguishable ($n\lambda > 2.6$)

- Predicted by Einstein and Bose in 1924

- Cornell and Wieman created first BEC in 1995 at Boulder
Rb-87 BEC

July 14th 1995 Boulder Group
The Lab

- The goal of the lab is to have ultra-cold Rb in a 2-D optical lattice with arbitrary potentials within a year.
- Optical arbitrary potentials are better to make configurations (harder to get running, easier to change).
  - Move really cold particles around easily.
- 2-D physics is fun.
  - Fractional quantum Hall effect.
  - Model transistor gates at small scales.
My Summer Project

- Increase my understanding of ultra-cold physics
- Work on various projects in order to optimize the apparatus
- Housekeeping
- Not doing anything specific
BEC Techniques

- Two steps used in order to make a BEC
  - Laser cooling
  - Evaporative cooling
Magneto-Optical Trap

- Photons impart a momentum equal to $\hbar k$ to an atom before absorption.

- Using the doppler shift one can allow light to only be absorbed if it heads toward the laser source (red detuned).

- Using magnetic trap (quadrupole coils) can shift spectral line in a radial direction.

  - More likely to get pushed toward center of trap.
MOT Pictures

MOTs cools to μK regime
Evaporative Cooling

- We use a cross-beam dipole trap in order to achieve evaporative cooling.

- Laser beam shifts energy levels of the atoms due to Stark effect and induces dipole moments.

- Atoms attracted to higher laser intensity if red-detuned (traps atoms in beam).

- Slowly decrease laser intensity to decrease temperature.
Coffee Cup Analogy

- Hottest particles escape from the cup as steam
- Lower the walls of the trap (decreasing intensity of beam)
- Left with cold molecules
Cross-Beam Dipole Trap

Atoms pulled to the crossing of the optical beams
Acousto-optic modulator (AOM)

- An incoming beam is split into two ordered beams. The zero ordered diffraction passes right through the AOM undeflected, but the first order diffraction beam is deflected at a certain angle.

- By applying a certain voltage to the AOM through a computer one can vary the intensity of the diffracted beam.

- Useful as an on/off switch and changing frequency.
Project #1

- Calculated parameters for an AOM so first order beam has an exponential decay
- Calibrated using LabView and experimental measurements
- Wrote program which displays output voltage, efficiency vs time plot, and volt vs time plot for a given efficiency
LabView Code Front
Project 2

- Modeling dipole trap capturing MOT atoms in free-fall

- Given various parameters will an atom from the MOT get collected into the dipole trap

- 3 Interactions to consider:
  - Gravity
  - Dipole Trap Potential
  - Particle collisions (random collisions where force is determined by Boltzmann distribution)

- Not much research has been done on capturing the MOT atoms into the dipole trap

- People are mostly trying to optimize it by hand instead of running computer simulations
MatLab Code 1

```matlab
% clear all
sym x y z w a b

% constants
perm = 8.854*10^-12;  % permittivity of free space
c = 2.9979*10^8;  % speed of light
eq = 1.602*10^-19;  % charge of electron
me = 9.109*10^-31;  % mass of electron
omega0 = pi*c/(780*10^-9);  % D2 line of Hb
num = 36.10*10^6;  % Hz D2 transition, from Stock
nu0 = 2.87*10^17;  % mass of Hb

bbar = 1.0546*10^-34;  % planck's constant
nbar = 529.10*10^-10;  % bohr radius

domega = 2*me

denray = 45

denray1 = 1550*10^-9

U0 = 2*domega*perm/(3*p^2 + gamma)/(pi*domega^2 * 2 * omega0^3))*(1)

deltat = 0.0018;  % in seconds
beam = domega

theta = pi/(2*domega

T = 1000;  % Kelvin

deltat = 0.005;
endtime = 0.1;

cross trap angle

theta = 90

for i = 0.1

% Maxwell-boltz dist constants
kb = 1.38*10^-23;  % Boltzmann Constant
T = 1000;  % Kelvin

deltat = 0.005;
endtime = 0.1;

% number density = 10^8/(2*(4/3)*p^3) = 10^8/16

% Beam waist = domega

% generate weighted list with all maxwell boltz speeds
w = 0;  % current w value
wlist = domega

for i = 0.1

end time = 0.1;

% list of speeds

for i = 1:length(wlist)

end
```

```matlab
% Graphing

time = 0:deltat:endtime;
yout = [y1];

% Finding initial potential energy due to dipole trap and gravity
U_plug = -u(0,plug.x,plug.y);
U_plug = -u(0,plug.y,plug.x);

% Maxwell-boltz dist (w = velocity)
C4 = (1 - sqrt((2*p)/pi))*exp(-w^2/(2*kb*mu));

% normal = int[w1, w2]

w = (1/2)*sqrt((2*pi)*(mass*kb^2)/(2*kb*mu));

% figures

% plot(w, [w0, w1, w2]);  % plots maxwell-boltz dist
% xlabel('Velocity (m/s)');
% ylabel('Probability Density');
% title('Maxwell-Boltzmann Distribution')

% generate weighted list with all maxwell boltz speeds
w = 0;  % current w value
wlist = domega

for i = 0.1

end
```

```matlab
% list of speeds

for i = 1:length(wlist)

end
```
MatLab Code 2

```matlab
if rand(1) > 0.5;
    vx = -velxpos;
else
    vx = velxpos;
end
if rand(1) > 0.5;
    vy = -velypos;
else
    vy = velypos;
end
if rand(1) > 0.5;
    vz = -velzpos;
else
    vz = velzpos;
end
updateStep = 1;

% resolve vel/pot equations
for i = 1:deletetime
    rand(new, sum([100*clock]));  % resseed random number generator each
    Utrap_z = subUtrap_z(x, z, x1);  % Plug in for x-y values to find a
    a_z = subUtrap_z(x, z, x1) + (beta + vz(1)/gamma);  
    Utrap_y = subUtrap_y(1, y, y1);  % Plug in for x-z values to find a
    a_y = subUtrap_y(1, y, y1) + (beta + vy(1)/gamma);  
    Utrap_x = subUtrap_x(1, x, x1);  % Plug in for y-z values to find a
    a_x = subUtrap_x(1, x, x1) + (beta + vx(1)/gamma);  
    vx1 = vz + a_z*deletetime;  % Update velocity
    vy1 = vy + a_y*deletetime;
    vz1 = vz + a_z*deletetime;
    z1 = z + vz1*deletetime;  % Save new position
    y1 = y + vy1*deletetime;
    x1 = x + vz1*deletetime;
ypos(updateStep) = y2;  % Append value to list to graph
end

% Probability of collision of 2 atoms
if rand(1) > ~ptatoms
    % Pick a number from the list of speed a particle has given
    % maxwellboltz dist, and then put it into a velocity
    the_lucky_number = floor(maxwell(ylistspeed) * rand(1));
    speed = ylistspeed(the_lucky_number);
    velxpos = speed/sqrt(3);
    velypos = speed/sqrt(3);
    velzpos = speed/sqrt(3);
end
```
MatLab Output 1
Particle gets stuck!
Matlab output 3
Project 3

- The light shutters used in the lab open/close on the millisecond scale
- Need to open/close it faster (something on the microsecond scale)
- Building a light shutter that can hopefully open/close at .5 microseconds
Hard Drive Shutter

- Building shutter out of a hard drive
- HD arm moves very quickly
- Attaching circuit to voice coil will allow control of arm
Shutter Circuit

RC combination stores charge and releases the instant the switch is desired

*University of Melbourne Atom Optics
Finished Product

*Magnet keeper
*Voice coil
*Sorbothane buffer
*Pivot arm
*Shutter flag

*University of Melbourne
Atom Optics
Hard Drive Progress

- Soldered the circuit to PCB board
- Created an enclosure for the circuit
- Had everything tested and working, until I broke it
- I fried the IC and am currently waiting for new ones
HD Shutter

P.S. Inputs

On/Off

TTL Input/Output
Project 4

- Created a program in LabView that allowed live updates of 3 parameters and graphed them instantaneously.
- The input parameters were O.D., N3D, and Nfitting.
- The output is 3 graphs.
Project 5

- Created LabView program that created a line of best fit for Bose-Einstein condensates

- During the transition to a BEC the particle distribution changes from a Gaussian distribution to a Thomas-Fermi distribution
Thomas-Fermi Distribution

Coherent Spin Dynamics of a Spin-1 Bose-Einstein Condensate

Ming-Shien Chang

\[ n_{\text{tof,th}}(\vec{r}) = A e^{-\frac{r_1^2 + r_2^2}{2\sigma^2}}, \ T \gg T_c \]

\[ n_{\text{tof,tot}}(\vec{r}) = A g_2(z e^{-\frac{r_1^2 + r_2^2}{2\sigma^2}}), \ T \gtrsim T_c \]

Riemann Zeta function \( g_1(z) = \sum_{j=1}^{\infty} \frac{z^j}{j!} \)
Mapped out a grounding scheme for the electrical equipment in the lab

Hopefully after locating all the grounding sources it will help clear up grounding noise which could be preventing us from making a BEC
Initially started as a project to prevent atom loss in the dipole trap

The idea is to use a magnetic field to counter-act the force of gravity (which may be causing atom loss in the dipole trap)

Will use a coil of wire to apply a B-field to the dipole trap which will apply a force on the atoms which is proportional to the gradient of the B-field
Magnetic Coils

Through calculations it has been determined that the mechanism for atom loss in the dipole trap we are experiencing is not gravity.

This project is now focused on using these magnetic fields to re-create the Stern-Gerlach experiment.
Stern-Gerlach Theory

A nonuniform magnetic field applies a force on neutral atoms and they undergo a deflection in their path.

This is caused by the spin of the atoms acting as a magnetic moment.

\[ \mu = -m_\perp g_j \mu_B \quad U = -\mu \cdot B \quad F = -\nabla U \]

\[ |F| = \mu_B \mu_\perp g_j \frac{\partial B}{\partial z} \]
Circuit Design
Future Circuit

ULTRACOLD ATOMS IN A DISORDERED OPTICAL LATTICE
MATTHEW ROBERT WHITE
Working on optimizing several parameters of the MOT stage on the BEC apparatus

Specifically changing re-pump intensity, magnetic field intensity, ramp of magnetic field intensity
Apparatus Control
Graphs of Data
Graphs of Data

PSD $\sim N/T^3$