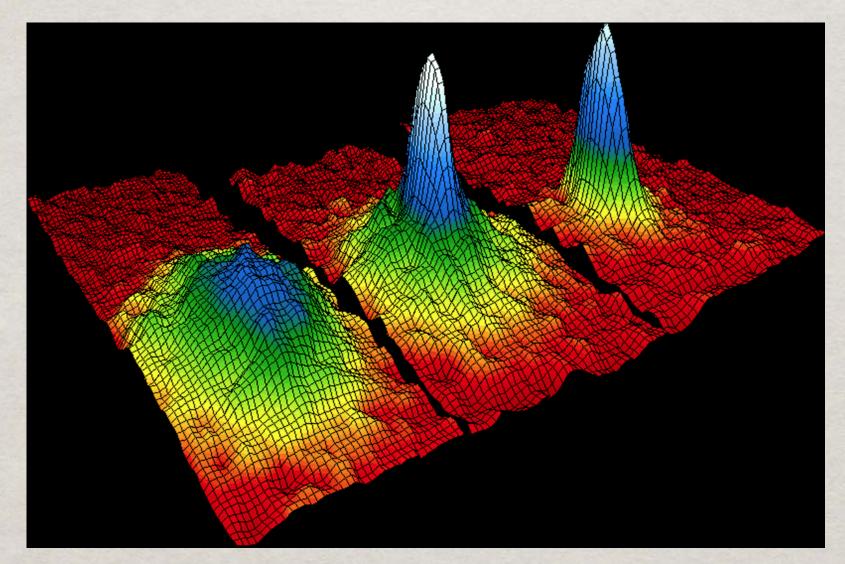
BEC's and Me

Conrad Hawkins 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 w/ 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

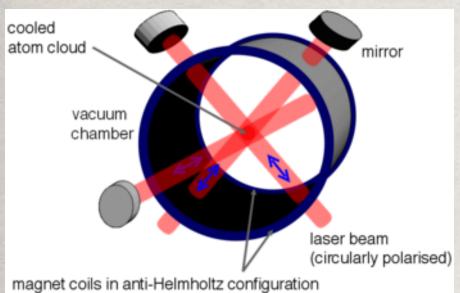
Two steps used in order to make a BEC
 Laser cooling

Evaporative cooling

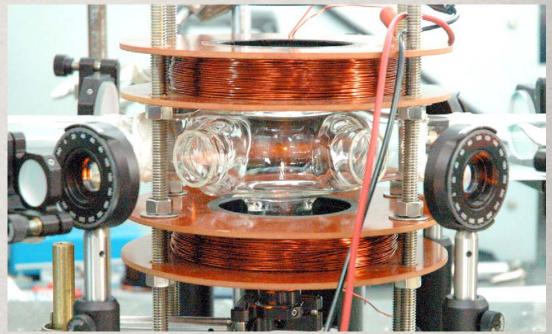
Magneto-Optical Trap

- Photons impart a momentum equal to ħk 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



<image>



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

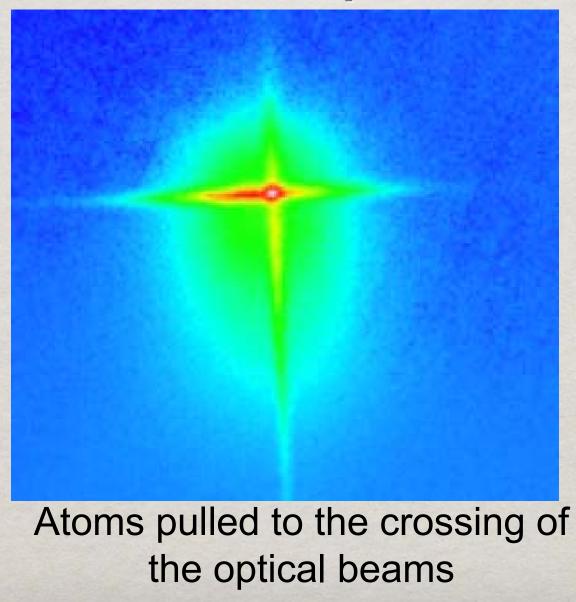


 Hottest particles escape from the cup as steam

Lower the walls of the trap (decreasing intensity of beam)

Left with cold molecules

Cross-Beam Dipole Trap



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

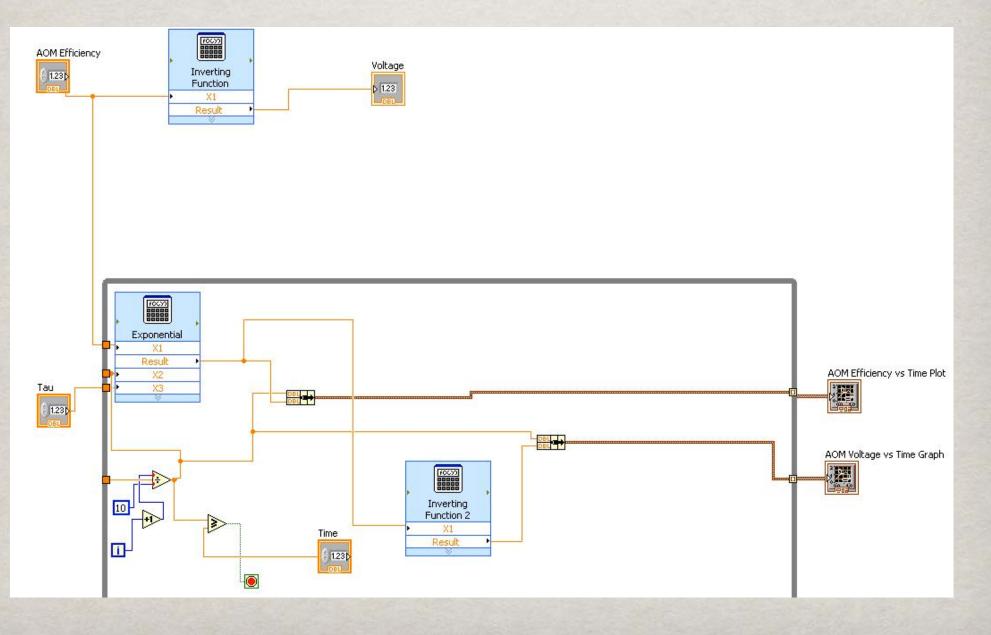
Project #1

Calculated parameters for an AOM so first order beam has an exponential decay

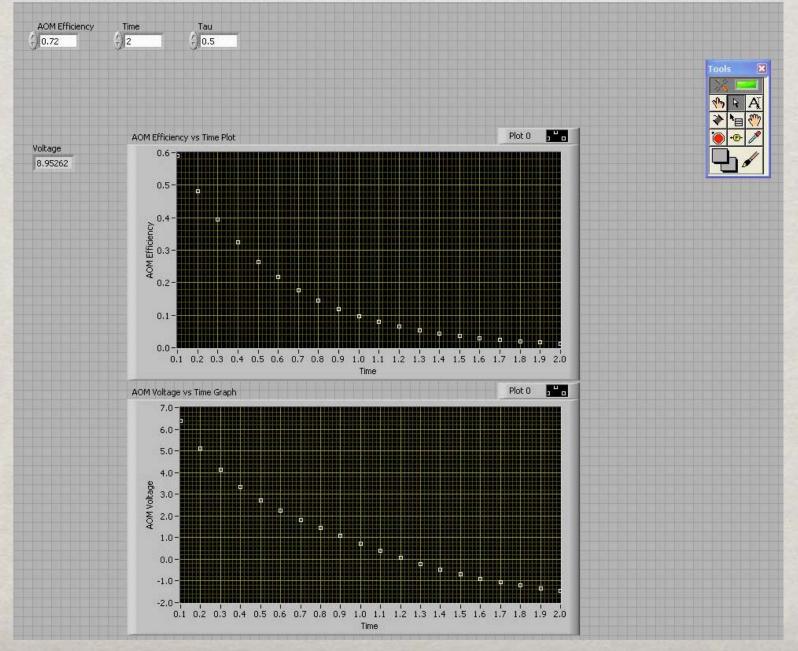
Calibrated using LabView and experimental measurements

Wrote program which displays output voltage, efficiency vs time plot, and volt vs time plot for a given efficiency

LabView Code Block



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

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MatLab Code 2

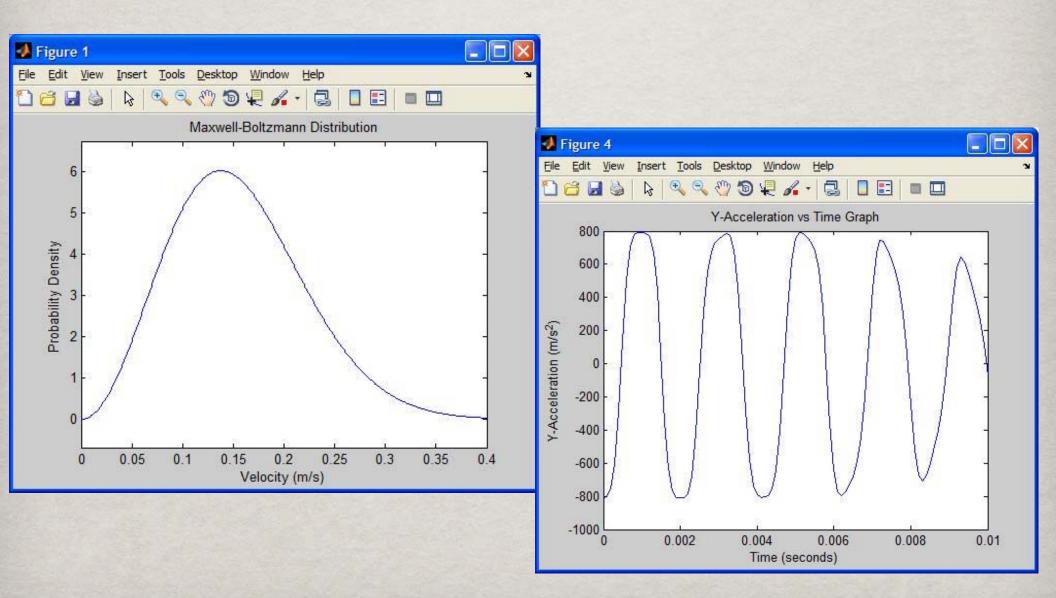
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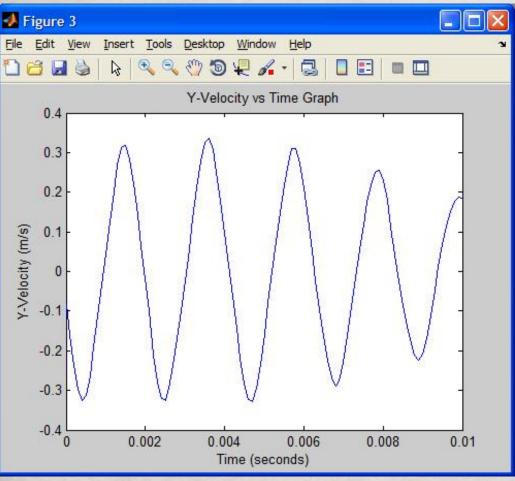
In 159 Col 23

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8 $vx = -1 + v,$ 9 else 0 $vx = velx$ 11 end 23 if rand(1) > 24 $vy = -1 + v,$ 26 else 27 else 28 if rand(1) > 29 if rand(1) > 29 else 29 else 20 vy = vely 21 else 22 vz = -1 + v, 23 end 35 updateStep=1; 6 if rand(1) > 22 vz = velz 33 end 4 opdateStep=1; 6 updateStep=1; 7 & Force/vel/po 8 0 9 utrap_21 34 utrap_22 35 utrap_y1 6 utrap_y2 7 a_x = sub 10 utrap_x2 11 a_x = sub 12 vz1 = vz 13 vz1 = vz <t< th=""><th>velxpos; xpos; .5; velypos; ypos; .5; velzpos; zpos; ; os equations</th><th>189 - 190 191 - 192 - 193 - 194 - 195 - 196 197 - 198 - 199 - 200 - 201 - 202 203 - 204 -</th><th><pre>velzpos = speed/sqrt(3); if rand(1) > .5; velx = -1*velxpos; else velx = velxpos; end if rand(1) > .5; vely = -1*velypos; else vely = velypos;</pre></th></t<>	velxpos; xpos; .5; velypos; ypos; .5; velzpos; zpos; ; os equations	189 - 190 191 - 192 - 193 - 194 - 195 - 196 197 - 198 - 199 - 200 - 201 - 202 203 - 204 -	<pre>velzpos = speed/sqrt(3); if rand(1) > .5; velx = -1*velxpos; else velx = velxpos; end if rand(1) > .5; vely = -1*velypos; else vely = velypos;</pre>
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12 if $rand(1) >$ 13 if $rand(1) >$ 15 else 16 vy = -1*v. 16 vy = vely. 16 vy = vely. 16 vz = vely. 17 end 18 if $rand(1) >$ 19 if $rand(1) >$ 22 vz = velz. 3- end 44 updateStep=1; 15 updateStep=1; 16 for i = 0:del 17 a_z = sub 18 utrap_21 19 utrap_y1 10 utrap_y2 13 a_z = sub 14 utrap_y1 15 utrap_x2 16 utrap_x1 17 a_x = sub 18 vy1 = vy 19 x2 = z1 + 10 utrap_x2 = 11 a_x = sub 12 vy1 = vy 13 vy2 = y1 + 14 y2 = y1 + 15 vx1 = vx 16 <td< td=""><td>velypos; ypos; .5; velzpos; zpos; ; os equations</td><td>193 - 194 - 195 - 196 197 - 198 - 199 - 200 - 201 - 202 203 - 204 -</td><td><pre>else velx = velxpos; end if rand(1) > .5; vely = -1*velypos; else vely = velypos;</pre></td></td<>	velypos; ypos; .5; velzpos; zpos; ; os equations	193 - 194 - 195 - 196 197 - 198 - 199 - 200 - 201 - 202 203 - 204 -	<pre>else velx = velxpos; end if rand(1) > .5; vely = -1*velypos; else vely = velypos;</pre>
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$i4 =$ $vy = -1*v$; $5 =$ else $6 =$ $vy = vely$; $6 =$ $vy = vely$; $7 =$ end $9 =$ if rand(1) > $0 =$ $vz = -1*v$; $10 =$ $vz = -1*v$; $10 =$ $vz = velz$; $10 =$ $vz = velz$; $10 =$ $vz = velz$; $10 =$ end $10 =$ for i = 0:del $10 =$ Utrap_21 $10 =$ Utrap_22 $3 =$ $a_z = sub$ $10 =$ Utrap_21 $10 =$ Utrap_22 $10 =$ Utrap_21 <	velypos; ypos; .5; velzpos; zpos; ; os equations	195 - 196 197 - 198 - 200 - 201 - 202 203 - 203 - 204 -	<pre>end if rand(1) > .5; vely = -1*velypos; else vely = velypos;</pre>
15 else 16 vy = vely 16 vy = vely 16 vz = vely 19 if rand(1) > 19 vz = -1*v 11 else 12 vz = velz 13 end 14 updateStep=1; 15 updateStep=1; 16 for i = 0:del 17 & Force/vel/po 18 for i = 0:del 19 rand(.see 10 Utrap_z1 12 Utrap_y1 15 Utrap_y2 16 Utrap_y2 17 a_x = sub 16 Utrap_y1 17 a_x = sub 18 vz1 = vz 19 Utrap_x2 11 a_x = sub 12 vz1 = vz 13 vz1 = vz 15 vz1 = vz 16 vy2 = y1 + 17 z2 = z1 + 19 x2 = x1 + 11 ypos(upd 12 vypos(upd	ypos; .5; velzpos; zpos; ; os equations	196 197 - 198 - 200 - 201 - 202 203 - 203 - 204 -	<pre>vely = -1*velypos; else vely = velypos;</pre>
7 - end 17 - end 18 - $vz = -1*w$ 10 - $vz = -1*w$ 11 - else 2 - $vz = velz$ 3 - end 5 - updateStep=1; 6 - for j = 0:del 9 - rand('.see 0 - Utrap_z1 2 - Utrap_z2 3 - a_z = sub 4 - Utrap_x2 6 - Utrap_x1 10 - Utrap_x2 17 - a_y = sub 18 - Utrap_x2 19 - Utrap_x2 10 - Utrap_x2 11 - a_x = sub 12 - vz1 = vz 13 - vz1 = vz 14 - vy1 = vy 15 - vx1 = vz 16 - vz1 = vz 17 - z2 = z1 + 18 - y2 = y1 + 19 - x20s(upda 2 - zypss(upda 2 - zpos(upda 2 - zpos(upda <t< td=""><td>.5; velzpos; zpos; ; os equations</td><td>198 - 199 - 200 - 201 - 202 - 203 - 204 -</td><td><pre>vely = -1*velypos; else vely = velypos;</pre></td></t<>	.5; velzpos; zpos; ; os equations	198 - 199 - 200 - 201 - 202 - 203 - 204 -	<pre>vely = -1*velypos; else vely = velypos;</pre>
8 if $rand(1) >$ 9 vz = -1*v 1 else 2 vz = vz = vz z 3 end 4 updateStep=1; 6 for i = 0:del 9 for j = 0:del 9 a_z = sub 4 a_z = sub 4 a_z = sub 5 Utrap_v1 6 Utrap_v2 7 a_z = sub 4 a_z = sub 5 Utrap_v1 6 Utrap_v2 7 a_y = sub 8 vz1 = vz 9 Utrap_v2 1 a_x = sub 23 vz1 = vz 44 vy1 = vy 55 vz1 = vz 56 vz1 = vz 57 vz1 = vz 58 vypos(upd 70 z2 = z1 + 9 x2 = x1 + 10 ypos(upd 25 zosa(upd 26 zpos(upd 27 spos(upd	velzpos; zpos; ; os equations	199 - 200 - 201 - 202 203 - 204 -	<pre>else vely = velypos;</pre>
99 if rand(1) > 00 vz = -1*v. 10 vz = vz = vz = 11 end 15 updateStep=1; 16 for j. = 0:del 17 %Force/vel/po 18 for j. = 0:del 19 rand('.sec 11 Utrap_z1 12 Utrap_z2 13 a_z = sub 15 Utrap_y1 16 Utrap_y2 17 a_y = sub 18 Utrap_v2 19 Utrap_v2 11 a_x = sub 12 Utrap_v2 13 ay = sub 14 a_x = sub 15 Utrap_v2 16 Utrap_v2 17 a_z = sub 12 vy1 = vy 13 vz1 = vz 14 vy2 = y1 + 15 vy2 = y1 + 16 ypos(upda 17 %Probabil 18 zpos(upda 19 if rand(1 19	velzpos; zpos; ; os equations	200 - 201 - 202 203 - 204 -	vely = velypos;
00 - vz = -1*v. 11 - else 22 - vz = velz. 33 - end 55 - updateStep=1; 66 - for i = 0:del 99 - rand(.see 01 - Utrap_z1 22 - Utrap_z1 23 - a_z = sub 24 - Utrap_y2 25 - Utrap_y2 26 - Utrap_x1 27 - a_y = sub 28 - Utrap_x2 29 - utrap_x1 20 - Utrap_x2 21 - a_x = sub 22 - vz1 = vz 23 - vz1 = vz 25 - vtrap_x1 26 - vx1 = vz 27 - z_2 = z1 + 28 - vypos(upda 27 - x20s(upda 28 - xpos(upda 29 - x2pos(upda 21 - xpos(upda 25 - zpos(upda 26 - zpos(upda 27 - zpos(upda 29 - if rand(1 <	velzpos; zpos; ; os equations	201 - 202 203 - 204 -	
1 else 2 vz = velz 3 end 4 updateStep=1; 6 for i = 0:del 9 for i = 0:del 1 Utrap_z1 2 Utrap_z1 3 a_z = sub 4 utrap_y1 5 Utrap_y1 6 Utrap_y1 6 Utrap_y2 7 a_y = sub 8 Utrap_x2 9 Utrap_x1 1 a_x = sub 2 vz1 = vz 4 vy1 = vy 5 vz1 = vz 5 vz1 = vz 6 vz1 = vz 7 z2 = z1 + 9 x2 = x1 + 1 ypos(upd 2 xypos(upd 3 axpos(upd 4 xpos(upd 5 zosa(upd 6 zosa(upd	zpos; ; os equations	202 203 - 204 -	ena
2 - vz = velz; 3 - end 5 - updateStep=1; 6 *Force/vel/po 8 - for i = 0:del 9 - rand('acc 0 - Utrap_21 3 - a_z = sub 4 - Utrap_22; 3 - a_z = sub 4 - Utrap_y1 6 - Utrap_y2; 7 - a_y = sub 9 - Utrap_x1; 0 - Utrap_x2; 1 - a_x = sub 2 - vy1 = vy; 5 - vx1 = vz; 4 - vy1 = vy; 5 - vx1 = vz; 6 - z2 = z1 + 9 - x2 = x1 + 1 - ypos(upda 2 - vypos(upda 3 - aypos(upda 5 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 9 - if rand(1 8 %Probabil 8 - spos(upda 9 - if rand(1) 8 %Probabil 8 - spos(upda 9 - if rand(1) 8 %Probabil 8 - spos(upda 9 - if rand(1) 8 %Probabil 8 - spos(upda -	; os equations	203 - 204 -	
3 - end 4 updateStep=1; 6 %Force/vel/po 7 %Force/vel/po 8 - for i = 0:del 9 - rand(.see 1 Utrap_21 2 - Utrap_22: 3 - a_z = sub 5 - Utrap_y2: 7 - a_y ≡ sub 9 - Utrap_x1: 0 - Utrap_x2: 1 - a_x = sub 2 - vx1 = vz 4 - vy1 = vy 5 - vx1 = vz 6 - vx1 = vz 7 - 22 = z1 + 8 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 2 - xpos(upda 2 - xpos(upda 7 - xpos(upda 7 - xpos(upda 7 - xpos(upda 7 - xpos(upda 9 - xpos(upda 9 - if rand(1 9 - if rand(1	; os equations	204 -	if rand(1) > .5;
<pre>4 5 - updateStep=1; 6 7 %Force/vel/po 8 - for i = 0:del 9 - rand('see 0 1 - Utrap_21 2 - Utrap_22 3 - a_z = sub 5 - Utrap_y1 6 - Utrap_y2 6 - Utrap_x2 1 - a_y sub 8 9 - Utrap_x2 1 - a_x = sub 3 - vz1 = vz 4 - vy1 = vy 5 - vx1 = vx 6 7 - z2 = z1 + 8 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 3 - aypos(upda 5 - zpos(upda 6 7 %Probabil 8 9 - if rand(1 0 %%pic</pre>	os equations	205	<pre>velz = -1*velzpos;</pre>
6 %Force/vel/po 7 %Force/vel/po 9 for i = 0:del 1 Utrap_z1 2 Utrap_z2 3 a_z = sub 4 Utrap_y1 6 Utrap_y1 7 a_y = sub 9 Utrap_x2 1 a_x = sub 2 Utrap_x1 0 Utrap_x2 1 a_x = sub 2 vz1 = vz 4 vy1 = vy 5 vx1 = vz 6 vz1 = vz 7 z2 = z1 + 9 x2 = x1 + 1 ypos(upda 2 xpos(upda 2 xpos(upda 5 zpos(upda 6 zpos(upda 7 %Probabil 8 if rand(1 0 %%pic	os equations		else
7 %Force/vel/po 8 for i, = 0:del 9 rand('.see 0 Utrap_21 1 Utrap_21 2 Utrap_21 3 a_z = sub 4 y = sub 5 Utrap_y1 6 Utrap_x1 0 Utrap_x1 0 Utrap_x1 1 a_x = sub 3 vz1 = vz 4 vy1 = vy 5 vx1 = vz 6 y2 = y1 + 9 x2 = x1 (upda 2 ypos(upda 2 ypos(upda 4 xpos(upda 5 zpos(upda 6 zpos(upda 7 %Probabil 8 %Probabil		206 -	velz = velzpos;
<pre>8 - b for i = 0:del 9 - rand('sace 0 1 - Utrap_z1 2 - Utrap_z2 3 - a_z = sub 4 - Utrap_y2 7 - a_y = sub 9 - Utrap_x1 0 - Utrap_x2 1 - a_x = sub 2 - Utrap_x2 1 - a_x = sub 3 - Vz1 = vz 4 - vy1 = vy 5 - vx1 = vz 4 - vy1 = vy 5 - vx1 = vz 6 - z2 = z1 + 8 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 3 - aypos(upda 3 - aypos(upda 5 - zpos(upda 5 - zpos(upda 6 - ypos(upda 5 - zpos(upda 6 - ypos(upda 5 - zpos(upda 6 - ypos(upda 6 - ypos(upda 6 - ypos(upda 7 * spos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 6 - ypos(upda 6 - ypos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 6 - ypos(upda 6 - ypos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 6 - ypos(upda 7 * spos(upda 7 * spos(upda 6 + ypos(upda 7 * spos(upda 6 + ypos(upda 7 * spos(upda 6 + ypos(upda 7 * spos(upda 7 * spos(upda) 7 * spos(upda 7 * spos(upda) 7 * spos(upda)</pre>		207 -	end
9 - rand('see 0 - Utrap_21 2 - Utrap_22 3 - a_z = sub 4 - Utrap_y1 6 - Utrap_y2 7 - a_y = sub 9 - Utrap_x1 0 - Utrap_x2 1 - a_x = sub 2 - vx1 = vz 4 - vy1 = vy 5 - vx1 = vz 6 - zpos(upda 2 - zpos(upda 3 - aypos(upda 5 - zpos(upda 6 - zpos(upda 7 %Probabil 8 - spos(upda 6 - zpos(upda 7 %Probabil 8 - spos(upda 7 %Probabil 8 - spos(upda 7 %Probabil 8 - spos(upda) 9 - if rand(1) 8 %Pice		208	%velx,vely,velz is the random particles velocity
0 1 - Utrap_21 2 - Utrap_22 3 - a_z = sub 4 - Utrap_y1 6 - Utrap_y2 7 - a_y = sub 9 - Utrap_x1 0 - Utrap_x2 1 - a_x = sub 2 - vy1 = vy 5 - vx1 = vz 4 - vy1 = vy 5 - vx1 = vz 7 - z2 = z1 + 9 - x2 = x1 + 9 - x2 = x1 + 1 - ypos(upda 2 - yypos(upda 3 - aypos(upda 5 - zpos(upda 6 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 5 - zpos(upda 6 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 5 - zpos(upda 5 - zpos(upda 6 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 5 - zpos(upda 6 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 5 - zpos(upda 6 - y2 = y1 + 1 - ypos(upda 5 - zpos(upda 6 - y2 = y1 + 1 - ypos(upda 5 - zpos(upda 6 - y2 = y1 + 1 - ypos(upda 6 - y2 = y1 + 1 - ypos(upda 6 - y2 = y1 + 1 - ypos(upda 7 - y2 = y1 + 1 - ypos(upda 6 - y2 = y1 + 1 - ypos(upda 7 - y2 = y1 + 1 - ypos(upda 6 - y2 = y1 + 1 - ypos(upda 6 - y2 = y1 + 1 - ypos(upda 7 - y2 = y1 + 1 - ypos(upda 6 - y2 = y1 + 1 - ypos(upda 7 - y2 = y1 + 1 - ypos(upda 6 - y2 = y1 + 1 - ypos(upda 7 - y2 = y1 + 1 - ypos(upda 7 - y2 = y1 + 1 - ypos(upda 7 - y2 = y1 + 1 - y2 = y	ed_,sum(100*clock)) %reseed random number generator each	210 -	vx = velx; %collided so takes random particles vel
1 - Utrap_21 2 - Utrap_22 3 - a_2 = sub 4 - Utrap_y1 6 - Utrap_y2 7 - a_y = sub 8 - Utrap_x1 0 - Utrap_x2 1 - a_x = sub 2 - vx1 = vx 4 - vy1 = vy 5 - vx1 = vx 6 - z2 = z1 + 8 - y2 = y1 + 9 - z2 = x1 + 1 - ypos(upda 3 - aypos(upda 3 - aypos(upda 5 - zpos(upda 5 - zpos(upda 6 - ypos(upda 5 - zpos(upda 6 - ypos(upda 6 - ypos(upda 7 - zpos(upda 6 - ypos(upda 7 - zpos(upda 6 - ypos(upda 7 - zpos(upda 6 - ypos(upda 6 - ypos(upda 7 - ypos(upda 6 - ypos(upda 9 - utrap_x1 - ypos(upda 9 - utrap_x1 - ypos(upda 6 - ypos(upda 6 - ypos(upda 6 - ypos(upda 7 - ypos(upda 6 - ypos(upda 7 - ypos(upda 6 - ypos(upda 6 - ypos(upda 7 - ypos(upda 6 - ypos(upda 7 - ypos(upda 6 - ypos(upda 7 - ypos(upda 6 - ypos(upda 7 - yp	,sum(100"CIOCK)) steseed tandom number generator each	210 -	vy = vely;
2 - Utrap_22 3 - a_z = sub 4 - Utrap_y1 5 - Utrap_y1 6 - Utrap_y2 7 - a_y = sub 8 - Utrap_x1 0 - Utrap_x2 1 - a_x = sub 3 - vz1 = vz 4 - vy1 = vy 5 - vx1 = vx 6 - z2 = z1 + 9 - z2 = x1 + 1 - ypos(upda 2 - xypos(upda 3 - aypos(upda 4 - xpos(upda 5 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda) 7 - spos(upda) 9 - if rand(1) 9 - spos(upda) 1	= subs(Utrap z,x,x1); %Plug in for x-y values to find a	212 -	vz = velz;
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$	= subs(Utrap z1,y,y1);	213 -	else
5 - Utrap_y1 6 - Utrap_y2 7 - a_y sub 8 - Utrap_x2 1 - a_x sub 2 - Utrap_x1 1 - a_x = sub 2 - vx1 = vz 4 - vy1 = vy 5 - vx1 = vz 6 - z2 = z1 + 9 - x2 = x1 + 1 - ypos(upda 2 - yyos(upda 3 - aypos(upda 5 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 7 - z2 = z1 + 9 - x2 = x1 + 0	bs(Utrap_z2,z,z1)+((beta*vz)/pmass);	214 -	vx = vx1; %did not collide so updates old velocity
6 - Utrap_y2 7 - a_y = sub 8 9 - Utrap_x2 1 - a_x = sub 2 3 - vz1 = vz 4 - vy1 = vy 5 - vx1 = vz 6 7 - z2 = z1 + 9 - x2 = x1 + 9 - x2 = x1 + 1 - ypos(upda 2 - yypos(upda 3 - aypos(upda 5 - zpos(upda 5 - zpos(upda 6 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 7 - spos(upda 6 - zpos(upda 7 - spos(upda 7 - spos(upda 6 - zpos(upda 7 - spos(upda 7 - spos(upd		215 -	vy = vy1;
7 - a_y sub 8 9 - Utrap_x1 0 - Utrap_x2 1 - a_x = sub 2 - vz1 = vz 4 - vy1 = vy 5 - vx1 = vx 6 - z2 = z1 + 8 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 2 - vypos(upda 3 - aypos(upda 5 - zpos(upda 6 - zpos(upda 7 - zpos(upda 6 - zpos(upda 6 - zpos(upda 7 - zpos(upda 6 - zpos(upda 6 - zpos(upda 7 - zpos(upda 6 - zpos(upda 7 - zpos(upda 6 - zpos(upda 7 - zpos(upda 7 - zpos(upda 6 - zpos(upda 7 - zpos(upda 6 - zpos(upda) 7 - zpos(u	<pre>= subs(Utrap_y,x,x1); %Plug in for x-z values to find a</pre>	216 -	vz = vz1;
8 Utrap_x1 99 - Utrap_x2 10 - Utrap_x2 11 - a_x = sub 12 13 - vz1 = vz 14 - vy1 = vy 15 - vx1 = vz 16 - 22 = z1 + 17 - z2 = z1 + 19 - x2 = x1 + 10 - ypos(upda 12 - vypos(upda 13 - aypos(upda 15 - zpos(upda 16 - zpos(upda 17 - spos(upda 18 - zpos(upda 19 - if rand(1 19 - if rand(1	= subs(Utrap_y1,z,z1);	217 - 218	end
9 - Utrap_x1 0 - Utrap_x2 1 - a_x = sub 3 - vz1 = vz 4 - vy1 = vy 5 - vx1 = vx 6 7 - z2 = z1 + 8 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 3 - aypos(upda 5 - zpos(upda 5 - zpos(upda 6 7 %Probabil 8 9 - if rand(1 0 %%pic	bs(Utrap_y2,y,y1)-g+((beta*vy)/pmass)	218 219	
$\begin{array}{c ccccc} 0 & - & Utrap_x^2 \\ 1 & - & a_x = sub \\ 2 \\ 3 & - & vz1 = vz \\ 4 & - & vy1 = vy \\ 5 & - & vx1 = vx \\ 6 \\ 7 & - & z2 = z1 + \\ 8 & - & y2 = y1 + \\ 9 & - & x2 = x1 + \\ 0 \\ 1 & - & ypos(upda \\ 2 & - & vypos(upda \\ 3 & - & aypos(upda \\ 5 & - & zpos(upda \\ 5 & - & zpos(upda \\ 6 \\ 7 & & & & & \\ 7 & & & & & & \\ 7 & & & &$	= subs(Utrap_x,y,y1); %Plug in for y-z values to find a	220 -	<pre>21 = 22; %Save new position</pre>
1 - a_x = sub 2 - vz1 = vz 4 - vy1 = vy 5 - vx1 = vx 6 - z2 = z1 + 9 - x2 = x1 + 1 - ypos(upda 2 - vypos(upda 3 - aypos(upda 5 - zpos(upda 5 - zpos(upda 6 - zpos(upda 7 - %Probabil 8 - zpos(upda 9 - if rand(1 0 - %Pic	= subs(Utrap x1,z,z1);	221 -	y1 = y2;
$\begin{array}{cccccccccccccccccccccccccccccccccccc$	bs(Utrap_x2,x,x1)+((beta*vx)/pmass);	222 -	x1 = x2;
4 - vyl = vy 5 - vxl = vx 6 7 - 22 = 2l + 9 - x2 = xl + 1 - ypos(upda 2 - vypos(upda 3 - aypos(upda 5 - zpos(upda 5 - zpos(upda 6 7 %Probabil 8 9 - if rand(1 0 %%pic		223 -	updateStep = updateStep +1;
5 - vx1 = vx 6 - z2 = z1 + 8 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 2 - vypos(upda 3 - aypos(upda 5 - zpos(upda 6 - 7 %Probabil 8 9 - if rand(1 0 %%pic	+ a_z*deltat; %Update velocity	224 -	end
6 7 - 22 = 21 + 8 - y2 = y1 + 9 - x2 = x1 + 0 1 - ypos(upda 2 - yypos(upda 3 - aypos(upda 4 - xpos(upda 5 - zpos(upda 6 - 7 %Probabil 8 9 - if rand(1 0 %%pic	+ a_y*deltat;	225	61
7 - 22 = 21 + 8 - y2 = y1 + 9 - x2 = x1 + 1 - ypos(upda 2 - yypos(upd 3 - aypos(upd 4 - xpos(upda 5 - 2pos(upda 6 - 2pos(upda 6 - if rand(1 0 %%pic	+ a x*deltat;	226 - 227 -	figure(2);
8 - y2 = y1 + 9 - x2 = x1 + 0 ypos(upda 2 - yypos(upda 3 - aypos(upda 4 - xpos(upda 5 - zpos(upda 6 - xpos(upda 6 - if rand(1 0 %%pic	+ vzl*deltat; %Update position	228 -	<pre>plot(time,ypos); xlabel('Time (seconds)');</pre>
9 - x2 = x1 + 0 - ypos(upda 2 - yypos(upda 3 - aypos(upda 4 - xpos(upda 5 - zpos(upda 6 - %Probabil 8 - if rand(1 0 %%pic	+ vyl*deltat;	229 -	<pre>ylabel('Y-Position (meters)');</pre>
0 1 - ypos(upda 2 - yypos(upda 3 - aypos(upda 4 - xpos(upda 5 - zpos(upda 6 - Probabil 8 - if rand(1 0 % Probabil	+ vx1*deltat;	230 -	title('Y-Positions vs Time Graph')
2 - yypos(upd 3 - aypos(upd 4 - ypos(upd 5 - zpos(upda 6 - 7 %Probabil 8 - 9 - if rand(1 0 %%pic		231	
3 - aypos(upd 4 - xpos(upd 5 - zpos(upd 6 7 %Probabil 8 9 - if rand(1 0 %%pic	ateStep) = y2; %append value to list to graph	232 -	figure(3);
4 - xoos(upda 5 - zpos(upda 6 %Probabil 8 9 - if rand(1 0 %%pic	dateStep) = vy1;	233 -	<pre>plot(time,vypos); plot('Mime (seconda)');</pre>
5 - zpos (upda 6 % 7 %Probabil 8 9 - if rand(1 0 %%pic	dateStep) = a_y;	234 - 235 -	<pre>xlabel('Time (seconds)'); ylabel('Y-Velocity (m/s)');</pre>
6 7 %Probabil 8 9 - if rand(1 %%pic	<pre>atestep) = x2; atestep) = z2;</pre>	235 -	title('Y-Velocity vs Time Graph')
7 %Probabil 8 9 - if rand(1 0 %%pic	10000097 - 227	237	the state of the s
8 9 - if rand(1 0 %%pic	listic collision of 2 atoms		<pre>% figure(4);</pre>
0 %%pic		239	<pre>% plot(time,aypos);</pre>
	1) < p2atoms		<pre>% xlabel('Time (seconds)');</pre>
	cks a number from the list of speeds a particle has giver		<pre>% ylabel('Y-Acceleration (m/s²)'); * title('Y Acceleration wa Mine Craph')</pre>
	xwellboltz dist and then turns it into a velocity	242 243	<pre>% title('Y-Acceleration vs Time Graph')</pre>
2 3 - the l	<pre>lucky number = floor(numel(listofspeed)*rand(1)1); %pic</pre>	243	figure(5);
4 the_i	rucky_number - rioor(numer(riscorspeed)-rand(r)1); spic	245 -	plot3(xpos,ypos, zpos, 'd')
	d = listofspeed(the lucky number);	246 -	<pre>xlabel('X-position (meters)')</pre>
6	A - TISCOISDEEDI CHE INCKA UNIDELI:	247 -	ylabel('Y-position (meters)')
7 - velxp	a - iiscoispeed(the_idcky_humber);	248 -	<pre>zlabel('Z-position (meters)')</pre>
	pos = speed/sqrt(3);	249	
9 - velzp	pos = speed/sqrt(3); pos = speed/sqrt(3);	250 - 251 -	end
	pos = speed/sqrt(3);	251	CITA

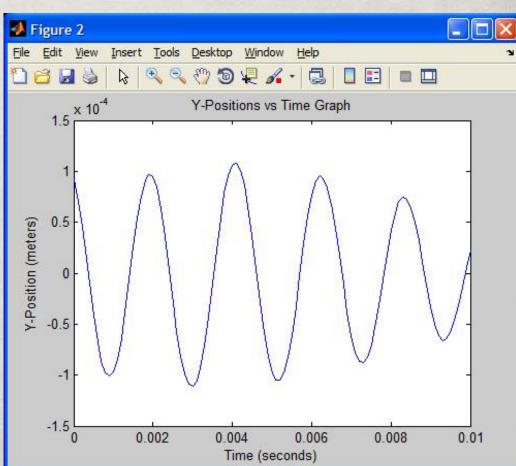
MatLab Output 1



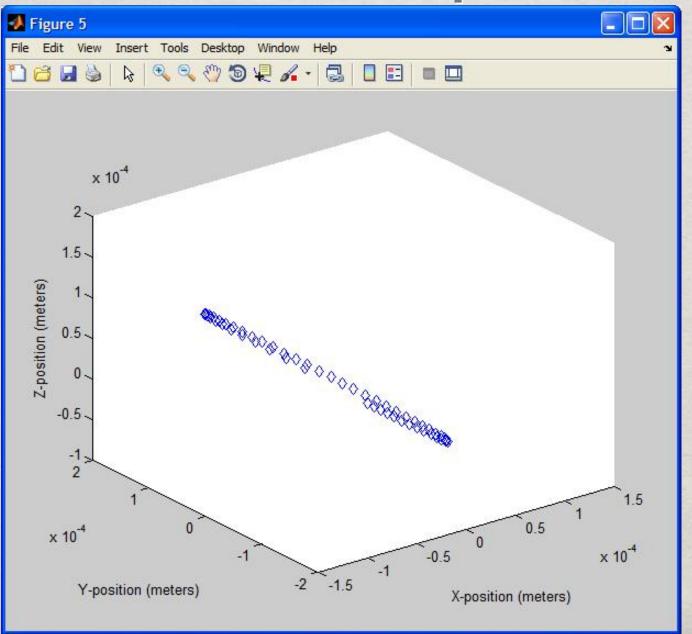
MatLab Output 2







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

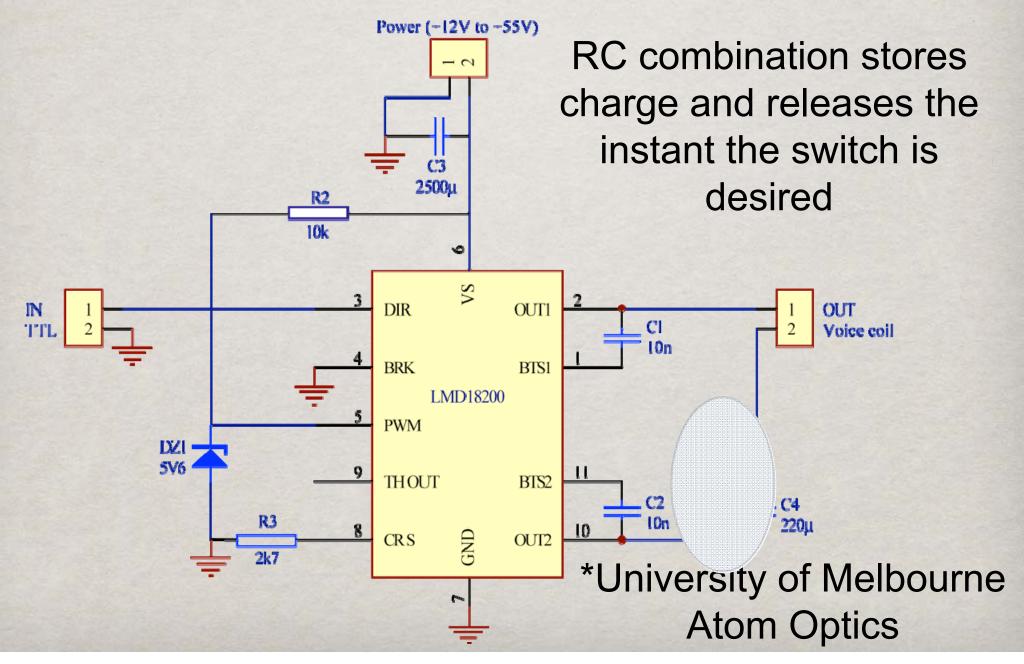


Building shutter out of a hard drive

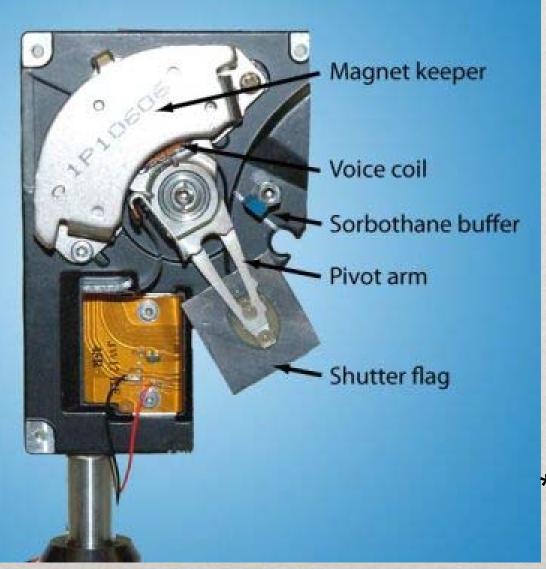
HD arm moves very quickly

Attaching circuit to voice coil will allow control of arm

Shutter Circuit



Finished Product



*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



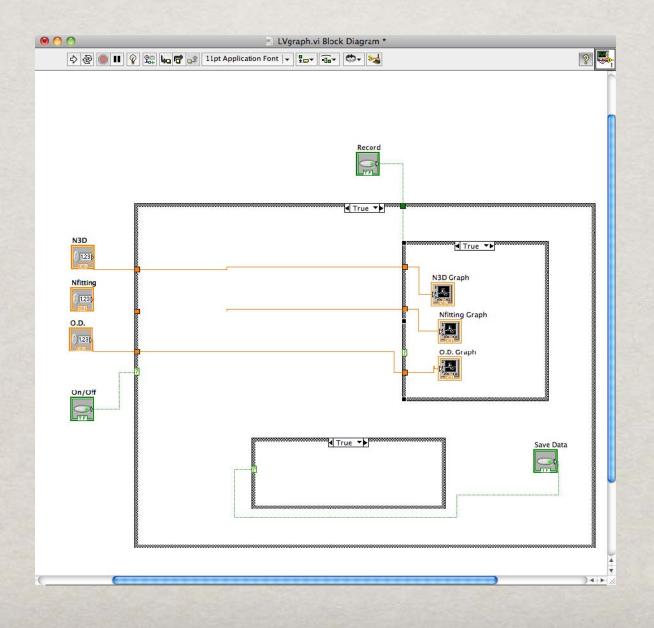
Project 4

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

LabView Code

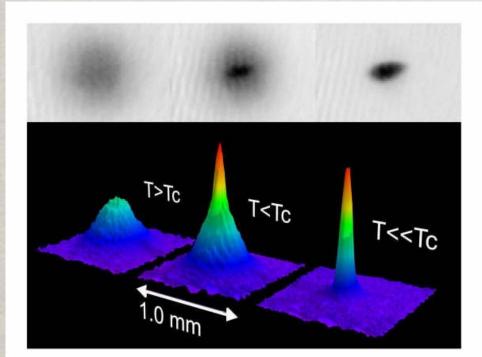


Project 5

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



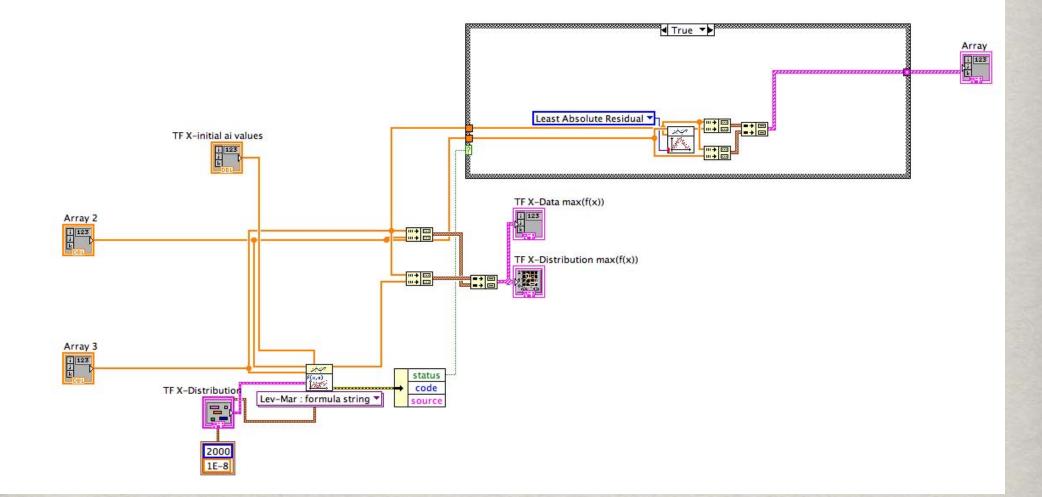
Coherent Spin Dynamics of a Spin-1 Bose-Einstein Condensate

Ming-Shien Chang

$$\begin{split} \widetilde{n}_{\rm tof,th}(\vec{r}) &= A \, \mathrm{e}^{-\frac{r_1^2 + r_2^2}{2\sigma^2}}, \ T \gg T_c \\ \widetilde{n}_{\rm tof,tot}(\vec{r}) &= A \, g_2(z \, \mathrm{e}^{-\frac{r_1^2 + r_2^2}{2\sigma^2}}), \ T \gtrsim T_c \end{split}$$

Riemann Zeta function $g_l(z) \equiv \sum_{i=1}^{\infty} \frac{z^j}{j^l}$

LabView Code

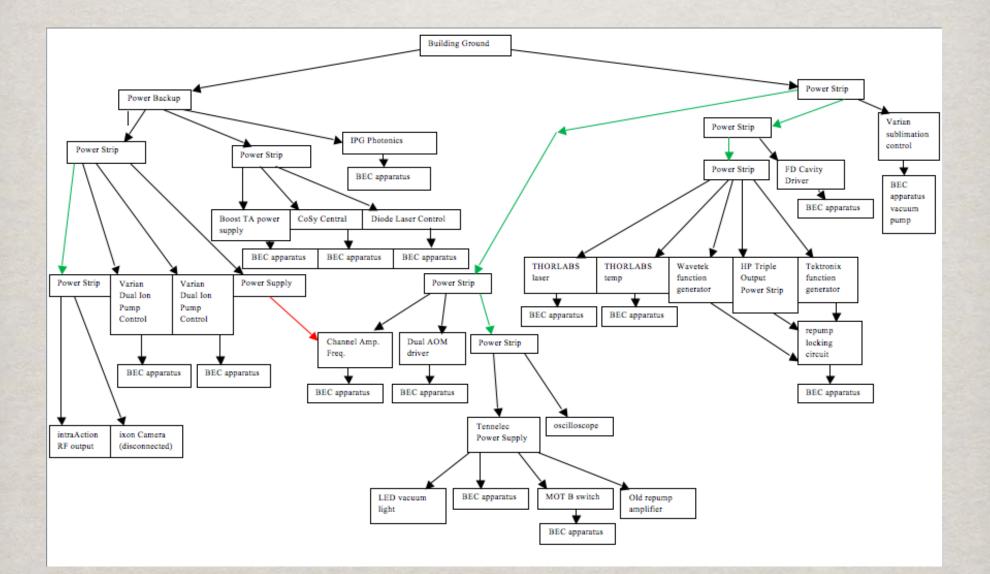


Project 6

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

Electrical Diagram





- 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

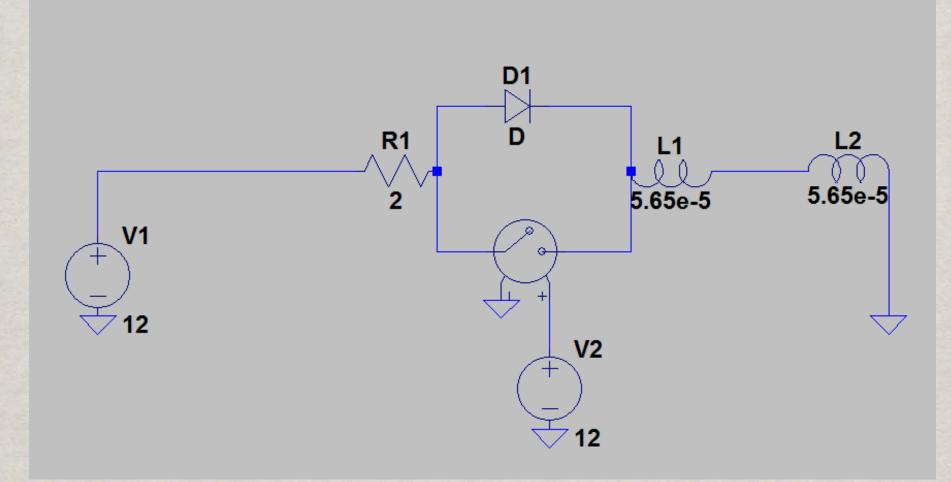
Stern-Gerlach Theory

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

$$\mu = -m_l g_j \mu_B \qquad U = -\mu \cdot B \qquad F = -\nabla U$$
$$|F| = \mu_B \mu_l g_j \frac{\partial B}{\partial z}$$

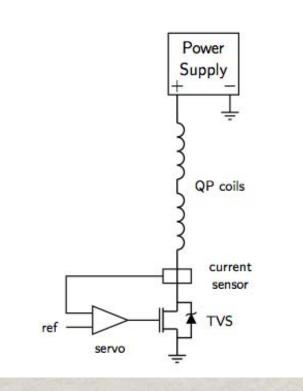
Circuit Design



Future Circuit

ULTRACOLD ATOMS IN A DISORDERED OPTICAL LATTICE

MATTHEW ROBERT WHITE

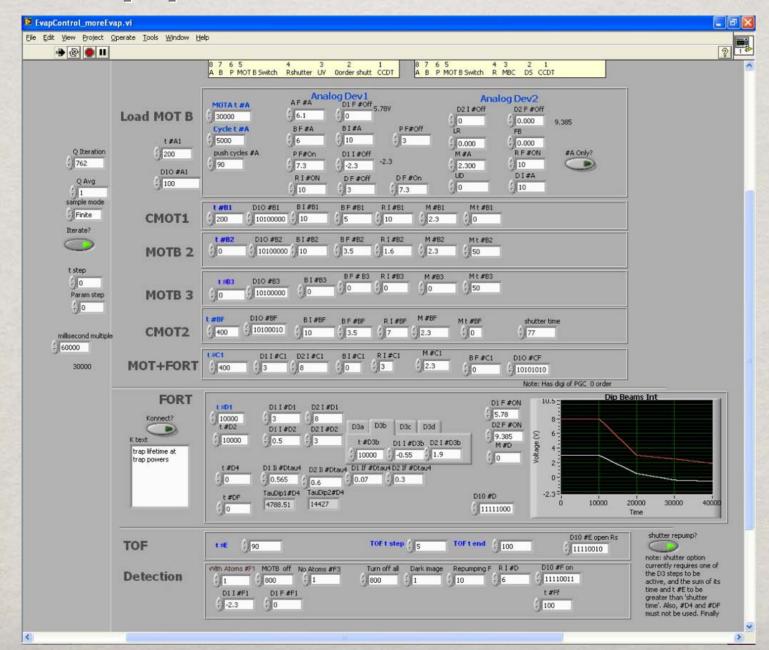


Project 8

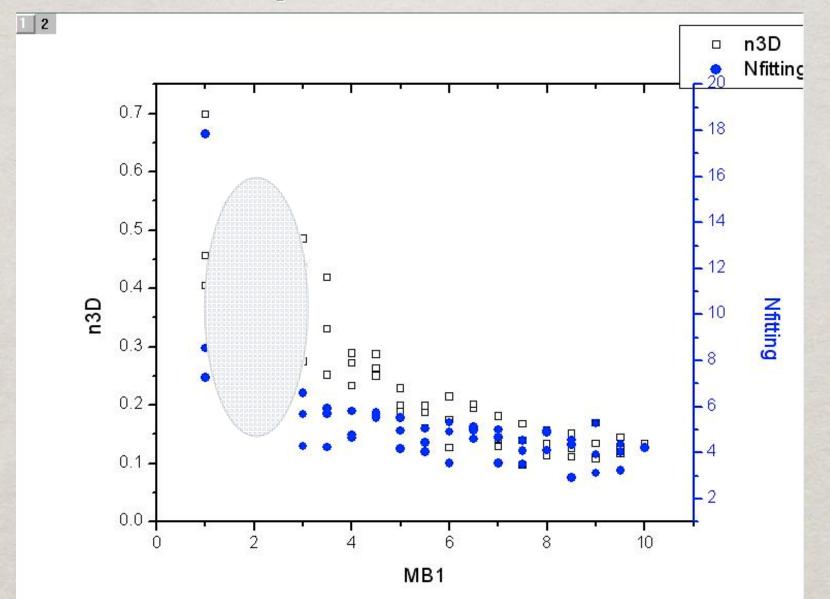
Working on optimizing several parameters of the MOT stage on the BEC apparatus

Specifically changing re-pump intensity magnetic field intensity, ramp of magnetic field intensity

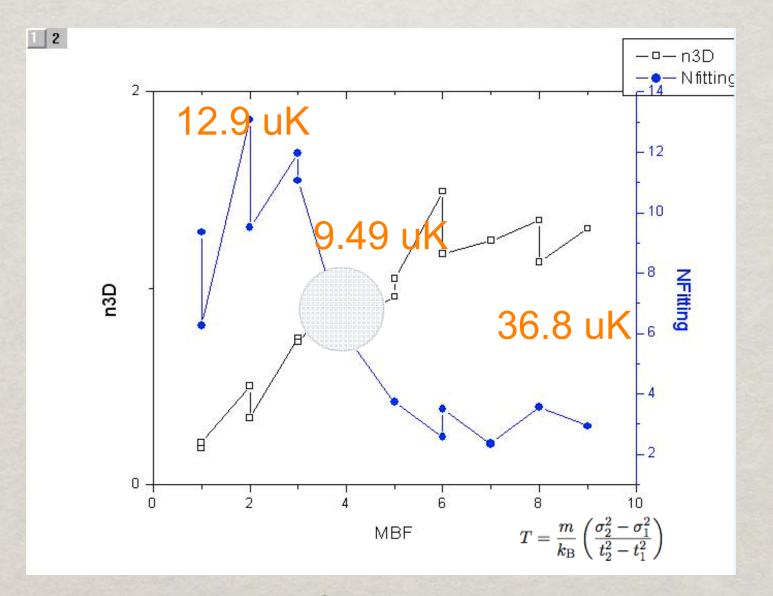
Apparatus Control



Graphs of Data



Graphs of Data



 $PSD \sim N/T^3$