8.422 Atomic Physics II
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Assignment #8

Due: Wednesday, April 15, 2009
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Office Hours: April 13th (Mon) & April 14th (Tue), 6pm - 8pm.

Consider the following questions for Na. Try to plug in numbers after obtaining an analytical expression.

Na oven temperature $T = 600K$

natural line width $\gamma = 2\pi\times$ 10 MHz

Zeeman splitting 1.4 MHz/gauss

wavelength $\lambda = 2\pi/k = 589$ nm

1. **A Zeeman Slower**

If you want to slow an atomic beam efficiently, you have to compensate for the changing Doppler shift ($\vec{k} \cdot \vec{v}$) during the deceleration. This can be done by sweeping the frequency of the slowing beam, i.e., chirping (as discussed in class). A method of producing a continuous beam of cold atoms is Zeeman slowing.

A well collimated beam of atoms is originating from an oven with a temperature T. The beam propagates along a distance L with a longitudinal magnetic field $B(x)$ ($0 < x < L$). A laser beam of intensity I is counter propagating. Its frequency is detuned by δ ($\delta \equiv \omega - \omega_0$) from the transition frequency at $B = 0$.

a) Calculate the maximum deceleration a_{max} you can achieve. Assume you could choose arbitrarily large laser intensities.

Assume you want to slow down atoms with speeds lower than the peak (most probable) velocity v_{peak} of the thermal distribution to a stand still using the constant deceleration fa_{max}. $(0 < f < 1)$ The Zeeman effect shifts the resonance $\omega_0 \to \omega_0 + g\mu_B B(x)$ (where $g\mu_B = (2\pi)1.4$ MHz/gauss, in this case).

b) Calculate the spatial dependence of the magnetic field $B(x)$ and the length L of the slower as a function of f.

c) Assume three different models for spontaneous emission: (i) Photons are emitted along the $+/-\hat{x}$ direction, (ii) isotropic emission, or (iii) emission in a dipole pattern. What is the momentum diffusion constant $\mathcal{D}$ for the (longitudinal) x-component of the momentum in the three cases, at a given photon scattering rate Γ_s?

2. **Slowing an atom with off-resonant light**

   Assume you want to slow an atom of velocity v_{peak} with a counter propagating laser beam that is on resonance with the atom at rest. (Use the same v_{peak} as in Problem 1, and $I = 5I_{sat}$.)

   a) How long would it take?

   b) How far would the atom travel?

      (Hint: Think about integrating the equation of motion)

3. **Classical molasses in a vapor cell**

   Assume you have an experimental setup with a 3 dimensional molasses in a spherical volume of radius $r = 2mm$. The molasses is surrounded by a gas with pressure $p = 10^{-8}$ torr and a temperature $T = 350K$.

   a) Estimate the velocity capture range v_{cap} of this classical molasses. (v_{cap} is the velocity of the fastest atom that can be captured.) There are six laser beams, each with intensity $I = I_{sat}/6$. When plugging in values, use the value of δ you find in part b) of this problem. (Hint: use an approximate expression for the force for $v \gg \gamma/k$)

   b) Choose the detuning and the laser intensity in order to maximize the diffusion time in the molasses. Calculate the maximum diffusion time.