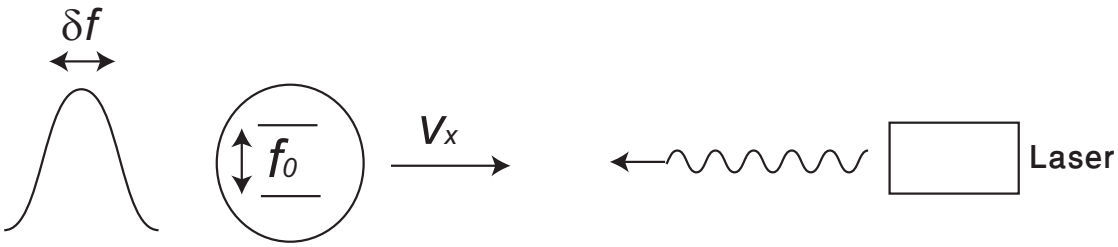
Assignment 6: Modern Physics
Due Date: 26th April 2018, 4 pm

Note: This is a collaborative assignment. Submit in upto groups of four. Write all four names and roll numbers clearly on the first sheet.

1. This question deals with the Doppler cooling of sodium atoms. I am happy that you are beginning to understand the principles underlying monumental pieces of work!

   (a) A laser beam of frequency f_L propagates towards an atom moving with an initial speed v_x towards the laser source.



   The atomic level spacing is hf_0 (in energy) and $f_L = f_0 + \Delta f$, where Δf is a detuning factor. Using the Doppler mechanism discussed in class, what should be Δf for the atom to efficiently absorb the photon? [3 Marks]

   (b) What is the change in momentum of the atom (sign and magnitude) when the incoming photon is absorbed? [2 Marks]

   (c) What is the force and the corresponding acceleration (with sign)? The mass of the atom is m. The force acts for a time τ which is the lifetime of the excited state. [4 Marks]

   (d) After a time τ, (on average) the excited atom will emit a photon by spontaneous emission and will be available to absorb another photon from the incoming laser beam. Discuss why we need to change the detuning factor Δf for the second absorption and all subsequent absorptions? [2 Marks]

   (e) Estimate how much time ($t_{\min}$)is required to almost completely halt the atom? [3 Marks]

(f) How far does the atom move in the time $t_{\min}$ calculated above? [3 Marks]

(g) Discuss when will the cooling stop? The linewidth δf is naturally broadened by the uncertainty principle. [3 Marks]

Hint: δf sets the limit on the minimum detuning factor Δf.

2. This question explores a similar problem this time using numerical values to give you orders of magnitude estimates.

A beam of cesium atoms travelling in the $+x$ direction is emitted from an oven. The temperature is 200°C. A laser beam of wavelength 852 nm propagate in the $-x$ direction and is used to cool the atoms. The excited level has a life-time of 32 ns. The relative atomic mass of cesium is 132.9.

(a) Initially what is the detuning of the laser relative to the transition that produces efficient laser cooling? [2 Marks]

(b) What is the average momentum change imparted to a cesium atom during an absorption-emission cycle? What is the maximum decelerating force that will be exerted on the atoms? [2 Marks]

(c) Estimate the number of absorption emission cycles required to cool the atoms to their minimum temperature. Estimate the time taken for the atoms to reach this temperature, and the distance they would travel during the cooling process. [2 Marks]

(d) Calculate the final temperature that the atoms reach after this experiment. [2 Marks]

3. (a) Consider a gas of hydrogen at room temperature= 300 K. What fraction of atoms would have the first excited state populated with respect to the ground state? Assume equilibrium. [3 Marks]

(b) At what temperature could I expect that 1% of the atoms would be in the first excited state and 99% in the ground state? [3 Marks]

4. I have a gas inside a sealed chamber. The line spectrum contains lines from various transitions. As I heat the chamber, all lines get broader. What could be the possible mechanism for this? [5 Marks]