Exercises "Introduction to the physics of cold gases"

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This exercise sheet is meant as a starting point for discussing and repeating basic laser cooling and trapping mechanisms.

1 Magnetooptical trapping

Typically, a cold atom experiment starts by accumulating atoms in a magneto-optical trap.

(a) Recall the basic mechanisms that lead to cooling (friction force) and trapping (restoring force) in a magneto-optical trap. Sketch briefly the derivation of the corresponding forces.

(b) The simple model of a magneto-optical trap suggests a specific choice of σ^+ and σ^- polarization in the setup. Which optics do you need to realize a magneto-optical trap? Describe a device with which you can measure and optimize circularly polarized light? How do you distinguish between circularly polarized light of opposite helicity in such a device? How do you choose the polarization in the experiment along different axis of the magneto-optical trap and why? (Discuss the selection rules for an atom interacting with circularly polarized light of a certain helicity when $\vec{B}$ field is pointing along the propagation axes of the light or in the opposite direction.) What will you measure with your device distinguishing between circularly polarized light of opposite helicity?

2 Magnetic trapping

After laser cooling and trapping, atoms will typically be transfered into a magnetic trap, where further cooling towards quantum degeneracy takes place. In this exercise, we will discuss magnetic trapping of alkali atoms.

(a) The electronic ground state of alkali atoms is a $n^2S_{1/2}$ state. Consider an alkali atom with a nuclear spin of $I = 3/2$ and sketch the hyperfine structure of the electronic ground state.

(b) Discuss the substructure of the hyperfine structure in an external magnetic field. Discuss the case of a weak magnetic field (Zeeman regime) and the transition to a strong magnetic field (Paschen-Back regime). Which states are low-field and which states are high field seeking states independent of the magnetic field? Which states change character as a function of magnetic field?

(c) Describe the basic building blocks of a Ioffe Pritchard trap.

(d) Assume that the radial gradient in a Ioffe Pritchard trap is $b_1 = 5$ T/m. Assume the offset field along the axial direction to be $B_0 = 10^{-4}$T and the curvature to be $b_2 = 500\text{T/m}^2$. Derive expressions for the trap frequencies of e.g. Rb atoms in a Ioffe pritchard trap and calculate typical trap frequencies.

(e) Apart from the forces due to the magnetic field configuration, an atom in a trap will also experience gravitation. Derive an expression for the equilibrium position of atoms in a magnetic trap with a trap frequency ω under the influence of gravitation. How does the gravitational sag depend on the trap frequency?