# Trapping - Cooling - Quantum Control

Summer term 2019 - Lecturer: Tobias Schätz, Leon Karpa

## Assignment sheet 5

please hand in your solutions by May 22, 18:00.

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**1) Laser Cooling of Atoms**

Questions to the paper Phys. Rev. Lett. **61** 169 (1988) by Paul D. Lett *et al.*

a) Sketch the experimental arrangement and label the individual components, including a simplyfied level scheme, the laser beams and parameters, the vacuum apparatus.

(3 Points)

b) Sketch the four detection schemes and the expected signals after the molasses is switched off. Discuss in which ways they are different and complementary.

(4 Points)

c) Create a one-dimensional model to simulate the fluorescence measurement used in the first method (time-of-flight). For this, assume that the phase-space density distribution of the molasses atoms is given by

$$n_0(x, v) = N \cdot f_x(x) \cdot f_v(v),$$

where $N$ is the total number of atoms in the molasses and $f_x(x)$ and $f_v(v)$ are normalized Gaussian distributions

$$f(x) = \frac{1}{\sqrt{2\pi}\,\sigma} \exp\left\{-\frac{x^2}{2\sigma^2}\right\},$$

with a spatial width $\sigma_x = 1$ mm and a velocity width $\sigma_v$ determined by $\frac{1}{2}m\sigma_v^2 = \frac{1}{2}k_\mathrm{B}T$. The time-evolution of the spatial density distribution is given by

$$n_x(x, t) = N \int_{-\infty}^{\infty} f_x(x_t(t)) f_v(v) dv,$$

where $x_t(t) = x - vt + \frac{1}{2}gt^2$ describes the center-of-mass motion of the cloud.

(i) Find an analytical expression for $n_x(x, t)$.
*Hint: for general Gaussian integrals*

$$\int_{-\infty}^{\infty} \exp\left\{-ax^2 + bx + c\right\} dx = \sqrt{\frac{\pi}{a}} \exp\left\{\frac{b^2}{4a} + c\right\}$$

(ii) Plot the spatial distribution of the cloud $n_x(x, t)$ for $t = 0$ ms, 30 ms and 60 ms for a temperature of $T = 50\,\mu$K.

(iii) Plot the expected relative fluorescence signal generated by the falling cloud of atoms when they pass through a thin light sheet placed 1 cm underneath the molasses, $n_x(-1\,\mathrm{cm}, t)$, for $T = 50$, 150, 300 μK. Compare with the experimental signal.

(8 Points)