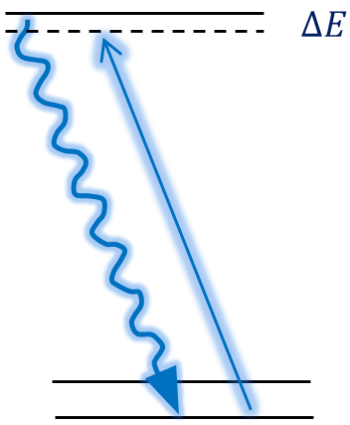
Quantum Information course 2019

First hand-in assignment

Hand-in deadline 17/4*[1]

Chapter 7 – Doppler cooling (please hand in your solution to Andreas Walther)

In an ion trap quantum computer, the first step to initialize the qubits is to cool them down using Doppler cooling. Consider a Calcium ion in a trap described by Harmonic oscillator with trap frequency $\omega = 2\pi \times 1.4$ MHz. The excited state used in the cooling procedure has a lifetime of T = 7 ns, and we can assume that the linewidth is lifetime limited (and thus Lorentz shaped), such that $\Gamma_{\text{fwhm}} = \frac{1}{2\pi T}$. (Note that this exercise doesn't follow the book, so use whatever resources you need from elsewhere.)



a) Assume that the cooling scheme can be described by photon scattering, where each scattering event removes ΔE energy from the ion, and the scattering rate is given by the Lorentzian. Now, put up an expression for the total cooling rate ("energy removed"/second), and find the detuning from the resonance that maximizes this cooling rate. (Assume also that we consider a steady state situation where the heating and cooling effects are balanced such that the velocity of the ion does not change over time.)

b) The lowest possible ion energy that can be reached with Doppler cooling is determined from balancing the cooling rate with the recoil given by single photons and can be approximated as $E_{\text{lowest}} \approx \hbar\Gamma$. In terms of the quantized motional harmonic oscillator levels of the ion trap, how many phonons does that energy correspond to?

c) What effective temperature does that lowest energy correspond to?

[1] *If handed in too late you might have to solve and hand in additional problems