QTFP Winter School 2023 - AION Tutorial

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Tutorial questions

Exercise 1. Pulse fidelity, velocity selection and large-momentum transfer

(i) Consider a two-level atom initially prepared in its ground-state at time $t = 0$, and driven by a quasi-resonant light field. Express the probability to find the atom in its excited-state as a function of the light pulse duration, detuning and Rabi frequency. Sketch/ plot the result as a function of pulse duration for different detunings, and identify the optimal pulse duration to realize a population inversion (called π-time) and the transfer efficiency, referred to as the pulse fidelity. Compare your sketch with other members of the group.

(ii) If the given atom has a non-zero velocity, what is the laser frequency that it sees due to the Doppler effect?

(iii) Consider a thermal atomic cloud at temperature T described by a Maxwell-Boltzmann velocity distribution. Qualitatively explain why a high temperature reduces the efficiency of the population transfer at the cloud scale. By making an appropriate choice of pulse duration, compute the cloud-averaged pulse fidelity. *Hint: To simplify the evaluation of the integral, we will approximate the central peak of the sinC function by a Gaussian of same RMS spread, namely* $\pi^2/4 \times sinC^2[\pi/2 \times \sqrt{1+u^2}] \approx e^{-u^2/2}$.

(iv) Which experimental parameters can be tuned to increase the pulse fidelity? Which other physical effects not accounted for here could also reduce the pulse fidelity? Discuss your answers with other members of the group.

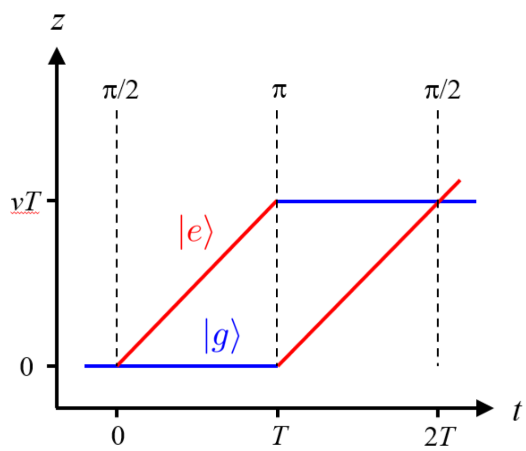
(v) *Bonus question:* In a large-momentum transfer interferometer based on sequential π-pulses, the large momentum separation is imparted by successively applying a large number of π pulses. In practice, they need to come from alternating directions; discuss why. Considering the case of strontium atoms interrogated via the intercombination line transition (wavelength $\lambda = 689$nm, mass $m = 1.44 \times 10^{-25}$kg, electric dipole $d = 7.35 \times 10^{-31}$C.m), calculate which temperatures would be required to maintain a fringe contrast above 5% for a momentum separation of $1000\hbar k$, assuming a laser intensity of $100 mW/cm^2$. *Hint: You can assume that the interferometer fringe contrast can be fairly estimated by the product of the individual pulse fidelities of the sequence.*

Exercise 2. Interferometer sensitivity

Consider a Mach-Zehnder interferometer where atoms are subjected to a uniform gravitational acceleration, g. The atomic trajectories of the ground and excited state are shown in blue and red respectively.

(i) If the phase shift of the interferometer to an acceleration g is given by

$$\Delta\phi = kgT^2, \tag{1}$$



where k is the wavevector of the laser, find an expression for the relative sensitivity to gravitational accelerations, $\delta g/g$.

Hint: In this shot noise limited regime, assume $\delta\phi = 1/\sqrt{N}$ *where* N *is the number of atoms per shot.*

(ii) Calculate the sensitivity achievable with an interferometer measuring 10^6 atoms with $T = 1.2$ s, operating at $\lambda = 689$ nm. How could this sensitivity be enhanced in an experiment? Discuss your answer with other members of the group.