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Stochastic simulation of narrow-line magneto-optical traps

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Laser cooling methods, which motivated the Nobel Prize in Physics of 1997, were revolutionary to produce and study cold atoms. They allow the experimental confirmation of the ultracold state of matter called Bose-Einstein condensate. The magneto-optical trap (MOT) (1) allows trapping and cooling atomic or molecular clouds until very low temperatures (usually the range of μK) and is the workhorse of the laser cooling experiments. Atoms in a MOT feel both a trapping and viscous force due to the scattering of photons by optical transitions. MOTs are usually composed of an inhomogeneous magnetic field and six circularly-polarized laser beams. The lowest temperature of the sample in a MOT is given by the Doppler limit ($T = \hbar\Gamma/2k\_B$), which means the lower the transition linewidth Γ the lower the temperatures. When Γ is close to the photonic recoil, the single-photon scattering can significantly change the scattering probability. In this case, we have narrow-line magneto-optical traps (nMOT). Whilst there are semi-classical theories describing Doppler cooling, quantitative models for MOTs can be more challenging due to the three-dimensional polarized light in the presence of an inhomogeneous magnetic field, and the effects of optical pumping. This can be a big problem for nMOTs because the semi-classical theory fails. (2) Computational simulations are usual approaches to predict MOT properties and can be very useful to study nMOTs. (3) We develop a stochastic simulation to study the dynamics of atoms in nMOTs aiming to predict experimental values and study alternative laser-beam configurations, with a special focus on few-beams assisted by gravity to still create a trapping environment. We consider the time evolution given by a Markov chain whose transition probabilities are given by the stationary solution of the optical Bloch equations. We obtained results for strontium and dysprosium nMOTs that agree with experimental values. Currently, we have been implementing and studying trap depth in the simulation to study the dynamics.

Palavras-chave: Magneto-optical trap. Stochastic simulation. Laser cooling.

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