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Analysis of narrow-line magneto-optical traps through stochastic simulation

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The deep understanding of light-matter interaction brought a myriad of scientific possibilities, such as improvements in atom interferometry, accurate spectroscopic methods, and control of ultracold gases. The 1997 Nobel Prize in Physics was awarded jointly to Steven Chu, Claude Cohen-Tannoudji, and William D. Phillips for developing methods to cool and trap atoms with laser light, also known as laser cooling. (1) The workhorse of laser cooling is the magneto-optical trap (MOT), a technique to trap and cool a dilute atomic gas. Briefly, cold gas in a magnetic quadrupole field scatters photons from a laser beam arrangement through electronic transitions. The momentum exchange, which relies on the scattering events, yields a trapping and viscous force whose magnitude depends on the scattering rate. Such rate is related to the atomic linewidth Γ so that the lower Γ, the lower the minimum reachable temperature. A MOT operating with Γ close to the photonic recoil is known as a narrow-line magneto-optical trap (2) (nMOT). The current MOT theories based on Doppler cooling are limited to predicting quantities such as temperature and the size of the atomic cloud size. In many experiments, there is either the absence of theoretical predictions or the necessity of adjustable scaling factors. The analytical MOT models rely on a 1D-MOT and ignore considerable difficulties from the spatial arrangement. (3) The case of nMOTs is even more delicate since gravity can be comparable with optical forces and, therefore, must be included. Then, to analyze 3D-nMOTs considering as many parameters as possible, we develop a stochastic simulation of the atomic dynamics. Our model relies on sampling trajectories through a Markovian process to infer a probability distribution of the atom position and velocities. We could precisely predict temperature, the centre of mass, and cloud shape relations of dysprosium and strontium nMOTs.

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

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