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Monte Carlo simulation proposal to narrow-line magneto-optical traps

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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, the atoms in a magnetic quadrupole field scatter photons from a laser beam arrangement. 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. An MOT operating with Γ close to the photonic recoil is known as a narrow-line magneto-optical trap (nMOT). (2) The current MOT theories based on Doppler cooling are limited to predicting quantities such as temperature and cloud size from analytical expressions. In many experiments, there is either the absence of theoretical predictions or the necessity of adjustable scaling factors. The difficulty arises from three-dimensional laser arrangement in the presence of a magnetic quadrupole field. (3) The case of nMOTs is even more delicate since gravity can be comparable with optical forces and, therefore, must be included. In this work, we proposed a Monte Carlo simulation in order to predict quantities of dysprosium and strontium nMOTs by considering as many parameters as possible. Our model relies on sampling atomic trajectories as a discrete stochastic process to infer probability distributions of position and velocity. We could predict the temperature, centre of mass, and cloud shape of dysprosium and strontium nMOTs in agreement with experimental data.

Palavras-chave: Magneto-optical trap. Monte Carlo simulation. Laser cooling.

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