Proposal for laser-cooling of rare-earth ions

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Ultracold gases of rare-earth neutral atoms are nowadays very promising in the context of dipolar scattering, many-body physics or metrology. In spite of their complex electronic structure, laser-cooling of rare-earth atoms turns out to be remarkably simple. In the pioneering experiment on erbium [1], McClelland and coworkers observed a strong cascade mechanism toward the ground state, which even made repumping unnecessary. That work inspired various studies which led *e.g.* to the Bose-Einstein condensation of dysprosium [2] and erbium [3].

Laser-cooling of trapped ions, which is today routinely achieved [4], has allowed for setting up extremely accurate clocks, and for observing chemical reactions in the ultracold regime [5]. However ion laser-cooling is limited to species with a closed electronic core and a single valence electron.

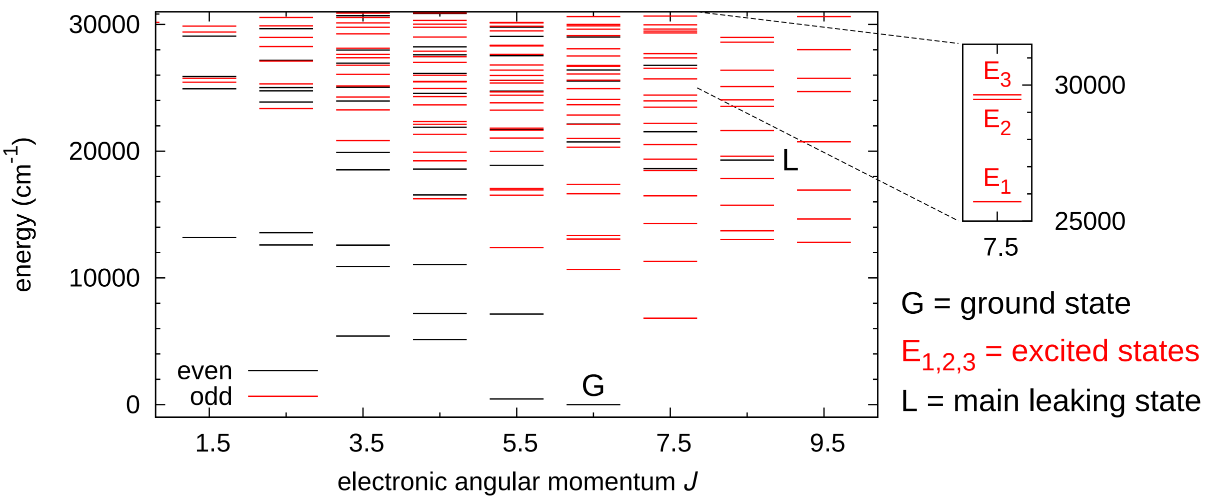

Figure 1: *Energy diagram of Er^+. The inset shows the three odd-parity excited states E_1, E_2 and E_3 with $J = 15/2$ which are the most suitable for laser-cooling.*

In this work we address the feasibility of laser-cooling of open-4f-shell rare-earth ions, taking the example of Er^+, whose spectrum was interpreted in great details [6]. To that end, using a semi-empirical approach based on the Cowan codes [7], we compute transition dipole moments between the ground state "G" and excited states suitable for cooling ("$E_{1,2,3}$"), but also with all states which represent possible leaks from the cooling cycle (see "L" on Fig. 1). By solving rate equations based on our computed Einstein coefficients, we demonstrate that laser-cooling of Er^+ does require repumping, and we identify a possible repumping scheme from the atomic state "L". We also observe a cascade dynamics, within a fraction of second, to the ground and first-excited states. This dynamics is found insensitive to the inclusion of electric-quadrupole and magnetic-dipole transitions in our model. Our results suggest that laser-cooling of Er^+ is feasible, with two repumping lasers, and within a time scale which is compatible with the stability of ion traps.

References

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