Photoexcitation of atoms by Laguerre-Gaussian beams

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Synopsis The photoexcitation of atoms by a Laguerre-Gaussian beam has been theoretically investigated. Detailed calculations were performed especially for the $4s\ ^2S_{1/2} \to 3d\ ^2D_{5/2}$ transition in Ca^+ ion. We demonstrate that the magnetic sublevel population of the excited atomic states varies significantly when the atoms are displaced from the beam axis.

With the recent experimental advances in optics, it became possible to produce *twisted* (or vortex) light beams, such as Laguerre-Gaussian (LG) or Bessel beams. These beams of light are known to have helical wavefronts and possess a nonzero projection of the orbital angular momentum (OAM). During the last few years, it was especially shown that the OAM may affect the fundamental light-matter interaction processes. In a recent experiment [1], for instance, it was demonstrated for an atom placed on the axis of the incident LG light beam that the sublevel population of excited atomic states is determined by the OAM of the beam. Following this experiment, here we investigate theoretically the sublevel population of atoms at arbitrary impact parameter b, that is the displacement of the atom from the beam axis. Using first-order perturbation theory, we have analyzed the $4s\ ^2S_{1/2}\ M_i = -1/2 \to 3d\ ^2D_{5/2}$ transition in Ca^+ ion, while the quantization z axis is chosen along the beam propagation direction.

Fig. 1 displays the relative partial excitation cross sections $\sigma_{M_f}/\sigma_{total}$ as a function of the impact parameter b. Here the calculations were carried out for the left-hand circularly polarized (i.e. helicity $\lambda = +1$) LG light beam with zero radial index and OAM $m = 1$. As seen from Fig. 1, the only magnetic sublevel $M_f = M_i + \lambda + m = 3/2$ is populated for the atoms centered on the beam axis ($b = 0$), which is in agreement with the experiment [1]. It differs from the selection rule $M_f = M_i + \lambda = 1/2$ for the plane-wave radiation of the same helicity incident along the z axis. However, if the impact parameter b increases, the excitation cross section σ_{M_f} for $M_f = 3/2$ decreases rapidly and the sublevel population aproaches the plane wave limit $M_f = 1/2$. Such changes in the sublevel population occurs because the field in the center of the beam contains only the multipole potentials with projection quantum number $M = m + \lambda$, while further from the center the most important contribution to the field arises from the multipole potentials with projection $M = \lambda$, as in the plane wave case. Let us note in addition that the atomic impact parameter also affects the angular distribution of the subsequent fluorescence emission, which can be measured in an experiment.

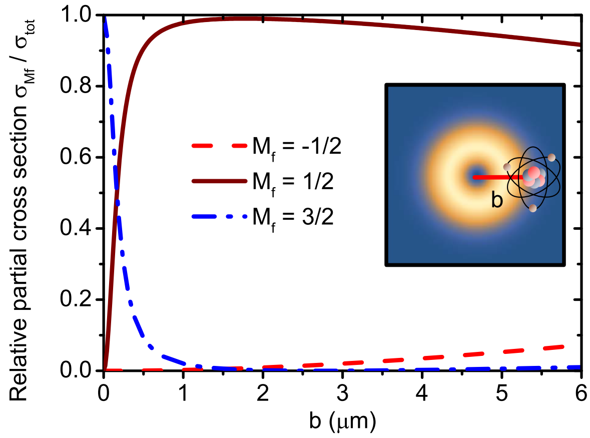

Figure 1. Relative partial cross sections for the $4s\ ^2S_{1/2}\ M_i = -1/2 \to 3d\ ^2D_{5/2}$ excitation of Ca^+ ion by LG beam as a function of the atomic impact parameter b. Results are presented for the beam of helicity $\lambda = +1$ with zero radial index and OAM $m = 1$. Calculations were performed for the beam waist $2.7\,\mu$m and photon energy $\hbar\omega = 1.699$ eV; the beam's intensity profile is shown in the inset.

References

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