LASER FOCUSING OF ATOMS: A PARTICLE OPTICS APPROACH

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The use of a TEM_{01}^{*} ("donut") mode laser beam has been proposed as a means of focusing an atomic beam to extremely small spot sizes.[1] In the initial analysis, Balykin and Letokhov showed that when a donut mode laser beam is focused to a small spot of order 1 μm, and an atom beam is passed concentrically through the focus, the dipole force on the atoms has the correct radial dependence to produce first order focusing. They then estimated the effects of atomic diffraction (due to the deBroglie wavelength of the atom), spherical and chromatic aberration, and diffusion arising from spontaneous emission. It was found that spot sizes of order a few Ångstroms could be obtained with reasonable values for atomic beam collimation and monochromaticity, and laser power and detuning.

Subsequently, Gould and Gallatin[2] showed that the assumption of thin lens conditions made by Balykin and Letokhov is not generally valid, and also that the cancellation of spherical aberration at a certain combination of laser power and detuning is incorrect. Using path integral formalism, they solved Schrödinger's equation for the motion of the atom through the lens, and also obtained estimates of the spherical and other aberrations in the thin lens limit. They predicted spot sizes of a few tens of Angstroms for conditions similar to those discussed by Balykin and Letokhov.

We have analyzed the classical trajectories of atoms through a donut mode laser beam using methods developed for particle optics. The potential generated by the dipole force is expanded in r (radius), and the equation of motion is solved. The first order paraxial equation is of exactly the same form as the equation first solved by Glaser in 1941[3] for magnetic electron microscope lenses. A simple analytic solution exists, which gives focal lengths and principal plane locations valid for the thick lens in either the asymptotic or immersion limit. This solution shows that the lens has a minimum focal length, equal to the Rayleigh length of the laser beam. For higher laser powers (or changes in any other parameter which make the lens stronger), the lens forms multiple crossovers.

We have also analyzed the third order aberrations of the laser lens (which are different from those in the magnetic field case solved by Glaser) and have obtained thick-lens analytic expressions for the spherical, chromatic and diffusion aberrations. Diffraction of the atom beam is treated in the Frauenhofer limit, where the diffraction spot diameter (FWHM) is given by $\delta = 0.61\lambda_{\text{dB}}\alpha^{-1}$ (λ_{dB} is the deBroglie wavelength of the atom, and α is the angle made by the trajectory at the focus).

The results obtained in this work allow the investigation of the properties of a donut mode atomic lens over a broad range of laser and atom beam parameters. Comparisons with previous work and overall optimization of the lens will be discussed.

References

[1] V.I. Balykin and V.S. Letokhov, Optics Comm. **64**, 151 (1987).

[2] P.L. Gould and G. Gallatin, Bull. Am. Phys. Soc. **35**, 1143 (1990).

[3] W. Glaser, Z. Physik **117**, 285 (1941). See also, e.g., P. Grivet, *Electron Optics, 2nd ed.* (Pergamon Press, Oxford, 1972), p. 260.