Advantages of aberration: Exploring the world of spherically aberrated optical traps for mesoscopic particles

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Spherical aberration is generally perceived as a nuisance in optical trapping since it weakens the trap stiffness in the axial direction. While this is generally true inasmuch that the presence of aberration reduces the intensity in the trap center, there are some other interesting effects caused by aberration which have not been explored previously. In this talk, we will present our work on spherically aberrated optical traps where we experimentally observed several interesting phenomenon which we then explained by theoretical analysis. The work started with the observation of hitherto unreported assembly of microscopic polystyrene beads in closed ring structures around the trap center with a simple Gaussian trapping beam. Theoretical analysis of the electric field at the trap focus revealed that for the cover slips we used for our trapping chamber (about 1.5 times thicker than cover slips generally used), the intensity reduced in the trap center only to get redistributed to the sides so that the trapping beam formed an annular intensity pattern near the focal plane [1]. Further experiments with single peapod-shaped soft oxometalate micro-particles showed that we could trap these particles in the ring, and then transport them along the ring perimeter by simply changing the polarization of the input linearly polarized trapping beam. Such peapods and quartz micro-particles could also be rotated while being trapped at certain positions in the ring using linearly polarized light, again contrary to the general experimental technique of spinning particles using circularly polarized light. An exhaustive theoretical analysis then revealed that spherical aberration led to giant spin-orbit interaction of light in the focal plane of the trap that resulted in the formation of polarization dependent intensity lobes (linear diattenuation), as well as to the optical spin-Hall effect that caused spatially separated regions of opposite circular polarization near the trap focal plane. Single particles could thus be controllably translated as well as rotated in such spherically aberrated optical traps - a finding that should lead to a new appreciation of spherical aberration in the world of optical trapping.

References

[1] Self-assembly of microparticles in stable ring structures in an optical trap, Arijit Haldar, Sambit Bikas Pal, Basudev Roy, Subhasish Dutta Gupta, and Ayan Banerjee, Physical Review A 85, 033832 (2012).