Optical Force on Toroidal Nanostructures: Toroidal Dipole Versus Renormalized Electric Dipole

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We study the optical forces acting on toroidal nanostructures. A great enhancement of optical force is unambiguously identified as originating from the toroidal dipole resonance based on the source-representation, where the distribution of the induced charges and currents is characterized by the three families of electric, magnetic, and toroidal multipoles. On the other hand, the resonant optical force can also be completely attributed to an electric dipole resonance in the alternative field-representation, where the electromagnetic fields in the source-free region are expressed by two sets of electric and magnetic multipole fields based on symmetry. The confusion is resolved by conceptually introducing the irreducible electric dipole, toroidal dipole, and renormalized electric dipole. We demonstrate that the optical force is a powerful tool to identify toroidal response even when its scattering intensity is dwarfed by the conventional electric and magnetic multipoles.