Supertoroidal Anapoles

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We report on a new type of non-radiating, anapole excitations in dielectric particles under illumination with toroidal light pulses. We show that such anapoles are linked to supertoroidal currents induced in the particle.

The emergence of toroidal electrodynamics has highlighted the role of toroidal moments in the multipole expansion of charge-current configurations and thus in the complete description of the optical response of matter. In particular, the toroidal dipole, represented by poloidal currents on the surface of a torus, is known to interfere with the electric dipole to form non-radiating configurations with null electromagnetic fields outside the source. Moreover, toroidal light pulses, also known as Flying Doughnuts (FDs), have been shown to efficiently excite such anapole modes in spherical dielectric. Alongside the toroidal multipoles, the full multipole expansion includes their mean square radii, related to the finite size of the charge-current configuration. Such terms can be represented by supertoroidal currents (or equivalently by nested poloidal currents, see Fig. 1a), fractal iterations of poloidal currents, but are considered higher order corrections and thus are typically omitted. Here, we show that torus-shaped dielectric particles under illumination with FD pulses support resonant modes, where the mean square radii not only provide a major contribution to the scattering response of the particle, but actually interfere with the electric and toroidal dipoles to substantially suppress scattering.

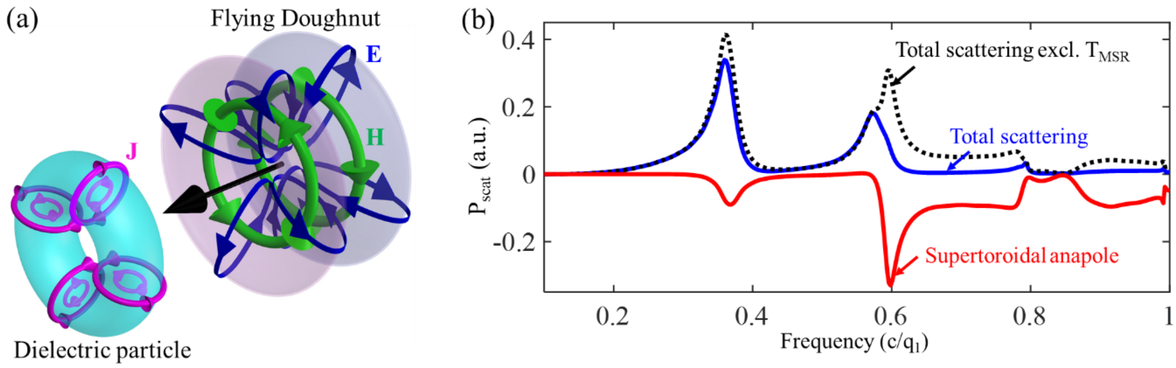

Fig. 1 (a) A radially polarized Flying Doughnut (FD) pulse interacts with a torus-shaped dielectric particle. Blue, green, and black arrows represent the electric field (**E**), magnetic field (**H**), and the propagation direction of the FD pulse, while purple arrows indicate the induced displacement current in the dielectric particle. (b) Power scattered by the particle as a function of frequency. Blue and dashed black lines show the total scattered power calculated by taking into account all multipoles up to magnetic octupole order including (solid blue line) or excluding (dashed black line) the toroidal dipole mean square radius, T_{MSR}. The contribution of the anapole term resulting from the interference of T_{MSR} with the electric and toroidal dipole is shown by the solid red line, where the negative values indicate destructive interference and thus suppression of scattering.

We studied numerically the response of a dielectric toroidal particle under FD illumination by finite element calculations (see Fig. 1a). We consider illumination with radially polarized (transverse magnetic) FD pulses with effective wavelength q_1 and Rayleigh range $q_2/2=2.5q_1$. The particle is placed at the focus of the FD pulse. It is considered to be lossless and dispersionless with refractive index n=4 and with major and minor radii $q_1/2$ and $q_1/4$, respectively. The response of the particle is analyzed in terms of multipole moments calculated by the displacement currents induced by the FD pulse. We consider multipole terms up to magnetic octupole and include both the toroidal multipole moments, as well as their mean square radii. The frequency response of the particle is presented in terms of scattered power calculated by summing contributions of all multipoles (see blue curve in Fig. 1b). Of particular interest here is the toroidal dipole mean square radius, T_{MSR}, which can interfere with the electric and toroidal dipole moments, resulting in a new type of non-radiating, anapole configuration. As shown in Fig. 1b (red line), the interference is predominantly destructive resulting in a significant reduction of scattering by over 65%.