Flying donuts: toroidal electromagnetic excitations
in matter and free space

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The toroidal dipole is a localized electromagnetic excitation, distinct from the magnetic and
electric dipoles. While the electric dipole can be understood as a pair of opposite charges and the
magnetic dipole as a current loop, the toroidal dipole corresponds to currents flowing on the surface
of a torus. Toroidal dipoles provide physically significant contributions to the basic characteristics
of matter including absorption, dispersion and optical activity. Toroidal excitations also exist in
free space as spatially and temporally localized electromagnetic pulses propagating at the speed of
light and interacting with matter. We review recent experimental observations of resonant toroidal
dipole excitations in metamaterials and the discovery of anapoles, non-radiating charge-current
configurations involving toroidal dipoles. While certain fundamental and practical aspects of
toroidal electrodynamics remain open for the moment, we envision that exploitation of toroidal
excitations can have important implications for the fields of photonics, sensing, energy and
information.

References

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