Re-visiting Veselago's Prediction of Negative Radiation Pressure: Does the Momentum of Light Reverse in Left-Handed Media?

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In 1968, Veselago postulated the existence of left-handed electromagnetic media bearing the unique ability to sustain electromagnetic plane waves with contradirectional power and phase flow (V. Veselago, Sov. Phys. Usp., 10, 509). Counter-intuitive optical properties predicted to be associated with left-handed media include negative refraction, a reversed Doppler effect, a reversed Cherenkov effect, and negative radiation pressure. While the phenomenon of negative refraction has been well-studied and realized across the electromagnetic spectrum using engineered structures known as metamaterials, the other traits predicted for left-handed media have received comparatively little attention.

Veselago's prediction of negative radiation pressure was formulated by considering a plane wave incident from a lossless left-handed medium striking a mirror. Assuming that the momentum of the plane wave in the left-handed medium reverses direction relative to power flow, reflection of the plane wave from the mirror must impart a negative radiation pressure (i.e. a pull) to conserve global momentum.

Our motivation for re-visiting Veselago's prediction of negative radiation pressure is to determine whether different formulations of electrodynamics predict electromagnetic momentum reversal necessary to achieve negative radiation pressure. We have modeled the radiation pressure imparted to mirrors immersed in left-handed media, invoking five unique electrodynamic postulates of energy and momentum based on the Abraham, Minkowski, Amperian, Einstein-Laub, and Chu formulations of electromagnetism. The stress tensors and momentum densities associated with each formulation are discretized and incorporated into a two-dimensional finite-difference time-domain algorithm solving Maxwell's equations. The key finding is that momentum reversal and negative radiation pressure are predicted by the formulations of Abraham and Minkowski, but not by those of Amperian, Einstein-Laub, and Chu. This work is important because it demonstrates that the opto-mechanical properties predicted for left-handed media are dependent upon the chosen electrodynamic framework, revealing a new facet of the century-old Abraham-Minkowski controversy.