# Study resolves century-long debate over how to describe electromagnetic momentum density in matter

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(PhysOrg.com) -- Researchers from the NIST Center for Nanoscale Science and Technology and the University of British Columbia have shown that the interaction between a light pulse and a light-absorbing object, including the momentum transfer and resulting movement of the object, can be calculated for any positive index of refraction using a few, well-established physical principles combined with a new model for mass transfer from light to matter.

This work creates a foundation for understanding light absorption in metamaterials, artificially tailored materials of intense interest in nanophotonics and microwave engineering that can have negative indices of refraction, and have potential applications in high resolution imaging, lithography, optical sensing, high gain antennas, and stealth radar coatings.

Light carries momentum and can transfer momentum to matter via radiation pressure. However, for the past century, there has been an ongoing debate over the correct form of the electromagnetic momentum density in matter. In the "Minkowski formulation," the momentum density is proportional to the index of refraction; in direct contrast, the "Abraham formulation" finds it to be inversely proportional. While light is known to carry mass, a detailed model for mass transfer from light to a medium that absorbs light had not been formulated to date.

The researchers propose a set of postulates for light-matter interaction that encompass: a) the Maxwell equations, which govern classical electromagnetic behavior; b) a generalized Lorentz force law, which describes the force felt by matter in the presence of an electromagnetic field; c) a model for electromagnetic mass density transfer to an absorbing medium; and d) the Abraham formulation of momentum density. Using both closed-form calculations and numerical simulations of the interaction between an electromagnetic pulse and a test slab, the researchers demonstrated that their postulates yield results that are consistent with conservation of energy, mass, momentum, and center-of-mass velocity at all times.

They further showed that satisfaction of the last two conservation laws unambiguously identifies the Abraham form as the true form of momentum density in a positive-index medium. In addition to the theoretical significance of these results and the implications for metamaterials, the results will enable more accurate modeling of light-matter interaction at the nanoscale and open new routes to optical control of nano-mechanical systems incorporating light absorbing materials.

**More information:** Revisiting the Balazs thought experiment in the presence of loss: electromagnetic-pulse-induced displacement of a positive-index slab having arbitrary complex permittivity and permeability, K. J. Chau and H. J. Lezec, *Applied Physics A* 105, 267-281 (2011).

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