Transverse Optical Magnetism

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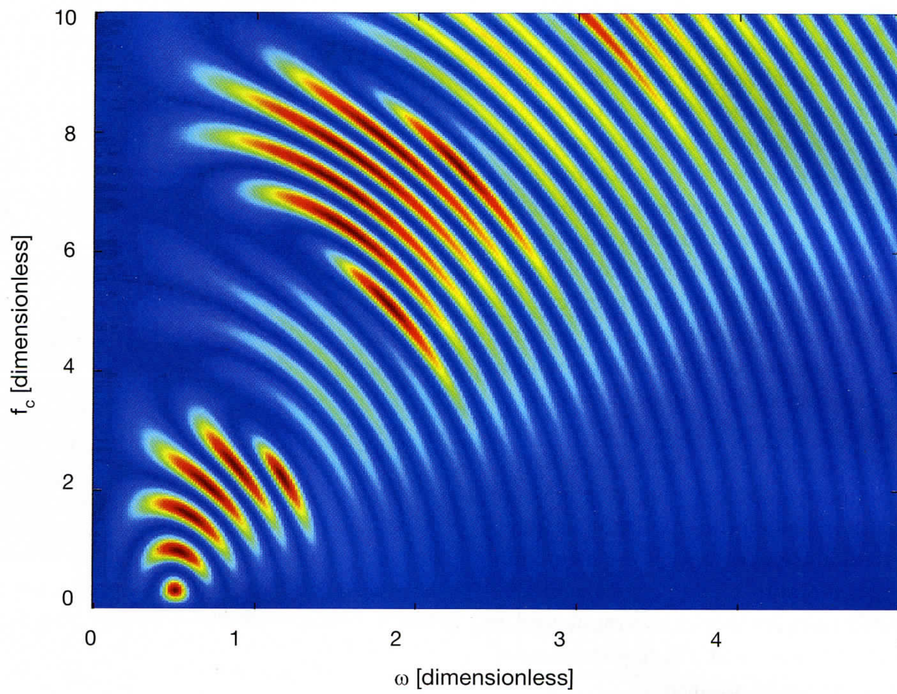
Magneto-optic interactions generally cause extremely weak changes in polarization or transient spin precession in magnetic materials.[1] However, University of Michigan applied physics student William Fisher recently discovered that the standard harmonic oscillator (SHO) model describing basic optical properties of nonmagnetic insulators contains some surprises. His solutions support intense magnetic interactions of a new kind at modest intensities, through parametric enhancement.[2]

In systems with bound electrons, it is well known that the electric component of light causes motion along the direction of the E field, and the magnetic Lorentz force causes motion perpendicular to E. However, because the magnetic field of a plane electromagnetic wave is very weak ($B=E/c$), the magnetic motion is generally ignored except at very high (relativistic) intensities.

Now, Fisher has shown that the SHO can be reduced to a complex Mathieu equation, which supports parametric growth of charge motions in which intrinsic coupling of magnetic and electric forces transfers energy efficiently from linear (electric) motion to circular (magnetic) current oscillations. At surprisingly low intensities, light can drive magnetic displacement currents to such high levels that magnetic dipole radiation becomes comparable in intensity to electric dipole radiation. The new work predicts this and other nonlinear effects like magnetically-induced charge separation in most corners of parameter space.

Fisher and coauthors confirmed that simple molecular liquids exhibit strong magnetic dipole scattering above $\sim 10^7$ W/cm^2 and that magnetic emission grows quadratically with respect to pump intensity.[3] Although quadratic electric nonlinearities are classically forbidden in centrosymmetric media, magneto-electric nonlinearities driven by both the E and B components of light are not. Different materials were also found to exhibit different magnetic saturation intensities.[4]



Parametric instability diagram showing that peaks for induced optical magnetism occur throughout parameter.[2]

Interestingly, while this new class of nonlinear optical effects is unanticipated, its origin is very old. Coupled mechanical oscillators often undergo parametric resonance that gives rise to spectacular, puzzling events. For example, coupling between vertical and torsional oscillations caused the Tacoma Bridge Collapse. But driving linear and torsional charge oscillations simultaneously with light to induce strong, high frequency transverse magnetization in Fisher's experiments is unprecedented. Magneto-electric interactions of light with matter are now being explored at Michigan for potential applications in energy conversion and THz generation.[5]

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References

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