Extremely high-order multiphoton scattering: Converting near infrared laser light to x-rays

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Electron–photon scattering, or Thomson scattering, is one of the most fundamental mechanisms in electrodynamics. It underlies laboratory and astrophysical sources of high-energy x-rays. It is also responsible for Comptonization of the photon energy spectrum of the cosmic radiation background and active galactic nuclei.

This scattering had first been investigated 1883 by J. J. Thomson [1], even prior to his discovery of the electron. Because the intensity of light available for his experiment was relatively weak, the scattering he observed was linear: the emitted light frequency was identical to the incident light frequency. Only recently, with the availability high intensity light sources, could the nonlinear regime of Thomson scattering be studied experimentally [2]. In this case, frequency of the emitted light differs from that of the incident light, because the electron oscillates not only along the electric field but also along the direction of wave propagation.

In this talk, we discuss recent results using yet even higher intensity light, in which case the scattering and electron motion are highly nonlinear, and the frequency of the emitted light is highly intensity-dependent [3]. Infrared laser light (~ 1.5 eV) back-scattered by a laser-accelerated relativistic electron beam (200 MeV) produced high energy x-rays (~ 20 MeV). In this case, the frequency spectrum of the scattered light differs from that of the incident light for two reasons: because of the relativistic Lorentz boost and because of extremely high-order multiphoton scattering. Measurements of the emitted radiation spectrum indicate that greater than 500 near-infrared laser photons are scattered by a single electron into a single x-ray photon. The scaling of the power radiated into a solid angle with laser intensity departs dramatically from the scaling predicted by linear theory, and is consistent with a numerical model of nonlinear relativistic electron motion and scattering. The observed angular distribution of scattered x-rays permits in-situ absolute measurement of incident light intensity during scattering [5], which was found to be 3×10^20 W-cm^-2, corresponding to a value of the normalized electric field vector potential \(a_0 = 12\). This is arguably the highest intensity ever measured in a laser-matter interaction experiment.

These results, coupled with those using the same experimental setup, but lower intensity [6], hold promise for development of a hard x-ray light source that is table-top, tunable, monoenergetic, and femtosecond in duration. Such a source can be used for low-dose radiography and ultrafast atomic and nuclear dynamics research. Furthermore, the x-ray pulses are predicted to have attosecond pulse duration [7].