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Direct Electron Acceleration in Multi-Kilojoule, Multi-Picosecond Laser Pulses[1]

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The physics mechanism behind the acceleration of electrons to energies much higher than the laser ponderomotive potential is reported on. Such electrons have been observed for the last twenty years [Perry], but they were small in number, about 1 percent of MeV electrons. Extended pulse durations, large focal spots and high intensities of current high-power lasers all favor generation of 'super-ponderomotive' electrons. Recent PIC simulations [Sorokovikova] give twenty times larger MeV electron doses than NOVA-PW. Such an enhancement, if realized in experiments, would boost all applications of short laser pulses (e.g., proton/ion acceleration, X-ray generation, and positron production). Evidence is provided that the dominant acceleration mechanism of super-pondermotive electrons is direct acceleration by transverse electromagnetic fields as they co-propagate in under-dense plasma; the most energetic electrons are initially Raman-scattered in the opposite direction of the laser pulse and then reflected by the electrostatic potential at the front of the plasma expansion into vacuum. In the classical figure-of-eight motion in a plane wave, electrons gain only a small average forward drift with momentum proportional to $a_0^2/2$ while oscillating in the laser field; in contrast, electrons injected at relativistic energy remain in phase with the laser field longer gain several times more energy, running in- and out of phase with the light; this continues until the laser is reflected by over-critical plasma, while fast electrons propagate into the target. Direct acceleration requires tens of plasma wavelengths of under-dense plasma, as well as pulse durations of tens of plasma periods, conditions that are found in large focal spot multi-picosecond laser pulses. References: Sorokovikova, A., Arefiev et al., Phys.Rev.Lett. 116, 155001 (2016). Perry, et al., Rev.Sci. Instr. 70, 265 (1999).

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