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Plasma Physics in Strong-Field Regimes[1]

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In strong electromagnetic fields, new plasma phenomena and applications emerge. In the classical regime, starting from megagauss magnetic fields, scattering of lasers becomes manifestly anisotropic. For the first time, a convenient formula for the three-wave coupling coefficient in arbitrary geometry is obtained and evaluated. By solving the fluid model to the second order, an alternative perspective of parametric instability is provided and magnetic-field effect on collective scattering is quantified. As an application, magnetic resonances are used to mediate laser pulse compression. Using magnetized plasmas, it is not only possible to achieve higher output intensity for optical lasers with more engineering flexibility, but also possible to compress UV and soft X-ray pulses that cannot be compressed using existing techniques. Taking advantage of the emerging feasibility of strong magnetic fields, a pathway to next-generation powerful lasers is identified, whose viability is supported by particle-in-cell simulations. In even stronger magnetic fields or intense laser fields, relativistic-quantum effects become important. At that point, plasma models based on quantum electrodynamics (QED) are necessary. Allowing for nontrivial background fields, a new formalism for QED plasmas is developed by computing the effective action using path integrals. The new formalism enables simple wave dispersion relations in strongly magnetized plasmas to be obtained for the first time, based on which the modified Faraday rotation and the anharmonic cyclotron absorptions near pulsars can now be quantified. Beyond the perturbative regime, real-time lattice QED is extended as a unique plasma simulation tool, especially when collective scales overlap with QED scales. Applying this tool to laser-plasma interactions, the transition from wakefield acceleration to electron-positron pair production is demonstrated for the first time when the laser fields exceed the Schwinger threshold.

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