Vacuum Polarization in Supercritical Magnetic Fields and Astrophysical Observations

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Heisenberg-Euler obtained the one-loop effective action in a constant electromagnetic field [1], and Schwinger introduced the proper-time integral method to systematically evaluate the one-loop action in the background field [2]. The enormous number of electron-positron pairs is spontaneously produced when an electric field is not much less than the critical field whose potential energy cross one Compton wavelength equals the rest mass of the pair. Similarly, the critical magnetic field has an energy per unit Compton volume equal to the rest mass of the pair. In comparison with the pulsed EM fields of ultra-intense lasers (current intensity of 1023 $\mathrm{W/cm^2}$ [3]), magnetars have been observed to possess supercritical magnetic fields in the macroscopic scale [4,5]. Magnetars are proposed as astrophysical laboratories of extreme QED phenomena [6].

Dittrich expressed the one-loop effective action in the proper time in a magnetic field in terms of the Hurwitz zeta-function [7-9]. In the in-out formalism [10-12], the one-loop effective action in a pure magnetic or electric field is shown to be equal to Dittrich's result [13]. In this presentation, I advance a new method for the effective action in a supercritical magnetic field together with a subcritical electric field, which can be observed in magnetars. And the photon propagation and spin-rotation are studied by computing the electric permittivity and magnetic permeability beyond the perturbation theory. Finally, possible observations of QED vacuum polarization effects are discussed in astrophysics.

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