QED Corrections in Unstable Vacuum

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It has long been realized that for sufficiently large nuclear charges the energies of the lowest bound states of the Dirac equation may fall below the negative-continuum threshold, $E_D < -mc^2$, where m is the electron mass, and c the speed of light. This phenomenon emerges for nuclear charge numbers $Z > Z_{\rm cr} \approx 173$ and is known as the *diving* of the Dirac bound states into the negative continuum. Once a bound state has undergone such diving, it is referred to as a *submerged* state. The wave functions of these states are no longer square-integrable and their energies have an imaginary component. This peculiar behavior is a manifestation of the instability of the quantum vacuum in the presence of a *supercritical* field. The corresponding physical process is the creation of an electron-positron pair, in which the electron fills the vacancy in the submerged Dirac state and the positron is emitted into the continuum. This effect, known as spontaneous pair creation (SPC), was predicted long ago but has not yet been observed.

There are vast experimental efforts directed to the creation and investigation of supercritical fields and unstable vacuum in two main directions. The first one involves high-power optical lasers and attempts to reach supercritical fields in laser-electron and electron-electron collisions. The theoretical investigations of such scenarios have not found confirmations of the Ritus-Narozhny prediction about breaking of QED series convergence. The second direction of experimental investigations of supercritical fields is connected to low-energetic collisions of two heavy nuclei. In a slow adiabatic collision, a quasimolecule can be formed by two colliding nuclei, with an enhanced nuclear Coulomb field that may reach the supercritical regime.

In my talk, I will discuss the convergence of the QED perturbation theory in a supercritical Coulomb field. In the subcritical regime, QED corrections are typically suppressed by a factor of α relative to the Dirac energy. A nonperturbative character of QED in the supercritical regime would manifest itself as a breakdown of the expansion in α, with QED corrections becoming comparable in magnitude to the Dirac energy. In order to test this conjecture, we calculate the first-order in α corrections to the Dirac energies in a supercritical Coulomb field, namely the electron self-energy and vacuum polarization. Moreover, knowledge of the imaginary part of these QED corrections gives us access to a new, radiative channel of spontaneous pair creation.