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非線形QED効果による放射の反作用の安定モデル
Stabilized Model of Radiation Reaction via Nonlinear QED Effects

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Radiation Reaction and Quantum Vacuum

With the progress of the laser technologies, they will discover the new regime of physics. In near future, laser intensities grow up over 10^{22}W/cm^2 [1]. In this regime, an electron emits significant energy as light in laser-electron interactions. Then, the motion of the electron is needed to correct by radiation feedback. It is a basic physical process, named 'radiation reaction'. This standard theory is built by Lorentz (1906) [2] Abraham (1905) [3] and Dirac (1938) [4]. Therefore, the equation of motion with radiation reaction is named the Lorentz-Abraham-Dirac (LAD) equation [4].

$$m_0 \frac{d}{d\tau} w^\mu = -eF_{\mathrm{ex}}^{\mu\nu} w_\nu - eF_{\mathrm{LAD}}^{\mu\nu} w_\nu \qquad (1)$$

$$F_{\mathrm{LAD}}^{\mu\nu} = -\frac{m_0 \tau_0}{ec^2}\left(\frac{d^2 w^\mu}{d\tau^2} w^\nu - \frac{d^2 w^\nu}{d\tau^2} w^\mu \right) \qquad (2)$$

Where, all of vectors in this equation belong to the 4-dimensional Minkowski spacetime $(\mathbb{A}^4, g)$ which is the mathematical set of the 4-dimensional affine space $\mathbb{A}^4$ and the Lorentz metric g with the signature of $(+,-,-,-)$. Now, $\mathbb{A}^4$ is described as 4-dimensional linear space. The field of $F_{\mathrm{LAD}} \in \mathbb{A}^4 \otimes \mathbb{A}^4$ is the effect of the radiation feedback, denoted the radiation reaction field. Many reader consider, it is very obvious and there is no room for discussion. However, this radiation reaction remains as one of the difficult problems in physics. However, Eq. (6) doesn't have a stable solution, which goes to infinite (run-away; see Eq(10)).

$$\frac{dw^\mu}{d\tau}(\tau) \propto C^\mu(\tau) \times \exp\left(\frac{\tau}{\tau_0}\right) \in \mathbb{A}^4 \qquad (3)$$

We reached new expression of radiation reaction with quantum vacuum. This is the model of vacuum is following the Heisenberg-Euler Lagrangian.

$$L = -\frac{1}{4\mu_0} F_{\alpha\beta} F^{\alpha\beta} + \frac{\varepsilon_0 c^2 \eta}{8}\left[\left(F_{\alpha\beta} F^{\alpha\beta} \right)^2 + \frac{7}{4}\left(F_{\alpha\beta}{}^{*} F^{\alpha\beta} \right)^2 \right] \qquad (4)$$

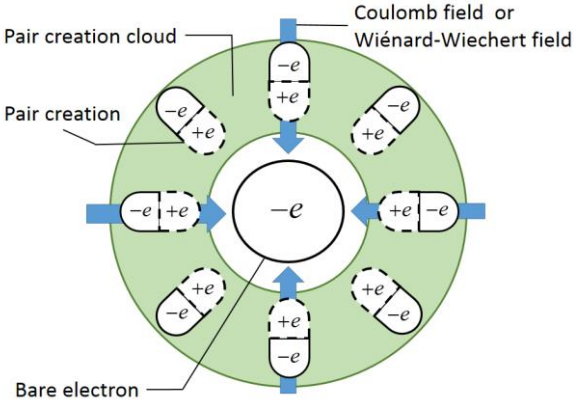

Fig.2 The electron model with quantum vacuum fluctuation, the "dressed electron". In QED, pair creations appear in space everywhere, whether the point is vacuum or an around (bare) electron. The dress charge of an electron behave the polarization via the Coulomb field or the Wiénard-Wiechert field.

From this dynamics in nonlinear-QED [5], we could obtain the new equation of motion with radiation reaction.

$$m_0 \frac{d}{d\tau} w^\mu = -eF_{\mathrm{ex}}^{\mu\nu} w_\nu - \frac{e}{1-\eta\left(F_{\mathrm{LAD}\,\alpha\beta} F_{\mathrm{LAD}}{}^{\alpha\beta} \right)} F_{\mathrm{LAD}}{}^{\mu\nu} w_\nu \qquad (5)$$

In this presentation, we will discuss this new model of laser & radiation – electron interactions.

References

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