The acceleration-dependent relativistic mass and acceleration limit of a charged sphere under radiation reaction

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The recent development of laser technology indicates that within several decades, the intensity of a laser pulse can reach 10^{29} W/cm^2, which corresponds to the Schwinger field E_S (= 10^{18} V/m). An accelerated charge in this strong field is expected to strongly recoil because of its radiation. Many researchers are motivated to observe this recoil effect (so-called the radiation reaction) in their laser-plasma experiments. For example, the first measurements of radiation reaction were published by Cole *et al.* and Poder *et al.* in 2018 via laser-beam interactions. Nevertheless, the exact calculation of the radiation reaction is still unclear; one of the main reasons is that the radiation reaction models published previously have yielded unphysical solutions for the particle's motion, such as runaway and pre-acceleration. Moreover, even the most accepted model, known as Landau-Lifshitz force, also has a big problem that it cannot explain the reaction of a uniformly accelerated charge. Most of these problems occur because it is normally assumed that a charged particle is a point-charge, where the self-force and self-energy diverge.

In this talk, we present a new charged sphere model for a particle, whose charge density embeds an image of a point-charge on its surface, making the sphere and the corresponding point-charge indistinguishable when observed outside. From the calculation of the momentum and self-force of this sphere, we obtained several interesting results: we discovered that the relativistic mass of the sphere is not only velocity-dependent (as the conventional mass is) but also acceleration-dependent. Furthermore, we found that that this acceleration-dependent mass explains well the radiation reaction in the uniform acceleration in a way that the charged sphere needs more external energy to get the acceleration [1]. Including this result, we will also present our recent calculation of the self-force on the sphere in a uniform circular motion,

$$\mathbf{F}_{\text{self}} = -\frac{\mu_0 q^2}{6\pi}\left[\frac{f(R_c)}{R_c}\frac{\mathrm{d}\mathbf{u}}{\mathrm{d}t} + g(R_c)\frac{\mathbf{v}}{c^3}\frac{\mathrm{d}u_\nu}{\mathrm{d}\tau}\frac{\mathrm{d}u^\nu}{\mathrm{d}\tau}\right]_{\text{retarded}}, \quad (1)$$

where R_c is the radius of the sphere. Figure 1 shows that the circular motion can also increase the mass as well (see the solid line), and interestingly, the radiation reaction seems able to vanish where $g(R_c) = 0$. These results imply that every motion of the charged sphere can potentially yield the mass of increase by strong electromagnetic fields. For experimental verification of our model, we expect that it may be possible to observe the mass increase by 3-5% in a field strength $0.05E_S$ (which corresponds to 6×10^{26} W/cm^2). From our new theory, we propose the existence of the upper limit to the acceleration of a charged sphere,

$$\frac{1}{c^6}\frac{\mathrm{d}^2u_\nu}{\mathrm{d}\tau^2}\frac{\mathrm{d}^2u^\nu}{\mathrm{d}\tau^2} + \left(\frac{1}{c^4}\frac{\mathrm{d}u_\nu}{\mathrm{d}\tau}\frac{\mathrm{d}u^\nu}{\mathrm{d}\tau}\right)^2 \le \frac{1}{4R_c^4},$$

and we discuss its relevance to the Schwinger limit.

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References

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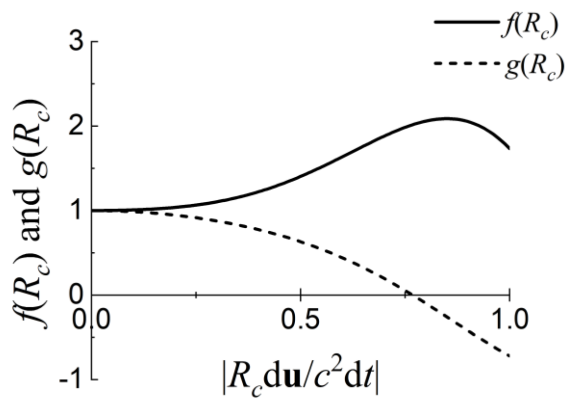

Figure 1. The functions $f(R_c)$ and $g(R_c)$ of Eq. (1), where $|\mathbf{v}/c| = 0.8$.