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Force approach to radiation reaction

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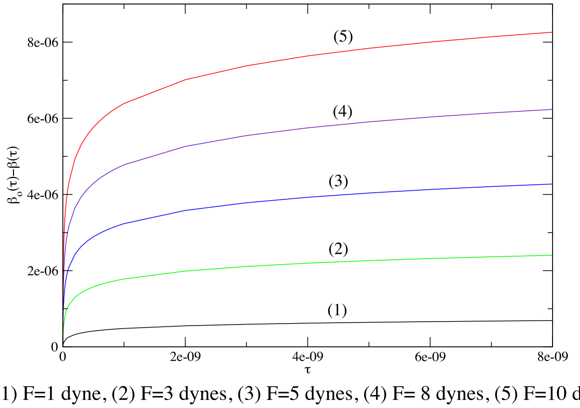
GRAPHICAL ABSTRACT

Difference of the normalized velocity of a charged particle under external constant force, with and without radiaction reaction force.



(1) F=1 dyne, (2) F=3 dynes, (3) F=5 dynes, (4) F= 8 dynes, (5) F=10 dynes

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ABSTRACT

The difficulty of the usual approach to deal with the radiation reaction is pointed out, and under the condition that the radiation force must be a function of the external force and is zero whenever the external force be zero, a new and straightforward approach to radiation reaction force and damping is proposed. Starting from the Larmor formula for the power radiated by an accelerated charged particle, written in terms of the applied force instead of the acceleration, an expression for the radiation force is established

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in general, and applied to the examples for the linear and circular motion of a charged particle. This expression is quadratic in the magnitude of the applied force, inversely proportional to the speed of the charged particle, and directed opposite to the velocity vector. This force approach may contribute to the solution of the very old problem of incorporating the radiation reaction to the motion of the charged particles, and future experiments may tell us whether or not this approach point is in the right direction.

1. Introduction

Radiation of electromagnetic waves due to the acceleration of charged particles is a very well known classical phenomenon predicted and explained by Maxwell's equations [1,2], and this phenomenon has been used for practical purposes worldwide [3–6]. This radiation, of course, implies dissipation of energy and damping motion of the charged particle, and the known modification to the equation of motion to take into account this damping effect are the so called Abraham–Lorentz (non relativistic case [7,8]) and Lorentz–Dirac (relativistic case [9]) equations. These equations have the particularity that even if the external force (responsible of the acceleration of the charged particle) is zero, a noncausal preacceleration of the particle still exists. On the other hand, one main experimental fact needed to take into account is that this radiation of electromagnetic waves due to acceleration of charges disappears as soon as the acceleration disappears, and this acceleration disappears as soon the external force is zero. This implies that radiation force (damping force associated to emission of electromagnetic waves) must be a function of this external force. From this point of view, I want to point out again that Abraham–Lorentz–Dirac formulation of radiation damping is not totally satisfactory [10–17] since one still has solutions of their equations with acceleration of the charged particle, even if the total external force is zero. In this paper, one considers a different point of view of this radiation force and arrives to an expression which is a function of the external force, that it takes into account the experimental fact, and which is worth to investigate and to be developed. Sections 2 and 3 analyze the radiation reaction force and damping for linear and circular motion respectively, and Section 4 discusses the conclusion and consequences of the force approach.

2. Linear radiation force

As it is well known, the total power radiated in a linear acceleration motion of a charged particle with charge "e" as a function of the external force; $\mathbf{F}$ with magnitude F, is (CGS units)

$$P = \frac{2}{3}\frac{e^2F^2}{m^2c^3}, \tag{1}$$

where "c" is the speed of light ($c \approx 3 \times 10^8$ m/s) and m is the mass of the charge. This means that the energy lost by the charged particle from the time $t = 0$ (time at which the external force is turned on) to the time t is

$$U = \frac{2e^2}{3m^2c^3}\int_0^t F^2 dt. \tag{2}$$

Assume that this energy lost is due to a non conservative radiation force, $\mathbf{F}_{rad}$, and that the charged particle travels from the point $\mathbf{x}_0$, at the time $t = 0$, to the point $\mathbf{x}$, at the time t. Then one gets that

$$U = \lambda_0 \int_0^t F^2 dt = \int_{\mathbf{x}_0}^{\mathbf{x}} \mathbf{F}_{rad} \cdot d\mathbf{x}, \tag{3a}$$