# FRICTIONAL RADIATION OF A ROTATING NANO PARTICLE

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**Abstract**— Using the quantized electromagnetic field and the matter field of a rotating nano particle in presence of vacuum fluctuations and a dielectric plane surface, we drive the radiation power of nano particle and focus on the frictional part of that. Frictional radiation power of rotating particle obtained and discussed in some limiting cases.

Index Terms— Quantum friction, Rotating nano-particle, field quantization, Radiation power.

## I. INTRODUCTION

Moving bodies experience the energy damping [1, 2] and a decoherence mechanism [3] due to the scattering of vacuum field fluctuations. The damping is accompanied by radiation of energy to conserve the total energy of combined system [4].

Radiation of neutral moving bodies can be categorized as quantum friction effect or dynamical casimir effect [5, 6] and both have been studied widely. There are some reported results, are showing the same radiation by simulating a motion in a static body such as using a time-varying boundary condition [7, 8, 9-11]. These are mostly used to obtain the dynamical casimir effect because the so-called casimir radiation is produced by dynamical changes in the boundary conditions of the electromagnetic field associated with photon states [12].

In this paper, we consider a rotating nano particle above a plane surface of a dielectric. Using the quantization of electromagnetic and matter fields by modeling the medium with a continuum of harmonic oscillators [13] and follow a systematic approach based on canonical quantization of the whole system [7], we drive the frictional radiation power of rotating particle and study the effect of rotation in some limiting cases.

## II. LAGRANGIAN

Let us consider the following Lagrangian for a spherical nanoparticle rotating along its symmetric axis (z axis) with angular velocity $\omega_0$, in the vicinity of a semi-infinite dielectric space

$$\ell = \frac{1}{2}\varepsilon_0(\partial_t \mathbf{A})^2 - \frac{1}{2\mu_0}(\nabla \times \boldsymbol{A})^2 + \frac{1}{2}\int_0^\infty d\upsilon\left[\left(\partial_t \mathbf{X} + \omega_0 \partial_\varphi \mathbf{X}\right)^2 - \upsilon^2 \mathbf{X}^2\right] \quad (1)$$

Where $X_i$ and $Y_i$ are the dielectric fields describing the nanoparticle and the bulk dielectric, respectively. The bulk considered to be in local thermodynamical equilibrium at temperature $T$. To derive this Lagrangian, the coordinate-derivative and field transformations between rotating and fixed or laboratory frames are used. Note that in the laboratory or fixed frame, the electromagnetic fields are non-rotating fields, therefore, there is no need to modify them in (1). The nanoparticle is moving so the coupling tensor $f_{ij}$ between the vacuum field and the field $Xi$ should be time dependent while the coupling tensor $g_{ij}$ between the vacuum field and the field $Yi$, describing the non-moving bulk dielectric, is time independent.

$$f_{ij}(\upsilon,t) = \begin{pmatrix} f_{xx}(\upsilon)\cos(\omega_0 t) & f_{xx}(\upsilon)\sin(\omega_0 t) & 0 \\ f_{yy}(\upsilon)\sin(\omega_0 t) & f_{yy}(\upsilon)\cos(\omega_0 t) & 0 \\ 0 & 0 & f_{zz}(\upsilon) \end{pmatrix}$$
$$g_{ij}(\upsilon,t) = \begin{pmatrix} g_{xx}(\upsilon) & 0 & 0 \\ 0 & g_{yy}(\upsilon) & 0 \\ 0 & 0 & g_{zz}(\upsilon) \end{pmatrix} \quad (2)$$

The equations of motion for the electromagnetic and matter fields can be obtained from Euler-Lagrange equations or equivalently from Hamiltonian, using Heisenberg equations. By making use of the azimuthal symmetry and non-relativistic approximation, we find

$$\mathbf{P}_P(r,\omega) = \mathbf{P}_P^N(r,\omega) + \varepsilon_0 \chi^P\left(\omega, -i\partial_\varphi\right)\mathbf{E}, \quad (3)$$

$$\left\{\nabla\times\nabla\times - \frac{\omega^2}{c^2}\mathrm{I} - \frac{\omega^2}{c^2}\chi^P\left(\omega,-i\partial_\varphi\right) - \frac{\omega^2}{c^2}\chi^B(\omega)\right\}.\mathbf{E} = \mu_0\omega^2(\mathbf{P}_P^N + \mathbf{P}_B^N)$$

Where $\mathbf{P}^N{}_P$ and $\mathbf{P}^N{}_B$ are the fluctuating or noise electric polarization components defined by

$$\mathbf{P}_{P,k}^N(r,t) = \varepsilon_0 \int_0^\infty d\upsilon\, f_{ij}(\upsilon) X_i^N(r,\upsilon,t),$$
$$\mathbf{P}_{B,k}^N(r,t) = \varepsilon_0 \int_0^\infty d\upsilon\, g_{ij}(\upsilon)\, Y_i^N(r,\upsilon,t). \quad (4)$$

The radiated power of the rotating nanoparticle can be written as [14]

$$\langle \mathcal{P} \rangle = \int dr \int_{-\infty}^{\infty} \frac{d\omega}{2\pi}\frac{d\omega'}{2\pi} e^{-i(\omega+\omega')t}(i\omega)\langle \boldsymbol{P}(r,\omega).\boldsymbol{E}(r,\omega')\rangle \quad (5)$$

Using the dyadic Green's tensor $G_{ij}$ and (3), we find

$$E_i(r,\omega) = E_{0,i}(r,\omega) + \mu_0\omega^2 \int dr' G_{ij}(r,r',\omega) \times \left[\mathbf{P}_{P,j}^N(r',t) + \mathbf{P}_{B,j}^N(r',t)\right] \quad (6)$$

## III. RADIATION POWER SPECTRUM

Let us consider a nanoparticle and a bulk dielectric made of silicon carbide (SiC) where the dielectric function is given by the oscillator model [15],

$$\varepsilon(\omega) = \varepsilon_{\infty}\left(1 + \frac{\omega_L^2 - \omega_T^2}{\omega_T^2 - \omega^2 - i\Gamma\omega}\right) \quad (7)$$

With $\varepsilon_{\infty} = 6.7$, $\omega_l = 1.823 \times 10^{14}$, $\omega_T = 1.492 \times 10^{14}$, and $\Gamma = 8.954 \times 10^{11}$. Inserting the dyadic Green's functions given in [16] into (6) and using (5), the spectrum of the frictional radiation power is plotted in figure (1).

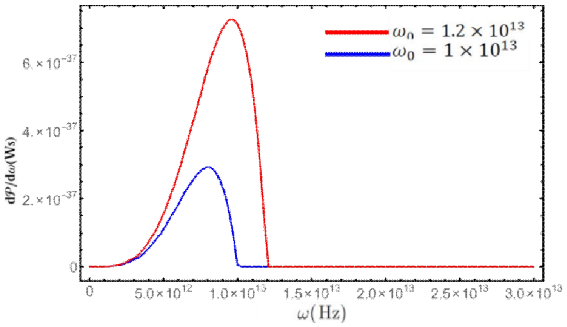
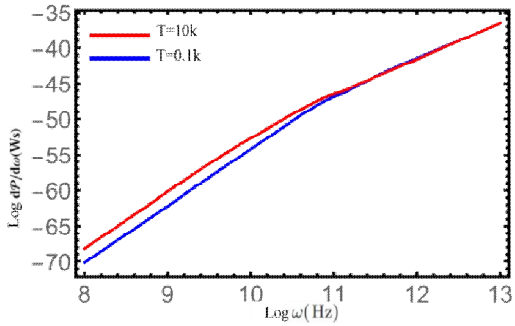



**Figure (1). The spectrum of the frictional radiation power as a function of frequency. The nanoparticle and plane surface have same temperature ($T_1$=$T_2$=0.1 k) and the nanoparticle is at 0.1 m far from the plane surface.**

Figure (1) shows the spectrum of the frictional radiation power is increasing by angular velocity of nanoparticle and so we would expect higher frictional torque. Another interesting future in Figure (1) pointed out that, 'no photon could be created with frequencies greater than the angular velocity of nanoparticle'.

Figure (1) shows Logarithmic plot of spectrum of the frictional radiation power of rotating nanoparticle for different temperature of nanoparticle an plane surface. In both cases the temperatures are equal. This figure explicitly shows an increase in the spectrum raising the angular velocity of nanoparticle.




**Figure(2). Logarithmic plot of spectrum of the frictional radiation power of rotating nanoparticle as a function of angular velocity of nanoparticle for the peak point of spectrum ($\omega = 0.8\omega_0$). The nanoparticle and plane surface have same temperature ($T_1$=$T_2$=0.1 k and 10k) and the nanoparticle is at 0.1 m far from the plane surface.**

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