Experimental evidence for radiation reaction thermalized at the Fulling-Davies-Unruh temperature

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The phenomenon of radiation is ubiquitous in the modern world. Yet despite its overwhelming worldwide applications, a paradox has persisted in our understanding of it - the problem of radiation reaction. Put simply, radiation reaction is the recoil experienced by a charged particle when it emits radiation. Considering an accelerated electron, the properties of the radiation emitted, such as its energy, will be determined by the electron's acceleration. However, when the electron radiates there will be a recoil, like when firing a bullet from a gun, that depends on the energy of the radiation. This recoil changes the acceleration which, in turn, changes the energy of the radiation thereby creating a "feedback loop". Understanding this feedback is the notorious problem of radiation reaction. Here we propose a novel way of looking at this problem; not by examining the radiation based on the Lorentz force equation of motion, but rather through a spacetime formulation of *accelerated quantum electrodynamics* (AQED) [1] via the use of a uniformly accelerated Unruh-DeWitt detector. *The outcome of this is not only a better understanding of radiation-reaction, but an indication that the Fulling-Davies-Unruh (FDU) temperature has already been witnessed, in a non-analog experiment.*

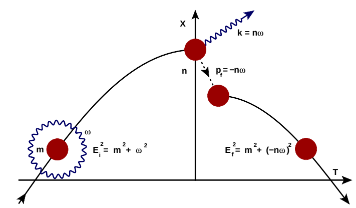

FIG. 1: The recoil momentum defines the energy gap of the Unruh-DeWitt detector, $\Delta E = \frac{\omega^2(n^2-1)}{2m}$.

If we examine an accelerated charge in an optical medium we can compute the power radiated per unit frequency,

$$\frac{d\mathcal{P}}{d\omega} = -i\frac{2}{3}\alpha\frac{n\omega^2}{a}e^{-2\pi\Delta E/a}\left[(2\gamma^2-1)H^{(2)}_{-\frac{2i\Delta E}{a}}\left(-\frac{2i\omega\gamma}{a}\right) - \frac{1}{2}\left(H^{(2)}_{-\frac{2i\Delta E}{a}+2}\left(-\frac{2i\omega\gamma}{a}\right) + H^{(2)}_{\frac{-2i\Delta E}{a}-2}\left(-\frac{2i\omega\gamma}{a}\right)\right)\right]. \quad (1)$$

Here, $H^{(2)}_\ell(x)$ is the Hankel function of the second kind. The presence of thermality be seen from the following identity, $H^{(2)}_\ell(x) = e^{i\ell\pi}H^{(2)}_{-\ell}(x)$. The implication of this property of Hankel functions is the manifest detailed balance at thermal equilibrium of the power spectrum. If we set the energy gap equal to the recoil momentum, see Fig. 1, then we are led to the conclusion that *the experimental observation of radiation reaction from a uniformly accelerated charge will simultaneously be the experimental observation of thermality at the FDU temperature.*

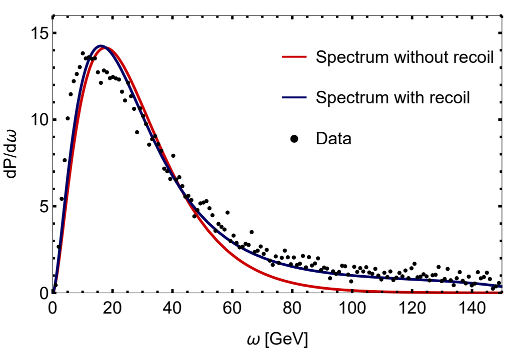

FIG. 2: The power spectrum from Eq. 1 compared to the recent radiation reaction data [2].

When a charged particle propagates in a solid along an axis of symmetry, the particle can be "channeled" and moves in an effective hollow wave guide produced by the structure. Then, the particle can oscillate back and forth transversely to its direction of propagation and therefore radiate. This process is known as channeling radiation. Radiation reaction has been observed in a recent channeling experiment [2]. The data from the photon power spectrum produced by accelerated positrons is presented in Fig. 2 and is compared to Eq. 1.

Our theoretical chi-squared statistic with the recoil correction yields $\chi^2_{the}/\nu = 38.87$. This is only slightly greater than the experimental signature for radiation reaction, $\chi^2_{\exp}/\nu = 38.2$ [2]. *As such, we are led to the conclusion that in addition to measuring quantum radiation reaction in aligned crystals, the experiment of Wistisen et al. [2] was also be simultaneously successful in the very first measurement of the Unruh effect in a non-analog system.*

[1] M. H. Lynch, *Accelerated quantum dynamics*, Phys. Rev. D **92**, 024019 (2015).
[2] T. N. Wistisen et. al *Experimental evidence of quantum radiation reaction in aligned crystals*, Nat. Comm. **9**, 795 (2018).

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