Phonons leap across a nanoscale gap?

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Abstract: Experiments of heat transfer across nanoscale gaps based on phonons mediated by the Casimir effect or quantum fluctuations of electromagnetic fields are assessed in relation to the simple QED theory of nanoscale heat transfer. Simple QED based on the Planck law denies atoms in nano structures and gap surfaces the heat capacity to conserve heat by an increase in temperature with conservation proceeding by the creation of non-thermal EM waves standing across the gap. Only a single simple QED photon is necessary to explain the experiment, and therefore phonon heat transfer mediated by the Casimir effect is insignificant. Further, the thermal kT energy of atoms in gap surfaces vanishes under EM confinement which means phonons that depend on temperature do not exist in the nano gap surfaces to transfer heat by leaping across the vacuum gap. Even the Casimir force in the phonon heat transfer theory is questionable. Over a decade ago, the Casimir effect was shown to have nothing to do with quantum fluctuations, but rather caused by photoelectric charging of the plates by simple QED induced EM waves standing across submicron gaps.

Keywords: Casimir, phonons, heat transfer, Planck law, simple QED

I. INTRODUCTION

Heat transfer mechanisms at the nanoscale differ significantly from classical physics where heat is conserved by an increase in temperature as the Planck law of quantum mechanics [1] denies the atom heat capacity to conserve heat by an increase in temperature. The heat transfer restriction not only applies to atoms in nanostructures, but also to atoms in the surface of nanoscale vacuum gaps between macroscale bodies.

Recently, phonons assisted by quantum fluctuations in the Casimir effect were proposed [2] yet another mechanism to explain heat transfer across a nanoscale vacuum gap between macroscopic bodies. A few decades ago, black body radiation given by the Stefan-Boltzmann law depending on surface temperature T^4 was shown [3] not applicable to vacuum gaps d << hc/kT. Instead, near-field thermal radiation by evanescent waves was suggested, but still heat transfer depended on temperature T of the gap surfaces. Later, the heat transfer mechanisms between evacuated nanoscale gaps [4] included phonons assisted by quantum fluctuations and van der Waals and electrostatic forces, all of which require distinctly different temperatures of hot and cold surfaces that cannot exist at the nanoscale.

Indeed, all known nanoscale heat transfer mechanisms including near field radiation, quantum fluctuations, evanescent waves, and phonons assisted by van der Waals or electrostatic forces find basis in temperature dependent multiplicative factors of Planck energy $E = (hc/\lambda)/[\exp(hc/\lambda kT) - 1]$ or $E = kT = hc/\lambda$ that vanish at the nanoscale. What this means nanoscale heat transfer is only possible with temperature independent mechanisms.

II. PURPOSE

To propose the simple QED mechanism [1] of heat transfer that is independent of temperature to explain heat transfer across nanoscale vacuum gaps. Comparisons are made to experimental [2] data and analytical predictions.

III. THEORY

Simple QED is a nanoscale heat transfer process based on the Planck law [5] of quantum mechanics differing significantly from that of classical physics. Research in nanoscale heat transfer [6-8] has been reported. But despite advances, there are still challenges in understanding the mechanism of nanoscale thermal transport. Perhaps, researchers have not appreciated the significant difference between classical physics and the Planck law with regard to the heat capacity of the atom illustrated in Fig. 1.

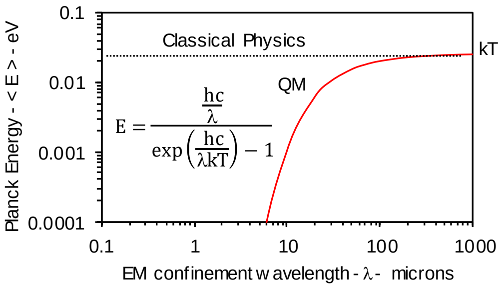

Figure. 1: Planck law of the Atom at 300 °K
In the inset, E is Planck energy, h Planck's constant, c light speed, k Boltzmann's constant, T absolute temperature, and λ the EM wavelength.

The Planck law at 300 K shows classical physics allows the atom constant kT heat capacity over all EM confinement wavelengths λ. QM differs as the heat capacity of the atom decreases for λ < 200 microns, and vanishes at the nanoscale for λ < 100 nm. Fig. 1 shows the atom has vanishing thermal kT heat capacity for all EM confinement wavelengths λ < 8 μm. Since an EM wave standing between gap d surfaces has a half-wavelength λ/2 = d, atoms in gap surfaces separated by d < 4 μm cannot conserve energy U by an increase in temperature. Implicitly, all of nanotechnology comprising submicron nanostructures is subject to the same Planck constraint.

What this means is all EM energy absorbed by a nano structure or gap can only be conserved by a non-thermal mechanism. Indeed, phonons depending on temperature cannot exist at the nanoscale. Atoms in nano gap surfaces preclude the temperature necessary for phonons to exist, let alone leap across the vacuum gap. Only non-thermal EM waves standing in the gap allow heat transfer between gap surfaces.

Simple QED nanoscale heat transfer evolved from the argument that the Planck law requires energy U may only be conserved by creating non-thermal EM radiation. In nano gaps, conservation proceeds by creating a number N of non-thermal EM waves standing having Planck energy E = hc/2d, where N = U/E. What this means is the minimum U' at 300 K required to create a single standing EM wave is, U' > E = hc/2d. For U < U', photons cannot be created to form standing EM waves in the gap.

Heat Q is transferred across nanogaps at the rate of energy dU/dt. Simple QED is based on conserving heat Q by creating standing EM radiation instead of increasing temperature. QED stands for quantum electrodynamics, a complex theory based on *virtual* photons advanced by Feynman [9] and others. In contrast, simple QED has nothing to do with *virtual* photons and only requires the heat capacity of the atoms in nanostructures or on the surface of nanogaps to vanish allowing conservation to proceed by the creation of *real* photons forming EM waves that stand across the nano structure or gap. Hence, the Planck energy E of the simple QED state is,

$$E = \frac{hc}{2nd}$$

where, n is the refractive index of the gap material, n = 1 for a vacuum. Like electron level quantum states with EM waves standing across orbitals, simple QED quantum states are size dependent based on the dimension of the nanostructure or nanogap over which the EM waves stand.

But EM confinement of absorbed heat Q at the surface is necessary to form EM waves standing across the nanostructure. The heating of a nanoparticle (NP) by an external source of heat having a wavelength λ_o >> d immerses the NP, but for a nano gap heat Q is 1-dimensional as depicted in Fig.2.

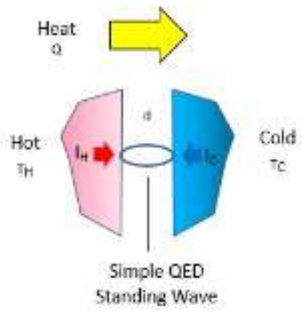

Figure 2. Nano gap heating

Heat Q is shown transferred from hot to cold bodies. For nano gaps, the thermal kT energy of atoms of hot and cold surfaces vanishes as shown in Fig. 1. To compensate for the surface atoms, other atoms in both hot and cold bodies having thermal kT energy $U_H \propto kT_H$ and $U_C \propto kT_C$ form Poynting vectors of momentum $I_H = U_H/c$ = and $I_C = U_C/c$ directed toward the respective gap surfaces provide the EM confinement of the standing EM waves in the gap.

Heat Q flows if the momentum $I_H > I_C$. In the gap, the Planck law precludes conservation of Q by a change in temperature, and instead proceeds by the creation of simple QED radiation in the form of non-thermal EM standing waves.

Importantly, the EM standing waves are non-thermal. The Planck law temperature dependence is given by,

$$E_H = (hc/2d)\cdot[\exp(hc/2dkT_H) - 1]^{-1}$$
$$E_C = (hc/2d)\cdot[\exp(hc/2kT_C) - 1]^{-1}$$

shows for d < 4 μm and T near 350 K, E_H and E_C cannot exist thermally which is precisely why simple QED requires non-thermal EM standing waves.

IV. APPLICATION

The simple QED application is based on heat transfer [2] between hot and cold baths separated by a quantum vacuum gap d as shown in Fig. 3.

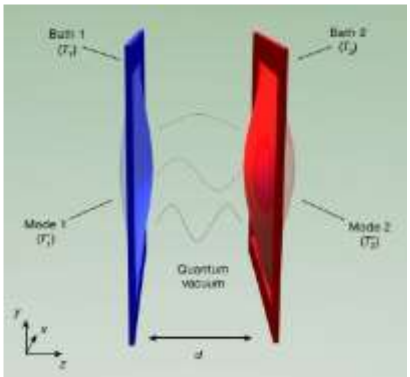

Figure. 3: Heat transfer across vacuum gap

The hot and cold baths undergoing thermal Brownian motion are thought mediated by Casimir interaction to transfer heat Q by phonons across the gap. The fundamental modes of the membranes have temperatures given by thermal Brownian motions.

Simple QED gives the Planck energy E = hc/2d of the standing EM wave, but the heat Q requires the time τ for the system to reach steady state which was estimated as the time scale of the feedback loop, τ=16 s. The simple QED and experiment data taken from (Fig. 2e of [2]) is shown in Fig. 4.

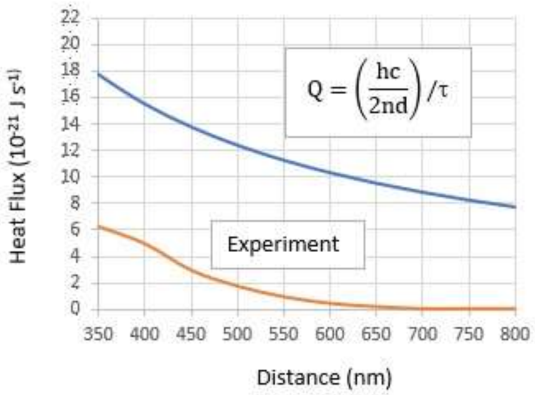

Figure. 4: Simple QED vs. Experiment

At 350 K, simple QED gives 3X higher heat Q flux than the experiment that also is consistent with phonons mediated with the Casimir effect. Of course, the time τ for heat Q to stabilize may be 50 s which provide a closer fit to experiment. Regardless, simple QED assumes only a *single* photon is standing in the gap at each gap distance d, and therefore phonon transfer of heat Q is relatively insignificant.

V. CONCLUSIONS

The Planck law denies atoms in nano gap surfaces the heat capacity to conserve heat by an increase in temperature. Phonons depending on temperature do not exist in nano gap surfaces $\rightarrow$ heat transfer by phonons leaping across the gap cannot occur.

Simple QED based on the Planck law conserves heat by the emission of EM radiation. At temperatures near 300 K, photons instead of phonons transfer heat across nano gaps.

The experiment of phonon heat transfer verification is complex and the Casmir effect based on the quantum vacuum itself is questionable. Simple QED suggests the Casimir effect is caused by photoelectric charging from standing EM radiation in the gap. Since one plate is electrically grounded, an electrostatic attraction occurs that has falsely been attributed to quantum fluctuations. See early 2005 and 2009 developments [14] of Casimir by simple QED.

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