Heat Transfer of a Nanoparticle in a Thermal Bath

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Abstract

Classical physics allows the atom to have heat capacity at the nanoscale, the conservation of heat proceeding by a change in temperature. However, the Planck law of quantum mechanics denies the atom the heat capacity to conserve heat by a change in temperature. Over the past decades, nanotechnology has ignored the Planck law and continued to perform nanoscale heat transfer based on classical physics, the consequence of which is an uncountable number of meaningless papers. In contrast, the simple QED theory of nanoscale heat transfer theory based on the Planck law is presented in this paper. Heat is conserved by creating standing EM waves inside the nanostructures. Unlike electronic quantum states, simple QED comprises size dependent quantum states depending on the dimensions of the nanostructure over which the EM waves stand. Simple QED is applied to the heat transfer of a nanoparticle immersed in a liquid bath at constant temperature to illustrate the differences with classical physics.

Keywords: Classical physics, Quantum Mechanics, Planck law, Nanoparticle.

1. Introduction

Heat transfer at the nanoscale is controlled by the Planck law [1] of quantum mechanics (QM) differing significantly from that of classical physics. Research in nanoscale heat transfer [2-4] has advanced over the past decades, and a large number of interesting phenomena have been reported. But despite the advances in nanotechnology, there are still challenges existing 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 without which nanoscale heat transfer cannot proceed.

In this regard, the Planck law denies atoms in nanostructures the heat capacity to change temperature upon the absorption of heat - a difficult notion to accept because of our prior training in classical physics. Even from personal experience, we know adding heat to an object increases its temperature. But classical physics and our experiences are relevant only to the macroscopic world - not the nanoscale.

Heat transfer without changes in temperature preclude the Fourier law of heat conduction commonly used in nanoscale heat transfer. Similarly, the Stefan-Boltzmann law for radiative heat transfer depending on temperature is not applicable to nanostructures. Although valid at the macroscale, the Fourier law and Stefan-Boltzmann equation are invalid at the nanoscale. Moreover, Molecular Dynamics (MD) simulations [5] based on classical physics thought to provide an understanding of the atomic response to thermal disturbances assume atoms in nanostructures have temperature. Researchers need both new theory and computational procedures to be developed to understand nanoscale heat transfer.

2. Purpose

The purpose of this paper is to present the simple QED theory [6] of nanoscale heat transfer. Application of simple QED to an iron nanoparticle (NP) heated in a liquid bath at constant temperature is made to illustrate difference with classical physics.

3. Analysis

Simple QED Is a method of nanoscale heat transfer analysis that conserves heat with EM radiation instead of temperature. QED stands for quantum electrodynamics, a complex theory based on virtual photons advanced by Feynman [7] and others. In contrast, simple QED is a far simpler theory based on the Planck law that requires the heat capacity of the atoms in nanostructures to vanish allowing conservation to proceed by the creation of real photons comprising EM waves that stand within and across the nanostructure. Unlike electron level quantum states, simple QED quantum states are size dependent based on the dimension of the nanostructure over which the EM waves stand.

3.1. Planck law and Heat Capacity

The Planck law at 300 K is illustrated in Fig. 1. By classical physics, the kT heat capacity of the atom is independent of the EM confinement wavelength λ, where k is the Boltzmann constant and T absolute temperature. QM differs as the heat capacity of the atom decreases under EM confinement λ < 100 microns, and at the nanoscale for λ < 100 nm, the heat capacity may be said to vanish.

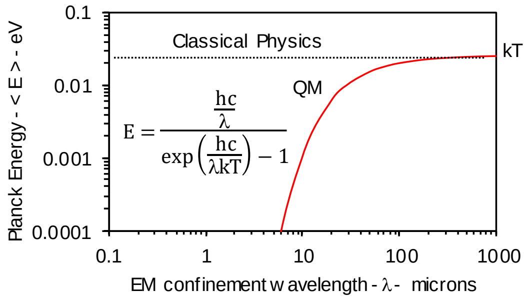

Fig. 1: Planck law of the Atom at 300 °K

In the inset, E is Planck energy, h Planck's constant, c light speed, k Boltzmann's constant, T temperature, and λ the EM confinement wavelength

3.2 EM confinement

EM confinement occurs by the high surface-to-volume (S/V) ratio of nanostructures that requires the heat Q to almost totally be confined in the surface, the surface heat itself as EM energy providing the brief EM confinement necessary to create EM waves standing across the internal dimension d of the nanostructure.

3.3 Planck Energy of EM Radiation

The simple QED Planck energy E is quantized by the dimension d of the nanostructure that defines the half-wavelength λ/2 of the nanostructure. Fig. 2 illustrates the standing EM radiation in a spherical NP has 1 quantum state corresponding to NP diameter d, but NP atoms still follow their quantized electron energy levels.

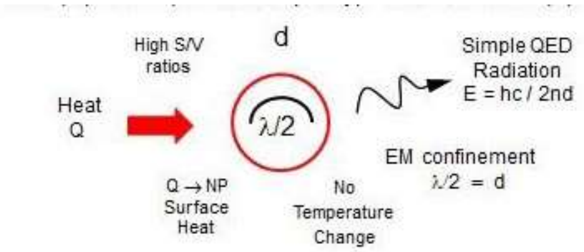

Fig. 2: Planck Energy of EM Radiation

In a rectangular NP with different dimensions of width, thickness, and length there are 3 simple QED quantum states corresponding to the different dimensions of the NP. Continuous variation in internal nanoscopic dimensions produces a broadband spectrum of simple QED quantum states. Historically, the notion of size dependent quantum states [8] is mentioned with metal clusters [9] in polymeric materials. Otherwise, size dependent quantum states are not found in the literature.

Fig. 2 shows simple QED absorbs heat Q in the NP surface because of the high EM confinement. Unable to conserve the surface heat by a change in temperature, conservation requires the creation of simple QED radiation. The Planck energy E depends on the refractive index n of the nanostructure to correct for the velocity c of the speed of light within the NP.

4. Analysis

The simple QED analysis of the thermal response of an iron NP in a thermal bath is illustrated in Fig. 3.

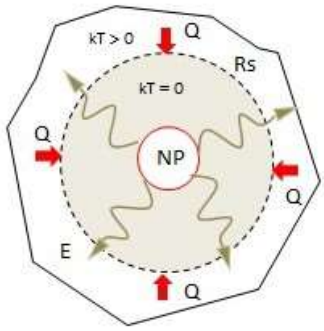

Fig. 3: NP in a Thermal Bath

The NP absorbs heat Q from the thermal bath at absolute temperature T by conduction, while convection is neglected. But Fourier's heat conduction equation is only valid in the bath for kT = 1. The radius Rs at which bath atoms at 300 °K have thermal kT energy is given by the Planck law at EM confinement wavelengths λ > 200 microns as shown in Fig. 1. For body tissue and water having refractive index n = 1.4, the radius Rs = λ/4n ~ 36 μm.

What this means is the heat flow Q from the bath at temperature T is converted at Rs to EM radiation in the far IR (λ = 4nRs) and upon being absorbed at by the NP is conserved by emitting simple QED radiation. Small temperature changes occur for R < 10 microns, but clearly vanish for NPs < 100 nm.

4.1 Energy Conservation

Classically, all iron atoms in the NP at equilibrium have temperature T equal to the bath temperature. In terms of the Boltzmann constant k and the number N of atoms, the total NP thermal energy U is,

$$U = \frac{3}{2}kNT$$

However, by the Planck law the N atoms do not have kT energy. Instead, simple QED conserves the energy U that otherwise would occupy the NP by creating standing EM radiation inside the NP diameter d as shown in Fig. 2. For an 85 nm iron NP with n = 1.5, the Planck energy E is in the UVC (254 nm), E ~ 4.88 eV. The number N of iron NP atoms is, N = (ρV/55)·Av, where volume $V = \pi d^3/6$ = 3.21×10^{-22} m^3, density ρ = 7854 kg/m^3 and Avagadro's number Av = 6.023 x 10^{26} atoms/kg-mol. Hence, N = 2.7×10^7 atoms and U ~1 MeV. What this means is the NP creates about 200,000 - UVC photons upon equilibrating with the 300 °K thermal bath temperature.

Once created, the emitted UVC photons are absorbed by the water bath, the bath temperature T once again produces the number of 200000 UVC photons repetitively. But how rapidly does the NP surface temperature recover?

4.2 Single Photon Creation

The simple QED creation of UVC having Planck energy E = 4.88 eV having wavelength λ = 254 nm absorbing a pulse of heat from the water changing the temperature ΔT given [10] by,

$$\Delta T = \frac{1.2}{\pi d^2 K}\left(\frac{E}{\Delta t}\right)\sqrt{\frac{\alpha}{\pi}}\left[\sqrt{t+\Delta t} - \sqrt{t}\right]$$

The Planck energy E = 4.88 eV is spread over the spherical surface area πRs^2 of the bath nearest the NP having kT energy. The pulse duration is Δt = 2d / (c /n) = 0.85 fs. The EUV heat Q = E/Δt ~ 900 μW. Here, thermal diffusivity α = K/ρC. For tissue in water, α = 1.24 x10^{-7} m^2/s and K = 0.52 W/m-K giving the initial drop in temperature ΔT of an imperceptible ~ 2 μ°C that recovers in < 1 ps as shown in Fig. 4.

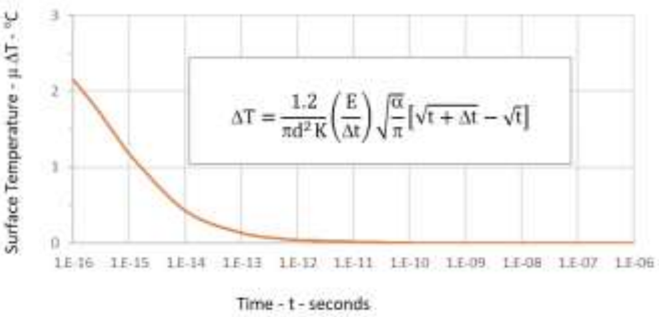

Fig. 4: Single Photon Creation Time

5. Conclusions

The Planck law provides a significantly different perspective of nanoscale heat transfer than classical theory held for past decades. In the literature, most of nanoscale heat transfer [2-4] has no physical meaning. MD was noted [4] to be inconsistent with assuming constant kT in the Planck distribution for phonons, but by the Planck law, phonons depending on temperature do not exist at the nanoscale.

Recently, phonons were reported [11] to transfer heat across nanoscale vacuum gaps based on quantum fluctuations in Casimir theory. Phonons were even proposed [12] as a new heat transfer mechanism. However, the Planck law denies phonons in the gap surfaces changes in temperature. Instead, heat is transferred across nanoscale gaps by simple QED creating standing EM radiation between surfaces.

The Planck theory of nanoscale heat transfer since 2012 used in diverse applications reported in [6] is recommended for review.

The heat transfer of an iron NP in a thermal bath has significant meaning as the single UVC photon is created in times < 1 ps. Hence, many UVC photons may be created every second. Aluminum NPs enter the brain upon vaccine injections in the blood stream and therefore cause [6] significant DNA damage that if not repaired by the immune system may lead to autism.

In 2019, the conversion of heat to EUV in myosin heads and fluorescence down to UV photons was shown [6] important in creating electrostatic charge to power muscle contraction. In mitochondria, ATP synthesis by dehydration reactions using endogenous UV was also shown [6] to supersede chemiosmosis by hydrolysis.

In addition to each and every myosin head producing UV to create charge to power muscle contraction, the heads also produces ATP by UV assisted dehydration. Hence, the myosin heads assist the mitochondria in supplying ATP to over-worked muscles avoiding the inefficient process of converting glucose to ATP by glycolysis.

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