Casimir Force by Blackbody Radiation

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ABSTRACT: Casimir assumed the electromagnetic (EM) radiation in the gap between plates was the zero point energy (ZPE). Irrespective of whether the ZPE exists, Casimir did not conserve ZPE in the gap as required by EM confinement. Conservation requires constancy of ZPE as the gap increases or decreases, and therefore the gradient of the ZPE with respect to the gap vanishes and the Casimir force does not exist. In contrast, the existence of blackbody (BB) radiation given by the thermal kT energy of surface atoms is without question. Under EM confinement, conservation proceeds by the quantum electrodynamics (QED) up-conversion of low-frequency thermal kT energy of surface atoms in Casimir's plates to the EM confinement frequency of the gap, typically at frequencies beyond the vacuum ultraviolet (VUV). In radiationless recombination, the excitons produce an attractive force if the positive hole of an exciton is created in one plate and an electron in the other. But excitons cannot span typical gaps between Casimir's plates, and therefore recombination proceeds by the emission of QED photons. In a vacuum, the QED photons by the photoelectric effect charge the plates equally and a net attractive force between the plates is not produced. However, the QED photons produce EM energy density in the gap that unlike EM energy is not constant, but increases as the gap decreases. Hence, the attractive force measured in Casimir experiments is the BB force produced as the gradient of the EM energy density in the gap interacts with the polarity of surface atoms is equal and opposite across the plates. Immersing the surfaces in the electron scavenger bromobenzene produces a repulsive BB force because unlike the vacuum the electrons removed from the plates by the QED photons in bromobenzene are scavenged leaving both plates with net positive charge.

KEYWORDS: Casimir force, blackbody radiation

I. INTRODUCTION

In 1948, Casimir [1] formulated the attractive QED force between a pair of electrically neutral metal plates separated by a gap in a vacuum based on the zero point energy of the field (ZPF). Unlike the ZPE for atoms, the ZPF remains controversial. Extending the ZPE of an atom to the speculative ZPF, W. Pauli once stated

For fields, it is more consistent not to introduce the ZPE

Casimir relied on Planck's derivation [2] of the law for BB radiation that included the ZPE. In terms of the average Planck energy E_{avg} of the harmonic oscillator at absolute temperature T,

$$E_{avg} = \frac{h\upsilon}{\left[\exp\left(h\upsilon / kT\right) - 1\right]} + \frac{1}{2}h\upsilon \tag{1}$$

where, ZPE = ½ hυ, h is Planck's constant, υ is the oscillator frequency, and k is Boltzmann's constant.

In contrast, Einstein's derivation [3] of the radiation law that excludes the ZPE is,

$$E_{avg} = \frac{h\upsilon}{\left[\exp\left(h\upsilon / kT\right) - 1\right]} \tag{2}$$

Spaarnay [4] presumably verified the Casimir force in tests of flat mirrors. In a 2002 review, Lambrecht [5] reported that Spaarnay's tests were swamped by electrostatic force, the mirrors kept neutral by first touching them together before each measurement.

In 1969, Boyer [6] derived the ZPE based on classical arguments to agree with Planck. Boyer took Spaarnay's apparent verification of the Casimir effect as affirmation of the existence of the ZPE. But if the measured force were caused by another mechanism, the Casimir effect and the inferred existence of the ZPE would not be supported.

Casimir's pair of plane mirrors was reasonably simulated in 2002 by Bressi et al. [7]. One surface was a chromium-coated silicon plate and the other a flat surface of a cantilever beam of the same material separated by a gap from 0.5 to 3 microns. By noting the change in resonant frequency of the beam with the gap, the Casimir force was claimed proven within 15%. However, flat plates are normally not used in Casimir experiments because of the difficulty in alignment. Instead, the interacting surfaces are usually [8-10] taken as a sphere and a flat plate.

In 1996, Lamoreaux [8] used the sphere and flat plate geometry to measure the Casimir force in the 0.6 to 6 micron range. The sphere was a 4 cm diameter spherical lens and the flat plate was a 2.5 cm diameter optical flat, the optical surfaces copper coated with a top gold coating. Similarly, Mohideen and Roy [9] in 1998 measured the Casimir force from 0.1 to 0.9 microns by attaching a gold coated 200 micron diameter sphere to the cantilever of an atomic force microscope (AFM) against a flat plate. Another variant in the measurement of the Casimir effect was performed in 2001 by Chan et al. [10]. A gold coated silicon plate was suspended on a torsion rod with a similar coated 200 micron diameter sphere placed off axis, the Casimir force between the sphere and plate causing a torque to rotate the plate. The Casimir force was measured over a range from 0.1 to 1 micron.

Given the attractive force measured over the past 50 years in Casimir experiments based on the ZPF is not yet resolved, the purpose of this paper is:

To present an alternative to the Casimir theory based on thermal BB radiation.

II. BACKGROUND

Casimir [1] assumed a pair of plates in a vacuum were separated by gap G, and therefore concluded that EM radiation having half-wavelengths $\lambda/2 > G$ is excluded from the gap, leading to a force unbalance that attracts the plates together. Casimir assuming Planck's ZPE [2] proceeded with a derivation of the force that balanced the excluded EM radiation.

However, there is a problem with Casimir's derivation. The ZPE radiation excluded from the gap does not lead to an unbalanced force because Nature requires the ZPE to spontaneously adjust to gap changes by a change in frequency. Absent a frequency change, the plates would indeed be attracted by the unbalance in ZPE radiation, but the response would not be instantaneous because of plate inertia. In effect, Casimir's mathematical derivation that assumes plates instantaneously respond to gap changes is unphysical.

If Casimir would have conserved the EM radiation for all gaps G, he would have realized the EM energy is constant, and therefore the Casimir force given by the gradient of the EM energy with respect to the gap vanishes. Indeed, there is no Casimir force.

If so, what are the attractive forces
being measured in Casimir experiments?

In 2004-5, Prevenslik [11, 12] showed the Casimir force did not exist because Casimir did not conserve EM energy in the gap G between the plates. Instead, Casimir's force was proposed caused by electrostatic attraction from photoelectric charging at VUV levels produced by the QED up-conversion of thermal kT energy of surface atoms upon the EM confinement of the thermal kT energy of surface atoms.

However, the removal of electrons by VUV radiation induced by QED does not mean that positive and negative charges are produced on opposite plate surfaces. Excitons with positive charged holes in one plate and electrons in the other produced by VUV would provide [13] electrostatic attraction across the gap. For metal plates with low dielectric constant, the spacing between holes and electrons of the Frenkel exciton is limited to the atom spacing. In high dielectric materials, the Mott-Wannier exciton may span a few tens of atoms, but not more than about 6 nm. Instead, the excitons produced by VUV radiation are likely localized in one or the other plates, and therefore unlikely to span typical gaps G of order 100 nm to produce the electrostatic attraction necessary to explain the measured forces in Casimir experiments.

In 2009, Prevenslik [14] argued the ZPF may have unnecessarily misled research on the force between the atom and a surface, by excluding BB radiation. For example, the Casimir-Polder (CP) force based on the ZPF assumed the surface at zero temperature even though BB radiation is undeniable.

Similarly, Lifshitz [16] extended the ZPF to allow finite temperatures to be included in the CP force by prescribing surface temperatures through temperature dependent dielectric properties. In contrast to the thermal equilibrium assumed by Lifshitz, Henkel et al. [17] proposed the notion of thermal non-equilibrium meaning the dielectric surface was assumed to be at a finite temperature with the surroundings at zero temperature, i.e., all interacting surfaces were not in equilibrium at the same temperature.

Both Lifshitz and Henkel et al. extended the CP force to allow finite temperatures for the surface by specifying temperature dependent dielectric properties. But the temperature of the surface cannot be known without prior heat transfer analysis.

Without the ZPF, the CP force between an atom and surface at temperature was shown [14] to be approximated by the interaction of the polarizability of the atom in the gradient of the BB energy density emitted from the surface that at ambient temperature corresponds to far infrared (FIR) radiation. Unlike Casimir's plates, the FIR radiation is not enhanced by QED because the CP force lacks a gap for the EM confinement of kT energy of surface atoms.

In this paper, the FIR radiation given by the thermal kT energy of surface atoms in Casimir's plates is placed under EM confinement by the gap. Unlike the CP force, the FIR is frequency up-converted to produce QED photons in the gap the interaction of which with the polarizability of the surface atoms attracts the plates together. Temperatures are not specified through material properties, but rather determined from prior heat transfer analysis.

Fig. 1 depicts the gradient of the electric field of the standing QED induced photon interacting with the polarizability of surface atoms to produce an attractive force F_{BB} between materials 1 and 2.

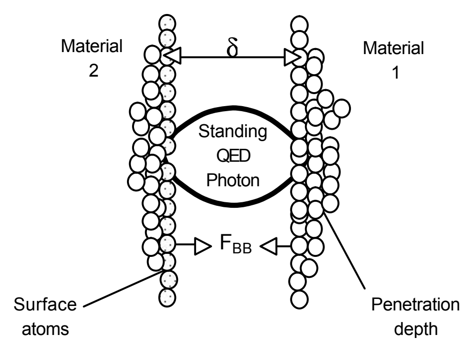

Fig. 1 BB Radiation Attractive Force F_{BB} from Polarizability of Surface Atoms under QED induced Radiation

III. THEORY

A. QM Restrictions

The quantum mechanical (QM) restrictions on the kT energy of the surface atoms depend on EM confinement. At 300 K, the Einstein-Hopf relation for the atom as a harmonic oscillator gives the QM restriction with wavelength λ as shown in Fig. 2.

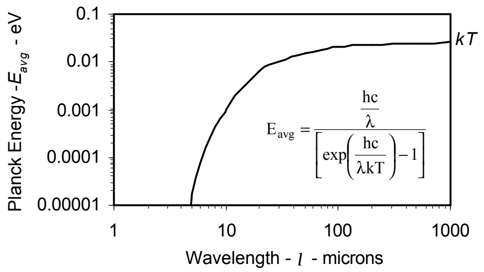

Fig. 2 Harmonic Oscillator at 300 K

QED photons induced by EM confinement may be understood from Fig. 2. For λ > 100 microns (G > 50 microns), the atom has heat content given by the kT energy. At gaps < 50 microns, the heat content decreases rapidly, and at VUV wavelengths < 0.2 microns is insignificant, and therefore conservation of excess kT energy by an increase in temperature does not occur. Conservation proceeds by EM emission that interacts with the polarizability of surface atoms to produce the BB force.

B. EM Confinement Frequencies

The EM confinement of thermal kT energy is analogous to creating photons of wavelength λ in a QM box with walls separated by λ/2. The EM confinement frequency f and Planck energy E_P,

$$f = \frac{c}{\lambda}, \quad \lambda = 2\delta, \text{ and } \quad E_P = \frac{hc}{2\delta} \tag{3}$$

IV. ANALYSIS

The EM force F induced [18] on an atom depends on the gradient of the EM energy density U and the atom polarizability α_o,

$$F = 4\pi\alpha_o \frac{\partial U}{\partial Z} \tag{4}$$

where, the EM energy density U induced from the EM confinement of kT energy is that of QED photons in having electric $\overline{E}$ and magnetic $\overline{H}$ fields,

$$U = \frac{1}{2}(\varepsilon \overline{E}^2 + \mu \overline{H}^2) \tag{5}$$

where, ε is the permittivity and μ is the permeability of the gap .

The QED photons are conserved by the total energy U_{kT} from the EM confinement of kT energy of surface atom groups on opposing plates,

$$U_{kT} = 2N_{atoms}kT \tag{6}$$

where, N_{atoms} is the number of sub-surface atoms depending on the penetration depth of the standing QED induced photon.

The EM energy density U is,

$$U = \frac{U_{kT}}{\delta^3} = \frac{2N_{atoms}kT}{\delta^3} \tag{7}$$

where, the volume of the EM energy in the gap is that of the standing QED photon having area δ^2 and height δ. For the Mat 1 surface in the X-Y plane, the EM energy density U of QED photons has a sinusoidal wave function in the Z direction,

$$U = \frac{2N_{atoms}kT}{\delta^3}\sin\left(\frac{\pi Z}{\delta}\right) \tag{8}$$

and depicted in Fig. 3.

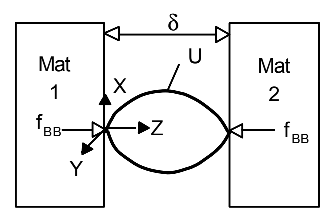

Fig. 3 Standing Group Pair QED Photon in Gap

The BB force f_{BB} induced in the group pair,

$$f_{BB} = 4\pi(\alpha_{o1} + \alpha_{o2})\frac{\partial U}{\partial Z} \tag{9}$$

where,

$$\frac{\partial U}{\partial Z} = \frac{2\pi N_{atoms}kT}{\delta^4}\cos\left(\frac{\pi Z}{\delta}\right)$$

and α_{o1} and α_{o2} are polarizability of surface atoms in Mat 1 and 2. The gradient U is positive at Z = 0 and negative at Z = δ giving an attractive force f_{BB} between pair groups. From Eqn. (4).

$$f_{BB} = \frac{8\pi^2}{\delta^4}N_{atoms}(\alpha_{o1} + \alpha_{o2})kT \tag{10}$$

The total blackbody F_{BB} force depends on the number N_{group} of group pairs in the plate surface area A and the cubic spacing Δ of atoms,

$$F_{BB} = N_{group} f_{BB} \tag{11}$$

where, $N_{group} = \frac{A}{\Delta^2}$

V. DISCUSSION

A. Comparison of BB and Casimir Forces

The Casimir force F_C between parallel flat plates is given by,

$$F_C = \frac{\pi hc}{240\delta^4} A \quad (12)$$

Experimental data [5] are found in reasonable agreement. At $\delta = 1$ micron and $A = 1$ cm^2, $F_C = 2.6 \times 10^{-7}$ N. Also, the Casimir pressure F_C/A is about 1 atmosphere at $\delta = 10$ nm.

In fact, the BB group force F_{BB} is comparable to the Casimir force F_C. At $\delta = 1$ micron, the gold and silicon plates having polarizability 6.1 and 5.4 $\times 10^{-30}$ m^3. The penetration depth [11] of 20 nm (or $N_{atoms} = 20/\Delta \sim 67$) for QED photons at VUV levels. Hence, the BB group pair force $f_{BB} \sim 2.5 \times 10^{-22}$ N. Over $A = 1$ cm^2, the number $N_{group} \sim 1.1 \times 10^{15}$ giving the BB force $F_{BB} \sim 2.8 \times 10^{-7}$ N that in addition to Casimir's theory is also consistent with experiment. Similar arguments show the BB pressure of 1 atmosphere at $\delta = 10$ nm is consistent with experiment.

B. Casimir Force and the ZPF

The Casimir force between parallel plates based on the thermal kT energy of surface atoms did not invoke the speculative ZPF. Therefore, measurements [4, 7-10] of the force in Casimir experiments cannot be taken as proof [6] of the ZPF or that the Casimir force [5] is a force from nothing.

C. Repulsive Casimir Force

In 2009, Munday et al. [19] reported experiments that suggested the attractive Casimir force between a gold coated sphere and a silicon plate may be made repulsive by immersion in bromobenzene.

Repulsion occurs because the bromobenzene scavenges the electrons removed by the QED photons leaving both surfaces with net positive charge. The electrostatic attraction by surface atom polarizability still occurs, but is offset by the repulsion from the positive charged plates.

VI. CONCLUSIONS

In 2004-5, the attractive Casimir force was shown to be reasonably estimated by the electrostatic force generated by photolysis from QED photons at VUV levels. Even though the QED photons charge the plates, a net attractive force between plates is unlikely. In 2009, Wannier-Mott and Frenkel excitons were shown to not span the gap across the plates, and therefore another mechanism is required to explain the attractive Casimir effect.

In this regard, the force measured in Casimir experiments is proposed caused by the polarizability of surface atoms interacting with the gradient of EM energy density in the gap by QED photons.

By immersing the plates in electron scavenger bromobenzene, the electrons removed in photolysis by QED photons produce net positive charged plates and a repulsive force. Polarizability induced attraction still occurs, but is offset by repulsion.

The BB attraction between Casimir's plates relying only on the thermal kT energy of surface atoms avoids the controversial ZPF. Similarly, the CP force between an atom and a surface as well as the van der Waals force between atoms is likely to find origin in BB radiation instead of the ZPF.

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