Repulsive Casimir Force?

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ABSTRACT: Casimir extended the short range van der Waals (vdW) force between atoms and molecules separated by a few angstroms to the attractive force between macroscopic bodies in a vacuum. However, recent experiments have suggested the Casimir force may be changed to repulsion by immersion in liquid bromobenzene. But this experiment not only falsely presupposes the Casimir force exists, but then extends that falsity to conclude the attractive Casimir force can be changed to repulsion. Indeed, the Casimir force is shown to not exist because Casimir did not conserve the electromagnetic (EM) radiation in the gap between the plates, for if he would have, Casimir would have found the frequency of the EM radiation increases as the gap decreases. At any instant during gap closure, conservation proceeds by the frequency up-conversion of EM radiation to the EM confinement frequency of the gap by quantum electrodynamics (QED). Hence, the force measured in the experiment has nothing to do with Casimir, but rather is electrostatic caused by the charging of the structures by the photoelectric effect from vacuum ultraviolet (VUV) radiation produced as the gap is decreased below 0.1 microns. The usual attractive force between gold and silicon structures in a vacuum is changed to repulsion upon immersion in bromobenzene because the latter is an electron scavenger that alters the charge distribution.

KEYWORDS: Casimir force, electrostatics

I. INTRODUCTION

In 1948, Casimir [1] formulated the attractive quantum electrodynamic (QED) force between a pair of electrically neutral metal plates in a vacuum in terms of the zero point energy (ZPE) of quantum mechanics (QM). Today, the ZPE more commonly called the energy of the vacuum remains controversial.

Casimir relied on Planck's derivation [2] of the law for blackbody (BB) radiation that included the ZPE. In terms of the average Planck energy E_{avg} of the harmonic oscillator,

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

where, ZPE = ½ hυ. Here, h is Planck's constant, υ is the oscillator frequency, k is Boltzmann's constant, and T is absolute temperature.

The ZPE is usually treated as a mathematical artifact of the blackbody (BB) radiation derivation and disposed of as non-physical because of the divergence of E_{avg} as the frequency υ approaches infinity.

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

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

and is used throughout this paper.

Spaarnay [4] presumably verified he 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 microns with an abrupt increase at about 0.1 micron. In these and many other Casimir experiments not reported here, the attractive Casimir force was found significant at separations below about 0.1 microns.

But why is the Casimir theory applicable to any gap only significant for gaps < 0.1 microns?

But answering this question on the attractive Casimir force may be premature because recent research has suggested the Casimir force may be made repulsive, and if so may require a different restriction on the size of the gaps other than < 0.1 microns.

In 2009, Munday et al. [11] reported experiments at Harvard suggested the attractive Casimir force between a gold coated sphere and a silicon plate may be made repulsive by simply immersing them in liquid bromobenzene provided once again the gap < 0.1 microns. Given the unresolved question of whether the attractive force that has been measured over the past 50 years is that predicted by Casimir or due to some other mechanism is not yet resolved, it is somewhat premature to conclude the attractive Casimir force may be changed to repulsion simply by immersing the structures in a liquid.

However, Munday et al. have claimed [11] the measured repulsive Casimir force is consistent with a generalized theory [12] for real materials by Lifshitz in 1956 and later extended [13] by Dzyaloshinskii et al. in 1961 called the Casimir-Lifshitz C-L theory.

The C-L theory claims a repulsive force occurs if the ordering of the permittivity of the materials: the gold coated sphere greater than bromobenzene which is greater than the silicon plate. By the C-L theory, the repulsive force works so that the bromobenzene is attracted into the gap thereby forcing them apart.

Paradoxically, the repulsive Casimir force derived by immersion in bromobenzene may disprove the C-L theory. Bromobenzene is an electron scavenger, and therefore any electron attachments found in the bromobenzene of the Harvard tests means the C-L theory that does not depend on charging of the gold coated sphere and silicon plate is held in question.

Of course, the argument could be made that the ZPE itself as a source of EM radiation charged the structures in the Harvard experiment. But the counter argument may be made that if the ZPE thought to exist throughout all of space is true, then the Universe should be filled with electrons. Obviously, the ZPE does not exist. Similarly, any electrons found in the Harvard experiment defeat the C-L theory.

Setting this difficulty with the ZPE aside, the purpose of this paper is:

To present an alternative to the C-L theory to
describe both attractive and repulsive Casimir forces.

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. Assuming Planck's ZPE [2] Casimir proceeded with a derivation of the force that balanced the excluded EM radiation.

However, there is a problem with Casimir's derivation. The EM radiation excluded from the gap does not lead to an unbalanced force because Nature requires the EM radiation to spontaneously adjust to adjust to gap changes by a change in frequency. Absent a frequency change, the plates would be attracted by the unbalance in EM radiation, but the response would not be instantaneous because of plate inertia. Casimir ignored the fact the excluded EM radiation is spontaneously conserved in the gap by a change in frequency instead of waiting for the plates to move to counter the excluded EM radiation. In effect, Casimir's mathematical derivation based on the ZPE is unphysical.

If Casimir would have conserved the EM radiation for all gaps G, he would have known 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.

But what are the attractive and repulsive forces
being measured in Casimir experiments?

What is being measured are electrostatic attractive and repulsive forces caused by the photoelectric effect from QED induced VUV radiation. Unlike stray charges that are removed by touching [5] of mirrors, the QED forces cannot be removed and heretofore have been erroneously interpreted as Casimir forces.

Since the photoelectric effect requires VUV radiation having wavelength $\lambda < 0.2$ microns, the earlier question posed of why the measured Casimir forces are only significant at gaps $G < 0.1$ microns is answered. To wit, the plates are charged spontaneously by the photoelectric effect from VUV radiation when the gap $G < \lambda/2 = 0.1$ microns..

The source of the electrostatic force is the EM thermal kT radiation from the atoms in the surfaces of the plates, which at ambient temperature corresponds to low-frequency radiation in the far infrared (FIR). Photoelectric charging requires the FIR to be induced by QED to undergo frequency up-conversion to VUV levels as the gap G closes to $G < 0.1$ microns, the process called QED induced EM radiation.

In 2004 -5, Prevenslik [14, 15] showed the Casimir force did not exist because Casimir did not conserve EM energy in the gap G between the plates. Instead, the attractive QED induced electrostatic force based on the photoelectric effect was shown to reasonably estimate the measured Casimir force.

In this paper, the attractive QED force is extended to explain the repulsive force [11] between the gold sphere and silicon plate upon immersion in liquid bromobenzene. Fig. 1 depicts QED induced EM radiation in the Casimir effect for solid materials 1 and 2 separated by a liquid 3.

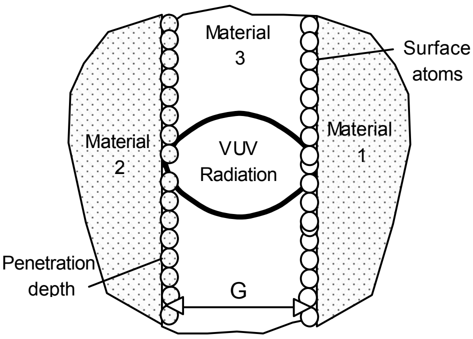

Fig. 1 Casimir Effect
QED Induced Attraction and Repulsion

The theory by which QED induced attractive and repulsive electrostatic forces are produced is described as follows.

III. THEORY

A. QM Restrictions

The kT energy of the surface atoms in Casimir's plates is restricted by QM depending on the EM confinement. At 300 K, the Einstein-Hopf relation [16] for the atom as a harmonic oscillator gives the QM restriction with wavelength λ as shown in Fig. 2.

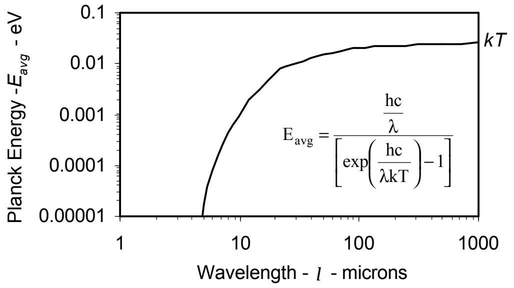

Fig. 2 Harmonic Oscillator at 300 K

The Casimir effect at gaps < 0.1 microns can be understood from Fig. 2. For λ > 100 microns (G > 50 microns), the kT energy of the atoms is emitted in the FIR. At gaps < 50 microns, the kT energy decreases rapidly, and at VUV wavelengths < 0.2 microns is insignificant. Hence, atoms in plate surfaces with gaps < 50 microns cannot conserve any EM radiation by an increase in temperature. Instead, conservation proceeds by EM emission. However, only the EM radiation in the VUV is important for the photoelectric charging. Hence, the Casimir effect only occur at gaps < 0.1 microns.

B. EM Confinement Frequencies

For gaps G < 0.1 microns, the EM confinement of material 3 is analogous to creating photons of wavelength λ in a QM box with walls separated by λ/2. For refractive index n_r, the EM confinement frequency f and Planck energy E_P,

$$f=\frac{c}{\lambda},\quad \lambda=2n_rG\text{ , and }\quad E_P=\frac{hc}{\lambda}=\frac{hc}{2n_rG} \qquad (1)$$

The Planck energy E_P and wavelength λ for bromobenzene having refractive index $n_r = 1.559$ and the vacuum are plotted in Fig. 3. The Planck energy $E_P \sim 5$ eV at G ~ 0.08 microns is consistent with the photoelectric effect for G < 0.1 microns.

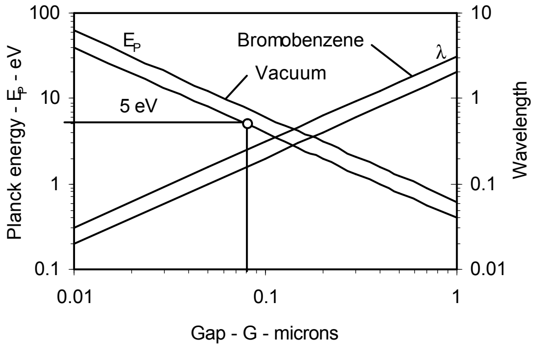

Fig. 3 Casimir Effect
QED induced Planck energy E_P and wavelength λ

IV. ANALYSIS

The QED induced VUV radiation produced in the gap G irradiates solids 1 and 2 with a number N_{VUV} of VUV photons. Depending on yields Y_1 and Y_2, the photoelectric effect produces positive charges q_1 and q_2 as depicted in Fig. 4.

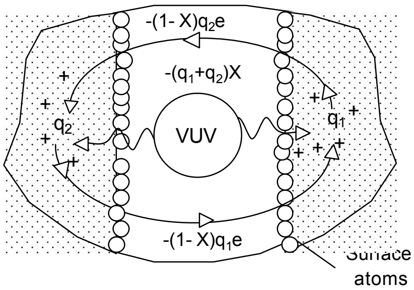

Fig. 4 Charging Configuration
Charges Q_1, Q_2, Q_3 and Electron yields Y_1,Y_2
X is the fraction of electrons captured in material 3.

For material 3 as a vacuum, the net charges Q_1 and Q_2 depend on electrons removed from material 1 all attaching to material 2, and vice versa. But if material 3 is an electron scavenger like bromobenzene, the charge Q_3 depends on some electrons e being absorbed or lost to the bulk [17] by diffusion. Calling X this fraction,

$$Q_3=-(q_1+q_2)Xe \qquad (6)$$

Hence, Q_3 does not appear in the net charge. The Q_1 and Q_2 charges produced in materials 1 and 2,

$$Q_1=q_1-(1-X)q_2e \quad\text{and}\quad Q_2=q_2-(1-X)q_1e \quad (7)$$

where, $q_1=N_{VUV}Y_1$ and $q_2=N_{VUV}Y_2$

The QED induced electrostatic force F_{QED} is,

$$F_{QED} = \frac{Q_1 Q_2}{4\pi\varepsilon_r\varepsilon_o G^2} \tag{8}$$

where, ε_r and ε_o are the relative and vacuum permittivity of material 3. The Q_1Q_2 product for an arbitrary charge distribution of $q_1 = 10e$ and $q_2 = 5e$ is shown in Fig. 5. The QED force F_{QED} is attractive for $X < 0.5$ and otherwise repulsive.

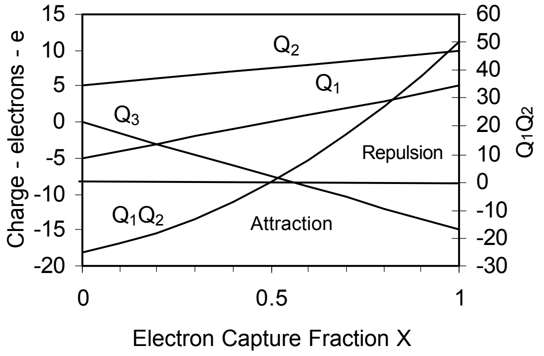

Fig. 5 QED Force and Charge Distribution
Charge $q_1 = 10e$ and $q_2 = 5e$

The QED force F_{QED} for fixed $q_2 = 5e$ is plotted for various q_1 in Fig. 6. The Q_1Q_2 product for $q_1 = 10e$ and 20e is observed to be attractive for $X < 0.5$ and 0.65. For $q_1 = 1e$, the crossover between attraction and repulsion is broad from $X < 0.75$ and 0.82.

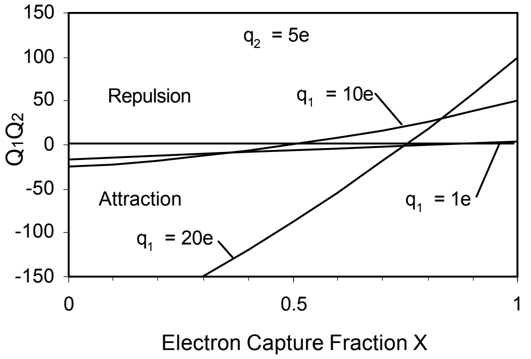

Fig. 6 QED Attractive and Repulsive Force
Charge q_1 = 1, 10, and 20e for $q_2 = 5e$

V. CONCLUSIONS

In 2004-5, the attractive Casimir force shown to be reasonably estimated by the QED electrostatic force is shown here to at least conceptually produce repulsive force if the liquid in the gap is an electron scavenger such as bromobenzene.

Electron scavenging was treated through a capture parameter to show how the usual attractive QED force at zero scavenging becomes repulsive as the scavenging increases. However, experimental data is lacking to support this conclusion at this time.

Consistent with observation, electrostatic forces rely on QED induced VUV radiation that requires gaps < 0.1 microns. Casimir and C-L theories lack the gap threshold cannot therefore be correct.

The C-L theory claims that liquid bromobenzene is attracted into the gap between the solids thereby forcing them apart or the ordering of permittivity has nothing to do with repulsion.

QED theory that depends on photoelectric yield suggests the quest for frictionless contact in MEMS devices should be directed to zero yield materials.

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