Blackbody Radiation supersedes the Zero Point Energy in Casimir-Polder forces

The Casimir–Polder (CP) interaction between atoms and surfaces based on the speculative zero point energy (ZPE) of the vacuum is superseded by real thermal blackbody (BB) radiation

Feb. 28, 2009 - *PRLog* **-- Background** In 1948, Casimir derived the attractive force between a pair of electrically neutral metal plates in a vacuum based on the ZPE for the electromagnetic (EM) field, sometimes called the zero point fluctuations (ZPF) of quantum mechanics (QM). The ZPF is the EM field equivalent of the ZPE of lowest quantum state of a discrete QM system, e.g., the ground state of a molecule.

But the ZPF is controversial. W. Pauli once said that the ZPE should not be extended to the ZPF because it gives rise to an unphysical infinite energy per unit volume of the vacuum. Nevertheless, the ZPF is widely used through physics and forms the basis for the explanations of various phenomena.

If the ZPF is unphysical, then it follows that areas of physics which have been heretofore explained by the ZPF may be explained by other mechanisms. One such example is the CP force between an atom and a surface. Instead of the speculative ZPF, the BB radiation from the surface may provide the other mechanism by which a BB force is produced that otherwise is equivalent to the CP force.

Indeed, the ZPF may have unnecessarily misled research on atom forces. EM radiation of any kind may produces forces on an atom instead of the ZPF. Laser are used manipulate atoms, but of interest here is whether natural sources of EM radiation can provide an alternative to the ZPF. BB radiation is such a natural radiation, but has been neglected to date. This is unfortunate because unlike the ZPF which is quite speculative, the existence of BB radiation is undeniable.

Current CP Methodology

Lifshitz extended the ZPF to allow finite temperatures to be included in the CP force by specifying temperature dependent dielectric properties for the surface. For separations larger than the thermal photon wavelength hc/kT, the Lifshitz force decays by 1/z4 and is proportional to temperature. Here, h is Planck’s constant, c is the speed of light, k is Boltzmann’s constant, and T is absolute temperature.

Later, Henkel et al. extended the thermal equilibrium theory of Lifshitz to non-equilibrium (NEQ) temperatures, i.e., the dielectric surface was assumed to be at a finite temperature with the surroundings at zero temperature. NEQ means all interacting surfaces are not at the same temperature. Only the force at submicron separation was studied.

Recently, Antezza et al. extended the NEQ interaction of atoms with a surface. Depending on whether the temperature of the surface is different than that of the surroundings, the attractive force decayed by 1/z3 at thermal photon wavelength separations and could even be repulsive. Measurements of rubidium atoms interacting with quartz surfaces using the Bose-Einstein Condensate (BEC) method by Obrecht et al. was found in agreement with the NEQ theory..

Problems with the CP Methodology

Lifshitz extended the CP force to allow finite temperatures for the surface by specifying temperature dependent dielectric properties. The same methodology is followed in subsequent CP studies by Henkel et al. and Antezza et al. Except by assumption, the temperature of the surface cannot be known without prior heat transfer analysis. Moreover, specifying the temperature dependent properties of the dielectric has nothing to do with the source of the CP force because the surface temperature depends on the heat transfer properties of thermal conductivity, specific heat, and density.

New Approach to the CP Force

Instead of the ZPF, the derivation of the force on the atom based on EM thermal BB radiation from the surface would allow the force on the atom to be determined along with the surface temperature in the heat transfer analysis. The advantage of this approach is that the heat transfer of the temperature response of the surface to arbitrary thermal loading can be followed by common finite element programs.

Results

The BB force at separations of the atom from the surface of a few microns was found to upper bound the CP force. Over the z = 6 to 14 micron range, the BB forces at 310, 479, and 605 K are observed to be about 2 orders of magnitude greater than the CP forces. The NEQ force for the surface at 605 K and surroundings at 310 K was found higher than all others. For the surface at 605 K and surroundings at 0 K, the NEQ forces tend to approach the BB force at 605 K. See “Blackbody Radiation Forces”, at www.nanoqed.net

Conclusions

Without any loss in accuracy, the CP and vdW forces between atoms and surfaces at separations beyond 6 microns are superseded by BB forces. Both BB and CP forces decay by 1/z, but the speculative ZPF is not used. However, the CP and vdW force between atoms at submicron separations exceeded the BB force.

Extensions to vdW Forces

The fundamental assumption in the derivation of the BB forces was that the location of the atom from the surface did not cause any distortion of the thermal BB radiation field at temperature. Excluded was the QED induced EM radiation that tends to increase the frequency of the BB radiation for separations less than a micron. Further study is required to derive the CP and vdW forces that include the QED effect on the BB radiation emission from atoms at submicron separations.

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About QED Indcued EM Radiation: Classically, thermal EM radiation conserves heat by an increase in temperature. But at the nanoscale, temperature increases are forbidden by quantum mechanics. QED radiation explains how heat is conserved by the emission of nonthermal EM radiation.

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