The Quantum Vacuum and the Casimir Effect

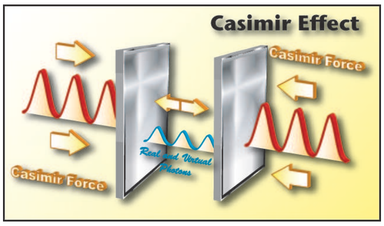

Figure 1: *Original geometrical configuration used by H.B.G. Casimir in 1948. Two flat plan parallel mirrors, which are facing each other in quantum vacuum, are attracted to each other. For two mirrors with a surface of 1cm^2, separated by a distance of 1μm, it equals 0.1μN.*

The Casimir force is maybe the most accessible experimental consequence of vacuum fluctuations in the macroscopic world and the study of the vacuum properties effect is relevant in different areas of physics, ranging from quantum gravity, condensed matter, up to nano-tecnology.

In the last years several experiments dealt with the measurement of this force reaching a high precision that allows to confirms the main theoretical predictions. For this reason the Casimir effect has recently been the object of a renewed interest both from theoretical and experimental point of view.

The aim of my Short Visit period in the American Laboratories was to analyze and work on some charactheristic features of the Casimir effect. In particular I analyzed some issues connected with the geometry of the system under study, new materials properties (metamaterials) and the strong connection between the Casimr Effect and the manipulations of ultracold atoms.

This work has been performed in three different places

- **Theoretical Division, Los Alamos National Laboratory (LANL)**

  The work was performed in collaboration with Diego Dalvit. We focus our attention on the two following particular topics.

  First of all we discussed about the plasmonic contribution to the Casimir effect. Indeed, in the case of a plane-plane geometry I proved that the plasmonic modes contribute to the Casimir force in a non-intuitive way, leading to the possibility to tailor the Casimir force if we were able to control their behavior. Dr. Dalvit has recently calculated the Casimir effect in other geometries like the cilinder-cilinder or plane cilinder one and we discussed on the possibility to calculate the plasmonic contribution this case. We also focus our attention on the possibility to study the crossover to repulsive Casimir force exploiting the recent advancement in the fabrication of artificial materials. Indeed, a repulsive force has been predicted for idealized magnetodielectric. Nowadays it is possible to build metamaterials with a tailored magnetic and dielectric characteristics from arrays of current-conducting elements, such as loops of wire. In order for these structures to modify the Casimir force in the micron range, the artificial material must have nanoscale spatial features that modify its magnetic-dielectric response in the visible range. Very recently in it has been experimentally put in evidence that one of this metamaterials, a nano-fabricated medium consisting of coupled pair of gold dots, exhibits a strong magnetic response at visible-light frequencies, including a band with negative magnetic permettivity. The very interesting fact is also that this behavior arise owing to the excitation of an antisymmetric plasmon resonance. From one side this means that a modification of the Casimir force could be realistic and from the other side this confirms the importance of the role of the plasmons. Basically we could say that in this case metamaterials and plasmonic manipulation are two faces of the same coin. Even if repulsion cannot be achieved in a first step this studies allows us to think that the Casimir attraction could be strongly reduced with a great advantage in preventing sticking phenomena. Diego Dalvit has recently started a collaboration with an experimetal group at the LANL to measure the Casimir force using BEC. The aim is to use a BEC to experimentally probe the modification of the force using nanostructered materials.

- **Department of Physics and Astronomy,Dartmouth College (Hanover, NH)**

  At the Darthmouth College my referent was Prof. Roberto Onofrio. With D. Dalvit, Roberto Onofrio has recently presented a proposal aiming at measuring the Casimir force in the cylinder-plane configuration. During may stay we longly discussed on the experimental issues and the several advantages that this configuration presents respect the plane-sphere one (the most used in the recent experiment). One for all, it allows for a stronger signal, which could allow a better theory-experiment comparaison. In parallel Prof. Onofrio carries an experiment on BEC. We discussed about the cooling efficiency for different-species Fermi-Bose mixtures in magnetic traps. A better heat capacity matching between the two atomic species is achieved by a proper choice of the Bose cooler and the magnetically trappable hyperfine states of the mixture. When a partial spatial overlap between the two species is also taken into account, the deepest Fermi degeneracy is obtained for an optimal value of the trapping frequency ratio between the two species. This can be achieved by assisting the magnetic trap with a deconfining light beam.

- **Center for Theoretical Physic Massachusetts Institute of Technology (MIT)**

  In recent years, R. Jaffe and collaborators have been developing analytical and computational tools for the study of quantum vacuum energies - Casimir energies - with applications to problems ranging from micromachinery to beyond the Standard Model. Recently they find the exact solution for a rectangular cross section. They showed that the claims of repulsive Casimir forces for related configurations, like the cube, are invalidated by cutoff dependence.

  With Prof. Jaffe we discussed about the amazing behavior of the plasmonic contribution to the Casimir energy. As shown in some previous papers, the contributions of plasmonic modes dominates the Casimir effect for small separations corresponding to Coulomb interaction between surface plasmons. However, plasmonic modes will turn out to have a much greater importance than usually appreciated. Contrary to naive expectations, they are found not to vanish for large separations. For distances larger than about $\lambda_p/4\pi$ ($\sim$10nm for typical metals) they even give rise to a contribution having simultaneously a negative sign and a much too large magnitude with respect to the Casimir formula. The repulsive character can be attributed to one of the two plasmonic modes. Despite this result the physical reason of this behavior is not still totally clear. We found out that the responsible of the change in sign could be the density of states and some calculation are in progress.

All the results of those collaborations are going to be published.