The Casimir effect: Theory, Experiments and Possible Applications

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The immersion of bodies of material into a medium changes its fluctuation spectrum which has to be in accord with the geometry and relative positions and orientations of the bodies as well as with their material properties. If these fluctuations are correlated, the dependence of their spectrum on the relative positions of the bodies generates effective force acting between them. The existence of such a force is called the ***Casimir effect***, while the force itself is called the ***Casimir force,*** after the Dutch physicist Hendrik Casimir who first in 1948 predicted the existence of an attractive force between two perfectly conducting, parallel metallic plates in vacuum. According to the contemporary understanding, the Casimir effect is a phenomenon common to all systems in which the interaction of their macroscopic parts is mediated by a fluctuating field. If the fluctuating field is the electromagnetic one, one addresses the *quantum mechanical Casimir effect,* which was convincingly verified experimentally for the first time half a century later in 1997 by Lamoroux. In the case of the fluctuating field of an order parameter describing a continuous phase transition of a many-body system one deals with the so-called *thermodynamic* or *critical Casimir effect*. In this latter form the effect was first discussed by Fisher and de Gennes in 1978 theoretically and directly experimentally verified in 2008 by C. Hertlein, L. Helden, A. Gambassi, S. Dietrich, and C. Bechinger. In 2011 the first experimental observations of the so-called *dynamical Casimir effect,* which was initially theoretically suggested by G. T. Moore in 1970, have been reported by C. Wilson, G. Johansson, A. Pourkabirian, J. Johansson, T. Duty, F. Nori, and P. Delsing.

According to the contemporary understanding, the Casimir effect is a phenomenon common to all systems in which the interaction of their macroscopic parts is mediated by a fluctuating field. The Casimir effect today is a subject of investigations in condensed matter physics, quantum electrodynamics, quantum chromodynamics, cosmology, as well as in emerging new areas such as nano-mechanics and the performance of nano-machines.

While tiny for normal distances the Casimir force becomes of the order of 1 atm for distances of the order of 10 nm. Thus it influences the work of the nano-machines. In all the experiments performed it is a force of attraction between any two bodies in a steady state in vacuum and can be a force of attraction or repulsion if they are separated by a fluid.

In the current talk a small overview of the state of the art in studying the Casimir effect will be presented. The last part of the talk will be devoted to two recent my articles related to the problem.

In the first one, D. Dantchev and G. Valchev, J. Coll. Int. Science 372 (2012) pp.148–163, together with G. Valchev we present *a new approach, which can be considered as a generalization of the Derjaguin approximation,* that provides exact means to determine the force acting between a three-dimensional body of any shape and a half-space mutually interacting via pairwise potentials. Using it, in the cases of the Lennard-Jones, standard and the retarded (Casimir) van der Waals interactions we derive exact expressions for the forces between a half-space or a slab of finite thickness and an ellipsoid in a general orientation, which in the simplest case reduces to a sphere, a tilted fully elliptic torus, and a body obtained via rotation of a single loop generalized Cassini oval, a particular example of which mimics the shape of a red blood cell. The results are obtained for the case when the object is separated from the plane via a non-polar continuous medium that can be gas, liquid or vacuum. Specific examples of biological objects of various shapes interacting with a plate like substrates are considered.

In the second one, J. Bergknoff, D. Dantchev, and J. Rudnick, Phys. Rev. E 84 (2011) 041134, together with J. Bergknoff and J. Rudnick, we investigate the three-dimensional lattice XY model with nearest neighbor interaction. The vector order parameter of this system lies on the vertices of a cubic lattice, which is embedded in a system with film geometry. The orientations of the vectors are fixed at the two opposite sides of the film. The angle between the vectors at the two boundaries is α where $0 \le \alpha \le \pi$. We make use of the mean field approximation to study the mean length and orientation of the vector order parameter throughout the film—and the Casimir force it generates—as a function of the temperature T, the angle α, and the thickness L of the system. Among the results of that calculation are a Casimir force that depends in a continuous way on both the parameter α and the temperature and that *can be attractive or repulsive*. In particular, *by varying α and/or T one controls both the sign and the magnitude of the Casimir force in a reversible way*. Furthermore, *for the case $\alpha=\pi$, we discover an additional phase transition occurring only in the finite system* associated with the variation of the orientations of the vectors.