

Direct measurement of critical Casimir forces

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Critical Casimir Forces in Colloidal Suspensions on Chemically Patterned Surfaces

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In 1948 Casimir predicted an attractive force between two neutral conducting plates arising from quantum fluctuations of the electromagnetic (EM) field in the intervening space [1]. In an equivalent dual perspective, the force is due to coordinated fluctuations of sources (charge dipoles and current loops) on the plates. Casimir's prediction has served as a signpost for fluctuation-induced interactions manifested in a wide range of physical situations. For example, one can inquire about the thermal fluctuations in a fluid placed between two plates. The changes in free energy of the fluid due to confinement again lead to an interaction between plates with overall strength set by temperature $k_B T$ (as opposed to $\hbar c$ in the quantum EM case). The range of the interactions is, however, limited by the correlation length in the fluid, which is typically small.

In 1978, Fisher and de Gennes [2] pointed out that long-range interactions can be obtained with thermal fluctuations by tuning to a critical temperature with infinite correlation length. This so-called critical Casimir force has a universal amplitude that is independent of microscopic details, and set by symmetry considerations (much like a critical exponent).¹ However, only within the last decade experiments on wetting films of binary fluids close to criticality [4], and helium near the superfluid transition [5], have enabled quantitative comparisons with theory.

The above Nature article by researchers in Stuttgart represents a significant advance by providing direct comparisons of measurement and theory for the critical Casimir force. Colloidal particles (of size around $2\mu\text{m}$) are placed in a mixture of water and oil (lutidine 2,6), which has an inverted critical (demixing) point at $T_c \approx 307\text{K}$ and $c_c^l \approx 0.286$. As the mixture with critical composition is heated towards T_c , the correlation length (and hence the range of fluctuation-induced interactions) increases strongly. Positions of the colloidal particles above a substrate are monitored at each temperature, and the observed distributions are used to infer (via Boltzmann weights) the interaction potential. The rapid changes in the inferred potential upon approaching T_c must be related to the increasing correlation length of collective concentration fluctuations.² The agreement between the interactions obtained from the experiment (as a function of $T_c - T$, and position) and the theoretical computations is quite remarkable.

¹Long-range correlations are also present away from a critical point in liquid crystals and superfluids due to Goldstone modes, and lead to similar Casimir forces [3].

²In the EM analogy, tuning away from the critical point would be like adding mass to the photon!

The second paper above employs the same setup as a means of assembling and manipulating colloidal particles. A key feature of critical Casimir forces—exploited to this end—is that the interaction can be attractive (if the two surfaces prefer the same component of the mixture) or repulsive (if they prefer different components). In one case the researchers pattern the substrate with alternating stripes of hydrophobic and hydrophilic chemicals. Away from the critical point the colloidal particles are distributed uniformly over the substrate. Upon approaching T_c the spatial variations of the emerging critical Casimir potential lead to lateral forces [6] which organize the particles along the stripes. In another demonstration, the particles are reversibly assembled/disassembled into a square pattern by changes in temperature. At higher densities the interactions between colloidal particles become important, causing them to self-organize into ordered monolayers.

For quite a while, critical Casimir forces have provided a fertile playground for theoretical analysis and rumination. The above papers have quickly moved the subject into the realm of practical applications. The ability to control the sign of the interaction (by making hydrophobic or hydrophilic surfaces), and to reversibly tune its strength (by moving around a critical point) should provide many opportunities for manipulating and organizing particles on scales of micrometers and smaller.

References

- [1] H.B.G. Casimir, Proc. K. Ned. Akad. Wet. **51**, 793 (1948).
- [2] M.E. Fisher and P.G. de Gennes, C. R. Acad. Sci. Ser. B **287**, 207 (1978).
- [3] M. Kardar and R. Golestanian, Rev. Mod. Phys. **71**, 1233 (1999).
- [4] A. Mukhopadhyay and B.M. Law, Phys. Rev. Lett. **83**, 772 (1999); M. Fukuto, Y.F. Yano, and P.S. Pershan, Phys. Rev. Lett. **94**, 135702 (2005).
- [5] R. Garcia and M.H.W. Chan, Phys. Rev. Lett. **83**, 1187 (1999); R. Garcia and M.H.W. Chan, Phys. Rev. Lett. **88**, 086101 (2002); A. Ganshin, S. Scheide-mantel, R. Garcia, and M.H.W. Chan, Phys. Rev. Lett. **97**, 075301 (2006).
- [6] The lateral QED Casimir force between modulated plates was theoretically predicted in R. Golestanian and M. Kardar, Phys. Rev. Lett. **78**, 3421 (1997), and experimentally demonstrated in F. Chen, U. Mohideen, G.L. Klimchitskaya, and V.M. Mostepanenko, Phys. Rev. Lett. **88**, 101801 (2002). Theoretical work on lateral critical Casimir forces is presented in M. Sprenger, F. Schlesener, and S. Dietrich, J. Chem. Phys. **124**, 134703 (2006); and M. Troendle, S. Kondrat, A. Gambassi, L. Harnau, and S. Dietrich, arXiv: 0903.2113.