Thermodynamic Casimir effect in isotropic and anisotropic systems

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In 1948, Casimir predicted the existence of an attractive force between two conducting plates resulting due to quantum fluctuations of electromagnetic field in the vacuum. Since that time, investigations of long-range fluctuation-induced forces in constrained systems attracted enormous interest. The Casimir effect has been associated with very different phenomena ranging from sticking of parts in nanoscale devices through the quantum levitation to cosmologic problems and reaching faster-than-light velocities.

The present communication addresses the theoretical treatment of a thermodynamic version of this effect induced by long-range nearly-critical fluctuations, performed in collaboration with M. Burgsmüller, H. W. Diehl, and D. Grüneberg from the Duisburg-Essen University.

In d dimensional slabs of isotropic systems, at bulk critical point the effective forces between boundaries decay as $\propto \Delta L^{-\lambda}$ with $\lambda = d$ for large thickness L. We showed that the usual $\varepsilon = 4 - d$ expansion of universal Casimir amplitudes Δ breaks down beyond first order when periodic or Neumann-Neumann boundary conditions (BC) are applied to the confining surfaces. We explicitly obtained non-analytic corrections $\propto \varepsilon^{3/2}$ preceding the usual $O(\varepsilon^2)$ term and predicted the integer powers of $\ln \varepsilon$ in higher-order contributions.

Strongly anisotropic systems (SAS) exhibit special features. They have (at least) two distinct correlation lengths parallel and perpendicular to the anisotropy axes related via $\xi_\| \sim \xi_\perp^\theta$ where the anisotropy index $\theta \neq 1$. Hence in film geometries, boundaries of different orientations with respect to these intrinsic directions produce different effects. The Casimir-like forces behave as $\propto \Delta_{\|,\perp} L^{-\lambda_{\|,\perp}}$ with different universal amplitudes, decay exponents, and nonuniversal prefactors. For m-axial SAS we found $\lambda_\| {=} d{-}m{+}\theta m$ and $\lambda_\perp {=} (d{-}m)/\theta{+}m$. We calculated the amplitudes $\Delta_{\|,\perp}$ for anisotropic slabs with periodic and free BC at bulk Lifshitz points in the Gaussian approximation, $\epsilon{=}4{+}m/2{-}d$ expansion, and spherical limit. In two special cases we reproduce the earlier results for smectic liquid crystals in film geometries of different orientations.