Optical Trapping and Critical Casimir Forces

Agnese Callegari*a, Alessandro Magazzùb, Andrea Gambassicd, Giovanni Volpea

aDepartment of Physics, University of Gothenburg, 41296 Gothenburg, Sweden; bCNR-IPCF, Istituto per i Processi Chimico-Fisici, Messina, Italy; cSISSA – International School for Advanced Studies, 34136 Trieste, Italy; dINFN, Sezione di Trieste, 34136 Trieste, Italy

ABSTRACT

Critical Casimir forces emerge between objects, such as colloidal particles, whenever their surfaces spatially confine the fluctuations of the order parameter of a critical liquid used as a solvent. These forces act at short but microscopically large distances between these objects, often reaching hundreds of nanometers. Keeping colloids at such distances is a major experimental challenge, which can be addressed by the means of optical tweezers. Here, we review how optical tweezers have been successfully used to quantitatively study critical Casimir forces acting on particles in suspensions. As we will see, the use of optical tweezers to experimentally study critical Casimir forces can play a crucial role in developing nanotechnologies, representing an innovative way to realize self-assembled devices at the nano- and microscale.

Keywords: Critical Casimir forces, optical trapping, colloids

1. INTRODUCTION

The Casimir effect consists of the attraction between two identical, parallel, uncharged, metallic plates placed in vacuum, at zero temperature and at a short distance from each other and is due to the quantum vacuum fluctuations of the electromagnetic field spatially confined between the two plates [1].

In soft matter systems, Casimir-like forces can be observed whenever a fluctuating field is spatially confined by the presence of objects. In particular, they may arise between bodies suspended in a critical binary mixture close to its critical point [2]. One of the model systems used to study critical Casimir forces is a diluted suspension of colloidal particles in a binary mixture of water and 2,6-lutidine at its critical concentration [3]. When the separation between the suspended particle and the substrate (or between two suspended particles) is comparable with the correlation length of the concentration fluctuations of one of the component of the critical mixture, then the fluctuations are confined and critical Casimir forces arise between the bodies [4]. Critical Casimir forces can be attractive or repulsive depending on the adsorption preferences of the surface of the confining bodies. They can be switched on and off, and tuned, by controlling the temperature of the critical mixture. This feature makes them a particularly suitable candidate to help counteract stiction between microscopic parts in micro- and nanoelectromechanical devices due to the Casimir-Lifshitz forces [5], which are the analogue of quantum Casimir forces at finite temperature and in material media, and are commonly attractive.

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nanometers. Keeping colloids at such distances is a major experimental challenge, which can be addressed by the means of optical tweezers [6–8] (see Fig. 1). Optical tweezers are well-established tools for trapping and manipulating micro and nano-particles suspended in liquids using light, capable of nanometric precision as well as of force measurements with femtonewton resolution [9, 10]. The classical optical tweezers is realized by focusing a laser beam through an high numerical aperture objective [6].

Here we focus on the investigation of critical Casimir forces using optical tweezers [11] describing the main experiments that have been performed in the last decade and concluding with some perspective.

2. OPTICAL TRAPPING TO STUDY CRITICAL CASIMIR FORCES

Optical tweezers has been used by Hertlein et al [12] for the direct measurement of the critical Casimir interaction between a colloidal particle and a substrate. Holographic optical tweezers [7, 8], obtained by shaping the phase of a laser beam with a spatial light modulator before focusing it through the high numerical aperture objective, has been employed for the study of critical Casimir forces between colloids [13, 14, 16].

To quantify the interaction between particle and substrate (or between two particles) as a function of their separation distance, we trap a particle at the desired distance, and allow the particle to explore the surrounding of its equilibrium positions to map the total potential around the equilibrium position [12, 15]. In the case two or more colloids are involved [13, 14], multiple traps are obtained by holographic optical trapping.

The direct measurement of the critical Casimir interaction comes from the independent measurement of the total potential, of the optical potential, and of other interactions (e.g., the electrostatic interaction) between a colloidal particle and a substrate [12], or between colloids in the bulk [13]. Tunability from attraction to repulsion as a function of the adsorption properties of the substrate has been shown in Ref. [15], while Ref. [13] provides the experimental evidence of non-additivity for critical Casimir forces, i.e., the emergence of many-body effects [17]. Critical Casimir forces have been shown capable to induce synchronisation in the motion of a pair of colloids immersed in a binary liquid mixture close to the critical temperature [16], hence allowing the transfer of energy between colloids. By employing a blinking optical tweezers, the effect of the critical Casimir forces on the dynamics of colloidal particles has been measured [14]. Recent results on the successful use of tunable repulsive critical Casimir forces to counteract Casimir-Lifschitz attraction [5] could be combined with optical manipulation techniques to gain further control in the development of micro- and nanoelectromechanical devices capable of self-adjusting and prevent stiction between their parts.

![Figure 1](image-url)
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