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Magnetic field effects in the Casimir force between two parallel anti-ferromagnetic slabs

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Abstract

We study the Casimir force F between two parallel anti-ferromagnetic slabs taking into account an external magnetic field in the Voigt configuration. Using a frequency and magnetic field dependent magnetic permeability tensor and a frequency independent dielectric permittivity, to describe the slabs, we calculate the Casimir force using non-normal incidence reflectivity of the electromagnetic waves in the free space between the slabs. We determine the Casimir force by performing two-dimensional calculations. F is investigated as a function of the layer thickness d, the vacuum gap width L between slabs, and the external magnetic field strength H. Features of F as function of the external field include the presence of sharp dips and peaks, which appear in the vicinity of the resonance frequency, and are consequences of the interaction of the external magnetic field with the electron spin. In addition, an external field may diminish F, which is an important effect not found in any other system.

Keywords: Casimir force; Anti-ferromagnetic slabs; Reflectivity; Magnetic field; Magnetic permeability; Dielectric permittivity

1. Introduction

In 1948 H. Casimir [1] predicted the existence of an attractive force between parallel slabs made up of perfect conductors. This force, termed as the *Casimir force*, is a consequence of the fluctuations of the electromagnetic energy in vacuum, and in the presence of surfaces. In recent years the force has been extensively studied. For instance, high precision measurements [2–5]

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of the force have been reported lately. The accuracy of the experiments demands a complete characterization of the optical response of materials. Optical properties may be described by the dielectric permittivity and magnetic permeability functions. Until now, a frequency dependent dielectric function $\varepsilon(\omega)$ [6] or a frequency and wave vector dependent dielectric function $\varepsilon(\omega, \vec{k})$ [7,8] has been used. However, several factors can influence the optical response of the system, such as the presence of external fields. Previously, Esquivel [6] studied plasmon effects on the Casimir force F using a local dielectric model of metals. Kats [9] made a qualitative estimate of the change in F due to the anomalous skin effect. However, nobody has addressed studies of the external magnetic field effects on the Casimir force. As it stands, it should be an interesting subject to explore such an effect on parallel slabs geometries, taking into account applied magnetic fields.

In the last few years researchers have devoted time to investigate the possible applications of the Casimir effect. Batra et al. [10] have analyzed pull-in instabilities of electrostatically actuated micro-electromechanical systems. Models of the deformable conductor consist in an elastic membrane in different geometries. Results show that beyond a certain critical size the pull-in instability occurs with zero applied voltage and the device may collapse during the fabrication process. The stability problem in micro- and nano-electromechanical devices, actuated by Casimir forces was recently explored by Sirvent et al. [11]. To enhance the stability of the system, authors proposed the use of curved surfaces to calculate the stability condition through the proximity force approximation. The radius of the curvature resulted as the control parameter. The influence of the Casimir and van der Waals forces was investigated [12] on the stability and bifurcation behavior of electrostatic torsional nano-electromechanical varactor systems. Two bifurcation points were obtained, one is a Hopf bifurcation and other is an unstable saddle point. The phase diagram shows periodic orbits around the Hopf bifurcation point, but the periodic orbit will break into a homoclinic orbit when meeting the unstable saddle point.

In this report we investigate the effects of external magnetic fields on the Casimir force between parallel slabs of anti-ferromagnetic materials, in the Voigt configuration (VC). Anti-ferromagnetic systems have spins ordered in an anti-parallel arrangement with zero net moment at temperatures below the Néel temperature. Above this temperature spins are randomly arranged. In the VC geometry the external magnetic field is applied parallel to the surface and perpendicular to the wave vector component parallel to the surface. External magnetic fields affect significantly the dielectric permittivity and magnetic permeability responses of materials. These effects should also modify the Casimir force between parallel slabs of anti-ferromagnetic systems. Taking into account these facts, we present calculations of the Casimir force between anti-ferromagnetic slabs, whose magnetic permeability tensor is magnetic field and frequency dependent. For the sake of simplicity we consider a constant dielectric permittivity. Anti-ferromagnets are of interest since they may be used in micro- and nano-devices, and as it has been shown Casimir force can be involved in snap down and sticking processes [13] in such devices. We anticipate that an external magnetic field may be used to control Casimir force in nano-devices.

Here we consider MnF_2 slabs to investigate the Casimir force performing three-dimensional studies accounting for applied magnetic fields. To calculate the force we use the general formula, which is written in terms of the reflection amplitudes, that allows a direct calculation of F if the reflectivities from the slabs are known [14,15]. The force is investigated as a function of the slabs thicknesses, vacuum gap width L of the separation between slabs, and the field strength. The paper is organized as follows: In Section 2 we describe the formalism. In Section 3 we discuss the results and make conclusions.