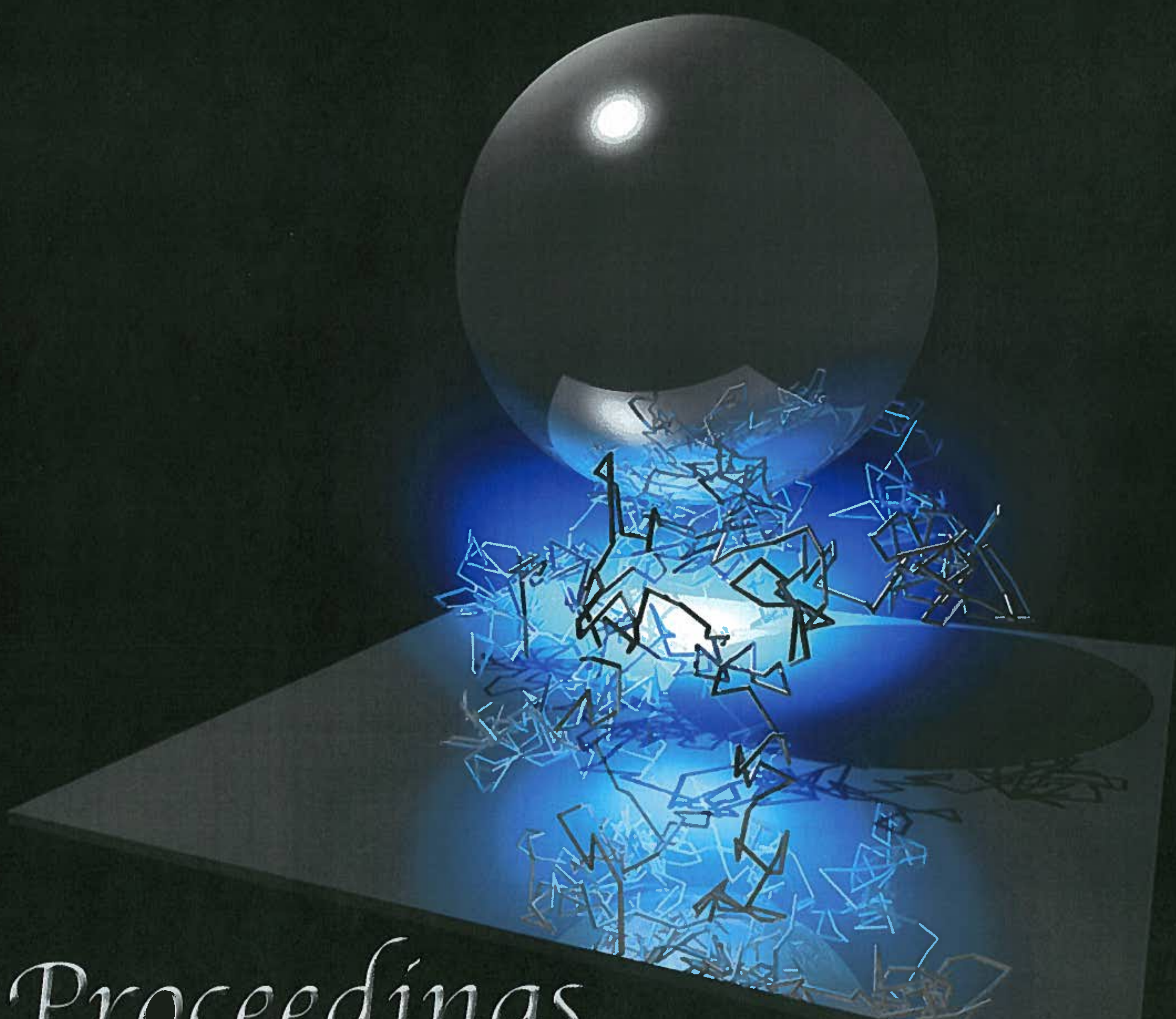
New Frontiers in

Casimir Force Control

September 27-29, 2009

Inn at Loretto, Santa Fe, New Mexico, USA



Proceedings Book

New Frontiers in Casimir Force Control

September 26-28, 2009
Inn at Loretto
Santa Fe, New Mexico, USA

AGENDA

Sunday, September 26, 2009

12:00 Lunch Reception & Opening Remarks
1:30 Session Talks
2:50 Poster Viewing
3:20 Session Talks
4:40 Poster Viewing
5:10 Session Talks

Monday, September 27, 2009

8:00 Breakfast
9:00 Session Talks
10:20 Poster Viewing
10:50 Session Talks
2:10 Session Talks
3:30 Poster Viewing
4:00 Round Table Discussion

6:30 Dinner Reception / Banquet

Tuesday, September 28, 2009

8:00 Breakfast
9:00 Session Talks
10:20 Poster Viewing
10:50 Session Talks
2:10 Session Talks
3:30 Poster Viewing
4:00 Session Talks
5:20 Closing

Organizing Committee:

Diego Dalvit (LANL)
Peter Milonni (LANL)
David Roberts (LANL)
Felipe da Rosa (LANL)

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Center for Nonlinear Studies, Los Alamos National Lab, European Science Foundation, LANL Quantum Initiative

Center for Nonlinear Studies
European Science Foundation
Setting Science Agendas for Europe
Quantum Initiative
Los Alamos National Laboratory

Image Credit: Klaus Klingmueller and Holger Gies.

SUNDAY, SEPTEMBER 27

12:00 PM – 1:30 PM Lunch Reception / Opening Remarks and Discussions
Tesuque Room

Session 1 Chair: Babb

1:30 PM – 2:10 PM
Lev Pitaevskii -- Physics of Repulsive van der Waals Forces
2:10 PM – 2:50 PM
Alex Cronin -- Improved C3 Measurements with Atom Interferometry

2:50 PM – 3:20 PM: Coffee Break / Poster Viewing
Acoma Room

Session 2 Chair: Maia Neto

3:20 PM – 4:00 PM
Carsten Henkel -- A Magnetic analysis of Casimir(Polder) forces
4:00 PM – 4:40 PM
Jeremy Munday -- Engineering the Casimir-Lifshitz force for levitation, ultra-low static friction devices, self-sorting, and QED torques

4:40 PM – 5:10 PM: Coffee Break / Poster Viewing
Acoma Room

Session 3 Chair: Aksyuk

5:10 PM – 5:50 PM
Umar Mohideen -- Using light and contour to control the Casimir force
5:50 PM – 6:30 PM
Thorsten Emig -- Shape and material dependence of Casimir-Lifshitz forces from scattering theory

Physics of Repulsive Van der Waals forces

L. P. Pitaevskii, CNR-INFM BEC Center and Dipartimento di Fisica, Universit`a di Trento, I-38050 Povo, Trento, Italy, and Kapitza Institute for Physical Problems,119334 Moscow, Kosygina 2, Russia

Difficulties in developing of the theory of Van der Waals forced between bodies separated by a liquid and the way to solve them are discussed. Necessary conditions for the stress tensor of equilibrium electromagnetic field in liquid are presented. The importance of the conditions of mechanical equilibrium and hydrodynamics effects in the separating liquid are stressed and physical meaning of the predicted and observed "Van der Waals repulsion" is explained.

Improved C3 measurements with Atom Interferometry

Alex Cronin, University of Arizona, Tuscon AZ, USA

We measured vdw C3 coefficients for Li, Na, and K atoms near silicon-nitride surfaces with 10% precision using atom diffraction and interferometry. I will describe improved Atom Optics techniques that make these measurements independent of nano-grating open fractions. We used this improved precision to detect modifications to C3 due to thin (5 nm) Au-Pd metal coatings on the silicon-nitride surfaces. In a separate experiment we tested the 1/r^3 dependence of the vdw potential by measuring de Broglie wave phase shifts with different atom-beam velocities.

A magnetic analysis of Casimir(Polder) forces*

Carsten Henkel, Harald Haakh, Francesco Intravaia,
Institut fuer Physik und Astronomie, Universitaet Potsdam, Germany

Dispersion interactions of the Casimir and Casimir-Polder type are often associated with charge fluctuations that explain, indeed, the leading order in some limiting cases. We discuss here a few examples where magnetic effects (current fluctuations, magnetic dipole moments) play a role. In particular, when dealing with conducting bodies (metals, superconductors),an analysis that separates electric and magnetic contributions provides valuable insight into the temperature dependence of the dispersion interaction, and into the role played by a finite DC conductivity. Our examples are inspired by recent work with superconducting atom chips.

* part of this work was done in collaboration with
F. Sols (Madrid), B. Power (Dublin), S. Spagnolo and R. Passante (Palermo)

Engineering the Casimir-Lifshitz force for levitation, ultra-low static friction devices, self-sorting, and QED torques

Jeremy N. Munday[1] *and Federico Capasso*[2]
[1]*Thomas J. Watson Laboratories of Applied Physics, California Institute of Technology, Pasadena, CA 91125.*
[2]*School of Engineering and Applied Sciences, Harvard University, Cambridge, MA 02138, USA.*

By engineering the boundary conditions between material interfaces, one can dramatically change the Casimir-Lifshitz force between surfaces as a result of the modified zero-point energy density of the system. Repulsive interactions between macroscopic bodies occur when their dielectric responses obey a particular inequality, as pointed out by Dzyaloshinskii, Lifshitz, and Pitaevskii. We will show an experimental verification of this behavior as well as a description of how this can be used to develop a scheme for quantum levitation. Based on these concepts, we will discuss the possible development of a new class of devices based on ultra-low static friction and the ability to sort objects based on their dielectric functions. Finally, we will conclude with a description of a quantum electrodynamic torque that is predicted to arise due to the quantum fluctuations between anisotropic materials.

Using light and contour to control the Casimir force

U. Mohideen, Department of Physics & Astronomy, UC Riverside, Riverside, CA, USA

Opportunities to control the Casimir force using light and structured surfaces will be presented, based on our experiments with the optical modulation of the Casimir force and the measurements of the geometry dependence of the lateral Casimir force with corrugated surfaces.

Shape and material dependence of Casimir-Lifshitz forces from scattering theory

Thorsten Emig, Universität zu Köln, Institut fur Theoretische Physik, Köln, Germany

The properties of fluctuation induced interactions like van der Waals and Casimir-Lifshitz forces are of interest in a plethora of fields ranging from biophysics to nanotechnology. In this talk,we discuss concrete shapes with characteristic material properties to showcase how the combination of methods from statistical physics and scattering theory are exquisitely suited to analyze a variety of phenomena. Examples are given to show how the interplay of geometry and material properties helps to understand and control these forces.

MONDAY, SEPTEMBER 28

Session 4 Chair: Bimonte

9:00 AM – 9:40 AM
Davide Iannuzzi -- What can we learn from Casimir force measurements under ambient conditions?
9:40 AM – 10:20 AM
Steven Johnson -- Numerical methods for Casimir interactions

10:20 AM – 10:50 AM: Coffee Break / Poster Viewing
Acoma Room

Session 5 Chair: Sernelius

10:50 AM - 11:30 AM
Vladimir Mostepanenko -- The Casimir Effect And Fundamental Physics
11:30 PM – 12:10 PM
Serge Reynaud -- The scattering approach to the Casimir force

12:10 PM – 2:10 PM: Lunch (on your own)

Session 6 Chair: Antezza

2:10 PM – 2:50 PM
Ricardo Decca -- Casimir force measurements using microelectromechanical systems
2:50 PM – 3:30 PM
Maarten De Boer -- Surface Forces in MEMS – Adhesion and Friction Experiments

3:30 PM – 4:00 PM: Coffee Break / Poster Viewing
Acoma Room

Session 7 Moderator: Milonni

4:00 PM – 6:00 PM: Round Table

7:30 PM Dinner Banquet
Tesuque Room

Keynote Speaker: Igor Dzyaloshinskii

What can we learn from Casimir force measurements under ambient conditions?

S. de Man, K. Heeck, R. Wijngaarden, D. Iannuzzi, Vrije Universiteit Amsterdam, Amsterdam, Netherlands

Our group has recently introduced a new technique for the measurement of the Casimir force between a sphere and a plate under ambient conditions (Phys. Rev. Lett. **103** (2009) 040402, Phys. Rev. **A79** (2009) 024102). In this talk, I will go through the details of the experimental set-up and of the data acquisition procedure, and I will show that measurements in gaseous atmosphere are complementary to those performed in vacuum or liquids, especially when one considers the role of the Casimir force in the development of MEMS and NEMS.

Numerical methods for Casimir interactions

Steven Johnson, Massachusetts Institute of Technology, Cambridge MA, USA

We show how well-understood techniques from computational classical electromagnetism (EM) can be applied to the study of Casimir interactions, yielding scalable, geometry-independent techniques to accurately predict forces and energies with no uncontrolled approximations, including dispersive dielectric materials. The basic principle is to reduce the problem to the solution of a sequence of partial differential or integral equations over unknowns parameterized by a generic grid or mesh, but the selection of the equations to solve requires some care. Mappings of the problem into the complex plane, computation of energies versus forces, and frequency versus time domain all have substantial consequences for computation. At a broader level, it is instructive to view the current variety of "competing" methods for Casimir problems that have appeared in the last few years in light of the experiences of computation in classical EM---despite many decades of development, no single technique has supplanted all others, but distinct strengths and weaknesses of different approaches have become apparent.

The Casimir Effect And Fundamental Physics

V.M. Mostepanenko, Institute for Theoretical Physics, Leipzig University, Germany (On leave from Noncommercial Partnership "Scientific Instruments, Moscow, Russia)

Several problems arising in the theoretical interpretation of experiments on measuring the Casimir force are discussed. The results are shown to be so unexpected that they demand a critical review of some basic theoretical concepts.

The scattering approach to the Casimir force

Serge Reynaud, Laboratoire Kastler Brossel, Ecole Normale Superieure, Paris, France

Abstract: TBD

Casimir force measurements using microelectromechanical systems

R. Decca, Indiana University – Purdue University Indianapolis, Indianapolis, IN, USA

In this talk we will describe our results in the Casimir regime, including the effect of other forces. We will present experimental details or our setup relevant for precise and sensitive measurements of the Casimir interaction. We will also describe the improvements underway for our experimental setup, as well as the new systems that we are currently investigating, with particular emphasis on materials with tunable electronic and geometric properties.

Surface Forces in MEMS – Adhesion and Friction Experiments

Maarten P. de Boer, MEMS Technology Dept. Sandia National Laboratories, Albuquerque, NM, USA

Long-range Casimir forces set the lower limit of unwanted adhesion of mcantilevers to a substrate [1]. To quantify this adhesion, we measure deflections of actuated MEMS cantilevers (Fig. 1a) by interferometry (Fig. 1b), and compare to an energy-release rate model. To understand the values, we develop a detailed model of the interface including surface roughness, contact mechanics and dispersion forces. We find that when surface roughness is less than 3 nm root mean square, the dispersion forces dominate adhesion. As surface roughness increases, the real area of contact dominates. Agreement between theory and model is within ± 20% when correlations between the upper and lower surfaces are taken into account [2].

In the second part of the talk, static friction measurements on a powerful MEMS stepper motor called the nanotractor (Fig. 2a), will be discussed. We observe logarithmic aging, which counter-intuitively is suppressed by increasing the static friction load [3] (Fig. 2b). "Release time", a newly measured parameter, explains the static friction dependencies of this MEMS interface.

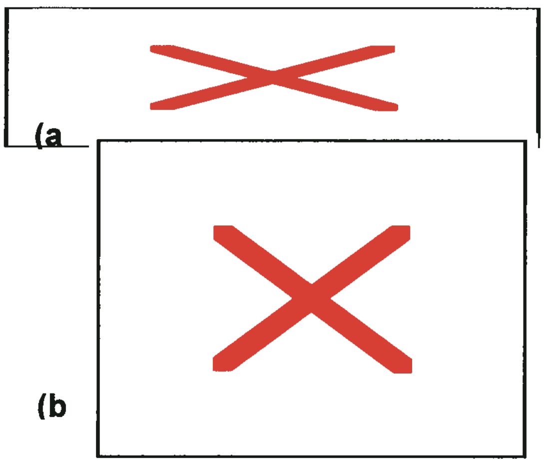

Fig. 1(a) Cantilever adhesion geometry
(b) interferograms

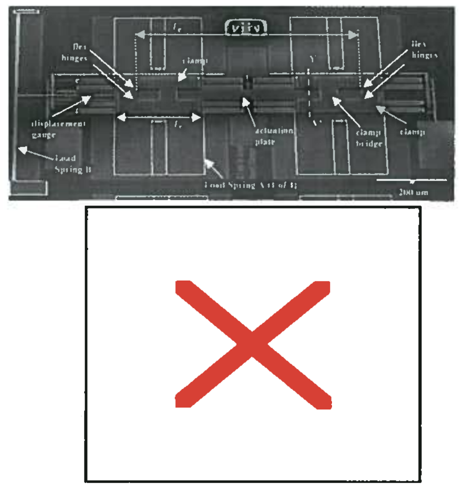

Fig. 2(a) Nanotractor stepper motor (b) static friction data showing aging is suppressed by increasing hold force F_h.

References:

[1] F. W. DelRio, M. P. de Boer, J. A. Knapp, E. D. Reedy, P. J. Clews and M. L. Dunn, "*The role of van der Waals forces in adhesion of micromachined surfaces*", Nature Materials, **4** 629 (2005).

[2] F. W. DelRio, M. L. Dunn, L. M. Phinney, C. J. Bourdon and M. P. de Boer, "*Rough surface adhesion in the presence of capillary adhesion*", Applied Physics Letters, **90** 163104 (2007).

[3] A. D. Corwin and M. P. de Boer, "*Frictional aging and sliding bifurcation in monolayer-coated micromachines*,". Journal of Microelectromechanical Systems, **18** (2) 250-262 (2009).

TUESDAY, SEPTEMBER 29

Session 8 Chair: Klimchitskaya

9:00 AM – 9:40 AM
Maarten DeKieviet -- Explorations in Casimir-Polder Forces
9:40 AM – 10:20 AM
Joel Chevrier -- Measures of Casimir force and of near-field radiative heat transfer

10:20 AM – 10:50 AM Coffee Break / Poster Viewing
Acoma Room

Session 9 Chair: Mazzitelli

10:50 AM – 11:30 AM
Clemens Bechinger -- Direct measurement of critical Casimir forces
11:30 AM – 12:10 PM
John O'Hara -- Metamaterial Design Considerations for Casimir Force Control

12:10 PM – 2:10 PM: Lunch (on your own)

Session 10 Chair: Ford

2:10 PM – 2:50 PM
Ho Bun Chan -- Measuring the geometry dependence of the Casimir force on nanostructured silicon surfaces
2:50 PM – 3:30 PM
Vitaly Svetovoy -- Optical and roughness characterization of gold films. Sample dependence of the Casimir force.

3:30 PM – 4:00 PM: Coffee Break / Poster Removal
Acoma Room

Session 11 Chair: Brevik

4:00 PM – 4:40 PM
Adrian Parsegian -- Carbon nanotubes, lipid bilayers, salt solution – forces from fluctuations across the spectrum

4:40 PM – 5:20 PM
Kimball Milton -- Multiple Scattering Casimir Force Calculations: Layered and Corrugated Materials, Wedges, and CP Forces

Explorations in Casimir-Polder Forces

Maarten F.M. Dekieviet, Universitat Heidelberg, Physikalisches Institut, Heidelberg, Germany

In my talk, I will present an Atomic Beam Spin Echo experiment, in which the Casimir-Polder force between a single atom and the surface of an arbitrary solid is determined quantitatively. The method is based on measuring 3He atoms quantum reflect from the substrate at impinging energies from some neV up to sub-meV. Quantum reflection depends very sensitively on the long-range details of the attractive atom-surface interaction, which allows us to identify the *C*4- (Casimir) and *C*3-branches (van der Waals) for different types of surfaces. These experiments have been used to investigate the influence of the spectral properties of the substrate, the surface geometry, and its temperature. I will discuss how the interaction potential can be modified through the use of nano-crafted and magnetic surfaces.
We are currently exploring the Spin Echo option of our method to study the energetics of the quantum reflection process more precisely. This is shown to be very useful for measuring quantum friction and to be an important tool for a quantitative determination of the high lying bound states determined by the long range attractive branch of the interaction. If time permits, I will describe a future application of the Casimir-Polder force to control and detect parity violating effects in very light atoms.

Measures of Casimir force and of near-field radiative heat transfer

Joel Chevrier, Institut Neel, CNRS and Universitè Joseph Fourier, 38042 Grenoble, France, and ESRF 6 Rue Jules Horowitz, 38043 Grenoble, France

Near-field force and energy exchange between two objects due to quantum and thermal induced electrodynamic fluctuations give rise to interesting phenomena such as Casimir and van der Waals forces and thermal radiative transfer exceeding Plancks theory of blackbody radiation. A theoretical explanation, in the framework of stochastic electrodynamics introduced by Rytov [1] in the late sixties, accounts for quantum and thermodynamic fluctuations and has been successfully applied to model Casimir forces [2] and radiative heat transfer [3]. While quantum fluctuations, related to zero point energy, yelds to the formulation of the Casimir force, near-field radiative heat transfer is only due to classical thermodynamics fluctuations. Although significant progress has been made in the past of the precise measurement of the Casimir force [4,5], a detailed quantitative comparison between theory and experiments in the nanometer regime is still lacking when speaking about heat transfer. After description of our quantitative measurement of the Casimir force and comparison with theory, we report experimental data on the thermal flux spatial dependence. Theory based on the Derjaguin approximation, successfully used here for the first time to describe radiative heat transfer from the far field to the near field regimes, reproduces the measured dependence.

Direct measurement of critical Casimir forces

Clemens Bechinger, Physikalisches Institut, Universität Stuttgart, Germany

Similar to electromagnetic vacuum fluctuations which can induce long-ranged interactions between uncharged, conducting surfaces, a rather similar effect was predicted almost 30 years ago to occur in confined binary mixtures close to their critical point. This so-called critical Casimir effect has attracted considerable attention because it can strongly modify the interaction potential of colloidal particles immersed in a binary fluid. We present a direct measurement of such critical Casimir forces between a colloidal particle and a flat surface in a water – 2,6-lutidine mixture. With total internal reflection microscopy (TIRM) which is capable to resolve forces down to 5fN, we obtain distance resolved particle-wall interaction profiles. Upon approaching the critical point we observe long-ranged interactions which are attractive or repulsive depending on the specific boundary conditions of the walls. This behavior is in good agreement with recent theoretical predictions. In addition, we demonstrate, how critical Casimir forces can be used for the assembly of ordered colloidal monolayers on chemically patterned substrates.

References:
[1] C. Hertlein, L. Helden, A. Gambassi, S. Dietrich, and C. Bechinger, Nature 451, 172 (2008).
[2] F. Soyka, O. Zvyagolskaya, C. Hertlein, L. Helden, and C. Bechinger, Phys. Rev. Lett. 101, 208301 (2008).

Metamaterial Design Considerations for Casimir Force Control

John O'Hara, Jiangfeng Zhou, Antoinette Taylor, Diego Dalvit, Felipe da Rosa, Peter Milonni,
Los Alamos National Laboratory, Los Alamos, NM, USA

The notion of neutralizing or reversing the Casimir force is founded on the ability to tune the magnetic material response. Metamaterials have opened a new realm of possibilities by promising magnetic behavior at very high frequencies, even into the optical regime. However, metamaterials that can desirably alter the Casimir force present a number of significant design challenges, both theoretical and practical. We present some of these difficulties in terms of basic materials properties, numerical electromagnetic simulations, and fabrication limitations. Basic materials properties are shown to exhibit fundamental limitations that restrict the ability to produce a magnetic metamaterial response while simultaneously suppressing electric effects. Being comprised of these basic materials, metamaterials are thus required to overcome the electric effects of both the background materials and any resonant modes introduced by the metamaterial structures themselves. Using numerical simulations we show some examples of practical and theoretical metamaterial structures that illustrate these ongoing difficulties and offer first-order solutions to specific functionality issues. The limitations of fabrication are also presented with particular emphasis on infrared and optical metamaterials, which are the most likely candidates for producing a significant cumulative magnetic response under the Casimir force integral.

References:
[1] J. A. Smith, M. B. Example, and M. Mustermann. Nature **123,** 456 (2009).
[2] Rytov, S.M., Kratsov, Yu.A., Tatarskii, V.I. Principles of statistical Radiophysics, vol 3, Springer-Verlag, New-York, (1987) (Chapter 3)
[3] A. V. Shchegrov, K. Joulain, R. Carminati, and J.-J. Greffet, Phys. Rev. Lett. **85**, 1548 (2000)
[4] U. Mohideen and A. Roy, Physical Review Letters **81**, 4549 (1998)
[5] G. Jourdan, A. Lambrecht, F. Comin, and J. Chevrier, Euro Physics Letters *in press.*

Measuring the geometry dependence of the Casimir force on nanostructured silicon surfaces

Ho Bun Chan[1], Y. Bao[1], J. Zou[1], R. A. Cirelli[2], F. Klemens[2], W. M. Mansfield[2], and C. S. Pai[2]
[1] Department of Physics, University of Florida, Florida, USA, [2] Bell Laboratories, Lucent Technologies, New Jersey, USA.

We present an experiment to demonstrate the strong geometry dependence of the Casimir force [1]. The interaction between a gold sphere and a silicon surface with an array of nanoscale, rectangular corrugations is measured using a micromechanical torsional oscillator. Deviation of up to 20% from PFA is observed. The data will be compared to recent theories on strongly deformed surfaces. In particular, the interplay between finite conductivity corrections and geometry effects complicates the comparison of data with theories. Ongoing efforts on corrugations with smaller depths will also be presented.

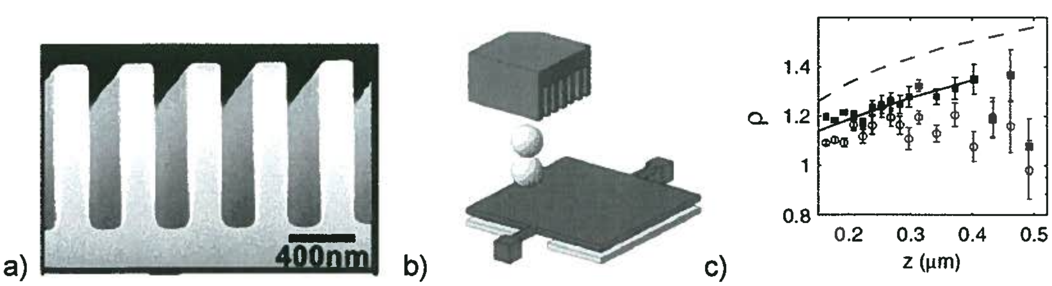

Figure 1: (a) Cross section of the nanoscale rectangular trenches on a silicon surface. **(b)** Schematic of the experimental setup (not to scale) including the micromechanical torsional oscillator, gold spheres and silicon trench array. **(c)** Ratio *r* of the measured Casimir force gradient to the force gradient expected from PFA, for two samples with trench arrays with different periodicity. The lines represent calculations based on perfect conductors

References:
[1] H. B. Chan, Y. Bai, J. Zou, R. A. Cirelli, F. Klemens, W. M. Mansfiled and C. S. Pai, Phys. Rev. Lett. **100,** 030401 (2008).

Optical and roughness characterization of gold films. Sample dependence of the Casimir force.

V. B. Svetovoy, G. Palasantzas and P. van Zwol
University of Twente, the Netherlands; University of Groningen, the Netherlands

Optical properties of gold films deposited in different conditions were measured ellipsometrically in a wide range of the wavelengths from 0.14 to 33 microns. Comparison of the dielectric functions of different films demonstrates considerable sample dependence. Different ways to determine the Drude parameters from the optical data are discussed. All methods are in good agreement with each other. Variation of the dielectric function from sample to sample leads to the variation of the Casimir force on the level of 5% or more.
Correlation of the optical properties with the roughness profiles of the films is discussed. It is discussed also how one can find the distance upon contact, d_0, between two rough surfaces using the AFM scans of the contacting bodies. It is demonstrated that d_0 depends on the nominal size of the contact area L and a simple expression for $d_0(L)$ via the surface roughness characteristics is given. The case of a sphere in contact with a plate is discussed specifically. It is shown how the scale dependence can influence measurement of the Casimir force.

Carbon nanotubes, lipid bilayers, salt solution – forces from fluctuations across the spectrum

Adrian Parsegian, *Department of Physics, University of Massachusetts, Amherst*
parsegian@physics.umass.edu

To control Casimir/Lifshitz/van-der-Waals forces immediately requires that we recognize the primacy of material polarizabilities and charge fluctuations rather than vacuum fluctuations between idealized metals. I will speak about two classes of system where we know dielectric response spectra well enough to see how they drive fluctuation forces:
* Carbon nanotubes where different chirality in twisting the graphene sheet create dielectric, semi-conducting, or conducting cylinders with qualitatively different interaction strengths and ranges of interaction;
* Bilayer lipid membranes in salt solutions, where varied and variable properties of the lipids and intervening solutions, create opportunities to modify charge fluctuations across the entire electromagnetic spectrum.
These systems show the unavoidable connection between the details of real spectra and even the qualitative properties of forces of resulting forces. They also point to a strategy for controlling forces to a precision that has previously eluded us.

Multiple Scattering Casimir Force Calculations: Layered and Corrugated Materials, Wedges, and CP Forces

Kimball A. Milton[1], Inés Cavero-Peláez[2], Prachi Parashar[1], K.V. Shajesh[3], and Jef Wagner[1]
[1] H.L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, OK 73019, USA,
[2] *Laboratoire Kastler Brossel, Université Pierre et Marie Curie, F-75252 Paris, France,* [3]*St Edward's School, Vero Beach, FL 32963, USA*

Multiple scattering methods have recently proven useful in calculating quantum vacuum forces between distinct bodies. In fact, 40 years ago such an approach was used to derive the Lifshitz formula for the force between parallel dielectric slabs. More generally, numerical results can be readily obtained in many cases, but more remarkably, for weak coupling (e.g., for dilute dielectrics), closed-form exact expressions can be derived, reflecting the summation of Casimir-Polder forces or their analogues. We have recently used such methods to derive forces between corrugated planar and cylindrical surfaces. (See Fig. 1.) For scalar and electromagnetic fields, the forces can be computed perturbatively in the corrugation amplitudes; 4th order perturbative results agree closely with the exact results for weak coupling. We are now extending such calculations to general multilayered surfaces (see Fig. 2), where again exact results, including those for Casimir-Polder forces, can be obtained in many cases. These results will have important applications to experimentally accessible situations, and to nanomachinery. The extension to finite temperature is being explored. New results are also being found for wedge geometries and annular pistons which are laboratories for developing methods useful for studying problems in other separable geometries, such as elliptic cylinder coordinates describing hyperbolic surfaces.

Poster Contributions

1. Photon generation in a tunable superconducting microwave cavity
P. Delsing

2. The Influence of Electrostatic and Casimir Forces on Cantilever Vibrations
G. P. Berman

3. Casimir Force and the Expanding Universe without the Zero Point Field
Thomas Prevenslik

4. Remarks on the Casimir Effects in models with Branes and Extra Dimensions
Antonino Flachi

5. Critical Casimir forces in the presence of a chemically structured substrate
Francesco Parisen Toldin

6. Superlubricity using repulsive van der Waals forces
Adam A. Feiler

7. Testing Casimir Cavities For Zero-Point Energy Extraction
Olga Dmitriyeva and Garret Moddel

8. Bragg spectroscopy for measuring Casimir-Polder interactions with Bose-Einstein condensates above corrugated surfaces.
G.A. Moreno

9. A Few Observations about Directions in Casimir Research
G. Jordan Maclay

10. Can Surface Plasmons tune the Casimir force between Metamaterials?
Francesco Intravaia and Carsten Henkel

11. Thermal effects in the magnetic Casimir-Polder interaction
Harald Haakh, Francesco Intravaia and Carsten Henkel

12. Title: TBD
Z.G. Moghaddam, University of Tehran, Tehran, Iran

13. Casimir Forces in the Time Domain
Alexander P. McCauley

14. Achieving Stable Levitation with Casimir Forces
Alejandro W. Rodriguez

15. Repulsive Casimir Force in Chiral Metamaterials
R. Zhao,[1, 2] J. Zhou,[1] Th. Koschny,[1, 3] E. N. Economou,[3,4] and C. M. Soukoulis[1, 3, 5]

16. Long Ranged Interactions in Cylindrical Structures
Lilia M. Woods, K. Tatur, and I.V. Bondarev

17. First principle calculations of the Casimir force between Silicon films
Marco Govoni and Carlo Calandra Buonaura, Andrea Benassi

18. A General Theory of Casimir Forces
C. Villarreal(1) and W. L. Mochan(2)

19. Role and applications of vacuum force in microscopic systems
Marco Govoni and Carlo Calandra Buonaura, Andrea Benassi

20. Casimir-life drag forces in superfluids
Andrew Sykes, Matt Davis, David Roberts

1. Photon generation in a tunable superconducting microwave cavity

P. Delsing, Department of Microtechnology and Nanoscience, Chalmers University of Technology, 412 96 Göteborg, Sweden

We demonstrate superconducting microwave cavities, with tunable effective lengths. The tuning is obtained by varying the Josephson inductance of a SQUID situated at one end of the cavity. We show data on four different samples and demonstrate tuning by several hundred line-widths in a time much shorter than the life-time of the photon in the cavity.
We exploit these fast tunable cavities by pumping the flux through the SQUID at twice the cavity frequency, corresponding to moving one mirror at the end of the cavity very fast. We can pump the cavity with an amplitude which is well above the threshold for photon generation. We observe photons coming out of the cavity with very high signal to noise. This can be interpreted either as parametric amplification of the vacuum fluctuations or alternatively in terms of the dynamical Casimir effect.

2. The Influence of Electrostatic and Casimir Forces on Cantilever Vibrations

G. P. Berman, Theoretical Division, Los Alamos National Laboratory, Los Alamos, New Mexico 87545, USA

The effect of an external bias voltage and fluctuating electromagnetic fields on both the fundamental frequency and damping of cantilever vibrations is considered. An external voltage induces surface charges causing cantilever-sample electrostatic attraction. A similar effect arises from charged defects in dielectrics that cause spatial fluctuations of electrostatic fields. The cantilever motion results in charge displacements giving rise to Joule losses and damping. It is shown that the dissipation increases with decreasing conductivity and thickness of the substrate, a result that is potentially useful for sample diagnostics. Fluctuating electromagnetic fields between the two surfaces also induce attractive (Casimir) forces. It is shown that the shift in the cantilever fundamental frequency due to the Casimir force is close to the shift observed in experiments of B. C. Stipe, H. J. Mamin, T. D. Stowe, T. W. Kenny, and D. Rugar, Phys. Rev. Lett. **87**, 096801 (2001). Both the electrostatic and Casimir forces have a strong effect on the cantilever eigenfrequencies, and both effects depend on the geometry of the cantilever tip. We consider cylindrical, spherical, and ellipsoidal tips moving parallel to a flat sample surface. The dependence of the cantilever effective mass and vibrational frequencies on the geometry of the tip is studied both numerically and analytically.

3. Casimir Force and the Expanding Universe without the Zero Point Field

Thomas Prevenslik, Discovery Bay, Hong Kong

Since 1948, the Casimir force based on the zero point field (ZPF) is thought to exist because of the hypothesis that the field should follow the well verified zero point energy (ZPE) for the ground state of atoms and molecules. However, the ZPF has never been measured in the laboratory. Nevertheless, the ZPF continues to be promoted on the false hope that something can be created from nothing. Instead, forces measured in Casimir experiments are inferred as proof of the existence of the ZPF. But this logic presupposes mechanisms other than the ZPF are not available to produce the said same measured Casimir forces.
In this regard, the blackbody (BB) radiation field produced from the thermal kT energy of atoms in the surfaces of Casimir's plates is available and unlike the speculative ZPF, the existence of BB radiation emitted from atoms is unequivocal. Analysis is presented that shows the force being measured in Casimir experiments finds origin in the thermal kT energy of surface atoms based on the theory of QED induced EM radiation. QED stands for quantum electrodynamics, EM for electromagnetic, k for Boltzmann's constant, and T for absolute temperature. The kT energy of the surface atoms is EM and remains constant as the gap G between the plates is changed. To conserve the kT energy during gap collapse, the low frequency kT energy is up-converted by QED to the frequency f of the instant gap resonance, $f = c/2G$, where c is the speed of light. But the Casimir force given by the gradient of the constant kT energy of the surface atoms with respect to the gap vanishes, and therefore the Casimir force does not exist. However, the EM energy density increases as the gap collapses, the gradient of which in combination with the polarizability of the surface atoms is shown to give a BB force that is consistent with the forces measured in Casimir experiments. With the BB force, there is no need to invoke the speculative ZPF embodied in Casimir theory to explain the measured forces.
Similarly, the BB radiation field places in question Einstein's notion that the ZPF is the cause of the expanding Universe after Hubble's in 1929 reported the redshift in distant galaxy light. In the typical Universe away from

galaxies as modeled in the Friedmann equations by a cloud of cosmic dust, the energy density of BB radiation from the emission of kT energy of dust atoms at 2.725 K is shown to provide a reasonable estimate of the cosmological constant. The BB radiation repulsion between any pair-wise dust particles in the typical Universe is shown to exceed that of gravitational attraction, and therefore the Universe now thought by astronomers to be expanding because of the ZPF is instead expanding by BB radiation. Like the Casimir force now thought to be a force from nothing, the notion that the Universe began from nothing in the Big Bang is also placed in question. By this theory, the Big Bang was likely caused by the collapse of the Universe on itself - certainly not from nothing. The next Universe collapse therefore begins as the dust temperatures in the typical Universe approach absolute zero, although taking eons for the collapse to reach Big Bang temperatures.

4. Remarks on the Casimir Effects in models with Branes and Extra Dimensions

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We consider the Casimir effect between two parallel plates localized on a brane. We argue that in order to properly compute the contribution to the Casimir energy due to any higher dimensional field, it is necessary to take into account the localization properties of the Kaluza-Klein modes. When the bulk field configuration is such that no massless mode appears in the spectrum, as, for instance, when the higher dimensional field obeys twisted boundary conditions across the branes, the correction to the Casimir energy is exponentially suppressed. When a massless mode is present in the spectrum, the correction to the Casimir energy can be, in principle, sizeable. However, when the bulk field is massless and strongly coupled to brane matter, the model is already excluded without resorting to any Casimir force experiment. The case which is in principle interesting is when the massless mode is not localized on the visible brane. We illustrate a method to compute the Casimir energy between two parallel plates, localized on the visible brane, approximating the Kaluza-Klein spectrum by truncation at the first excited mode.
We treat this case by considering a piston-like configuration and introduce a small parameter, ε, that takes into account the relative amplitude of the zero mode wave function on the visible brane with respect to the massive excitation.
We find that the Casimir energy is suppressed by two factors: at lowest order in ε, the correction to the Casimir energy comes entirely from the massive mode and turns out to be exponentially suppressed; the next-to-leading order correction in ε follows, instead, a power-law suppression due to the small wave function overlap of the zero-mode with matter confined on the visible brane.

5. Critical Casimir forces in the presence of a chemically structured substrate

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Motivated by recent experiments on a binary liquid mixture, we study the critical properties of a system in the Ising universality class, in a film geometry in the presence of a chemically structured substrate, with alternating adsorption preference.
By means of Monte Carlo simulations and finite-size scaling analysis, we determine the thermodynamic Casimir force and the corresponding universal scaling function. We also compute the order-parameter profiles and the associated universal scaling function.

6. Superlubricity using repulsive van der Waals forces

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Friction force measurements using colloid probe atomic force microscopy have been conducted to investigate superlubrication between surfaces interacting with repulsive van der waals force. We show that if repulsive van der Waals force exists between two surfaces prior to their contact then friction is essentially precluded and supersliding is achieved. Normal force measurements between a gold sphere against a smooth Teflon surface (templated on mica) in cyclohexane, revealed a repulsive van der Waals force that diverged at short separations. The friction coefficient associated with this system is on the order of 0.0003. When the refractive index of the liquid is changed, the force can be tuned from repulsive to attractive and adhesive. The friction coefficient increases as the Hamaker constant becomes more positive and the divergent repulsive force, which prevents solid-solid contact, gets switched off.
The friction measurements presented here are of the same order as the lowest ever recorded friction coefficients in liquid. This work clearly shows that two surfaces experiencing a repulsive surface force, which diverges at small separations, can slide essentially without friction. The number of systems in which repulsive van der Waals forces could occur is limited but includes metal bearings in a PTFE housing with organic lubricant and certain

combinations of technically interesting ceramic materials.

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7. Testing Casimir Cavities For Zero-Point Energy Extraction

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We describe an experiment to measure energy emission from gas entering Casimir cavities. According to stochastic electrodynamics (SED) the ground state of an electron orbital is assumed to emit Larmor radiation, which would cause the electron to spiral inward if it were not balanced by absorption of zero-point energy from the vacuum. By suppressing the electromagnetic quantum vacuum energy at appropriate frequencies the electron energy levels will change, and this will result in release of energy. Mode suppression of quantum vacuum radiation is known to take place in Casimir cavities. The idea of harvesting zero-point energy using Casimir effect was patented in 2008 [1]. When atoms enter into suitable Casimir cavities a decrease in the orbital energies of electrons in atoms should occur according to SED. Such energy emission can be detected (extracted). Upon emergence from the Casimir cavities the atoms will be re-energized by the ambient electromagnetic quantum vacuum. In this way energy is extracted locally, and replenished globally from the electromagnetic quantum vacuum.

We describe the experiment that we are using to investigate zero-point energy emission from Casimir cavities. The device is a nanopore polycarbonate membrane coated with gold metal to form Casimir cavities. Gas is pumped through the membrane and emitted energy is measured using a broadband pyroelectric detector and lock-in amplifier.

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8. Bragg spectroscopy for measuring Casimir-Polder interactions with Bose-Einstein condensates above corrugated surfaces.

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We propose a method to probe dispersive atom-surface interactions by measuring via two-photon Bragg spectroscopy the dynamic structure factor of a Bose-Einstein condensate above corrugated surfaces.

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9. A Few Observations about Directions in Casimir Research

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In the last decade, researchers in Casimir phenomena have made great strides in many areas. This progress has enriched our fundamental understanding of the physics involved, and it has also changed the perception of Casimir effects from being primarily a curiosity to a potential source of technological interest.

The Landau-Lifshitz formulation and equivalent formulations have proven to be the workhorse for computations for the convenient and popular "infinite" parallel plate configuration. Since this formulation includes some material properties it is quite useful. Similarly most experiments have been with parallel plate configurations or equivalent configurations, such as the curved surface-flat plate, or with nearly flat surfaces. The AFM techniques have been very successful in these measurements.

The first predictions of the parallel plate Casimir effect were based on a fundamental theory, quantum electrodynamics (QED), the most accurately verified physical theory we have. QED also makes predictions for non-parallel plate geometries. QED has been used to predict the vacuum energy and vacuum forces for atoms, surfaces and structures that have never been tested, and there are many configurations for which no QED calculations have yet been done because of the complexity. With the continuing development of nanotechnology, exploration of these areas will open new and challenging vistas in Casimir research. QED formulations will have to be modified to include material properties and actual geometrical features. New boundary conditions can be explored. New tests of QED and a deeper understanding of the relationship between matter and electromagnetic fields will result.

10. Can Surface Plasmons tune the Casimir force between Metamaterials?

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Metamaterials are able to modify the electromagnetic density of modes also at the level of vacuum fluctuations. The basic manifestation of the latter is the Casimir force, a universal attraction between mirrors and polarizable objects. Previous work has shown that this force can be significantly tuned and even made to reverse its sign, using bulk or layered metamaterials [1–5]. This prediction is currently an experimental challenge because metamaterials with high-frequency resonances are needed, i.e. with small-scale building blocks. We build here on recent interpretations of the Casimir force in terms of coupled surface plasmon and plasmonic modes [6-8] and split the Casimir repulsion for a mixed configuration (metallic plate+metamaterial plate) into the corresponding contributions. The metamaterial is described using an effective medium approach. The Drude-Lorentz functional is taken, allowing therefore for resonance frequencies. We discuss the role of polarization and comment on the small amplitude of the resulting overall repulsion whose sign is typically quite small compared to the normal Casimir force. For example, TE-polarized surface modes on one magneto-dielectric surface are not subject to resonant frequency shifts if the other surface is mainly dielectric. But this is the "mixed" geometry where the maximum repulsion is found [1,2].

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11. Thermal effects in the magnetic Casimir-Polder interaction

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Exact knowledge of the Casimir-Polder interaction of an atom with a conducting surface is rapidly becoming important in modern experimental setups such as atom chips [1-7]. We investigate the magnetic dipole contribution to the atom-surface interaction for thermally excited atoms, ground state atoms and atoms prepared in a trappable hyperfine state. The magnetic dipole contribution differs greatly from its electrical counterpart [2-4,,7], on which previous research has concentrated [5]. We compare different models for the optical response of metallic surfaces in the normal and superconducting state [2,6], each of which includes dissipation in a fundamentally different way. This leads to characteristic signatures in the Casimir-Polder interaction. The most striking effect is a strong suppression of the magnetic dipole interaction in dissipative media. Furthermore, in special configurations we could recover a non-vanishing entropy at T=0 in full analogy to the Casimir interaction between two conducting plates [8]. These results suggest that experimental testing of the Casimir-Polder interaction, e.g. in atom chip setups, could also give answers to remaining questions in the Casimir interaction. This would also offer the advantages of a well-defined system that can be handled with high precision.

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12. Title: TBD

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After Casimir Effect's prediction In 1948 and some years later when experimental measurements were consistent with the theory, its widespread application were manifested in different parts of physics' fields. Physicists demonstrated that Casimir force effected Micromachine's structures. Hence, it, also, must be considered in designing and manufacturing applied physics' apparatus. Likewise, the Casimir Effect has its own application in cosmology and theoretical physics which has been mentioned in different articles. In this thesis through a new approach, Casimir Effect has been probed. in other words, by means of field quantization in Krein space instead of Hilbert space, one can reach to the accurate calculated answer of Casimir force without being involved with infinities which is known by natural quantization.

13. Casimir Forces in the Time Domain

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We introduce a formulation of Casimir forces in arbitrary geometries in the time domain, rather than the frequency domain. This allows us to compute the contribution of the entire frequency spectrum in a single simulation, merely accumulating a single time integral of the fields as the simulation progresses. Moreover, we show how a carefully chosen transformation of the problem into the complex-frequency domain (not a Wick rotation) is equivalent to adding a dissipation everywhere in the model, which makes it converge very quickly to the force in a short simulation. Put together, this allows Casimir forces to be computed with off-the-shelf electromagnetic simulation software such as the popular finite-difference time-domain (FDTD) method. Using free FDTD software, we demonstrate this method with computations in a variety of circumstances, including three-dimensional objects with cylindrical symmetry and interactions between periodic surfaces.

14. Achieving Stable Levitation with Casimir Forces

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We use accurate computational methods to investigate the interplay of attractive and repulsive Casimir forces for fluid-separated surfaces in a variety of geometries. Using the first accurate calculation of such forces for very non-planar geometries, we show that stable equilibria arise for eccentric cylinders and spheres above patterned surfaces. Furthermore, we demonstrate that material dispersion can have dramatic consequences. It can lead to transitions in the stable orientation of asymmetrical objects. The dispersion, especially in conjunction with non-planar geometries, can also lead to transitions in the sign of the force with separation, creating positions of stable as well as other effects.

15. Repulsive Casimir Force in Chiral Metamaterials

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There is increased interest recently [1–3] in determining whether there is a combination of media 1 and 2 capable of producing a repulsive force. There have been mainly three mechanisms to obtain a repulsive Casimir force: (1) Dzyaloshinskii [1]: Immersing the interacting plates of ε_1 and ε_2 in a fluid of ε_3, satisfying the condition $\varepsilon_1(i\xi) < \varepsilon_3(i\xi) < \varepsilon_2(i\xi)$; (2) Boyer [2]: Based on an asymmetric setup of mainly (purely) nonmagnetic/vacuum/mainly (purely)magnetic; (3) Leonhardt [3]: Employing a perfect lens sandwiched between the interacting plates. Even through Capasso's group experimentally realized the repulsion, based on the theoretical prediction of Dzyaloshinskii et al. [1], this kind of system still has friction because of the existence of the liquid. Boyer's approach faces the essential obstacle that such nontrivialmagneticmaterials in the optical regime do not exist in nature. And for Leonhardt's approach, it is extremely difficult to obtain a perfect lens in a broad-band range, and impossible at all frequencies.

Recently, we found theoretically that one can obtain repulsive Casimir forces and stable nanolevitations by using chiral metamaterials [4]. By extending the Lifshitz theory to treat chiral metamaterials, we find that a repulsive force and a minimum of the interaction energy possibly exist for strong chirality, under realistic frequency dependencies and correct limiting values (for zero and infinite frequencies) of the permittivity, permeability, and chiral coefficients. We consider a special setup with two identical chiral metamaterial plates with the following parameters: $\varepsilon_1 = \varepsilon_2 = \varepsilon$; $\mu_1 = \mu_2 = \mu$; $\kappa_1 = \kappa_2 = \kappa$. The chirality, if strong enough, is expected to lead to a repulsive Casimir force, which is confirmed by the numerical evaluation of the interaction energy per unit area as shown in Fig. 1.

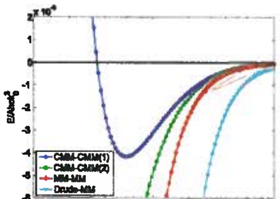

FIG. 1: (Color online) Casimir interaction energy per unit area E/A (in units of $\hbar c k_0^3$) versus $k_0 d$; $k_0 = \omega_R/c$. The triangle curve corresponds to the interaction between Drude metal and nonchiral metamaterials. The diamond curve is the case between two nonchiral metamaterials. The squares curve is the case between two chiral metamaterials, but the chirality is not large enough. Finally, the circle curve, the case with large enough chirality, shows repulsion for $k_0 d < 0.0586$ and a stable equilibrium point at $k_0 d = 0.0586$.

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16. Long Ranged Interactions in Cylindrical Structures

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We consider the interaction energy due to electromagnetic field fluctuations in various infinitely long cylindrical systems. The structures of interest are a single cylindrical layer with a finite thickness, *N* concentric infinitely thin shells, and two parallel full cylinders. In all cases, the mode summation method is applied to calculate the zero-point energy. The derived analytical expressions are used to investigate the energy dependence on the cylindrical radial curvature, size of the system, and the dielectric response properties of the involved objects and the medium. Of particular interest is the case of two parallel cylinders, for which we show that the interaction can be changed from attractive to repulsive by a suitable choice of the material composition of the cylinders and the environment. Our studies can serve as a test ground for future, more advanced theories of long ranged interactions in cylindrical systems. The presented results can also be viewed as a model of interactions due electromagnetic field fluctuations between tubular formations, such as nanotubes and nanowires.

17. First principle calculations of the Casimir force between Silicon films

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Thin solid films are among the basic components of contemporary nanodevices. For this reason in the last few years an increasing attention has been addressed to electromagnetic vacuum fluctuation forces between them [1-5]. Theoretical determinations of the force between metal and silicon films have been performed mainly using a continuum model under the assumption that the macroscopic dielectric function of the film be the same of the bulk material. Attempts to include size quantization effects in simple metal films adopting various models of the boundary potential have shown that the calculated force may be significantly different from the one derived with bulk dielectric properties, although the difference is somewhat dependent on the assumed potential profile [4,6]. To avoid the uncertainties related to the boundary potential and to gain information about the importance of size effects, we have calculated the force between two Si films using the Lifshitz theory at T = 0_K with the film macroscopic dielectric function obtained by a first principle approach. We consider a film obtained by regularly stacking 24 atomic planes of Si along the (111) direction and two different surface configurations: (i) with the surface dangling bonds saturated by hydrogen atoms, (ii) in the presence of surface relaxation giving rise to the 2x1 reconstruction.

In the first case the Si atoms are in their ideal position, while in the second case zig-zag chains of dimers are formed in the outer layer. The total thickness of the film is 1.9 nm in the first case and 1.7 nm in the second. In both cases the film has perfect periodicity in the plane normal to the (111) direction. The one electron energies and wavefunctions have been calculated self-consistenly using Density Functional Theory in LDA approximation and norm conserving pseudopotentials. Plots of the band structure along the high symmetry directions of the two-dimensional Brillouin zone allow to point out the effects of the reduced size and of the presence of surface or chemisorption states. With the calculated energies and wavefunctions we have determined the macroscopic dielectric tensor from the microscopic linear response: this allows to include non-local effects arising from the crystal periodicity. Taking the z axis along the (111) direction and the y axis along the zig-zag chains we have found that the dielectric tensor has biaxial character for reconstructed films with $e_{yy}(iw) > e_{xx}(iw) > e_{zz}(iw)$, and is uniaxial for the hydrogen terminated film with $e_{yy}(iw) = e_{xx}(iw) > e_{zz}(iw)$. These differences are significant and caused by the rearrangement of the electronic structure that occurs at the _lm surfaces. The calculation of the force has been performed using the generalization of Lifshitz theory to treat anisotropic media [7]. The results show that the state of the surface is very important to determine the intensity of the force in both the large and the low distance range. The deviations from the bulk dielectric function is more significant when surface states are present, since they introduce new optical transitions at energies below the Si band gap.

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18. A General Theory of Casimir Forces

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We study the Casimir forces for a quantum field with spin s=0, 1/2, or 1, subject to boundary conditions with arbitrary dispersive and dissipative properties. Based on a Green's function formalism, we consider a surface impedance approach to evaluate the momentum flux difference of the field impinging on both sides of a given boundary and calculate the expectation value of the energy-momentum tensor. We apply our results to electromagnetic, electronic, and acoustic fields both at zero and finite temperature.

19. Role and applications of vacuum force in microscopic systems

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Recent developments on nano- and micromechanical systems (NEMS and MEMS) have focused the attention on the investigation of those forces that affect the dynamics of small pieces of materials separated by distances in the submicron scale. The vacuum force plays a fundamental role at the nano- and micro-scale and sometimes it affects the correct operation of those systems. The role and features of the vacuum force have been investigated within a three-layer scheme and at zero temperature using the Lifshitz formulation for two different applications: i) the attraction between plane parallel slabs and ii) the morphology of deposited thin films. In both cases Drude-Lorentz models have been employed to describe the dielectric properties of simple metals and extrinsic semiconductors. For plane parallel slabs it has been shown that their dielectric properties can affect their oscillations around the equilibrium distance and the role of the doping has been considered in detail. In the latter application, the morphology of the free surface of the deposited film has been predicted using a simple model that takes into account the dispersion, strain and surface energy of the film.

20. Casimir-life drag forces in superfluids

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We calculate the drag force acting on an impurity moving through a quasi-1D BEC using analytic solutions for the quantum fluctuations in the system. We find a non-zero force arises for zero and finite temperature at all velocities due to an imbalance in the Doppler shift in the scattering of quantum and thermal fluctuations.

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