EUROPEAN SCIENCE FOUNDATION
SETTING SCIENCE AGENDAS FOR EUROPE

Exploring the Physics of Small Devices (EPSD)

FLUCTUATIONS AND CASIMIR FORCES

Vilaflor, Tenerife (Spain), November 4–6, 2010

Convenor:

Ricardo Brito
Departamento de Física Aplicada I
Universidad Complutense, 28040 Madrid

Scientific Committee:

Ricardo Brito
U. Complutense de Madrid

Chris Van den Broeck
Hasselt University, Belgium

Thorsten Emig
Université Paris Sud

Rodrigo Soto
Universidad de Chile

SCIENTIFIC REPORT

1.- Executive summary

The Workshop *Fluctuations and Casimir Forces* was aimed to bring together researchers and scientists working in the field of fluctuations in small systems and its manifestations in micro or macroscopic properties. This field of fluctuations is becoming very active because of the experimental access to nanometric scales, and the development of techniques to create, manipulate and measure physical quantities at such tiny scales. Inherently, small systems are subject to fluctuations. As a result, one needs to go beyond the traditional macroscopic concepts and techniques to describe or exploit their behavior. The small number of particles and minimal distances make it very difficult, in some cases, to define averages. Even when one can define them, the fluctuations are so important that make the average meaningless. Therefore, in order to describe the physics of such systems, one must deal with theories that take into account the fluctuations. Recent developments include Brownian motors and refrigerators, stochastic resonance, stochastic Thermodynamics, as examples of developments in this direction. There is however one surprising but momentous implication of small scale fluctuations that has been identified for a long time, namely the attractive force that can be induced between fluctuating entities. The most famous example is the Casimir force. However, such force has not been interpreted in terms of fluctuations in the context of Statistical Mechanics of NonEquilibirum systems.

The purpose of the workshop is to explore recent developments of this concept, and to confront it with the other developments in the physics of small systems. Special emphasis will be given to classical realizations of the phenomena, to the influence of non equilibrium constraints, and to its possible relevance on the above cited more "traditional aspects" such as Brownian motors stochastic Thermodynamics. Following this ides, the Workshop was structured around three main lines, that did not exclude each other, but had certain overlaps. They could be summarized as:

1. Foundations of Thermodynamics and the Second Law. Theorems of work and heat. Foundations of Irreversible Thermodynamics.

2. Fluctuations on Statistical Mechanics. Fluctuations of thermal origin. Violation of Fluctuation Dissipation theorem and NonEquilibrium cases and Casimir Forces: Fluids at criticality, liquid crystals, reaction-diffusion systems, granular fluids, etc

3. Fluctuations in Quantum Mechanics. Casimir Forces in Quantum Electrodynamics. Geometrical configurations. Entropic considerations.

Participants were requested to talk about their current research, open projects, work in perspective or unsolved problems in their fields of interest. The aim was to provoke discussions, remarks, interchange of opinions and promote the exchange of ideas, approaches and different techniques. With this idea in mind, the talks were planned of 30 minutes followed by 10 min discussions, questions and comments. Moreover, the conference venue had at our disposal some offices and rooms where participants could meet and

have scientific discussions. The small number of participants and the reduced size of the hotel was very appropriate for such exchange of information.

2.- Scientific contents of the event

During the morning session of the first day of the Workshop, there were two talks of 5 minutes each, first by the Convenor, Ricardo Brito, from Universidad Complutense de Madrid, about the goals of the workshop. It was followed by the ESF director of the program *Exploring the Physics of Small Devices*, Prof. C. Van den Broeck, from the University of Hasselt, that presented that program of the ESF, stating the aims and goals of it, together with the actions that are covered by the program.

Then, a series of 17 talks followed, that can be grouped in the areas described in the previous section. Their contents, objectives and goals are described below.

1. *Foundations of Thermodynamics and the Second Law. Theorems of work and heat. Foundations of Irreversible Thermodynamics.*

   This subject was introduced by Chris Van den Broeck, that reviewed a number of problems where fluctuations are important, like the adiabatic piston, Brownian motors, refrigerators, etc, which are all phenomena driven by fluctuations with a related energy given by $k_B\,T$, that is, the temperature of the system. It was followed by a talk of Alberto Imparato, that explored one of the topics described by Van Den Broeck, the case of a Brownian particle interacting with its surroundings. He developed a theory for work and heat in this particular situation, and compare his results with the predicted distributions for such quantities.

   The talk of Gert-Ludwig Ingold treated the particularities of a quantum Brownian particle interacting with its environment, and how in this case Thermodynamic quantities are not uniquely defined. The results for Thermodynamic quantities differ depending on its definition, and some quantities, like the specific heat can become negative. He finished by making a link with the Casimir Forces, one of the main topics of the workshop.

   Within the same topic, Miguel Rubi showed how a probabilistic interpretation of non equilibrium Thermodynamics can be used to analyze the fluctuating dynamics of the entropy driven diffusion in systems with entropic barriers. The confinement originates a bias that leads to a rectification of fluctuations, a phenomenon also described in the talk of C. Van den Broeck.

   Along that line, Jun M.R. Parrondo derived a generalization of the Fluctuation-Dissipation relation valid for non equilibrium systems by an appropriate election of the variables and its conjugated. He described the key ingredient for such relation to hold, which essentially consists of a system with a Markovian dynamics.

   Application to an experimental situation was developed by Sergio Ciliberto, that studied the fluctuations of the nematic orientation in a liquid crystal. Near the critical point, fluctuations are not Gaussian, and the system presents aging. During the

slow relaxation related with aging, he proposed to define an effective temperature so that the Fluctuation Dissipation relation holds. This temperature is not related with the bath temperature.

2. *Fluctuations on Statistical Mechanics. Fluctuations of thermal origin. Violation of Fluctuation Dissipation theorem and Non Equilibrium cases and Casimir Forces: Fluids at criticality, liquid crystals, reaction-diffusion systems and granular fluids*

   In this subject, the opening talk was given by the Convenor, Ricardo Brito. He described how the fluctuation induced forces, or Casimir forces, can be obtained via a Langevin equation, that takes into account both the deterministic dynamics and the internal fluctuations of the fields. He showed how this formalism can be applied to equilibrium systems, like liquid crystals, but also to non equilibrium ones (in particular to a granular fluid, a system intrinsically out of equilibrium). It was elucidated how the forces are created by the long range correlations that are present in the systems due to the fact that Fluctuation-Dissipation theorem does not hold, making clear connection with the first subject of the Workshop.

   In the same spirit of fluctuations in non equilibrium systems, Rodrigo Soto presented a derivation of such forces based on the formalism of Green Functions. He showed how, for non equilibrium cases, the third law of Newton (action-reaction) can be violated for asymmetric bodies immersed in a fluctuating field whose fluctuations are not in equilibrium. Also, torques can be realized. As a last application, Ignacio Pagonabarraga showed a Casimir force in a non equilibrium fluid with some inclusions. The fluid was modeled as a dissipative DPD fluid, where the presence of long range correlations induced the Casimir forces.

   Other systems with long range correlations are critical fluids. In this case the nature of the long range correlations is different: the system is at equilibrium, but at a critical point. Siegfried Dietrich made an exhaustive description of such systems for an object immersed in a lutidine–water mixture, discussing about the universality in these systems. In fact, he could relate binary mixtures with superfluid helium mixtures, and relate it with critical Casimir forces. As a continuation, Andrea Gambassi detailed the results for that physical system. He discussed about lateral forces when the substrate is patterned, levitation and the non equilibrium dynamics presented in the system.

   To finish with this sub-topic, Clemens Bechinger described the advanced experimental techniques to measure such effects. In particular, he described a technique which is able to measure forces as tiny as 5 femto Newtons. He was able to observe the long range correlations in the mixture of lutidine–water mixture, which are repulsive or attractive depending on the boundary conditions, and allowed Andrea Gambassi to make his theoretical predictions.

   Finally, David Dean discussed how the drag on a test particle moving through a fluctuating field a constant velocity can induced a fluctuating Casimir-type force.

He implemented his model in an Ising model with a strong magnetic field acting on one site of the lattice, but this site was moving in time at constant speed.

3. *Fluctuations in Quantum Mechanics. Casimir Forces in Quantum Electrodynamics. Geometrical Configurations. Entropic considerations.*

   The main talk in this topic of the Workshop was given by Thorsten Emig. He and his coworkers have developed a very powerful method to derive Casimir forces for Electromagnetic Field under Quantum fluctuations. It combined ingredients of scattering theory and Statistical Mechanics and can be applied to complicated geometries, that cover test geometries, but also configurations of great technological interest, like those of carbon nanotubes confronted to a plane, or two carbon nanotubes. Their method also allow to obtain torques and include material properties. Using this technique Pablo Rodriguez Lopez explained how to derive Casimir energies and forces for two cylinders. These cylinders can be parallel, case where their force of proportional to its length, but also tilted, when the former scaling does not apply. Also, torques can be derived in this case that promote cylinders to get parallel.

   In the context of Casimir forces between metals, Antonie Canaguier-Durand discussed about the Casimir energy between a plane and a sphere in the Drude and lossless plasma approximations. He developed a theory that went beyond the Proximity Force approximation. He discussed in detail the interplay between the curvature of the object and the temperature of the thermal photons, that can even lead to a repulsive force.

   Davide Iannuzzi explained the experimental setup to measure Casimir forces, and he offered his equipment and know-how to all the participants in the workshop with interesting experimental proposals. As an example of his research, he describe how to measure deviations from the QED Casimir effect for two plates in vacuum. Such deviations, if exists, could give an indication of a possible mechanism to explain the dark matter/energy of the Universe.

3.- Assessments of the results, contribution to the future direction of the field

The objectives of the workshop were completely fulfilled. They consisted in putting in common the knowledge of different techniques, approaches, fields of interest and points of view in the study of systems subjected to fluctuations. In particular, some of the ideas that were put forward and will be considered for future research are the energetics of Casimir Forces, the connection between quantum and thermal (critical or not) fluctuations, possible experimental techniques to measure fluctuation induced forces in classical and quantum systems (classical systems at critical points, but also non critical systems), quantum Casimir forces in realistic geometries, and some more.

As a matter of fact, some common projects were started during these workshop and some existing ones were consolidated. Just to mentioned few, the collaboration between A. Gambassi and S. Ciliberto was consolidated by a research visit of A. Gambassi to the ENS in Lyon, whose director is S. Ciliberto. Moreover, a collaboration between Universidad de Chile and Universidad Complutense (led by R. Soto and R. Brito) was extended and includes now the Universidad de Barcelona (I. Pagonabarraga). Another possible collaboration between Universidad Complutense and Laboratoire Kastler Brossel in Paris was discussed (via Pablo Rodriguez Lopez and Antoine Canaguier Durand).

The ESF representative, Chris Van Den Broeck, informed in his presentation of the ESF program, that these collaborations or common projects could be financed via the ESF research program *Exploring the Physics of Small Devices.*

The possibility of a Proceedings Book was discussed among some participants. However, there were some opinions that discouraged it. The main reason was that the nature of the Workshop, of exploratory type, encouraged participants to present on going research, open problems without conclusive results. Therefore, it was decided not to publish a Proceedings book. The same applied to the publication in a public Web site of the presentations handed by the participants.

To conclude, many participants expressed their satisfaction with the format, contents, orientation and reduced number of participants of the Workshop. Moreover, they expressed their wishes to participate (or organize) in a (possibly) forthcoming edition of a similar workshop with the same topics.

4.- Final Programme

Wednesday 3rd November 2010

Evening: Arrival, Registration, Welcome Dinner

Thursday 4th November 2010

Chair: Rodrigo Soto

09:00–09:05	Welcome by Ricardo Brito
09:05–09:40	Ricardo Brito Casimir Forces from Langevin Equations out of Equilibrium
09:40–10:20	Thorsten Emig Casimir Forces: Geometry and Material dependence
10:20–11:00	Miguel Rubi Thermodynamics and stochastic dynamics of transport in confined media
11:00–11:30	*Coffee Break*
11:30–11:40	Chris Van den Broeck Presenting ESF Program: Exploring the Physics of Small Devices
11:40–12:10	Chris Van den Broeck Brownian forces
12:10–12:50	Davide Iannuzzi From 100 nm to the edge of the Universe with Casimir force experiments
13:00–15:00	*Lunch*

Chair: Umberto M.B. Marconi

15:00–15:40	Siegfried Dietrich Critical Casimir Forces
15:40–16:20	Rodrigo Soto Fluctuation-induced self-force in a nonequilibrium steady state fluid
16:20–16:40	*Coffee Break*
16:40–17:20	Gert-Ludwig Ingold Casimir effect and quantum Brownian motion
17:20–18:00	Pablo Rodriguez-Lopez Some results of Casimir energy
18:00–20:00	Discussions—Free time
20:00	*Dinner*

Friday 5th November 2010

Chair: Andrea Gambassi

09:00–09:40 Clemens Bechinger
Direct measurement of critical Casimir forces

09:40–10:20 Ignacio Pagonabarraga
Fluctuation-induced interactions between solid inclusions in a dissipative fluid

10:20–11:00 David Dean
Out of equilibrium fluctuation induced interactions

11:00–11:30 *Coffee Break*

Chair: Davide Iannuzzi

11:30–12:10 Alberto Imparato
Work and Heat Probability Distribution of a Driven Brownian Particle

12:10–12:50 Juan M.R. Parrondo
Non-Equilibrium Fluctuation-Dissipation Theorem

13:00–15:00 *Lunch*

15:00–17:30 Discussions—Free time

17:30–18:00 *Coffee Break*

Chair: Siegfried Dietrich

18:00–18:40 Andrea Gambassi
Steering the Casimir effect: lateral forces, levitation, and dynamics

18:40–19:20 Antoine Canaguier-Durand
Thermal Casimir effect for Drude metals in the plane-sphere geometry

19:20–20:00 Sergio Ciliberto
Finite size effects and aging near a critical point

20:00 *Dinner*

Saturday 6th November 2010

09:00–11:00 Discussions and Farewell

Final List of Participants

Clemens Bechinger	University of Stuttgart c.bechinger@physik.uni-stuttgart.de
Ricardo Brito	Universidad Complutense, Madrid brito@fis.ucm.es
Chris Van den Broeck	Hasselt University christian.vandenbroeck@uhasselt.be
Antoine Canaguier-Durand	Laboratoire Kastler Brossel, Paris Antoine.Canaguier@spectro.jussieu.fr
Sergio Ciliberto	École Normal Supérieure Lyon sergio.ciliberto@ens-lyon.fr
David Dean	Université de Toulouse dean@irsamc.ups-tlse.fr
Siegfried Dietrich	MPI for Metals Research, Stuttgart dietrich@mf.mpg.de
Thorsten Emig	Université Paris Sud emig@lptms.u-psud.fr
Andrea Gambassi	SISSA, Trieste gambassi@sissa.it
Davide Iannuzzi	VU University Amsterdam iannuzzi@few.vu.nl
Alberto Imparato	University of Aarhus imparato@phys.au.dk
Gert-Ludwig Ingold	Universität Augsburg Gert.Ingold@Physik.Uni-Augsburg.de
Umberto M.B. Marconi	Università di Camerino Umberto.Marini.Bettolo@roma1.infn.it
Ignacio Pagonabarraga	Universidad de Barcelona ipagonabarraga@ub.edu
Juan M.R. Parrondo	Universidad Complutense, Madrid parrondo@fis.ucm.es
Pablo Rodriguez-Lopez	Universidad Complutense, Madrid parodrilo@gmail.com
Miguel Rubi	Universidad de Barcelona mrubi@ub.edu
Rodrigo Soto	Universidad de Chile rsoto@dfi.uchile.cl

Participation from Countries

Country	**Number**
Spain	5
France	4
Germany	3
Italy	2
Netherlands	1
Belgium	1
Denmark	1
Chile	1

Three other participants were invited to the workshop, but two of them canceled their participation because of Visa (Ramin Golestanian and Tony Maggs), and a third one due to plane cancellations (Audrey Steinberger).