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Dynamical Casimir effect in Braneworlds

One assumes that our universe is a variety of codimension 1 in a 5-dimensional space-time. The latter becomes a time dependent boundary condition for the metric, so leading to particle creation, namely gravitons in this case. The problem has a close analogy with photon creation between conducting plates.

Dynamical Casimir Effect in Braneworlds

Ruth Durrer* and Marcus Ruser†

(Received 6 April 2007; published 15 August 2007) PRL 99, 071601 (2007)

In braneworld cosmology the expanding Universe is realized as a brane moving through a warped higher-dimensional spacetime. Like a moving mirror causes the creation of photons out of vacuum fluctuations, a moving brane leads to graviton production. We show that, very generically, Kaluza-Klein (KK) particles scale like stiff matter with the expansion of the Universe and can therefore not represent the dark matter in a warped braneworld. We present results for the production of massless and KK gravitons for bouncing branes in five-dimensional anti – de Sitter space. We find that for a realistic bounce the back reaction from the generated gravitons will be most likely relevant. This Letter summarizes the main results and conclusions from numerical simulations which are presented in detail in a long paper [M. Ruser and R. Durrer, arXiv

Dynamical Casimir effect for gravitons in bouncing braneworlds
Marcus Ruser* and Ruth Durrer†
(Received 6 April 2007; published 9 November 2007) Phys. Rev. DD76, 104014

We consider a two-brane system in five-dimensional anti – de Sitter space-time. We study particle creation due to the motion of the physical brane which first approaches the second static brane (contraction) and then recedes from it (expansion). The spectrum and the energy density of the generated gravitons are calculated. We show that the massless gravitons have a blue spectrum and that their energy density satisfies the nucleosynthesis bound with very mild constraints on the parameters. We also show that the Kaluza-Klein modes cannot provide the dark matter in an anti – de Sitter braneworld. However, for natural choices of parameters, backreaction from the Kaluza-Klein gravitons may well become important. The main findings of this work have been published in the form of a Letter [R. Durrer and M. Ruser, Phys. Rev. Lett. 99, 071601 (2007)].
PHYSICAL REVIEW D 76, 104014 (2007)

Markus Buttiker *University of Geneva*

Entanglement energetics

Vacuum fluctuations have been of interest to us in connection with the equilibrium state of mesoscopic systems coupled to an environment. Since the system-bath coupling constant is typically not small, as assumed in statistical mechanics, the fact that a small system is entangled with its environment can have profound effects. A small system even in its ground state can, due to vacuum fluctuations of the bath, be found in an excited state: we have a number of papers were we discuss such vacuum effects which we term "entanglement energetics"

Phys. Rev. Lett. 92, 247901-1

Entanglement Energetics at Zero Temperature

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(Received 17 November 2003; published 16 June 2004)

We show how many-body ground state entanglement information may be extracted from subsystem energy measurements at zero temperature. Generically, the larger the measured energy fluctuations are, the larger the entanglement is. Examples are given with the two-state system and the harmonic oscillator. Comparisons made with recent qubit experiments show that this type of measurement provides another method to quantify entanglement with the environment.

Phys. Rev. Lett., 84, 346

Zero-Point Fluctuations and the Quenching of the Persistent Current in Normal Metal Rings

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(Received 5 May 1999)

The ground state of a phase-coherent mesoscopic system is sensitive to its environment. We investigate the persistent current of a ring with a quantum dot which is capacitively coupled to an external circuit with a dissipative impedance. At zero temperature, zero-point quantum fluctuations lead to a strong suppression of the persistent current with decreasing external impedance. We emphasize the role of displacement currents in the dynamical fluctuations of the persistent current and show that with decreasing external impedance the fluctuations exceed the average persistent current.

G.M. Graf *ETH-Zürich*

Regularization procedures in the Casimir effect

There are some questions which I still find puzzling. In most approaches the substraction of infinities is based on some procedure (e.g. mode summation with cutoff) for which one may wish to have a more fundamental understanding. That would in my opinion require a regularization in which the Hamiltonians of the two models under comparison can be realized on the same Hilbert space. There are attempts in this direction, but to my knowledge not for the electromagnetic field and for general geometries.

Ann. H. Poincaré. 4, 1001-1013 (2003)

F. Bernasconi, G.M. Graf, D. Hasler,

The heat kernel expansion for the electromagnetic field in a cavity.

Ph. A. Martin *EPF-Lausanne*

Microscopic theory of the Casimir effect at thermal equilibrium

Role of thermal fluctuations in the electromagnetic Casimir effect

Joint work with Pascal Buenzli

Microscopic origin of universality in Casimir forces
J. Stat. Phys. 119, 273, 2005

Thermal quantum electrodynamics of non relativistic charged fluids
Phys.Rev. E, 75, 041125, 2007

Microscopic theory of the Casimir effect at thermal equilibrium: large separation asymptotics
Phys. Rev. E, 77,011114, 2008

In standard calculation of the Casimir force, the plates at distance d are treated as **macroscopic** conductors (vanishing of the tangential electric field).
Boundary conditions leads to a d-dependence of the electromagnetic spectrum, which is the source of the Casimir force.

- ***If field and charge fluctuations inside the conductors are ignored:***

Casimir's result at T=0 $f^{\mathrm{vac}}(d) = -\frac{\pi^2 \hbar c}{240 d^4}$

High temperature-long distance

$$f(d) = -\frac{\zeta(3)}{4\pi\beta d^3} + \mathcal{O}\left(\exp\left(-\frac{b}{\alpha}\right)\right), \qquad \alpha \to 0 \quad \alpha = \frac{\beta\pi\hbar c}{d}$$

- ***Introduce material properties via the dielectric function*** $\epsilon(\omega)$ ***in Lifshitz theory***

The predictions of the Lifshitz theory are ambiguous in the metallic limit depending on the choice of $\epsilon(\omega)$

Drude model: $\epsilon(\omega) \sim \frac{4\pi i\sigma}{\omega}$ **Plasma model** : $\epsilon(\omega) \sim 1 - \frac{\omega_p^2}{\omega^2}$

High temperature - long distance

$$f(d) \sim -\frac{\zeta(3)k_B T}{4\pi d^3}, \qquad \text{if } r^{\mathrm{TE}}(0, \boldsymbol{k}) = 1$$ plasma

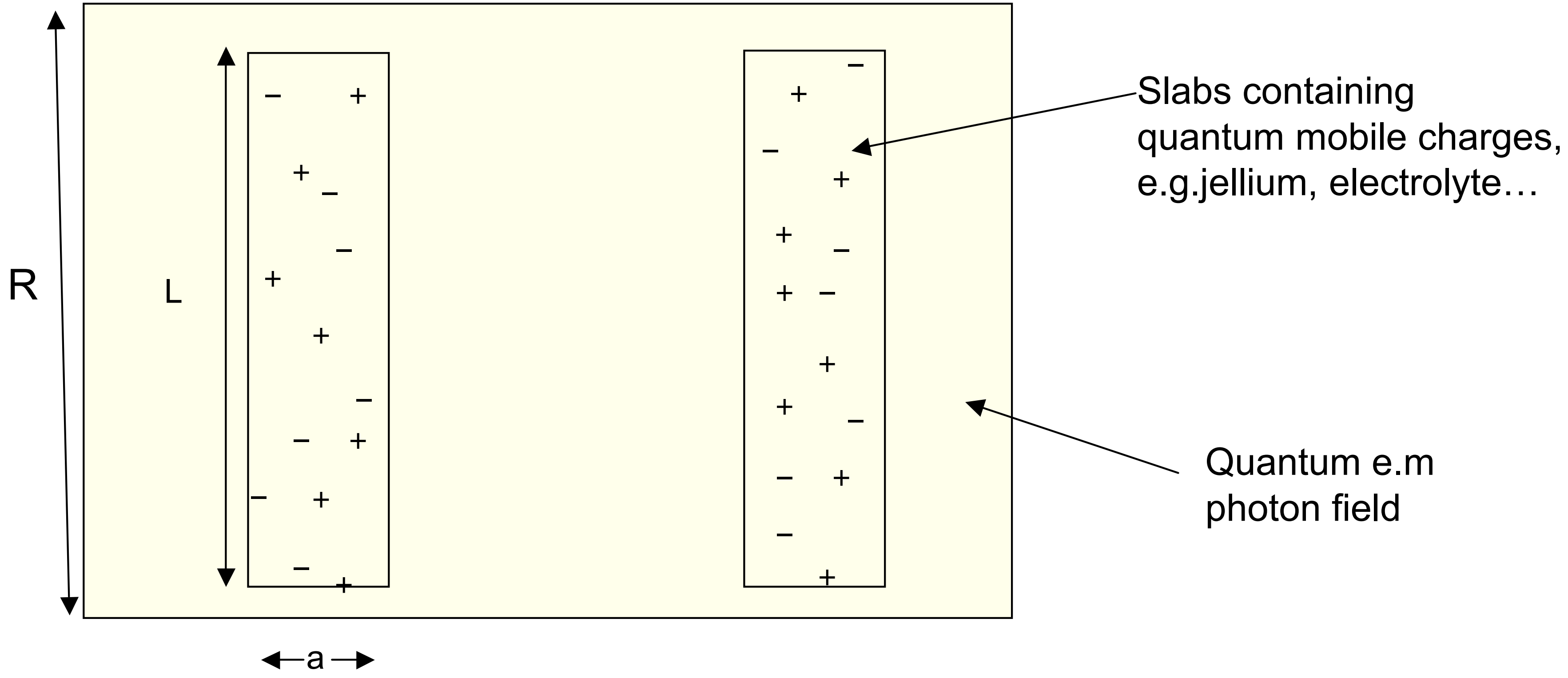
$$f(d) \sim -\frac{\zeta(3)k_B T}{8\pi d^3}, \qquad \text{if } r^{\mathrm{TE}}(0, \ ) = 0.$$ Drude

Decide about the 1/2 factor from first principle without using the Lifshitz theory ⟶ fully microscopic theory

Two principles

- Quantum electrodynamics of non relativistic charged particles
- Equilibrium statistical mechanics

The model: Microscopic conductors with internal fluctuations



Hamiltonian of non relativistic charges coupled to the quantum electromagnetic field through Maxwell equations in transverse gauge

$$H_{L,R} = \sum_{i=1}^{N} \frac{\left(\mathbf{p}_i - \frac{e_{\gamma_i}}{c}\mathbf{A}(\mathbf{r}_i)\right)^2}{2m_{\gamma_i}} + \sum_{i<j}^{N} \frac{e_{\gamma_i} e_{\gamma_j}}{|\mathbf{r}_i - \mathbf{r}_j|} + \sum_{i=1}^{N} V_{\mathrm{ext}}(\gamma_i, \mathbf{r}_i) + H_0^{\mathrm{rad}}$$

Coupling of particles to the radiation field

Coulomb interaction

External potential confining the particles in the slabs

Free field energy

Result

exact: involves no approximations or intermediate assumptions

$$f(d) = -\frac{\zeta(3)}{8\pi\beta d^3} + R(\beta, \hbar, d)\ , \qquad R(\beta, \hbar, d) = \mathcal{O}(d^{-4})$$

Universal classical Casimir amplitude

The asymptotic force is:

- independent of h and c
- the factor is 1/8 and not 1/4, supporting that TE modes do not contribute in this regime
- universal with respect to the microscopic constitution of the plates
- does not require regularization procedures

Subdominant terms depend on h and c and contain non universal contributions

Particle fluctuations inside the conductors account for reducing the force by a factor 1/2 at high temperature.

Calculations of the Casimir force based on macroscopic boundary conditions are not correct when the temperature is different from zero.

Open questions

How to deal with the low temperature-short distance regime within the microscopic model ?

Is the standard Casimir force formula modified by quantum charge fluctuations in the ground state of the metals ?

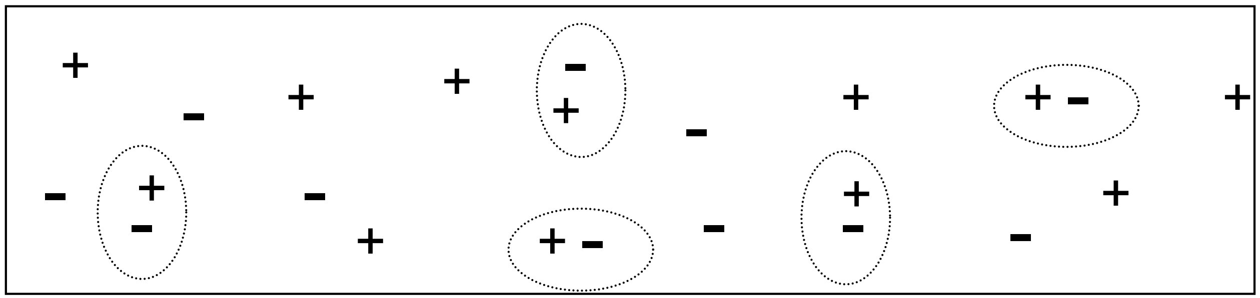
Corrections to the leading asymptotic term ?

Make explicit connections with Lifshitz theories

Van der Waals-London and Casimir-Polder retarded forces in a non-zero density and finite temperature medium

Atomic limit (*Fefferman 1985, Conlon, Lieb, Yau, 1989*)
Sufficiently low density to have individual non overlapping atoms
Sufficiently low temperature to prevent full ionization

Take into account non zero temperature and density effect in a partially recombined electron-proton gas (Saha regime of equilibrium phase ionization)



Alastuey, Cornu, Martin 2007 J.Chem. Phys.

Non retarded regime: treat in a coherent way all effects originating from the Coulomb potential, quantum binding,ionisation, screening , atomic forces,…

The proton-proton correlation behaves as

$$\rho_{pp}^{(2)T}(r) \underset{r\to\infty}{\sim} -\beta^{-1}\frac{C(T,\rho)}{r^6}$$

In the ionization equilibrium phase regime, the coefficient $C(T,\rho)$ takes the form at lowest order in the ideal densities:

$$C(T,\rho) = \left\{\left[\rho_f^{\mathrm{id}}\right]^2 C^{f-f}(T) + \rho_f^{\mathrm{id}}\rho_{at}^{\mathrm{id}} C^{f-at}(T) + \left[\rho_{at}^{\mathrm{id}}\right]^2 C^{at-at}(T)\right\}\left(1+\mathcal{O}(e^{-c/k_BT})\right)$$

Higher density contributions

giving rise to three effective potentials:

$$u^{f-f}(r) = -\frac{C^{f-f}}{r^6}, \quad u^{f-at}(r) = -\frac{C^{f-at}}{r^6}, \quad u^{at-at}(r) = -\frac{C^{at-at}}{r^6}$$

charge-charge *charge-atom* atom-atom

$1/r^6$ van der Waals type potentials exist between **free charges** as the result of dipole fluctuations generated by their screening clouds

Retardation phenomena at finite temperature: work in progress.
Collaboration: Françoise Cornu, Paris-Sud, Orsay