Physical Aspects of the Non Equilibrium Casimir Effect

Adrián E. Rubio López[1]*; Fernando C. Lombardo[1].
[1] Departamento de Física, FCEyN, UBA
*arubio@df.uba.ar

In this talk I will show how to set the theoretical framework for the ***quantization of fields interacting with material boundaries at non-equilibrium scenarios***. For this purpose, we implement the closed time path ***(CTP) or Schwinger-Keldysh formalism in a open quantum system*** framework. We show the procedure for scalar and EM fields **[1,2]**. This allow us to study the time evolution for the interaction between a quantum field and real materials, modeled as a composite environment consisting in quantum polarization degrees of freedom in each point of space, at arbitrary temperatures, connected to thermal baths. We solve the full dynamical problem from initial conditions. Therefore, setting the basis for a field quantization, we look at the long-time limit and ***deduce the steady state*** dynamics. We show that, depending on the material boundaries configuration, ***different contributions*** coming from different parts of the total system are present in the steady state**[3]**. They depend of course on the material bodies but also on its size, allowing the.appearance (or not, depending the situation) of a separated contribution entirely related to the field initial state and its dissipative dynamics, which is very promising for ***tailoring dispersion effects at the nanoscale***. Moreover, in the context of the Casimir physics, we also demonstrate the extension of the Lifshitz's formula for non-equilibrium situations from a first principle quantum approach.

State of the Problem: Objective and Model

Objective: Non Equilibrium Casimir Physics from full quantum framework

Quantum Field ⟷ (Current) Polarization DOFs ⟷ Thermal Baths

(QBM in each material point)

Polarizable media interacting with field
(bounded electrons)

$$S_{\mathrm{Free}}[\mathrm{Field}] + S_{\mathrm{Free}}[\mathrm{PDOFs}] + S_{\mathrm{Free}}[\mathrm{Thermal\ Baths}] + S_{\mathrm{Curr}}[\mathrm{Field\text{-}PDOFs}] + S_{\mathrm{Int}}[\mathrm{PDOFs\text{-}Thermal\ Baths}]$$

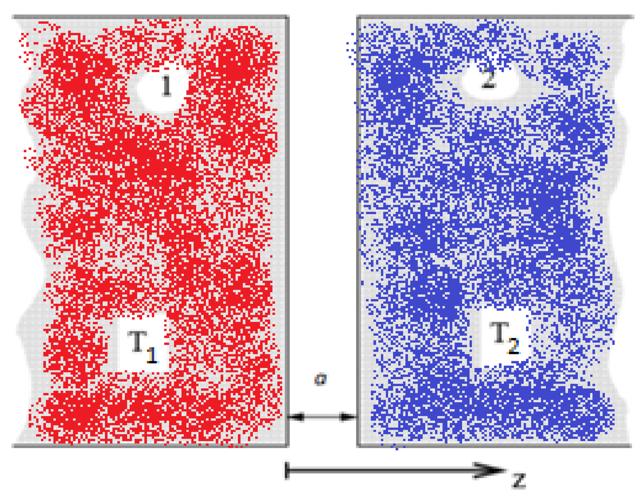
At t_0:
- Free subsystems
- Uncorrelated state
- Thermal state for each part

$t_0 \to -\infty$ (Closed Time Path method) → Steady Situation: ***Non-Eq.*** Casimir from "Open" QFT

Tracing out Thermal Baths and PDOFs → $S_{\mathrm{Eff}}[\mathrm{Field}]$ (Dissipation + Noise)

→ $Z_{\mathrm{Field}}[J, J']$ Generating Functional → $\mathcal{G}_{\mathrm{H}}(x_1, x_2)$ Hadamard Propagator

Example: Non-Eq. Lifshitz Problem



Non Equilibrium Contribution Splitting

The Hadamard propagator for the EM field is given by:

$$\mathcal{G}_{\mathrm{H}}^{jk}(x_1,x_2) \equiv \underbrace{\left\langle A_0^j(x_1) A_0^k(x_2) \right\rangle_{\mathbf{A}_i,\mathbf{\Pi}_i}}_{\text{Initial Conditions}} + \underbrace{\left[\mathcal{G}_{\mathrm{Ret}} * \left(\partial^2_{tt'}\mathbb{N}\right) * \left(\mathcal{G}_{\mathrm{Ret}}\right)^T\right]^{jk}(x_1,x_2)}_{\text{Material}}$$

→ $P_{\mathrm{Cas}}(x_1)$

Contributions at arbitrary time:
(Transient Stage)

$$P_{\mathrm{IC}}(x_1) + P_{\mathrm{DOFs}}(x_1, \beta_{\mathrm{P}_{\mathbf{x}}}) + P_{\mathrm{B}}(x_1, \beta_{\mathrm{B},\mathbf{x}})$$

Long-time limit $t_0 \to -\infty$

Contributions at steady state: $P_{\mathrm{Cas}}^{\infty} = P_{\mathrm{IC}}^{\infty} + P_{\mathrm{B}}^{\infty}(\beta_{\mathrm{B},\mathbf{x}})$ → **Source's Contribution**

Dissipation VS Free field fluctuations

The physical presence of each contribution at the steady state are completely related to the **role of dissipation** in each part of the composite system:

P_{IC}^{∞}

- Depends on the **initial conditions**
- Reproduces the **modified modes** contribution (homogeneous solution in "steady" problems)
- Matches with the flux of the quantum **vacuum fluctuations** in infinity
- Is <u>**NOT**</u> zero if **infinite-size dissipationless regions** are present (zero for the Lifshitz problem)
- It is space-dependent for **non-thermal** initial states (after a time average)

$P_{\mathrm{B}}^{\infty}(\beta_{\mathrm{B},\mathbf{x}})$

All the material's subsystems with **dissipationless internal dynamics** present a long-time contribution

Baths': dissipationless oscillators, steady

DOFs as QBM particles:
Dissipation wins (NO steady contribution)

Results and Forthcoming Work

<u>**Two plates scenario:**</u>

	Half-spaces	Finite width
Equilibrium	Lifshitz formula	Lifshitz formula
Non-Equilibrium (thermal states)	• Left Plate • Right Plate	• Left Plate • Right Plate • Field's ICs
Thermal States for Plates + Non-thermal state for field at t_0	• Left Plate • Right Plate	• Left Plate • Right Plate • Field's T = 0 + space dependent

Single T

Dissipation wins

Time average

- <u>**Canonical quantization:**</u> The simple framework for non-thermal states (work in preparation).
- <u>**Measurements:**</u> Study the incidence of the finite width in realizable experimental setups (work in preparation).
- <u>**Microscopic modeling:**</u> Include conduction electrons to the model (Drude Vs Plasma controversy in Casimir community; partial results).
- <u>**Graphene as candidate:**</u> Obtain the force splitting for graphene material sheets (modeled as 2+1 free Dirac field), where the contributions splitting has to be clearly present (partial results).
- <u>**Dynamical phenomena:**</u> Quantum friction and dynamical Casimir effect (some clues with the canonical quantization method).
- <u>**Adiabatic Vs Non-adiabatic process:**</u> Study transient terms in different situations, entropy production, work (ideas).
- <u>**Non-local materials (nanotechnology):**</u> Combined with non-equilibrium situations allows to tailoring dispersion effects, as heat transfer and forces.

[1] Rubio López A. E., Lombardo F. C., Phys. Rev. D **89**, 105026 (2014).
[2] Rubio López A. E., Lombardo F. C., Eur. Phys. J. C **75:93** (2015)..
[3] Lombardo F. C., Mazzitelli F. D., Rubio López A. E., Turiaci G. J., submitted to Euro. Phys. Jour. C. (2015). arXiv: 1509.07459[quant-ph].