Entropy production and entanglement forces?

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merci à:

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Outline

- Quantum Field Theory for lossy systems
  history
  system+bath paradigm
  Langevin vs. Rytov
- current issues
  "thermodynamic cut"
  energy conservation
  entropic/entanglement forces

Quantum Field Theory for lossy systems

Quantum Dissipative Systems
Ulrich Weiss
Modern Condensed Matter Physics vol. 13
(3rd ed., World Scientific 2008)

The Theory of Open Quantum Systems
Heinz-Peter Breuer and
Francesco Petruccione
(Oxford University Press 2002)

bath: Feynman-Vernon influence functional
spin-boson physics: NIBA & co

(non)Lindblad master equation
damped oscillator, Brownian motion,
Born-Markov & co

History

A Note on the Quantization of Dissipative Systems

Wesley E. Brittin

Phys. Rev. **77** (1950) 396–97

criticizing Kanai (*Progr Theo Phys* 1948)
and Caldirola

$$\Delta x \Delta \dot{x} \geqslant \hbar e^{-\alpha t}/m \tag{4}$$

violates the uncertainty principle for an oscillator,

$$\Delta x \Delta \dot{x} \geqslant \hbar/m. \tag{5}$$

Equation (5) is valid for the oscillator even when damping is taken into account, but to get the correct result one must treat the coupled system—oscillator plus radiation field.[2] Kanai conjectures that it is prob-

[2] Bauer & Jensen [*Z Phys* 1948]

$$H = \frac{1}{2}p^2 \mathrm{e}^{-\alpha t} + \frac{1}{2}\omega^2 x^2 \mathrm{e}^{+\alpha t}$$
$$p = \mathrm{e}^{\alpha t}\dot{x}$$

History

Irreversibility and generalized noise

Herbert B. Callen and Theodore A. Welton

Phys. Rev. **83** (1951) 34

quantum Johnson-Nyquist voltage noise

$$\langle V^2\rangle = (2/\pi)\int_0^\infty R(\omega)E(\omega, T)d\omega, \qquad (4.8)$$

where

$$E(\omega, T) = \tfrac{1}{2}\hbar\omega + \hbar\omega[\exp(\hbar\omega/kT)-1]^{-1}. \qquad (4.9)$$

It may be recognized that $E(\omega, T)$ is, formally, the expression for the mean energy at the temperature T of an oscillator of natural frequency ω.

impedance $\delta V = Z\delta\dot{Q}$, $R = \mathrm{Re}\, Z$

dissipation: system "acts on" bath

loss of coherence: bath fluctuations acting on system

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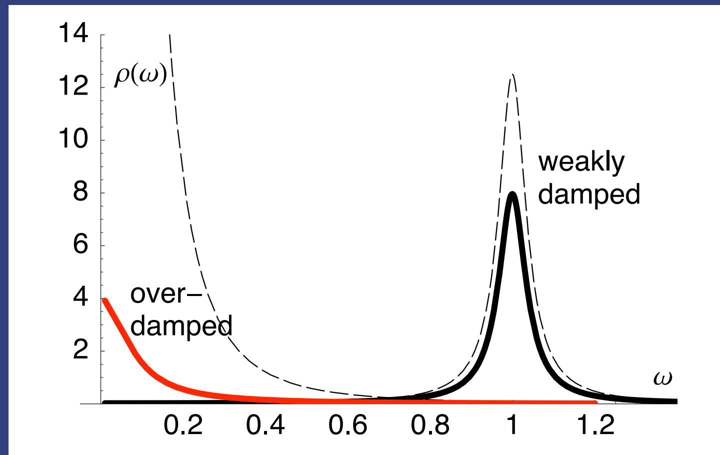
resistance $R(\omega) \mapsto \rho(\omega)$ spectral weight



"remarkable formula"

Ford, Lewis & O'Connell [*Phys Rev Lett* 1985]

van Kampen, Nijboer & Schram [*Phys Lett A* 1968]

Davies [*Chem Phys Lett* 1972]

Obcemea [*Int J Q Chem* 1987]

History

Einige Probleme aus der Theorie der elektrischen Schwankungserscheinungen

W. L. Ginsburg

Fortschr. Phys. **1** (1953) 51

zero-point potential energy of damped circuit

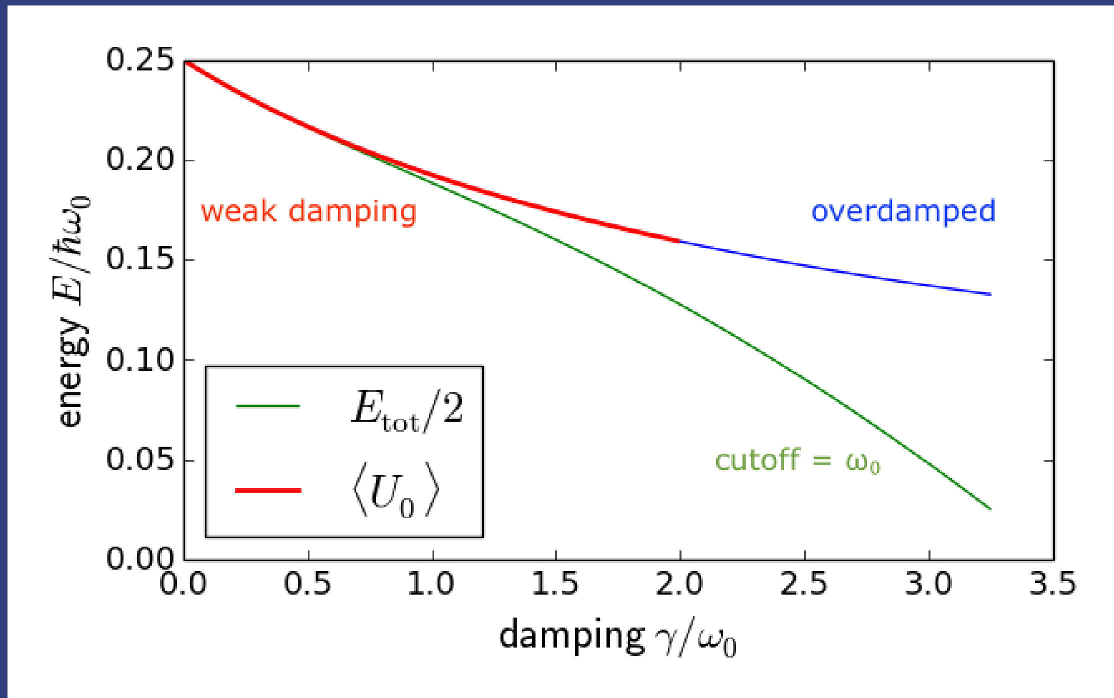
$$\langle U_0 \rangle = \frac{\hbar}{2\pi\sqrt{LC}} \cdot \frac{1}{\sqrt{4-\alpha^2}} \left[\frac{\pi}{2} - \operatorname{arctg} \frac{\alpha^2 - 2}{\alpha\sqrt{4-\alpha^2}} \right]$$

damping $\alpha = RC\omega$, resonance $\omega = (LC)^{-1/2}$

dissipation: system “acts on” bath

loss of coherence:

bath fluctuations acting on system



History

Theory of Electrical Fluctuations and Thermal Radiation

S. M. Rytov

(Academy of Sciences USSR 1953)

$$\begin{aligned} \mathrm{i}\omega\varepsilon(\omega)\mathbf{E} + \nabla \times \mathbf{H} &= \mathbf{j}_{\mathrm{th}} + \mathbf{j}_{\mathrm{ext}}\,, \\ -\mathrm{i}\omega\mu(\omega)\mathbf{H} + \nabla \times \mathbf{E} &= \mathbf{0}\,, \end{aligned}$$

Maxwell–Langevin equations

$$\begin{aligned} \langle j_{\mathrm{th}} \rangle &= \mathbf{0} \\ \langle j_{\mathrm{th}}(x) j_{\mathrm{th}}(x') \rangle &= \kappa T\ \mathrm{Re}\,\sigma\,\delta(x - x') \\ \langle j^*_{\mathrm{th}k}(\mathbf{x},\omega) j_{\mathrm{th}l}(\mathbf{x}',\omega') \rangle &= \frac{2\hbar\omega^2}{\mathrm{e}^{\hbar\omega/\kappa T} - 1}\,\mathrm{Im}\,\varepsilon_{kl}(\omega) 2\pi\delta(\omega - \omega') + \text{magn.} \end{aligned}$$

fluctuation–dissipation theorem (“2nd”: W. Eckhardt 1982)

consistent quantization for linear, causal media (Scheel, Knöll & Welsch 1998)

History

PHYSICAL REVIEW VOLUME 119, NUMBER 2 JULY 15, 1960

Dissipation in Quantum Mechanics. The Harmonic Oscillator

I. R. SENITZKY
U. S. Army Signal Research and Development Laboratory, Fort Monmouth, New Jersey

(Received February 29, 1960)

Phys Rev **119** (1960) 670

equation of motion for system energy

$$\langle H_{\text{osc}}\rangle = \langle H_{\text{osc}}{}^{(0)}\rangle e^{-\beta t} + \hbar\omega\{\tfrac{1}{2} + [\exp(\hbar\omega/kT) - 1]^{-1}\}(1 - e^{-\beta t}). \quad (60)$$

commutators preserved

zero point energy preserved

- dissipative losses balanced by fluctuating forces

Energy balance for a dissipative system
X. L. Li, G. W. Ford, and R. F. O'Connell,
Phys Rev E **48** (1993) 1547
comment by Senitzky: *Phys Rev E* **51** (1995) 5166

approximations:

– bath near thermal equilibrium (M. Lax)

– weak damping $\beta \ll \omega$

– small renormalization

History

Coupled surface polaritons and the Casimir force

Carsten Henkel, Karl Joulain, Jean-Philippe Mulet, and Jean-Jacques Greffet

Phys. Rev. A **69** (2004) 023808

surface plasmon contribution to pressure

$$F = \frac{\hbar\Omega}{4\pi d^3}\left(\alpha(z) - \frac{\gamma \mathrm{Li}_3(z^2)}{4\pi\Omega}\right), \qquad (12)$$

short distance d,

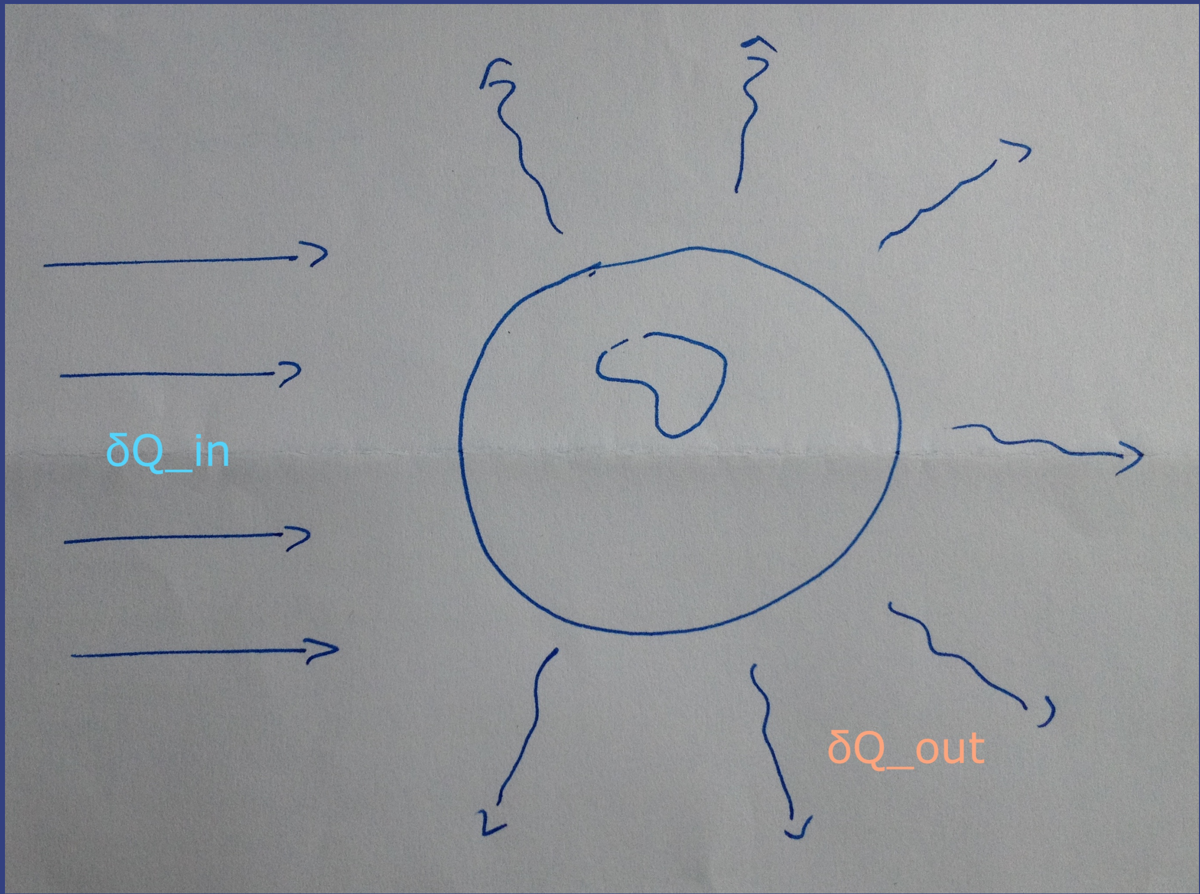
Drude damping γ, surface plasmon frequency Ω,

metal: $z = 1$, $\alpha(1) \approx 0.1388$, $\mathrm{Li}_3(1) = \zeta(3)$

summation over surface plasmons:

Intravaia and Lambrecht [*Phys Rev Lett* 2005] [*Phys Rev A* 2007]

Energy and Entropy



Energy flux balance

$$\delta\dot{Q}_{\mathrm{in}} = \delta\dot{Q}_{\mathrm{out}}$$

...otherwise climate heating

Net entropy flux

$$\mathrm{d}\dot{S}_{\mathrm{in}} - \mathrm{d}\dot{S}_{\mathrm{out}} \simeq \frac{\delta\dot{Q}_{\mathrm{in}}}{T(\odot)} - \frac{\delta\dot{Q}_{\mathrm{out}}}{T(\text{♁})} < 0$$

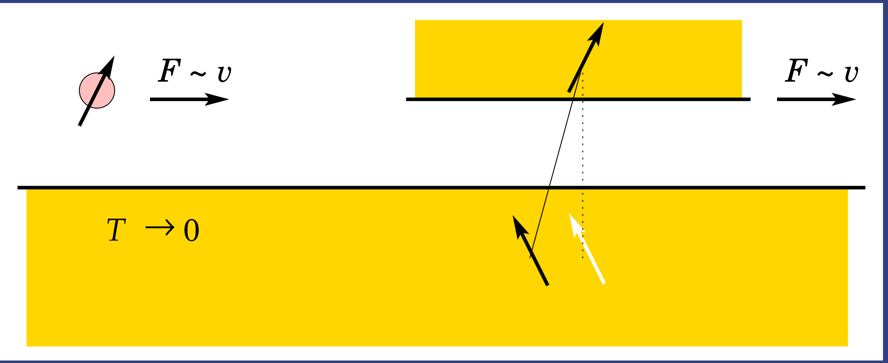
“solar information source”

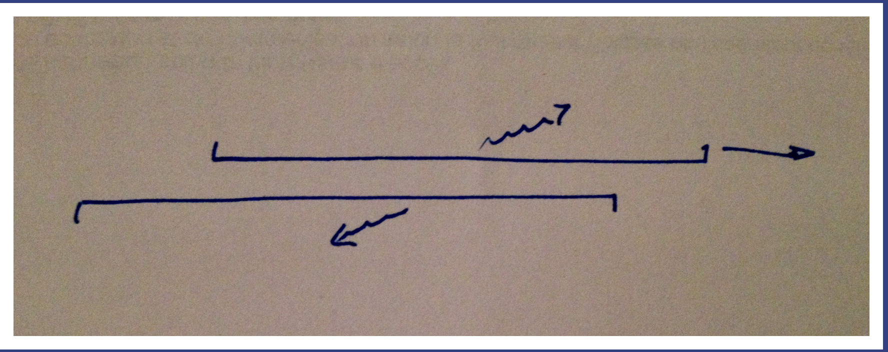
[L. Boltzmann/E. Schrödinger]

entropy source/sink:
material bodies, complex many-body systems

“Entanglement forces”

example: “quantum friction force”





heuristics:

lateral delay of image charge, dipole . . .

pair production (“unstable vacuum”)

plate-plate entangled state

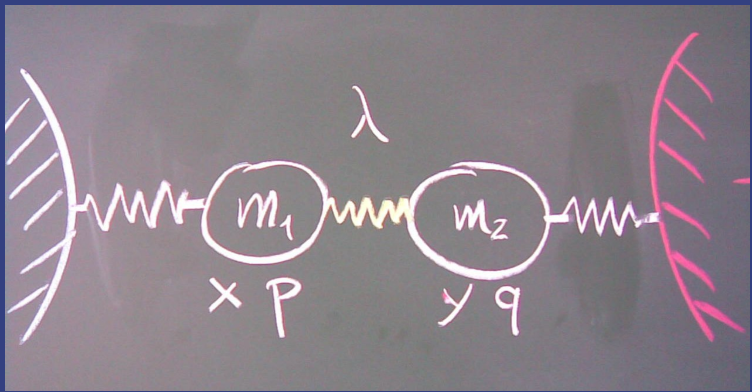
“afresh” zero temperature baths

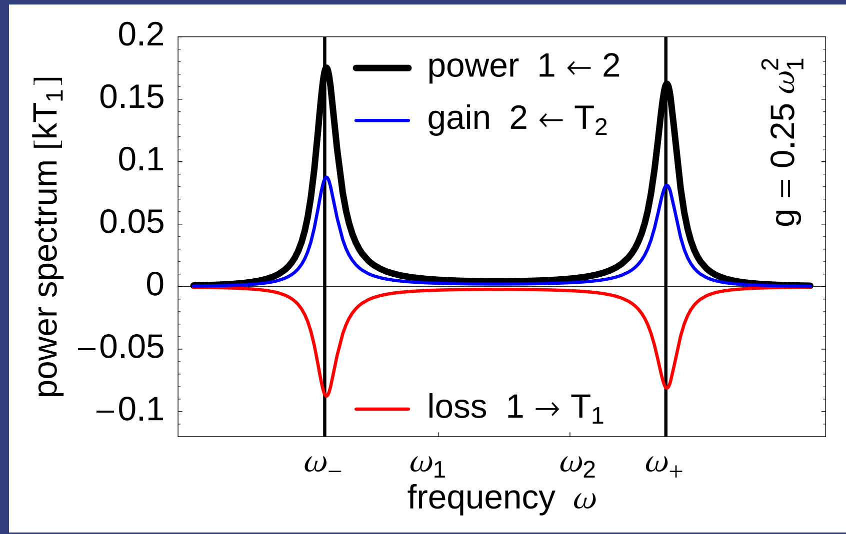
• non-equilibrium stationary state

Barton [*New J Phys* $\geq$ 2010],
Behunin & Hu [*Phys Rev A* 2010],
Pieplow & Henkel [*New J Phys* 2013],
Intravaia & al [*J. Phys. Condens. Matt.* 2015], . . .

Pendry [*J mod Opt* 1998],
Philbin & Leonhardt [*New J Phys* 2009]

Thermodynamic cut – toy model





spectrum of heat current

competition: interaction vs bath coupling

standard language: 'continuous variables' (covariance matrix $\langle q_i q_j \rangle$, partial transpose . . .)

- goal here: extend the entanglement criterion to spectral correlations $S_{ij}(\omega) \leftarrow \langle q_i(t) q_j(t') \rangle$

Dorofeyev [*Can J Phys* 2013], Biehs & Agarwal [*JOSA B* 2013], Barton [*J Stat Phys* 2015] . . .
Two-Temperature van der Waals Potentials,
J. P. Rosenkrans, B. Linder, and R. A. Kromhout,
J Chem Phys **49** (1968) 2927

Summary & Perspectives

Mystery of vacuum fluctuations?

. . . challenge to cosmology

. . . down to earth: regularized by matter (de)coupling

System+bath physics

. . . roots of thermodynamics (fluctuation–dissipation)

. . . poor men's master equations vs NEGF

Challenges

. . . thermal anomaly (low Matsubara frequencies)

. . . heat transport: take materials/interfaces seriously