Energy exchanges in a damped Langevin-like system with two thermal baths and an athermal reservoir
INCT-SC
CBPF - 8/11/2023

Welles A. M. Morgado (PUC-Rio) & Eduardo S. Nascimento (UFPI)

Papers

- E.S.N. & W.A.M.M., J. Phys. A **55** (2022) 395003
- E.S.N. & W.A.M.M., JSTAT (2021) 013301
- E.S.N. & W.A.M.M., J. Phys. A **55** (2020) 065001
- J. Bergenholtz et al., EPL **127** (2019) 00000
- E.S.N. & W.A.M.M., EPL **126** (2019) 10002 (Editor's choice)

Pedro B. Melo (PUC-Rio), Eduardo dos S. Nascimento (UFPI), Pedro V. Paraguassú (PUC-Rio)

Brownian Fluctuations of a non-confining potential

Abstract

We study a Langevin-like model which describes an inertial particle in a onedimensional harmonic potential and subjected to two heat baths and one athermal environment. The thermal noises are white and Gaussian, and the temperatures of heat reservoirs are different. The athermal medium act through an external non-Gaussian noise of Poisson type. We calculate exactly the time dependent cumulant-generating function of position and velocity of the particle, as well as an expression of this generating function for stationary states. We discuss the long-time behavior of first cumulants of the energy injected by the athermal reservoir and the heat exchanged with thermal baths. In particular, we find that the covariance of stochastic heat due to distinct thermal reservoirs exhibits a complex dependence on properties of athermal noise.

Outline

- What are Brownian Gyrators (BGs)?
- Memory function & torque in BGs due to memory
- Two internal reservoirs & an external Poisson noise source
- Manipulating Work and Heat statistics via external Poisson noise
- Inverting heat flow from reservoirs via external Poisson noise
- Conclusions

What are Brownian Gyrators?

- Small 2D Brownian engine system
- A single particle, gyrating around a generic potential energy minimum under the influence of friction and thermal noise forces from two simultaneously acting heat baths (RF & PR, PRL **99**).

Types of Brownian Gyrators

PRL **99**, 230602 (2007) PHYSICAL REVIEW LETTERS week ending 7 DECEMBER 2007

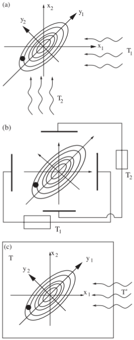
Brownian Gyrator: A Minimal Heat Engine on the Nanoscale

Roger Filliger
Engineering and Information Technology, Berne University of Applied Sciences, 2501 Biel/Bienne, Switzerland

Peter Reimann
Fakultät für Physik, Universität Bielefeld, 33615 Bielefeld, Germany
(Received 23 August 2007; published 5 December 2007)

A Brownian particle moving in the vicinity of a generic potential minimum under the influence of dissipation and thermal noise from two different heat baths is shown to act as a minimal heat engine, generating a systematic torque onto the physical object at the origin of the potential and an opposite torque onto the medium generating the dissipation.

DOI: 10.1103/PhysRevLett.99.230602 PACS numbers: 05.40.−a, 05.60.−k, 05.70.Ln



What are Brownian Gyrators?

PHYSICAL REVIEW E **106**, 014137 (2022)

Spectral fingerprints of nonequilibrium dynamics: The case of a Brownian gyrator

Sara Cerasoli,[1] Sergio Ciliberto,[2] Enzo Marinari,[3,4] Gleb Oshanin,[5,*] Luca Peliti,[6] and Lamberto Rondoni[7,8]
[1]*Department of Civil and Environmental Engineering, Princeton University, Princeton New Jersey 08544, USA*
[2]*Laboratoire de Physique (UMR CNRS 567246), Ecole Normale Supérieure, Allée d'Italie, 69364 Lyon, France*
[3]*Dipartimento di Fisica, Sapienza Università di Roma, P.le A. Moro 2, I-00185 Roma, Italy*
[4]*INFN, Sezione di Roma 1 and Nanotech-CNR, UOS di Roma, P.le A. Moro 2, I-00185 Roma, Italy*
[5]*Sorbonne Université, CNRS, Laboratoire de Physique Théorique de la Matière Condensée (UMR CNRS 7600), 4 place Jussieu, 75252 Paris Cedex 05, France*
[6]*Santa Marinella Research Institute, Santa Marinella, Italy*
[7]*Dipartimento di Scienze Matematiche, Politecnico di Torino, Corso Duca degli Abruzzi 24, 10129 Torino, Italy*
[8]*INFN, Sezione di Torino, Via P. Giuria 1, 10125 Torino, Italy*

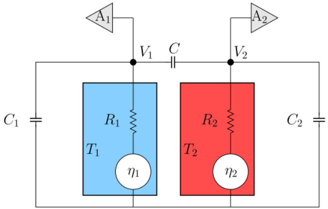


FIG. 1. A sketch of the circuit in Refs. [54,55]. The two resistances R_1 and R_2 are kept in separate screened boxes at the temperatures T_1 and T_2, respectively, and are coupled only by the capacitance C. The signal consists of the voltages V_1 and V_2, which are measured via the amplifiers A_1 and A_2, respectively. The noise sources η_i and the capacitances C_i, $i = 1, 2$, of the two circuits are also sketched. The corresponding mathematical model is defined in Eq. (1).

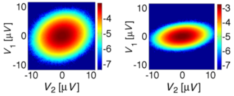


FIG. 2 (color online). The joint probability $\log_{10} P(V_1, V_2)$ measured at $T_1 = 296$ K equilibrium (a) and out of equilibrium $T_1 = 88$ K(b). The color scale is indicated on the color bar on the right side.

What are Brownian Gyrators?

PHYSICAL REVIEW E **96**, 032123 (2017)

Electrical autonomous Brownian gyrator

K.-H. Chiang, C.-L. Lee,* P.-Y. Lai, and Y.-F. Chen†
Department of Physics, National Central University, Zhongli 32001, Taiwan

(Received 28 April 2017; published 15 September 2017)

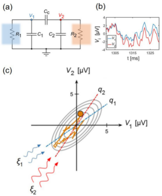


FIG. 1. Electrical autonomous Brownian gyrator. (a) Schematics of the experimental system, featuring a capacitively coupled RC circuit agitated by two heat baths. (b) A snapshot of concurrent $V_1(t)$ and $V_2(t)$ over 30 ms with $C_c = 1.0$ nF and $T_1 = 120$ K. (c) A virtual particle evolving in the 2D phase space formed by V_1 and V_2. A small segment of its trajectory [corresponding to the data in (b)] is shown by the orange line. The dashed lines indicate the q_1 and q_2 axes; see text. The virtual particle is influenced by two heat baths and experiences two random noises ξ_1 and ξ_2 from directions parallel to q_1 and q_2 axes, respectively, as noises are depicted by two sets of wavy arrows. The tilt ellipses designate potential contours with a minimum in the origin.

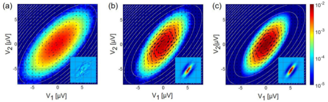


FIG. 2. Behavior of Brownian gyrator. The figures present the main results of this work. The value of $C_c = 1.0$ nF is used here. White contour: the equipotential contours of the coupled RC circuit. Color map: the steady-state distribution $P_{ss}(\vec{V})$. Vector field: the probability flux, $\vec{J}_{ss}(\vec{V})$. The inset color map shows the curl of the probability flux, $\nabla \times \vec{J}_{ss}$. The experimental results are listed in (a) and (b). (a) Equilibrium case ($T_1 = T_2 = 296$ K). The contour lines in P_{ss} and U mutually agree, and $\vec{J}_{ss}$ hardly exhibits any flowing trend as the detailed balance is valid. (b) NESS case ($T_1 = 120$ K). Contour lines of P_{ss} are tilted with respect to those in U, and $\vec{J}_{ss}$ reveals a circulating trend about the origin. (c) Theoretical counterparts of (b).

What are Brownian Gyrators?

OtM2E.1.pdf

Optics in the Life Sciences 2017 (BODA, NTM, OMP, OTA, Brain) © 2017 OSA

Brownian Gyrator: An Experimental Realization

Jalpa Soni[a,*], Aykut Argun[b], Lennart Dabelow[c], Stefano Bo[d], Ralf Eichhorn[d], Giuseppe Pesce[e] and Giovanni Volpe[a,b]

[a] Soft Matter Lab, Department of Physics, Bilkent University, Ankara, Turkey,
[b] Department of Physics, University of Gothenburg, Gothenburg, Sweden,
[c] Nordita, Royal Institute of Technology and Stockholm University – Roslagstullsbacken, Stockholm, Sweden
[d] Friedrich Schiller University, Jena, Germany
[e] Dipartimento di Fisica, Universita degli Studi di Napoli, Complesso Universitario Monte S. Angelo, Napoli, Italy
**Corresponding author: jalpaben.soni@bilkent.edu.tr*

Abstract: We present an experimental realization of a minimal heat engine in the form of a single Brownian particle, performing gyrating motion by systematic torque generation due to dissipation from two different heat baths in a simple optical tweezer set-up.

OCIS codes: (000.6850) Thermodynamics; (020.7010) Laser trapping

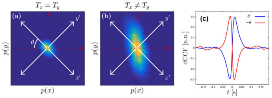
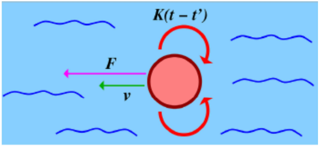


Figure 1: (a) Probability distribution of a Brownian particle inside an elliptical potential. Fundamental axes of this elliptical potential is x′ and y′, which is rotated from original x and y by θ. (b) The distribution of the same particle under the same trap when the effective temperature along y axis is increased, and (c) Differential cross correlation function shown for a particle trapped in an elliptical trap oriented at θ = 45° (blue lines) and θ = 45° (red lines), in the presence of electric field showing the rotation of the Brownian gyrator.

Memory function



- Brownian particles in a fluid medium may generate slow hydrodynamic modes that correlate dissipation at time t with its velocity at time $t' < t$.
- The action of such modes is represented by a memory function $M(t - t') \propto \langle \eta(t')\, \eta(t) \rangle$.

Memory time-scale τ

- A typical memory function exhibits a time scale τ

$$M(t-t') = \frac{\langle \eta(t')\,\eta(t) \rangle}{k_B T} = \frac{\gamma}{\tau}\, e^{-\frac{|t-t'|}{\tau}}\,.$$

- For Hamiltonian systems, the memory function is proportional to the (internal) noise-correlation.

Equations of motion

- Langevin-like equations

$$\gamma \dot{x}_i + \int_0^t ds\, K(t-s)\, \dot{x}_i(s) = -\partial_i \Phi + f_i, \tag{1}$$

- We assume f_i as Gaussian colored noises

$$\begin{aligned} \langle\langle f_i(t) \rangle\rangle &= 0, \\ \langle\langle f_i(t_1)\, f_j(t_2) \rangle\rangle &= T_i \delta_{ij} \left[2\gamma\delta(t_1 - t_2) + K(t_1 - t_2) \right], \\ K(t) &= \frac{\Gamma}{\tau} \exp\left(-\frac{|t|}{\tau} \right), \end{aligned} \tag{2}$$

where T_i (with $k_B = 1$) is the effective temperature of bath i, Γ is a friction coefficient, τ is the correlation time-scale, and δ_{ij} is the Kronecker delta.

Brownian Gyrator model

- Potential: $\Phi\left(x_1, x_2\right)$

$$\Phi\left(\mathbf{x}\right) = \sum_{ij} x_i V_{ij} x_j, \tag{3}$$

  where $\mathbf{x} = (x_1, x_2)$ and V_{ij} are elements of a symmetric matrix.
- The desired stability properties are achieved if one considers matrix elements V_{ij} which obey the conditions $V_{ii} > 0$ and $V_{11} V_{22} > V_{12}^2$.
- In our case $V_{11} = V_{22} = k/2, V_{12} = V_{21} = k\,u/2$, with $u^2 < 1$.

Distribution Function

- Probability distribution

$$P_s(\mathbf{x}) = \frac{1}{Z} \exp\left(-\frac{1}{2}\mathbf{x}^{\mathsf{T}} \mathbb{M}^{-1} \mathbf{x}\right), \tag{4}$$

where

$$\mathbb{M} = \begin{pmatrix} \langle\langle x_1^2 \rangle\rangle & \langle\langle x_1 x_2 \rangle\rangle \\ \langle\langle x_1 x_2 \rangle\rangle & \langle\langle x_2^2 \rangle\rangle \end{pmatrix}, \tag{5}$$

- The cross cumulant reads

$$\langle\langle x_1 x_2 \rangle\rangle = -\frac{u\,(T_1 + T_2)}{2k\,(1 - u^2)}, \tag{6}$$

with

$$\zeta = (\gamma + \Gamma)^2 + k\tau\left[2\gamma + k\tau\left(1 - u^2\right)\right]. \tag{7}$$

Stochastic gyration properties

- Due to $I \to 0$ the total torque vanishes:

$$N_{diss} + N_f + N = 0, \tag{8}$$

- Dissipative torque

$$N_{diss} = -\sum_{ij} \varepsilon_{ij}\, x_i \left[\gamma \dot{x}_j + \int_0^t ds\, K(t-s)\, \dot{x}_j\,(s)\right], \tag{9}$$

- Harmonic forces torque

$$N = -\sum_{ij} \varepsilon_{ij}\, x_i \partial_j \Phi, \tag{10}$$

- Thermal fluctuation torque

$$N_f = \sum_{ij} \varepsilon_{ij}\, x_i\, f_j, \tag{11}$$

Torque due to thermal noise

- Average thermal torque

$$\langle N_f \rangle = \frac{4\Gamma\tau uk\,(T_1 - T_2)}{(2\gamma+\Gamma)^2 + 4k\tau\,[(2\gamma+\Gamma) + k\tau\,(1-u^2)]}. \qquad (12)$$

  Notice the dependence on friction constant Γ and persistence τ, and the denominator is positive and non-zero, since $u^2 < 1$. The average thermal torque (12) is different from zero if one assumes $\Gamma \neq 0$ and $\tau \neq 0$. Nevertheless, by taking the Markovian limit, we obtain a null average thermal torque,

- Taking $\tau \to 0$ above reobtains the result of [Filliger R and Reimann P (2007) Phys. Rev. Lett. 99 230602].

Torque due to harmonic force

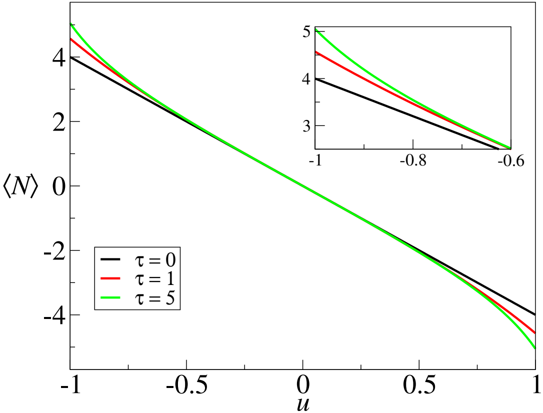


Figure: Average torque $\langle N \rangle$ as a function of coupling parameter u, for distinct values of memory time-scale τ. The values of model parameters used are $T_1 = 5$, $T_2 = 1$, $\gamma = \Gamma = 1$, $k = 1$. The inset magnifies the graph's left extremity.

Second cumulant of N

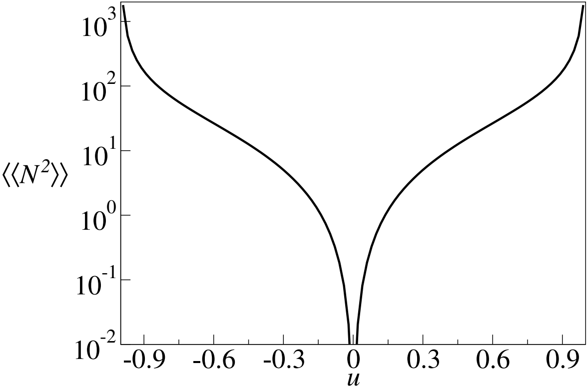


Figure: Second cumulant $\left\langle\left\langle N^2 \right\rangle\right\rangle$ as a function of u, for $T_1 = 5$, $T_2 = 1$, $\gamma = \Gamma = 1$, $k = 1$, and $\tau = 1$.

Fourth cumulant

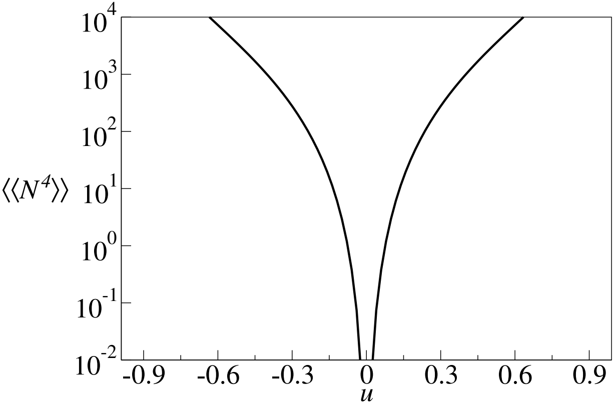


Figure: Fourth cumulant $\langle\langle N^4 \rangle\rangle$ as a function of coupling parameter u of harmonic potential, for $T_1 = 5$, $T_2 = 1$, $\gamma = \Gamma = 1$, $k = 1$, and $\tau = 1$.

Stationary energetics

- Heat exchanged with reservoir-i

$$\langle \mathcal{Q}_i \rangle = \int_t^{t+t_o} dt' \, \langle \dot{x}_i \, \partial_i \Phi \rangle \, . \tag{13}$$

- By assuming large values of t, we find

$$\langle \mathcal{Q}_1 \rangle = h_1 \, t_o, \tag{14}$$

$$h_1 = \frac{(T_1 - T_2)\, k u^2}{2\gamma} \left\{ \frac{\gamma\,(\gamma+\Gamma) + k\tau \left[2\gamma + \Gamma + k\tau\left(1-u^2\right)\right]}{(\gamma+\Gamma)^2 + k\tau\,[2\gamma+\Gamma+(\Gamma+k\tau)\,(1-u^2)]} \right\}, \tag{15}$$

Mean heat flux

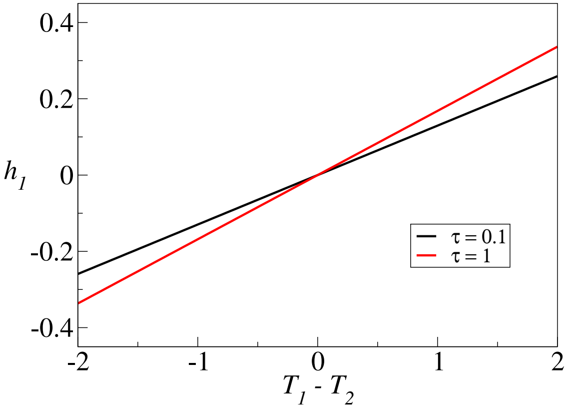


Figure: Mean heat flux h_1 as a function of temperature difference $T_1 - T_2$, for distinct values of memory time-scale τ. Parameters used: $\gamma = \Gamma = 1$, $k = 1$, and $u = 0.7$.

External athermal reservoirs & thermal heat baths

J. Phys. A: Math. Theor. 55 (2022) 395003 E S Nascimento and W A M Morgado

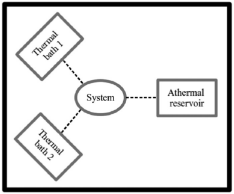


Figure 1. Schematic representation of a physical system simultaneously influenced by two thermal baths and an athermal reservoir.

- We mix an external athermal reservoir with a non-equilibrium mix of 2 heat baths
- The athermal force has Poisson statistics

Dynamics

2. Langevin-like dynamics

The model we are interested in consists of a damped harmonic oscillator with different types of stochastic forces. One can imagine that the confined inertial particle represents a system coupled to two thermal reservoirs and an athermal environment, see figure 1. The system evolves in time according to the Langevin-like dynamics

$$\begin{aligned} m\dot{V}(t) &= -(\gamma_1 + \gamma_2)V(t) - kX + \xi_1(t) + \xi_2(t) + F(t), \\ \dot{X}(t) &= V(t), \end{aligned} \quad (1)$$

Noises: thermal and athermal

J. Phys. A: Math. Theor. **55** (2022) 395003 E S Nascimento and W A M Morgado

The Langevin force ξ_i is a white Gaussian noise with cumulants

$$\begin{aligned} \langle\langle \xi_i(t) \rangle\rangle &= 0, \\ \langle\langle \xi_i(t_1)\xi_j(t_2) \rangle\rangle &= 2\gamma_i T_i \delta_{ij}\delta(t_1 - t_2), \end{aligned} \tag{2}$$

$$\begin{aligned} \langle\langle F(t) \rangle\rangle &= 0, \\ \langle\langle F(t_1)F(t_2)\ldots F(t_{2n}) \rangle\rangle &= C_{2n}\prod_{j=1}^{2n-1}\delta(t_{j+1} - t_j). \end{aligned} \tag{3}$$

The external force $F(t)$ corresponds to unbiased Poisson rate (λ) noise, where the impulse kicks J follow a chosen Gaussian distribution

$$p(J) = \frac{e^{-\frac{J^2}{2b^2}}}{\sqrt{2\pi b^2}} \Rightarrow C_{2n} = (2n-1)!!\,\lambda\, b^{2n}.$$

Average Energy of the Harmonic oscillator

J. Phys. A: Math. Theor. **55** (2022) 395003 E S Nascimento and W A M Morgado

Notice that E is the average energy of the harmonic oscillator in steady-state regime:

$$E = \frac{m}{2}\langle\langle V^2 \rangle\rangle + \frac{k}{2}\langle\langle X^2 \rangle\rangle, \tag{16}$$

$$\langle\langle X^2 \rangle\rangle = \frac{\gamma_1 T_1 + \gamma_2 T_2}{\gamma k} + \frac{C_2}{2\gamma k}, \quad \langle\langle V^2 \rangle\rangle = \frac{\gamma_1 T_1 + \gamma_2 T_2}{\gamma m} + \frac{C_2}{2\gamma m}. \tag{17}$$

For high-order cumulants of the type $\langle\langle X(t)^{n_1} V(t)^{n_2} \rangle\rangle$, with $n_1, n_2 \geqslant 2$, and F symmetric, one can find

$$\langle\langle X(t)^{n_1} V(t)^{n_2} \rangle\rangle = C_{n_1+n_2} \left[\prod_{i=1}^{n_1} \int_0^t \mathrm{d}s_i\, A_x(t - s_i)\right] \times \left[\prod_{j=1}^{n_2} \int_0^t \mathrm{d}u_j\, A_v\left(t - u_j\right)\right]$$
$$\times\, \delta(s_1 - s_2) \ldots \delta(s_l - u_1) \ldots \delta(u_{n-1} - u_n), \tag{18}$$

Higher order cumulants due to the Poisson force

$$\langle\langle X^4 \rangle\rangle = \frac{3C_4}{4\gamma k(3\gamma^2 + 4km)}, \quad \langle\langle V^4 \rangle\rangle = \frac{3C_4(\gamma^2 + km)}{4\gamma m^3(3\gamma^2 + 4km)}, \tag{27}$$

$$\langle\langle X^2V^2 \rangle\rangle = \frac{C_4}{4\gamma m(3\gamma^2 + 4km)}, \ \langle\langle XV^3 \rangle\rangle = \frac{C_4}{4m^2(3\gamma^2 + 4km)}. \tag{28}$$

The stationary cumulant $\langle\langle X^3V \rangle\rangle$ is zero. As a matter of fact, every cumulant of the type $\langle\langle X^{n-1}V \rangle\rangle$, with $n \geqslant 1$, tends to zero for steady-states:

Stochastic Heat & Work

Within the assumption mentioned above, we introduce the dimensionless heat associated with the thermal baths

$$Q_i(t) = \frac{1}{T_a}\int_0^t \mathrm{d}t_1\, V(t_1)[\xi_i(t_1) - \gamma_i V(t_1)], \tag{33}$$

and the dimensionless work-like quantity due to the non-Gaussian noise

$$W(t) = \frac{1}{T_a}\int_0^t \mathrm{d}t_1\, F(t_1)V(t_1), \tag{34}$$

where

$$T_a = \frac{\gamma_1 T_1 + \gamma_2 T_2}{\gamma}. \tag{35}$$

Work Statistics for Gaussian

$$T_a\langle W\rangle = \frac{C_2 t}{2m}, \tag{39}$$

$$T_a^2\langle W^2\rangle = \frac{C_2^2 t^2}{4m^2} + (t\gamma - m)\frac{C_2 E}{m\gamma}, \tag{40}$$

$$T_a^3\langle W^3\rangle = \frac{C_2^3 t^3}{8m^3} + \left(t^2\gamma^2 + t\gamma m - 4m^2\right)\frac{3C_2^2 E}{2m^2\gamma^2}, \tag{41}$$

$$T_a^4\langle W^4\rangle = \frac{C_2^4 t^4}{16m^4} + \frac{3C_2^3 t^3 E}{2m^3} + (3C_2 + 2\gamma E)\frac{3C_2^2 t^2 E}{2m^2\gamma} - (6C_2 + 2\gamma E)\frac{6C_2^2 E}{\gamma^3}, \tag{42}$$

where E is the average energy of the system shown in (14). Now, using the relations between moments and cumulants [41, 49] and the dimensionless quantities (36), it is possible to show that

$$\frac{1}{t_o}\langle\langle W\rangle\rangle = \Gamma, \quad \frac{1}{t_o}\langle\langle W^2\rangle\rangle = 2\Gamma(1+\Gamma), \tag{43}$$

$$\frac{1}{t_o}\langle\langle W^3\rangle\rangle = 12\Gamma^2(1+\Gamma), \quad \frac{1}{t_o}\langle\langle W^4\rangle\rangle = 24\Gamma^2(1+\Gamma)(1+5\Gamma). \tag{44}$$

Work Statistics for Poissonian

$$T_a\langle W\rangle = \frac{C_2 t}{2m}, \tag{48}$$

$$T_a^2\langle W^2\rangle = \frac{C_4 t}{4m^2} + \frac{C_2^2 t^2}{4m^2} + (C_2 + 2\gamma_1 T_1 + 2\gamma_2 T_2)\frac{(t\gamma - m)C_2}{2m\gamma^2}, \tag{49}$$

$$\begin{aligned} T_a^3\langle W^3\rangle = {}& \frac{C_6 t}{8m^3} + \frac{3(t\gamma - m)}{2(m\gamma)^2}(\gamma_1 T_1 + \gamma_2 T_2)C_4 + \frac{3\left[(t\gamma)^2 + 4t\gamma m - 4m^2\right]}{8m^3\gamma^2}C_4 C_2 \\ & + \frac{3\left[(t\gamma)^2 + t\gamma m - 4m^2\right]}{2m^2\gamma^3}(\gamma_1 T_1 + \gamma_2 T_2)C_2^2 \\ & + \frac{\left[(t\gamma)^3 - 24m^3 + 6(t\gamma)^2 m + 6\gamma t m^2\right]}{8(m\gamma)^3}C_2^3. \end{aligned} \tag{50}$$

The cumulants are obtained through the expressions $\langle\langle W\rangle\rangle = \langle W\rangle$, $\langle\langle W^2\rangle\rangle = \langle W^2\rangle - \langle W\rangle^2$ and $\langle\langle W^3\rangle\rangle = \langle W^3\rangle - 3\langle W\rangle\langle W^2\rangle + 2\langle W\rangle^3$, which lead to

$$\frac{1}{t_o}\langle\langle W\rangle\rangle = \Lambda B, \tag{51}$$

$$\frac{1}{t_o}\langle\langle W^2\rangle\rangle = \Lambda B[2(1 + \Lambda B) + 3B], \tag{52}$$

$$\frac{1}{t_o}\langle\langle W^3\rangle\rangle = 6\Lambda B^2(3 + 2\Lambda) + 3\Lambda B^3(5 + 2\Lambda)(1 + 2\Lambda), \tag{53}$$

Work Statistics for Poissonian

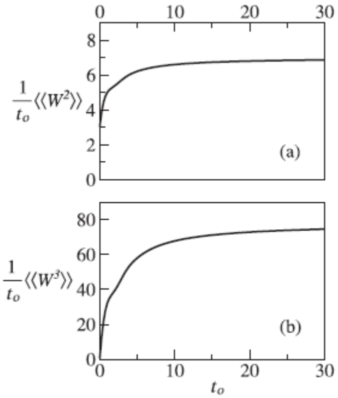


Figure 2. $\langle\langle W^2\rangle\rangle/t_o$ and $\langle\langle W^3\rangle\rangle/t_o$ versus the dimensionless time t_o for $\Lambda = 1, B = 1$, and $\Upsilon = 2$. When $t_o \gg 1$, the cumulants achieve a long-time behavior where $\langle\langle W^n\rangle\rangle$ are proportional to t_o.

Heat Statistics for Poissonian

J. Phys. A: Math. Theor. **55** (2022) 395003 E S Nascimento and W A M Morgado

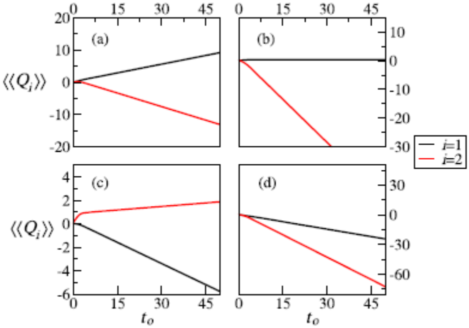


Figure 3. Average heat $\langle\langle Q_i\rangle\rangle$ versus dimensionless time t_o with $\eta_1 = 0.2$, $\Upsilon = 2$, (a) $\widetilde{T}_1 = 2$, $\Lambda = 0.1$, $B = 1$; (b) $\widetilde{T}_1 = 2$, $\Lambda = 1$, $B = 1$; (c) $\widetilde{T}_1 = 0.5$, $\Lambda = 0.1$, $B = 1$; and (d) $\widetilde{T}_1 = 0.5$, $\Lambda = 2$, $B = 1$. The values of η_2 and $\widetilde{T}_2$ are given by (37).

Heat Statistics for Poissonian

J. Phys. A: Math. Theor. **55** (2022) 395003 E S Nascimento and W A M Morgado

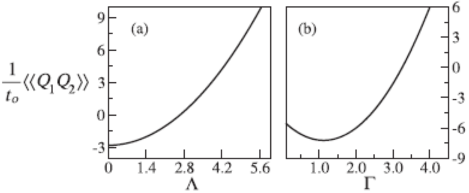


Figure 4. Effects of athermal noise on cumulant $\langle\langle Q_1 Q_2 \rangle\rangle$ over t_o. (a) Poisson noise with $\eta_1 = 0.2$, $\widetilde{T}_1 = 2$ and $B = 0.5$. (b) Gaussian limit of external noise ($\Lambda \to \infty$, $B \to 0$, $\Lambda B = \Gamma$ fixed) with $\eta_1 = 0.2$ and $\widetilde{T}_1 = 4$. The values of η_2 and $\widetilde{T}_2$ are obtained through (37).

Conclusions

- We exploited the role of memory & non-standard forces, acting in simple systems (that may be used to build Brownian machines)
- Memory allows for new non-equilibrium torques to act upon Brownian gyrators
- Memory can also be a channel to recover order lost to the thermal bath
- Mixing usual thermal reservoirs, and athermal (work) reservoirs, it is shown that work statistics can be substantially altered
- The presence of a strong athermal force might induce changes of heat flow in non-equilibrium situations

Thanks to

FAPERJ
Fundação Carlos Chagas Filho de Amparo à Pesquisa do Estado do Rio de Janeiro

CNPq

CAPES

PUC RIO

CBPF
CENTRO BRASILEIRO DE PESQUISAS FÍSICAS

inct-sc