The Ring of Brownian Motion: the good, the bad and the simply silly

Peter Hänggi [1,2]

[1] *Institute of Physics, University of Augsburg, 86135 Augsburg, Germany*
[2] *Department of Physics and Centre for Computational Science and Engineering, National University of Singapore, Republic of Singapore 117542*

Abstract. In this plenary talk I give an account on the blossoming role that Brownian motion Theory and Experiment played – and still keeps doing so – in germinating and advancing several, partially diverse physical disciplines. Although the use of Brownian motion concepts generally most favorably impacted those scientific areas there are also some abuses where the application of such concepts may not describe satisfactorily physical reality.

Keywords: Brownian motion, equilibrium and non-equilibrium statistical mechanics, Stochastic Resonance, Brownian motors
PACS: 05.60.-k, 47.61.-k, 81.07.-b, 85.25.-j, 85.35.-p, 87.16.-b

ROLE AND IMPACT OF BROWNIAN MOTION FOR PHYSICS AND RELATED FIELDS

Since the turn of the 20-th century Brownian hiss has continuously disclosed a rich variety of phenomena in and around physics. The understanding of this jittering motion of suspended microscopic particles has undoubtedly helped to reinforce and substantiate those pillars on which the basic modern physical theories are resting. – Its formal description provided the key to great achievements in statistical mechanics, the foundations of quantum mechanics and also astrophysical phenomena, to name only a few [1]. Brownian motion also determines the rate limiting step in most transport phenomena via escape events that help to overcome obstructing bottlenecks [2], or triggers those intriguing oscillatory dynamics occurring in excitable media [3].

My purpose here is as follows: Rather than presenting yet another sketchy overview of Brownian motion phenomena from an abundance of most useful and not so useful applications I instead prefer to point out a few timely such topical areas which are in the limelight of present and ongoing research activities. Different aspects and perspectives of these have been repeatedly reviewed in the recent literature with comprehensive reviews and features being available, see the cited literature given below. So, rather than presenting yet an additional such account I prefer to guide the interested reader to a selection of overviews. Next, I shall briefly highlight three such recent activities.

CP1129, *Noise and Fluctuations, 20th International Conference (ICNF 2009)*
edited by M. Macucci and G. Basso

Stochastic Resonance

Although noise is usually thought of as the enemy of order it in fact can – given the necessary conditions – also be of constructive influence. The phenomena of Stochastic Resonance [4] presents one such paradigm. In a nutshell, Stochastic Resonance refers to the phenomenon for which the addition of the appropriate dose of noise can boost a (information-carrying) signal and hence facilitate its detection in a noisy environment. Due to its intrinsic simplicity and robustness the phenomenon has widespread applications and impacts a rich abundance of interdisciplinary fields.

Given its slow start after its invention in the 80's of the last century Stochastic Resonance spurred interest ever since and widened in scope and breadth of applications exhibiting still growing momentum. Presently its most salient applications apply to noisy physical biology [4, 5, 6] and to quantum information processing schemes [4, 7, 8].

Brownian motors

Noise can also induce directed transport: In systems possessing spatial or dynamical symmetry breaking, Brownian motion combined with unbiased external input signals, deterministic or random, alike, can assist directed motion of particles and continuous phases at the submicron scales. The by now common terminology for this paradigm of noise-assisted directed transport is "Brownian motors" [9, 10, 11, 12].

The concept of Brownian motors has given rise to novel design and implementation of various transport and separation devices in physics, chemistry, and in physical biology that operate on the nano-and/or microscale [12]. Most importantly, the combination of ever present thermal hiss with additional, unbiased non-equilibrium disturbances enables the rectification of haphazard Brownian thermal noise so that quantum and classical objects can be directed around on a priori designed routes.

Relativistic Brownian motion and relativistic thermodynamics

A commonly less known topic within the community of Brownian motion practitioners is the relativistic generalization of Brownian motion. The theoretical description of relativistic Brownian motion, relativistic (then necessarily non-Markovian) diffusion processes and relativistic thermodynamics *per se* has experienced considerable progress over the past decade [13]. The theory of relativity implies that the progression of time experienced by a physical object is tightly linked to its state of motion. This then has salient implications for fast moving Brownian particles. In view of the experimental progress in high energy physics, astrophysics, and cosmology, relativistic Brownian motion concepts will play an increasingly important role in these fields as well. It is, therefore, important to understand how the underlying ideas can be consistently embedded into the theories of special and general relativity. This progress then naturally carries over to improved formulations of relativistic thermodynamics and relativistic statistical mechanics [13].

ACKNOWLEDGMENTS

Financial support by the German Excellence Initiative via the *Nanosystems Initiative Munich* (NIM), the Volkswagen Foundation (project I/80424), the DFG-collaborative research centers SFB-486, SFB-631 and SFB-484 is gratefully acknowledged.

REFERENCES

1. W. Ebeling and I. M. Sokolov, *Statistical thermodynamics and stochastic theory of nonequilibrium systems*, Adv. Stat. Mech., Vol. **8** (World Scientific, Singapore 2005).
2. P. Hänggi, P. Talkner, and M. Borkovec, *Reaction-rate theory: fifty years after Kramers*, Rev. Mod. Phys. **62**, 251–342 (1990).
3. B. Lindner, J. Garcia-Ojalvo, A. Neiman and L. Schimansky-Geier, *Effects of noise in excitable systems*, Phys. Rep. **392**, 321–424 (2004).
4. L. Gammaitoni, P. Hänggi, P. Jung and F. Marchesoni, *Stochastic Resonance*, Rev. Mod.Phys. **70**, 223–288 (1998).
5. P. Hänggi, *Stochastic Resonance in Biology: how noise can enhance detection of weak signals and help improve biological information processing*, ChemPhysChem **3**, 285–290 (2002).
6. K. Wiesenfeld and F. Moss, *Stochastic Resonance and the benefits of noise*, Nature **373**, 33–36 (1995).
7. M. Grifoni and P. Hänggi, *Driven Tunneling*, Phys. Rep. **304**, 229–354 (1998).
8. T. Wellens and A. Buchleitner, *Stochastic Resonance*, Rep. Progr. Phys. **67**, 45–105 (2004).
9. R. D. Astumian and P. Hänggi, *Brownian motors*, Physics Today **55** (11), 33–39 (2002).
10. P. Reimann, *Brownian motors: noisy transport far from equilibrium* Phys. Rep. **361**, 57–265 (2002).
11. P. Hänggi, F. Marchesoni, and F. Nori, *Brownian motors*, Ann. Phys. (Berlin) **14**, 51–70 (2005).
12. P. Hänggi and F. Marchesoni, *Artificial Brownian motors: Controlling transport on the nanoscale*, Rev. Mod. Phys. **86**, 1–56 (2009); arXiv:0807.1283.
13. J. Dunkel and P. Hänggi, *Relativistic Brownian motion*, Phys. Rep. **471**, 1–73 (2009).