Ratchets in point-particle systems and in extended models: Mechanisms, control and applications.

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Book of Abstracts

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- Grupo de Física Cuántica y Matemáticas, Universidad de Granada

Invited lectures

1. **C. Van den Broeck**

   Title: Brownian motors: the fight between the engine and the refrigerator.

   Abstract: We review the issue of Carnot efficiency from the point of view of Brownian motors. We show that it can in principle be achieved, but it requires a very stringent structural constraint. Turning to information processing Brownian engines, we show that the work theorem allows to exact microscopic equalities which in particular verify the Landauer principle.

   References: C. Van den Broeck, R. Kawai and P. Meurs, Phys Rev Lett 93, 090601 (2004); P. Meurs, C. Van den Broeck and A, Garcia, Phys Rev E70, 051109 (2004); C. Van den Broeck, P. Meurs and R. Kawai, New J Phys 7, 10 (2005); C. Van den Broeck, Phys Rev Lett 95, 190602 (2005); C. Van den Broeck and R. Kawai, Phys Rev Lett 96, 210601 (2006); C. Van den Broeck, Carnot efficiency revisited, Adv Chem Phys, to appear; R. Kawai, JMR Parrondo and C. Van den Broeck, Work theorem and thermodynamics of computation, preprint.

2. **J. Casado-Pascual**

   Title: Flux reversal in a simple random-walk model on a fluctuating symmetric lattice.

   Abstract: A rather simple random-walk model on a one-dimensional lattice is put forward. The lattice as a whole switches randomly between two possible states which are spatially symmetric. Both lattice states are identical, but translated by one site with respect to each other, and consist of infinite arrays of absorbing sites separated by two nonabsorbing sites. Exact explicit expressions for the long-time velocity and the effective diffusion coefficient are obtained and discussed. In particular, it is shown that the direction of the steady motion can be reversed by conveniently varying the values of either the mean residence times in the lattice states or the transition rates to the absorbing and nonabsorbing sites.

3. **S. Denisov**

   Title: ac-driven quantum ratchets

   Abstract: I will give an introduction into the symmetry analysis of ac driven particles in periodic potentials and the main mechanisms of current rectification for the classical case. I will then present recent results on the treatment of the quantum problem. The symmetric zero transport case is characterized by a Floquet evolution matrix and eigenstates bearing the symmetry of the generating equations. As a result all Floquet eigenstates

contribute with zero average velocity. For the asymmetric case we observe an essential change of Floquet eigenstates which are now characterized by a finite average velocity. In addition we identify an intermediate region of eigenstates which give the strongest desymmetrization and thus contribute most strongly to a direct transport. These states are shown to reside in the classical chaotic phase space part by means of Husimi distributions. We then launch an initial state with zero momentum and compute the corresponding average velocity using the Floquet eigenstates properties. We find several quantum signatures of the rectification effect: i) the average velocity depends on the initial phase of the ac field ii) weak and strong resonant enhancement or suppression of the average velocity (as compared to the classical case) happens upon tunning a control parameters due to avoided crossings and iii) the maximum value and the fluctuations of the average velocity upon tuning a control parameter strongly depend on $\hbar$.

4. **A. H. Flood**

   Title: Single Power Strokes and Brownian Ratchet Steps from one Family of Molecular Machines

   Abstract: Chemists are looking to engineered and biological varieties of machines and motors to design analogous versions at the molecular level. To this end, a series of synthetic molecular machines from within one family will be presented in order to highlight their biophysical likenesses. The mechanical energy available for work has been measured in a simple molecule that breaks into two parts during its show of force. However, if the two halves are previously tethered together like the Ouroboros image – the Serpent biting its own tail – it is possible to keep a handle on both components when they are split apart. Finally, if the steric constraints are relaxed, the two halves can reform to display single power strokes and Brownian ratchet steps.

5. **D. Leigh**

   Title: Exercising Demons: Synthetic Molecular Motors and Machines

   Abstract: The machines we use in everyday life are made up of ordered assemblies of moving parts (cogs, wheels, spindles, pistons etc), the movement of each of which is used to perform a task necessary for the overall function of the machine. An exciting contemporary area of chemistry is making molecules with moving parts, with the goal that they can be built up into ordered assemblies that function as nanoscopic machines capable of performing physical tasks. To do so requires the introduction of ratchet principles into synthetic molecular structures. We will discuss some of the latest developments in this field including the experimental realisation of both energy ratchets and information ratchets.

For papers from the Leigh group see: Nature, 406, 608-611 (2000); Science, 291, 2124-2128 (2001); Nature, 424, 174-179 (2003); Science, 299, 531 (2003); Proc. Natl. Acad. Sci. USA, 100, 10-14 (2003); Science, 306, 1532-1537 (2004); Proc. Natl. Acad. Sci. USA, 102, 13378-13382 (2005); Nature Mater., 4, 704-710 (2005).

6. **H. Linke**

Title: Experimental Ratchet Systems

Abstract: I will review two recent ratchet experiments: (i) the heat-activated motion of millimeter-sized Leidenfrost droplets on hot, ratchet-shaped metal surfaces [1], and (ii) an ongoing program to demonstrate a Brownian heat engine near Carnot efficiency, using semiconductor, heterostructure nanowires [2]. Project (i) may have applications in heat-activated liquid cooling systems, whereas project (ii) is relevant to thermoelectric energy conversion. Time permitting, I will discuss an ongoing effort to set up an experimental system for the realization and test of ratchet-based models for molecular motors. A scanning-line optical trap will be used to produce a time-dependent potential for a bead that represents the motor coordinate. This system will also include feedback-mechanisms.

[1] H. Linke, B. Alemàn, L. D. Melling, M. J. Taormina, M. J. Francis, et al., Phys. Rev. Lett. 96, 154502 (2006). [2] M. O'Dwyer, T. E. Humphrey, and H. Linke, Nanotechnology 17, S338 (2006).

7. **F. Marchesoni**

Title: Brownian diffusion in restricted geometries

Abstract: In 1D and for long times, the mean square displacement $\delta x^2(t)$ of a freely diffusing particle with unit mass, subject to thermal fluctuations, grows with time, that is $\delta x^2(t) = 2D_0 t$, where $D(T) = kT/\gamma = D_0$ is the Einstein's diffusion coefficient. However, for restricted diffusive dynamics, a variety of different effects can occur:

(a) If the particle diffuses on a tilted periodic substrate (washboard potential), mimicking e.g. a narrow channel, then $D(T)$ gets anomalously large at or close to the depinning tilt; the normal diffusion excess increasing with lowering T and the damping constant γ;

(b) In a 1D assembly of identical non-passing Brownian particles (stochastic single-file), the diffusion law itself becomes anomalous, i.e. $\delta x^2(t) = 2Ft^{1/2}$, with F a function of the particle density and D_0.

The microscopic mechanisms underlying anomalous diffusion in restricted geometries will be discussed in impact representation.

8. **J. L. Mateos**

   Title: Phase Synchronization in Inertial Deterministic Ratchets

   Abstract: We analyze the transport properties of deterministic inertial particles in a tilted ratchets potential with an external periodic forcing. The ratchet potential has to be tilted in order to obtain a rotator or self-sustained nonlinear oscillator that can be synchronized with the external driving force. We introduce a linear phase through a set of discrete time events and the associated average frequency, and show that this frequency can be synchronized with the frequency of the external driving. In this way, we can properly characterize the phenomenon of synchronization through Arnold tongues, and discuss their implications for transport in ratchets.

9. **F. Mertens**

   Title: Optimization of soliton ratchets in inhomogeneous sine-Gordon systems

   Abstract: Unidirectional motion of solitons can take place, although the applied force has zero average in time, when the spatial symmetry is broken by introducing a potential $V(x)$, which consists of periodically repeated cells with each cell containing an asymmetric array of strongly localized inhomogeneities. A collective coordinate approach shows that the positions, heights and widths of the inhomogeneities (in that order) are the crucial parameters so as to obtain an optimal effective potential that yields a maximal average soliton velocity. The optimal potential essentially exhibits two features: double peaks consisting of a positive and a negative peak, and long flat regions between the double peaks. Such a potential can be obtained by choosing inhomogeneities with opposite signs (e.g., microresistors and microshorts in the case of long Josephson junctions) that are positioned close to each other, while the distance between each peak pair is rather large. These results of the collective variables theory are confirmed by full simulations for the inhomogeneous sine-Gordon system.

10. **M. Morillo**

    Title: Forced synchronization in a quantum dissipative system

    Abstract: We study, within the spin-boson dynamics, the synchronization of a quantum tunneling system with an external, time-periodic driving signal. As a main result we find that at a sufficiently large system-bath coupling strength the thermal noise plays a constructive role in yielding forced synchronization. This noise-induced synchronization can occur when the driving frequency is larger than the zero-temperature tunneling rate. As an application evidencing the effect, we consider the charge transfer dynamics in molecular complexes.

11. **J.M.R. Parrondo**

Title: Reading DNA by molecular motors: the RNA polymerase

Abstract: We will present some recent experimental results on the RNA polymerase, a molecular motor responsible of DNA transcription, and a simple model explaining the motion of the motor and its step-time statistics.

12. **P. Reimann**

Title: Anomalous response behavior of a Josephson junction

Abstract: We predict three quite unusual transport properties of a Josephson junction in the form of current and voltage of opposite sign. Numerical simulations are complemented by intuitive explanations of the basic mechanism and analytical approximations. Suitable parameter values are quite realistic experimentally.

13. **F. Renzoni**

Title: Symmetry and transport in a rocking ratchet for cold atoms.

Abstract: Brownian motors, or ratchets, are devices which "rectify" Brownian motion, i.e. they can generate a current of particles out of unbiased fluctuations.

We experimentally implemented a Brownian motor using cold atoms in an optical lattice. This is quite an unusual system for a Brownian motor as there is no a real thermal bath, and both the periodic potential for the atoms and the fluctuations are determined by laser fields.

With the help of such a system, we investigated experimentally the relationship between symmetry and transport in a rocking ratchet, both in the periodic and in the quasiperiodic case.

References

[1] P.H. Jones, M. Goonasekera and F. Renzoni, Rectifying fluctuations in an optical lattice, Phys. Rev. Lett. 93, 073904 (2004)

[2] R. Gommers, P. Douglas, S. Bergamini, M. Goonasekera, P.H. Jones and F. Renzoni, Resonant activation in a nonadiabatically driven optical lattice, Phys. Rev. Lett. 94, 143001 (2005)

[3] R. Gommers, S. Bergamini and F. Renzoni, Dissipation induced symmetry breaking in an driven optical lattice, Phys. Rev. Lett. 95, 073003 (2005)

[4] R. Gommers, S. Denisov and F. Renzoni, Quasiperiodically Driven Ratchets for Cold Atoms, Phys. Rev. Lett. 96, 240604 (2006)

14. **M. Salerno**

Title: Soliton ratchets in continuous and discrete systems

Abstract: We review the mechanism underlying the formation of soliton ratchets both in continuous and in discrete nonlinear systems. In particular, we discuss the existence of asymmetric internal modes which couple, through the damping in the system, to the soliton translational degree of freedom. Effective soliton transport is shown to be achieved when the internal mode and the external force are phase locked. The role played by the spatial temporal symmetries in establishing soliton ratchets is also investigate. For discrete systems we show that the phenomenon becomes more complicated due to the existence of nonzero depinning thresholds for the onset of the motion, locking to rational fractions of the driving frequecy and existence of diffusive ratchet dynamics. As specific examples we consider the damped and driven double sine-Gordon equation with asymmetric potential, the damped sine-Gordon equation with temporal asymmetric drivers and the Gross-Pitaevskii equation with time dependent asymmetric optical lattices.

15. **L. Schimansky-Geier**

Title: Low randomness in ratchets and steppers

Abstract: We introduce the diffusion coefficient and the Peclet-number as a measure of quality for transport in ratchets and for the motion of steppers. We calculate both for simple discrete ratchet models and give conditions which reduce randomness of the transport. In addition periodic forcing can be used to synchronize the motion of Brownian steppers which corresponds to a state with low randomness.

In the second part we discuss coupling of particles in flashing ratchets and calculate the mean velocity in dependence on the coupling parameters.

J. A. Freund, and L. Schimansky-Geier, Phys. Rev. E 60, 1304 -1309 (1999).

B. Lindner, M. Kostur, and L. Schimansky-Geier, Fluctuations and Noise Letters 1, R25 (2001).

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T Prager, L Schimansky-Geier and I M Sokolov, J. of Physics: Cond. Matter 17, 3661 (2005).

J. Menche and L. Schimansky-Geier, Phys. Lett. A 359, 90 (2005)

16. **J. L. Vicent**

Title: Experimental ratchet effect in nanostructured superconductors.

Abstract: Superconducting vortex lattice is a powerful tool to study the ratchet effect due to interacting particles and to explore the commensurability effects between the vortex lattice and the array of asymmetric defects which govern rocking ratchet behavior.

In this talk we will show that:

i)A reversible ratchet occurs in nanostructured superconductors.

ii)The interaction between the whole vortex lattice and the array of asymmetric pinning potentials is the mechanism which leads the ratchet effect.

Short Talks

17. Alejandro B. Kolton. Universidad Complutense de Madrid.
Title: Transverse rectification of disorder-induced fluctuations in a driven system.
Abstract: We study numerically the overdamped motion of particles driven in a two dimensional ratchet potential. In the proposed design, of the so-called geometrical-ratchet type, the mean velocity of a single particle in response to a constant force has a transverse component that can be induced by the presence of thermal or other unbiased fluctuations. We find that additional quenched disorder can strongly enhance the transverse drift, in spite of reducing the transverse mobility. We show that, under general conditions, the rectified transverse velocity of a driven particle fluid is equivalent to the response of a one dimensional flashing ratchet working at a drive-dependent effective temperature, defined through generalized Einstein relations.

18. Luis Dinis. Dpto. Física Atómica, Molecular y Nuclear. Universidad Complutense de Madrid.
Title: Influence of lattice configurations in a superconducting vortex ratchet.
Abstract: We present 2D Langevin simulations for vortices in a periodic lattice of triangular pinning sites. When vortices are rocked applying an AC force, rectification of the signal is observed in the movement of the vortex lattice, and a net current appears. Simulations show the proper current reversal behavior as compared to experimental data, when the applied force is changed. In our simulations vortices move coherently as a lattice with some defects, and the current reversal correspond to a change in the conformation of the vortex lattice. An specific change in the separation of the pinning sites can favour one of the lattice configurations over the other, resulting in the disappearance of the inversion phenomenon. These results provide new insights to increase control over the vortex ratchet device.

19. Edward Goldobin. University of Tuebingen.
Title: Josephson vortex ratchet: experiments and simulations.
Abstract:

20. Alex Gómez-Marin. Universidad de Barcelona.
Title: Tight coupling in thermal Brownian motors
Abstract: We study analytically a thermal Brownian motor model and calculate exactly the Onsager coefficients. We show how the reciprocity relation holds and that the determinant of the Onsager matrix vanishes. Such condition implies that the device is built with tight coupling. This explains why Carnot's efficiency can be achieved in the limit of infinitely slow velocities. We also prove that the efficiency at maximum power has

the maximum possible value, which corresponds to the Curzon-Alhborn bound. Finally, we discuss the model acting as a Brownian refrigerator.

21. Veronica I. Maroni. Universidad Complutense de Madrid.
Title: Rocking ratchets in 2D Josephson networks: collective effects and current reversal
Abstract: A detailed numerical study on the directed motion of ac-driven vortices and anti vortices in 2D Josephson junction arrays (JJA) with an asymmetric periodic pinning potential is reported. Dc-voltage rectification shows a strong dependence on vortex density as well as an inversion of the vortex flow direction with ac amplitude for a wide range of vortex density around f=1/2 (f=$Ha2/\Phi_0$), in good agreement with recent experiments by Shalóm and Pastoriza [Phys. Rev. Lett. **94**, 177001 (2005)]. The study of vortex structures, spatial and temporal correlations, and vortex-anti vortex pairs formation gives insight into a purely collective mechanism behind the current reversal effect.

22. Juan J. Mazo. Universidad de Zaragoza. juanjo@unizar.es
Title: Ratchet effects in 1D Josephson arrays
Abstract: A fluxon in a Josephson-junction parallel array behaves like a single particle in a periodic pinning potential. Different configurations of critical currents and cell areas result in different profiles for the fluxon potential. We analyze the minimal conditions to achieve an effective potential in which mirror symmetry is absent, namely a fluxon ratchet potential. Following one of the configurations, we designed circular arrays and probed some of the fluxon properties. Theoretical predictions are fulfilled by the experiments.

23. Bernardo Sánchez-Rey. Universidad de Sevilla.
Title: Kink ratchet in a two-state symmetric potential.
Abstract: We present a simple model that exhibits kink ratchet dynamics using a symmetric periodic potential that alternates between two possible states. A symmetry analysis shows that the direction of motion depends sensitively on the duration of the two states so that we can reverse or cancel the energy flux adjusting those parameters. Numerical simulations also show interesting resonant behaviors of the kink averaged velocity. The system preserves both, symmetry properties and resonant behaviors, when periodic switching between the two states is replaced by random fluctuations.

24. Horacio Wio. Instituto de Físsica de Cantabria.
Title: Random walker on a ratchet: effect of a non Gaussian noise.
Abstract: Some recent results on the effect of a noise source taken as colored and non-Gaussian –generated by a nonextensive q-distribution– on several noise induced phenomena have shown that the system behavior is strongly affected by a departure of the noise source from the Gaussian behavior, with an enhancement and/or a marked broadening of the corresponding system´s response. Here we analyze a recent model of a walker

moving on a ratchet potential, when the system is subject to the indicated non Gaussian noise. We present a simple, approximate, approach that qualitatively reproduces the results for Gaussian white noise, and allows to gain some analytical insight into the effect of the indicated form of noise on the present case.

25. Elías Zamora Sillero. Universidad de Sevilla.
Title: Flux of Energy in symmetrical extended systems.
Abstract: Recent studies show that to produce a net flux of energy in Nonlinear Klein Gordon Systems is necessary to break the spatial [1] symmetry, destroying the symmetry of the on-site potential, or breaks temporal symmetry [2] by means of the addition of a non symmetric ac driving force. In this talk I want to show how coupling an additive and a parametrical general and symmetric ac forces it is possible to obtain a net flux of energy [3]. Necessary conditions of the on-site potential and between the frequencies of both forces to obtain a net transport of energy [4] will be presented. Finally we will show how these results generalize previous ones that only deal either with additive or nonsymmetric potentials.

References

[1]. Luis Morales-Molina, Niurka R. Quintero, Franz G. Mertens and Ángel Sánchez, Phys. Rev. Lett. 91 234102 (2003)

[2]. Niurka R. Quintero, Bernardo Sánchez Rey, Mario Salerno , Phys. Rev. E. 72 016610 (2005)

[3]. Elías Zamora-Sillero, Niurka R. Quintero, Franz G. Mertens, Phys. Rev. E. 74, 046607 (2006).

[4]. Elías Zamora-Sillero, Niurka R. Quintero, Franz G. Mertens, preprint

Posters

26. Martin Brown. Department of Physics and Astronomy University College London.
Title: Theoretical investigation of supersymmetric ratchets.
Abstract:

27. Jesús Cuevas Maraver. Universidad de Sevilla.
Title: Ratchets and defect migration in solids
Abstract: Interstitials and vacancies, in one-dimensional lattices, are point defects that can be modelled by means of kinks or antikinks in a discrete Frenkel-Kontorova model, with a sine-Gordon on-site potential. The properties of kinks and antikinks are the same if a harmonic interaction potential is considered. The ratchet properties of these defects in the above mentioned context has been studied by Zolotaryuk and Salerno when the system is driven by a biharmonic field. The properties of these solutions are strongly altered when an anharmonic interaction potential is introduced in the model, as the Peierls-Nabarro barrier is higher for antikinks than for kinks. The aim of this poster is to show the effects of the anharmoniciy of the interaction potential in the properties of kinks and antikinks focusing in the assymetry between the properties of these two species of topological solitons.

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[2] J. Cuevas, C. Katerji, J.F.R. Archilla, J.C. Eilbeck, F.M. Russell. Phys. Lett. A 315 (2003) 364

[3] J. Cuevas, J.F.R. Archilla, B. Sánchez-Rey, F.R. Romero. Physica D 216 (2006) 115

28. David Cubero. Universidad de Sevilla.
Title: Flux reversal in a two-state symmetric lattice
Abstract: We study a simple random-walk model on a one-dimensional lattice. The lattice as a whole switches periodically between two possible states which are spatially symmetric. Both lattice states are identical, but translated by one site with respect to each other, and consist of infinite arrays of absorbing sites separated by two nonabsorbing sites. Exact explicit expressions for the long-time velocity and the effective diffusion coefficient are obtained and discussed. This model can be regarded as a simple approximation for the experiment studied by Lee and Grier in [1]. A comparison between the exact results obtained from our simple model and those expected from the experiment is achieved by numerical simulations.

[1] S.-H. Lee and D. G. Grier, Phys. Rev. E 71, 060102(R) 2005 .

- Elías Zamora-Sillero. Universidad de Sevilla.
Title: Soliton Ratchet effect in Nonlinear Klein Gordon equations analyzed by symmetry, Collective Coordinates and perturbational techniques.

Abstract: During the last five years an intense impulse has been done in the study of the ratchet effect in extended systems. Two approaches have been used to understand the causes, properties and dynamics of the extended structures subjected to the ratchet effect. Flach and coworkers [1] used symmetry analysis to obtain necessary conditions to obtain a non zero mean flux of energy in the system. After it other authors [2,3,4] using CC techniques obtained results in agreement with whose based in symmetry methods. In this poster using a generalization of the system proposed in [1], with additive and parametrical forces, we show how the collective coordinates equations and its perturbational approach fulfills the same symmetry properties than the original PDE equation that impose a zero mean velocity in the flux of energy of the system [5], explaining the agreement between both techniques.

[1]. S. Flash et al. Phys. Rev. Lett. 88 184101 (2002)

[2]. Luis Morales-Molina, Niurka R. Quintero, Franz G. Mertens and Ángel Sánchez, Phys. Rev. Lett. 91 234102 (2003)

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[5]. Elías Zamora-Sillero, Niurka R. Quintero, Franz G. Mertens, preprint

Other Participants

29. Renato Alvarez-Nodarse. Universidad de Sevilla, Spain.
30. José Pablo Baltanás. Universidad de Sevilla, Spain.
31. José Luis Cardoso. Universidade de Trás-os-Montes e Alto Douro, Portugal.
32. Francisco J. Esteban. Universidad de Jaén, Spain.
33. Rosario González Ferez. Universidad de Granada, Spain.
34. Steven Lade. The Australian National University, Canberra, Australia.
35. Niurka R. Quintero. Universidad de Sevilla, Spain.
36. Angel Sánchez. Universidad Carlos III, Spain
37. José M. Sancho. Universidad de Barcelona, Spain.