Gaspard, Pierre

Scattering theory and thermodynamics of quantum transport. (English) Zbl 1337.82018

Ann. Phys., Berlin 527, No. 9-10, 663-683 (2015).

The purpose of the present article is to explain how the time-reversal symmetry of Hamiltonian microdynamics can be compatible with the thermodynamic time asymmetry. There the key issue is that the equations of motion may have solutions that do not share the symmetry of the equations. The symmetry breaking takes place at the statistical level of description due to the fact that forward and time reversed paths have different probabilities under nonequilibrium conditions. Temporal disorder, as it occurs in scattering processes, can be characterized by the concept of ϵ-entropy per unit time [*P. Gaspard* and *X.-J. Wang*, "Noise, chaos, and (ε, τ) entropy per unit time", Phys. Rep. 235, No. 6, 291–343 (1993; doi:10.1016/0370-1573(93)90012-3)]. This concept was generalized to quantum systems by Connes, Narnhofer, and Thirring. It allows to describe temporal disorder in many-body quantum systems of fermions and bosons (see [*A. Connes* et al., Commun. Math. Phys. 112, 691–719 (1987; Zbl 0637.46073)]; [*H. Narnhofer* and *W. Thirring*, Lett. Math. Phys. 14, 89–96 (1987; Zbl 0628.46065)]). Here, the theory is applied to study the scattering theory in open systems, where scattering particles may also randomly arrive from surrounding reservoirs.

From the abstract: "Scattering theory is complemented by recent results on full counting statistics, the multivariate fluctuation relation for currents, and time asymmetry in temporal disorder characterized by the Connes-Narnhofer-Thirring entropy per unit time, in order to establish relationships with the thermodynamics of quantum transport. Fluctuations in the bosonic or fermionic currents flowing across an open system in contact with particle reservoirs are described by their cumulant generating function, which obeys the multivariate fluctuation relation as the consequence of microreversibility. Time asymmetry in temporal disorder is shown to manifest itself out of equilibrium in the difference between a time-reversed coentropy and the Connes-Narnhofer-Thirring entropy per unit time. The difference is shown to be equal to the thermodynamic entropy production for ideal quantum gases of bosons and fermions. The results are illustrated for a two-terminal circuit."

Reviewer: Claudia-Veronika Meister (Darmstadt)

MSC:

82C70 Transport processes in time-dependent statistical mechanics
81U05 2-body potential quantum scattering theory

Keywords:

plasma physics; scattering theory; quantum transport; nonequilibrium statistical mechanics

Full Text: DOI

References:

[1] Joachain, Quantum Collision Theory (1975)
[2] Taylor, Scattering Theory (2000)
[3] Datta, Electronic Transport in Mesoscopic Systems (1995)· doi:10.1017/CBO9780511805776
[4] Imry, Introduction to Mesoscopic Physics (1997)
[5] Ferry, Transport in Nanostructures, 2nd Edition (2009)· doi:10.1017/CBO9780511840463
[6] Nazarov, Quantum Transport (2009)· doi:10.1017/CBO9780511626906
[7] Landauer, IBM J. Res. Develop. 1 pp 223– (1957)· doi:10.1147/rd.13.0223
[8] Büttiker, Phys. Rev. B 31 pp 6207– (1985)· doi:10.1103/PhysRevB.31.6207
[9] Sivan, Phys. Rev. B 33 pp 551– (1986)· doi:10.1103/PhysRevB.33.551
[10] Levitov, JETP Lett. 58 pp 230– (1993)
[11] Levitov, J. Math. Phys. 37 pp 4845– (1996) · Zbl 0868.60099 · doi:10.1063/1.531672

[12] Blanter, Phys. Rep. 336 pp 1– (2000)· doi:10.1016/S0370-1573(99)00123-4
[13] Tasaki, Chaos, Solitons & Fractals 12 pp 2657– (2001) · Zbl 0994.82049 · doi:10.1016/S0960-0779(01)00080-7
[14] Tasaki, Fundamental Aspects of Quantum Physics pp 100– (2003)· doi:10.1142/9789812704412$_0$006
[15] Tasaki, Prog. Theor. Phys. Suppl. 165 pp 57– (2006)· doi:10.1143/PTPS.165.57
[16] Jakšić, Commun. Math. Phys. 217 pp 285– (2001) · Zbl 1042.82031 · doi:10.1007/s002200000339
[17] Jakšić, J. Stat. Phys. 108 pp 787– (2002) · Zbl 1025.82011 · doi:10.1023/A:1019818909696
[18] Aschbacher, J. Math. Phys. 48 pp 032101– (2007) · Zbl 1137.82331 · doi:10.1063/1.2709849
[19] Bruneau, Commun. Math. Phys. 319 pp 501– (2013) · Zbl 1277.82055 · doi:10.1007/s00220-012-1628-3
[20] Jakšić, Quantum Theory from Small to Large Scales (2012)
[21] Jakšić, Ann. Henri Poincaré 14 pp 1775– (2013) · Zbl 1281.82017 · doi:10.1007/s00023-013-0231-2
[22] Sâad, J. Math. Phys. 55 pp 075202– (2014) · Zbl 1297.82033 · doi:10.1063/1.4879238
[23] Eckmann, Rev. Mod. Phys. 57 pp 617– (1985) · Zbl 0989.37516 · doi:10.1103/RevModPhys.57.617
[24] Gaspard, Phys. Rep. 235 pp 291– (1993)· doi:10.1016/0370-1573(93)90012-3
[25] Kolmogorov, Dokl. Akad. Nauk SSSR 124 pp 754– (1959)
[26] Sinai, Dokl. Akad. Nauk SSSR 124 pp 768– (1959)
[27] Connes, Commun. Math. Phys. 112 pp 691– (1987) · Zbl 0637.46073 · doi:10.1007/BF01225381
[28] Narnhofer, Lett. Math. Phys. 14 pp 89– (1987) · Zbl 0628.46065 · doi:10.1007/BF00403474
[29] Gaspard, J. Stat. Phys. 117 pp 599– (2004) · Zbl 1113.82036 · doi:10.1007/s10955-004-3455-1
[30] Gaspard, New J. Phys. 7 pp 77– (2005)· doi:10.1088/1367-2630/7/1/077
[31] Andrieux, Phys. Rev. Lett. 98 pp 150601– (2007)· doi:10.1103/PhysRevLett.98.150601
[32] Andrieux, J. Stat. Mech. pp P01002– (2008)
[33] Gaspard, J. Math. Phys. 55 pp 075208– (2014) · Zbl 1298.82051 · doi:10.1063/1.4881534
[34] Gaspard, Phys. Rev. Lett. 65 pp 1693– (1990) · Zbl 1050.82547 · doi:10.1103/PhysRevLett.65.1693
[35] Dorfman, Phys. Rev. E 51 pp 28– (1995)· doi:10.1103/PhysRevE.51.28
[36] Gaspard, Chaos, Scattering and Statistical Mechanics (1998) · Zbl 0915.00011 · doi:10.1017/CBO9780511628856
[37] Evans, Phys. Rev. Lett. 71 pp 2401– (1993) · Zbl 0966.82507 · doi:10.1103/PhysRevLett.71.2401
[38] Gallavotti, Phys. Rev. Lett. 77 pp 4334– (1996) · Zbl 1063.82533 · doi:10.1103/PhysRevLett.77.4334
[39] Kurchan, J. Phys. A: Math. Gen. 31 pp 3719– (1998) · Zbl 0910.60095 · doi:10.1088/0305-4470/31/16/003
[40] Lebowitz, J. Stat. Phys. 95 pp 333– (1999) · Zbl 0934.60090 · doi:10.1023/A:1004589714161
[41] Maes, J. Stat. Phys. 95 pp 367– (1999) · Zbl 0941.60099 · doi:10.1023/A:1004541830999
[42] Maes, J. Stat. Phys. 110 pp 269– (2003) · Zbl 1035.82035 · doi:10.1023/A:1021026930129
[43] Esposito, Rev. Mod. Phys. 81 pp 1665– (2009) · Zbl 1205.82097 · doi:10.1103/RevModPhys.81.1665
[44] Campisi, Rev. Mod. Phys. 83 pp 771– (2011)· doi:10.1103/RevModPhys.83.771
[45] Seifert, Rep. Prog. Phys. 75 pp 126001– (2012)· doi:10.1088/0034-4885/75/12/126001
[46] Andrieux, J. Chem. Phys. 121 pp 6167– (2004)· doi:10.1063/1.1782391
[47] Andrieux, J. Stat. Mech. pp P01011– (2006)
[48] Andrieux, J. Stat. Mech. pp P02006– (2007)
[49] Andrieux, J. Stat. Phys. 127 pp 107– (2007) · Zbl 1115.82023 · doi:10.1007/s10955-006-9233-5
[50] Andrieux, New J. Phys. 11 pp 043014– (2009)· doi:10.1088/1367-2630/11/4/043014
[51] Gaspard, New J. Phys. 15 pp 115014– (2013)· doi:10.1088/1367-2630/15/11/115014
[52] Tobiska, Phys. Rev. B 72 pp 235328– (2005)· doi:10.1103/PhysRevB.72.235328
[53] Saito, Phys. Rev. B 78 pp 115429– (2008)· doi:10.1103/PhysRevB.78.115429
[54] Brantut, Science 342 pp 713– (2013)· doi:10.1126/science.1242308
[55] Krinner, Nature 517 pp 64– (2015)· doi:10.1038/nature14049
[56] Burghardt, J. Chem. Phys. 100 pp 6395– (1994)· doi:10.1063/1.467049
[57] Landau, Quantum Mechanics (1977)
[58] Folman, Phys. Rev. Lett. 84 pp 4749– (2000)· doi:10.1103/PhysRevLett.84.4749
[59] Sánchez, Phys. Rev. Lett. 104 pp 076801– (2010)· doi:10.1103/PhysRevLett.104.076801
[60] Cuetara, Phys. Rev. B 84 pp 165114– (2011)· doi:10.1103/PhysRevB.84.165114
[61] Cuetara, Phys. Rev. B 88 pp 115134– (2013)· doi:10.1103/PhysRevB.88.115134
[62] Knudsen, Ann. d. Physik 28 pp 999– (1909) · Zbl 40.0825.03 · doi:10.1002/andp.19093330505

[63] Present, Kinetic Theory of Gases (1958)
[64] Pathria, Statistical Mechanics (1972)
[65] Cohen-Tannoudji, Quantum Mechanics (2006)
[66] Wigner, Phys. Rev. 98 pp 145– (1955) · Zbl 0064.21804 · doi:10.1103/PhysRev.98.145
[67] Narnhofer, Phys. Rev. A 23 pp 1688– (1981)· doi:10.1103/PhysRevA.23.1688
[68] Balian, Ann. Phys. 85 pp 514– (1974) · Zbl 0281.35029 · doi:10.1016/0003-4916(74)90421-7
[69] Gutzwiller, Chaos in Classical and Quantum Mechanics (1990)· doi:10.1007/978-1-4612-0983-6
[70] Voros, J. Phys. A: Math. Gen. 21 pp 685– (1988) · Zbl 0655.58039 · doi:10.1088/0305-4470/21/3/023
[71] Pollicott, Invent. Math. 81 pp 413– (1985) · Zbl 0591.58025 · doi:10.1007/BF01388579
[72] Ruelle, Phys. Rev. Lett. 56 pp 405– (1986)· doi:10.1103/PhysRevLett.56.405
[73] Ruelle, J. Stat. Phys. 44 pp 281– (1986) · Zbl 0655.58026 · doi:10.1007/BF01011300
[74] Gaspard, Scholarpedia 9 pp 9806– (2014)· doi:10.4249/scholarpedia.9806
[75] Gaspard, J. Chem. Phys. 90 pp 2225– (1989)· doi:10.1063/1.456017
[76] Gaspard, J. Chem. Phys. 90 pp 2242– (1989)· doi:10.1063/1.456018
[77] Gaspard, J. Chem. Phys. 90 pp 2255– (1989)· doi:10.1063/1.456019
[78] Gaspard, Phys. Rev. E 50 pp 2591– (1994)· doi:10.1103/PhysRevE.50.2591
[79] Barra, Phys. Rev. E 65 pp 016205– (2001)· doi:10.1103/PhysRevE.65.016205
[80] Haake, Quantum Signatures of Chaos, 2nd Edition (2001) · Zbl 0985.81038 · doi:10.1007/978-3-662-04506-0
[81] Rammer, Quantum Field Theory of Non-equilibrium States (2007) · Zbl 1123.82001 · doi:10.1017/CBO9780511618956
[82] Büttiker, Phys. Rev. B 41 pp 7906– (1990)· doi:10.1103/PhysRevB.41.7906
[83] Smilansky, Mesoscopic Quantum Physics pp 373– (1995)
[84] Nakamura, Quantum Chaos and Quantum Dots (2004)
[85] Onsager, Phys. Rev. 37 pp 405– (1931) · Zbl 0001.09501 · doi:10.1103/PhysRev.37.405
[86] Donder, Affinity (1936)
[87] Prigogine, Introduction to Thermodynamics of Irreversible Processes (1967)
[88] Groot, Non-Equilibrium Thermodynamics (1984)
[89] Callen, Thermodynamics and an Introduction to Thermostatistics (1985) · Zbl 0989.80500
[90] Klich, Quantum Noise in Mesoscopic Physics (2003)
[91] Avron, Commun. Math. Phys. 280 pp 807– (2008) · Zbl 1144.82033 · doi:10.1007/s00220-008-0449-x
[92] Gaspard, Nonequilibrium Statistical Physics of Small Systems: Fluctuation Relations and Beyond pp 213– (2013)· doi:10.1002/9783527658701.ch7
[93] Huang, Statistical Mechanics (1963)
[94] Cornfeld, Ergodic Theory (1982)· doi:10.1007/978-1-4615-6927-5
[95] Gaspard, Quantum Chaos pp 348– (1991)
[96] Gaspard, Quantum Chaos - Quantum Measurement pp 19– (1992)· doi:10.1007/978-94-015-7979-7_2
[97] Gaspard, Prog. Theor. Phys. Suppl. 116 pp 369– (1994) · Zbl 1229.82103 · doi:10.1143/PTPS.116.369
[98] Wehrl, Rev. Mod. Phys. 50 pp 221– (1978)· doi:10.1103/RevModPhys.50.221
[99] Cover, Elements of Information Theory, 2nd edition (2006) · Zbl 1140.94001
[100] Callens, Physica D 187 pp 383– (2004) · Zbl 1054.82016 · doi:10.1016/j.physd.2003.09.022
[101] Wees, Phys. Rev. Lett. 60 pp 848– (1988)· doi:10.1103/PhysRevLett.60.848
[102] Cleuren, Phys. Rev. E 74 pp 021117– (2006)· doi:10.1103/PhysRevE.74.021117
[103] Gaspard, J. Stat. Mech. pp P03024– (2011)
[104] Gaspard, Acta Phys. Polon. B 44 pp 815– (2013) · Zbl 1371.82087 · doi:10.5506/APhysPolB.44.815
[105] Utsumi, Phys. Rev. B 81 pp 125331– (2010)· doi:10.1103/PhysRevB.81.125331
[106] Nakamura, Phys. Rev. Lett. 104 pp 080602– (2010)· doi:10.1103/PhysRevLett.104.080602
[107] Nakamura, Phys. Rev. B 83 pp 155431– (2011)· doi:10.1103/PhysRevB.83.155431
[108] Küng, Phys. Rev. X 2 pp 011001– (2012)
[109] Benatti, Commun. Math. Phys. 198 pp 607– (1998) · Zbl 0927.37008 · doi:10.1007/s002200050489
[110] Balescu, Equilibrium and Nonequilibrium Statistical Mechanics (1975)
[111] Gaspard, Physica A 392 pp 639– (2013)· doi:10.1016/j.physa.2012.10.006

paper as accurately as possible without claiming the completeness or perfect precision of the matching.