

## PSA Symposium Proposal

# New Approaches to Equilibrium in Thermodynamics and Statistical Mechanics

Organiser: Roman Frigg

Chair: Lawrence Sklar

Speakers: Robert Batterman, Craig Callender, Roman Frigg, David Lavis, Jos Uffink

## Description of the Topic

Thermodynamics (TD) and statistical mechanics (SM) occupy center stage in the edifice of modern physics and since their inception in the 19<sup>th</sup> century they have seen spectacular developments, extending their range of application far beyond what their founding fathers had envisaged. However, at the same time it has also been well-known ever since that both theories face serious conceptual difficulties. Many of these became most palpable when the relation between the two theories was studied. TD was (and is) believed to reduce to SM, but Loschmidt's reversibility objection Zermelo's recurrence objection soon showed that the two theories do not enter into any simple reductive relationship.

However, scientific success and conceptual problems notwithstanding, it was not until the 1980s that philosophers of science started engaging with the philosophical and foundational problems surrounding SM and TD. And even then, these matters have never got the same level of attention as other issues in the philosophy of physics, in particular the foundations of quantum mechanics and relativity. (For instance, while there was at least one major conference on the foundations of quantum mechanics every year since 1980, the same period has only seen five conferences on SM/TD and there has not been a PSA symposium on this topic for 20 years).

The aim of this symposium is to put unexplored yet important foundational issues surrounding the notions of entropy and equilibrium into the spotlight. Rather than focusing on stock problems such as the ones concerning the status of ergodicity or coarse graining, this symposium brings together five papers that either expose radically new ideas and/or deal with questions that have not yet been addressed.

David Lavis suggests the notion of equilibrium be abandoned altogether and replaced by a new concept, commonness, which, unlike equilibrium, allows for degrees. This not only makes certain time-honored puzzles in connection with equilibrium vanish, it also points the way towards a reconciliation of the two different frameworks, Boltzmann's and Gibbs', in which SM is formulated.

Craig Callender focuses on what are called the paradoxes of gravitational thermodynamics, for instance the negative heat capacity of self-gravitating systems and the absence of a thermodynamical limit. Are these paradoxes genuine? Here we face an interesting dilemma. If they are, then the scope of TD has to be restricted. If not, then there must be a good explanation for it, which sheds light on the nature of TD. In his paper Callender resolves this dilemma.

It is widely believed that TD reduces to SM. However, as is well-known, TD does not reduce to SM in any of the usual senses of ‘reduction’. Robert Batterman explores a new approach to the issue of reductionism which is based on renormalization techniques (originating in quantum field theories and the theory of critical phenomena). He proposes a particular probabilistic understanding of the renormalization group, on the basis of which (at least Gibbsian) SM and TD can be brought in a neat reductive relationship.

One of the key questions of SM is how we are to account for the irreversible behavior of many systems. An influential answer to this question (championed by Penrose, Streater, van Kampen, and others) is that we obtain a satisfactory account of irreversible processes when we describe them as Markov processes. Jos Uffink reconsiders this approach and argues that, despite appearances to the contrary, it is ultimately both unsuccessful and untenable and should therefore be given up. This claim, if successful, renders an entire research program in theoretical physics obsolete.

Probabilities lie at the heart of SM. But what kind of probabilities are these? Objectivists argue that probabilities are based on features of the real system. However, the only well-worked out account of objective probability in SM, the time average interpretation, cannot be extended to the non-equilibrium case, which makes it untenable as an account of SM probabilities. Roman Frigg puts forward an objectivist account of SM probabilities based on Lewis’ Humean/Best-System approach and shows that this approach can circumvent the difficulties that beset the time average interpretation.

## **Short Descriptive Summary of the Proposal**

Thermodynamics (TD) and statistical mechanics (SM) occupy center stage in the edifice of modern physics. Well-know conceptual and foundational problems notwithstanding, it was not until the 1980s that philosophers of science started engaging with these theories. Even then, these matters have never got the same level of attention as other issues in the philosophy of physics. The aim of this symposium is to put unexplored yet important foundational issues surrounding the notions of entropy and equilibrium into the spotlight by bringing together five papers that either expose radically new ideas and/or deal with questions that have not yet been addressed. The first three papers deal with the notion of equilibrium, asking how to define and characterize equilibrium and how TD and SM equilibrium concepts relate to one another. The latter two papers focus on non-equilibrium situations and look at how the approach to equilibrium can be understood and how the probabilities involved should be interpreted.

## **Titles and Abstracts**

### ***David Lavis - Boltzmann, Gibbs and the Concept of Equilibrium***

There are three levels of description in classical statistical mechanics, the microscopic/dynamic, the macroscopic/statistical and the thermodynamic. There is a well-used concept of equilibrium in thermodynamics; however, dynamic equilibrium does not exist in measure-preserving reversible dynamic systems. Statistical mechanics situates equilibrium at the macroscopic level in the Boltzmann approach and at the statistical level in the Gibbs approach. Consequently these two approaches lead to very different definitions of equilibrium and entropy. In the Gibbs approach equilibrium is an ensemble property, defined as the state where the distribution of the phase point is a time-independent solution of Liouville's equation. The development of this approach has been very successful, but its extension to non-equilibrium presents contentious problems. In the Boltzmann approach equilibrium is the state where the phase point is in the largest macrostate. I shall discuss problems associated with this definition and argue that they are resolved by taking the Boltzmann entropy (which is a measure of the size of the occupied macrostate) not as the demarcation of a binary property (being/not being in equilibrium) but of a continuous property (which I call 'commonness') intended to capture degrees of equilibrium. I suggest that the relationship with thermodynamics entails an expectation of the kind of Boltzmann entropy profile which would count as 'thermodynamic-like', namely one in which the entropy spend most of it time near to its maximum value with frequent small and rare large fluctuations. For this to be 'typical' it is sufficient that the system is ergodic and I explore, using the idea of an ergodic decomposition, the possibility of obtaining behavior consonant with the notion of thermodynamic-like which is typical for a wider class of systems. Within this framework the role of the Gibbs approach is to provide an approximation to the time-average behavior of *any* system, not simply one at equilibrium.

### ***Craig Callender - Do "Boxes" of Stars Obey Thermodynamics?***

Normally classical phenomenological thermodynamics is described in environments wherein a system's interaction with gravity is insignificant. In systems that fit in laboratories, short-range forces trump any contributions from gravity. What happens when (non-relativistic) gravity is significant? What happens if our "gas in a box" is a system of stars interacting primarily through gravity? Do the generalizations of classical thermodynamics still hold? There is no reason, a priori, that they must. And given the different character of the force – long-range, always attractive, with a gravitational potential energy that grows faster than linear with the mass of the system – one might even suspect they the generalizations do not hold. In fact, physicists looking at the thermodynamics of self-gravitating systems speak of various "paradoxes": for instance, it is said that the systems display a negative heat capacity, have non-extensive entropy, possess no thermodynamic limit, and more. Some of this paradoxical behavior is so much at odds with classical thermodynamics that it seems natural to say classical thermodynamics does not hold when a significant gravitational interaction is turned on.

We face an interesting dilemma: either these paradoxes are genuine or they are not. Either option promises to increase our understanding of the nature and scope of

thermodynamics. If the paradoxes are genuine, thermodynamic behavior would be a phenomenon crucially tied to a regime wherein short-distance forces dominate. Thermodynamics would be more “local” than we normally believe. One of the many costs of this move is that the early universe would no longer be considered one of low entropy. If the paradoxes are not genuine, then the reason why would shed light on various topics in the foundations of thermodynamics. It would also vindicate, to a surprising extent, the reach and robustness of the phenomenological laws of thermodynamics. In this paper I resolve this dilemma.

***Robert Batterman - Reduction and Renormalization***

This paper discusses the supposed reduction of Thermodynamics to Statistical Mechanics. It begins with an historical discussion of J. Willard Gibbs' famous caution concerning the connections between thermodynamic properties and statistical mechanical properties---his so-called “Thermodynamic Analogies.” The reasons for Gibbs' caution are then considered in light of recent work in statistical physics on the existence of the thermodynamic limit and the explanation of critical behavior using the renormalization group apparatus. A probabilistic understanding of the renormalization group arguments allows for a kind of unification of Gibbs' approach with contemporary understanding of the reduction problem.

***Jos Uffink - Taking algebra too seriously. On the illusion of irreversible behaviour in statistical dynamics***

An influential approach to the foundations of classical non-equilibrium statistical mechanics (by authors as Oliver Penrose, Nico van Kampen Michael Mackey, and Ray Streater) claims to obtain a satisfactory explanation of irreversible behavior by characterizing the evolution of macroscopic physical systems as a Markov process, or more abstractly, in terms of a semigroup of non-invertible evolution operators. The general formalism developed in this approach, sometimes called ‘stochastic dynamics’, can in fact be obtained from a variety of physical motivations, e.g. by assuming that the physical system interacts with an environment (the “open systems” or “interventionist” approach) or that only a few macroscopic variables from the detailed microscopic state of the state are relevant for its physical description. (“coarse graining”).

I will argue that, despite appearances, this approach remains fully time-reversal invariant, and hence, does not embody irreversible behavior. It is argued that the illusionary appearance of irreversibility is due to a misleading analogy between Markovian transition probabilities and linear algebra.

***Roman Frigg - Objective Chance in Statistical Mechanics***

Probabilistic reasoning lies at the heart of statistical mechanics (SM) and discussion of foundation of SM typically focuses on how to justify the use of a certain probability measure to characterize equilibrium. But what are these probabilities? Subjectivists like Jaynes deny that SM probabilities reflect objective features of the system and hold that they represent our lack of knowledge about the system’s micro-condition. Objectivists resist this conclusion and argue that SM probabilities are based on the properties of the system. But what properties? The received view, first proffered by Boltzmann and then

further developed by von Plato, is that SM probabilities are time averages. However, not only does this view suffer from various technical difficulties, it is also well-known that it is impossible to extend it to the non-equilibrium case. This is a serious impediment. It is one of the principal aims of SM to explain the approach to equilibrium and an interpretation of probability that cannot account for the non-equilibrium situation makes this impossible. One might now argue that this is not a problem because all we need now is a different interpretation of probabilities for non-equilibrium situation. This, however, does not seem satisfactory. Characteristically systems approach equilibrium gradually and there is no reason why probabilities should suddenly be given a different interpretation once the system reaches its equilibrium state (in particular because, as is well-known, systems can also fluctuate away from equilibrium every now and then). Hence, the time average interpretation should be rejected even for the equilibrium case and we have to go back to the drawing board. This paper takes up this challenge and presents an interpretation of SM probabilities based on Lewis' Humean/Best-System approach and shows that this approach can circumvent the difficulties that beset the time average interpretation.

### **Session Participants – Abbreviated CVs**

**Robert Batterman** received his PhD from the University of Michigan in 1987 and is now Professor of Philosophy at the University of Western Ontario. His areas of specialization are philosophy of science and the foundation of physics. He is the author of *The Devil in the Details: Asymptotic Reasoning in Explanation, Reduction, and Emergence* (Oxford UP 2002). Selected publications relevant to the symposium are “‘Fundamental’ Theory: Molecular Dynamics vs. Hydrodynamics”, *Erkenntnis*, forthcoming; ‘Critical Phenomena and Breaking Drops: Infinite Idealizations in Physics’, *Studies in History and Philosophy of Modern Physics* 36 (2005), 225-244; ‘Response to Belot's “Whose Devil? Which Details?”’ *Philosophy of Science* 72 (2005), 154-163; ‘Asymptotics and the Role of Minimal Models’, *British Journal for the Philosophy of Science* 53 (2002), 21-38; ‘Intertheory Relations in Physics’, *Stanford Encyclopedia of Philosophy*; ‘Multiple Realizability and Universality’, *British Journal for the Philosophy of Science* 51 (2000), 115-145. ‘Why Equilibrium Statistical Mechanics Works: Universality and the Renormalization Group’, *Philosophy of Science* 65 (1998), 183-208; ‘Into a Mist: Asymptotic Theories on a Caustic’, *Studies in History and Philosophy of Modern Physics* 28 (1997), 395-413. ‘Theories Between Theories: Asymptotic Limiting Intertheoretic Relations’, *Synthese* 103 (1995), 171-201. ‘Irreversibility and Statistical Mechanics: A New Approach?’, *Philosophy of Science* 57 (1990), 395-419.

**Craig Callender** received his PhD from Rutgers University in 1997 and is now Professor of Philosophy at UCSD. His areas of specialization are philosophy of science, Metaphysics, philosophy of physics. He is the author of *Introducing Time* (Totem Press), has edited *Time, Reality and Experience* (Cambridge UP 2002) and co-edited *Physics Meets Philosophy at the Planck Scale* (with Nicholas Huggett, Cambridge UP 2001). Selected publications relevant to the symposium are ‘Measures, Explanation and Time: Can We Explain the Boundary Conditions of the Universe?’, *British Journal for the*

*Philosophy of Science* 55 (2004), 195-217; ‘Who’s Afraid of Maxwell’s Demon—and Which One?’, in *Quantum Limits to the Second Law*, edited by D. Sheehan, American Institute of Physics, December 2002, pp. 399-407; ‘Taking Thermodynamics (Too) Seriously’, *Studies in the History and Philosophy of Modern Physics* 32 (2001), 539-53; ‘Thermodynamic Time Asymmetry’, *The Stanford Encyclopedia of Philosophy*; ‘Why Quantize the Gravitational Field (or any other Field for that Matter)?’, *Philosophy of Science* 68 (2001), S382-S394, with Nick Huggett; ‘Humean Supervenience and Rotating Homogeneous Matter’ *Mind* 110 (2000), 25-43; ‘Shedding Light on Time’, *Philosophy of Science* 67 (2000), S587-S599; ‘Reducing Thermodynamics to Statistical Mechanics: The Case of Entropy’ *Journal of Philosophy* XCVI (1999), 348-373; ‘The View From No-when’, *British Journal for the Philosophy of Science* 49 (1998), 135-159; ‘What is “The Problem of the Direction of Time”?’’, *Philosophy of Science* 63 (1997), S223-S234.

**Roman Frigg** received his PhD from the University of London in 2003 and is now Lecturer in Philosophy at LSE. His areas of specialization are philosophy of science and philosophy of physics. Publications relevant to this symposium are ‘Chaos and Randomness: An Equivalence Proof of a Generalised Version of the Shannon Entropy and the Kolmogorov-Sinai Entropy for Hamiltonian Dynamical Systems’, *Chaos, Solitons and Fractals* 28 (2006), 26-31; ‘In What Sense Is the Kolmogorov-Sinai Entropy a Measure for Chaotic Behaviour? – Bridging the Gap Between Dynamical System’s Theory and Communication Theory’, *British Journal for the Philosophy of Science* 55 (2004), 411-434; ‘Self-Organised Criticality – What It Is and what It Isn’t’, *Studies in the History and Philosophy of Science* 34 (2003), 613-632; ‘On the Property Structure of Realist Collapse Interpretations of Quantum Mechanics and the So-Called “Counting Anomaly”’, *International Studies in the Philosophy of Science* 17 (2003), 43-57; Review of Peter Smith: ‘Explaining Chaos’, *British Journal for the Philosophy of Science* 52 (2001), 201-205, with Joseph Berkovitz. Forthcoming publications relevant to the symposium include ‘Models in Science’, *Stanford Encyclopaedia of Philosophy*; ‘A Field Guide to Recent Work on the Foundations of Thermodynamics and Statistical Mechanics’, to be published in Dean Rickles (ed.): *The Ashgate Companion to the New Philosophy of Physics*. London: Ashgate.

**David Lavis** received his PhD from the University of Manchester in 1965 and is now Senior Research Fellow in the Department of Mathematics of King’s College London. His main research interests are the investigation of phase transitions in complex lattice systems using mean-field, real-space renormalization, series and exact methods as well as the foundations of statistical mechanics. He is the co-author, with G. M. Bell, of *Statistical Mechanics of Lattice Systems. Volume 1 Closed-Form and Exact Solutions* (Springer 1999) and *Statistical Mechanics of Lattice Systems. Volume 2: Exact, Series and Renormalize Group Methods* (Springer 1999). Recent publications relevant to this symposium include ‘Boltzmann and Gibbs: an attempted reconciliation’, *Stud. Hist. Phil. Mod. Phys.* 36 (2005), 245-273; ‘Equilibrium and (ir)reversibility in classical statistical mechanics’, *forthcoming in the Proceedings of the 5th International Symposium on the Frontiers of Fundamental Physics*, Hyderabad, India. ‘The spin-echo system reconsidered’, *Found. Phys.* 35 (2004), 669-688. ‘Monte Carlo study of an extended 3-state Potts model on the triangular lattice’, *Phys. Rev. B* 67 (2003) 054415-1—0544156,

with Z. F. Wang, B.W. Southern; Essay Review: Physics from Fisher information, *Stud. Hist. Phil. Mod. Phys.* 33 (2002), 327-343, with R. F. Streater; ‘The concept of probability in statistical mechanics’, in *Frontiers of Fundamental Physics 4*, Ed. B.G. Sidarth and M.V. Altaisky, Kluwer 2001, 293-308.

**Lawrence Sklar** is the author of *Space, Time and Spacetime* (awarded the Matchette Prize in philosophy for 1973-74), *Philosophy and Spacetime Physics* (1985), *Philosophy of Physics* (1992), *Physics and Chance* (awarded the Lakatos Prize in philosophy of science for 1995), and *Theory and Truth* (2000), and is the editor of *Philosophy of Science: Collected Papers* (2000). He has also published numerous articles on such topics as philosophical issues in statistical mechanics, the nature of theories, structures for rational belief, inter-theoretic reduction, and the philosophy of space and time. He has held fellowships from the Guggenheim Foundation, the American Council of Learned Societies, the National Science Foundation, and the National Endowment for the Humanities, and is a Fellow of the American Academy of Arts and Sciences. He delivered the John Locke Lectures in Philosophy at Oxford University in 1997-98, and has been a Visiting Fellow at All Souls College in Oxford. He is currently Past-President of the American Philosophical Association, Central Division.

**Jos Uffink** received his PhD from the University of Utrecht in 1990 and is now a Senior University Lecturer in the Institute for History and Foundations of Science at the University of Utrecht. His main research interests are the investigation of the foundations of thermodynamics, statistical mechanics, and quantum theory. Recent and forthcoming publication that are relevant to this symposium include ‘Issues in the foundations of classical statistical physics’, forthcoming in J. Earman and J. Butterfield (eds.): *Handbook for the Philosophy of Physics*. Amsterdam: Elsevier; ‘Insuperable difficulties: Einstein's statistical road to molecular physics’, Einstein Commemoration Issue, M. Janssen (ed.), *Studies in History and Philosophy of Modern Physics* to appear March 2006; ‘Time and Ageing: A physicist's look at gerontology’, in J. Baars (ed.): *Concepts of Time in the Study of Aging*. Amityville N.Y.: Baywood Publishing, to appear; ‘Rereading Ludwig Boltzmann. In: P. Hajek e.a. (eds.): *Logic, Methodology and Philosophy of Science*, London: King's College Publications 2005; ‘Boltzmann's work in statistical physics’, *Stanford Encyclopedia of Philosophy*; ‘The preface paradox reconsidered’, *Erkenntnis* 59 (2003) 389-420, (with I. Douven). ‘The origins of time asymmetry in thermodynamics: the minus first Law’, *Studies in History and Philosophy of Modern Physics* 32 (2001), 525-538 (with H.R. Brown). ‘Thermodynamic uncertainty relations again: a reply to Lavenda’, *Foundations of Physics Letters*, 14 (2001) 187-193, with J.H. van Lith; ‘Bluff your way in the second law of thermodynamics’, *Studies in History and Philosophy of Modern Physics* 32 (2001) 305-394.

## **Session Participants – Institutional Affiliations and Email**

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