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Book Review: Non-Equilibrium Entropy and Irreversibility

Non-Equilibrium Entropy and Irreversibility, G. Lindblad, D. Reidel Publishing Comp. Dordrecht, Holland, 1983, ix + 166 pp., $29.50.

The notions of *nonequilibrium entropy* and *irreversibility* have an unambiguous and universally accepted meaning in the field of hydrodynamics. No doubt, the notion of entropy is the same one as in thermal equilibrium; however, in a local version. Small volume elements of the fluid are assumed to be in thermal equilibrium with the equilibrium parameters changing throughout space-time according to the solution of the fluid dynamical equations. Irreversibility is a property of the viscuous Navier–Stokes equations, since their solutions have a positive local entropy production. Boltzmann's dynamical description of a low-density gas shares the same properties but it goes one step further: Boltzmann introduces a notion of entropy which coincides with the equilibrium entropy whenever the velocity distribution is Maxwellian but is applicable also to states of the gas which are not locally Maxwellian. Ever since, physicists have tried to extend the notion of entropy to moderately dense fluids and to general microscopic systems with Gibbs' postulate serving as a highly successful paradigm restricted however to systems in thermal equilibrium.

Now Göran Lindblad adds his book to the long list of attempts. He has been working on problems in this area for many years and therefore one should be curious to see what he has to say. The present book has the character of a research monograph. It is not supposed to cover all aspects of irreversibility (which would be a monumental task anyhow). Only the thermodynamic arrow of time is treated, the electromagnetic and cosmological arrows of time remaining undiscussed. In the last chapter of the book a short summary of other approaches can be found. But, clearly, Lindblad's goal is to give a coherent and well-argued account of his own approach to nonequilibrium entropy and irreversibility.

Lindblad's framework is fairly abstract and has a system theoretical

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flavor. He exploits the fact that the fundamental property of Hamiltonian systems is the multiple roles of the Hamiltonian in defining the dynamics, the concepts of energy and work, and the entropy of equilibrium states. As he emphasizes himself the boundaries of his approach are set by our understanding of the dynamics of systems with many degrees of freedom.

Lindblad deals from the outset with systems described in terms of quantum mechanics, as *the* theory covering matter at thermal energies. There are two problems to be faced for a closed, spatially confined quantum mechanical system with finitely many degrees of freedom.

(1) The Hamiltonian has a discrete spectrum. All expectations and the state are almost periodic functions in time which complicates a precise notion of irreversibility.

(2) The usual entropy, $-\mathrm{Tr}\,\rho \log \rho$, is constant in time and therefore not a very useful concept for nonequilibrium states.

Lindblad's approach relies on the idea that the connection between microscopic dynamics and thermodynamics should be based on the concept common to both, namely, (mean) energy and work done on the system by time-dependent external forces. The class of admitted external forces depends on the type of experiments one can perform on the system. Thereby Lindblad's notion of nonequilibrium entropy and irreversibility looses an absolute meaning. They are to be understood always relative to a given class of operations (experiments) which can be performed on the system. This notion of irreversibility thereby depends on the state of art in our technology. Needless to say that such a man-centered view of irreversibility is not unanimously agreed upon.

Systematically Lindblad discusses other important aspects and refines his notion of nonequilibrium entropy as to cover not only isolated systems.

(i) Thermodynamic processes, as the Carnot cycle, also allow for energy and matter exchange with the surroundings. Therefore in addition to external forces one has to provide for the possibility of coupling the system to idealized heat (and matter) reservoirs. This may be achieved by coupling the system to a quasifree Fermi gas in equilibrium or, even more idealized, by a non-Hamiltonian time evolution (quantum dynamial semigroup) of the system representing the exchange with the surroundings.

(ii) No systems is completely isolated and the effects of external perturbations have to be taken into account.

(iii) Typically one deals with systems of macroscopic extensions. In equilibrium this is reflected by the scaling of the thermodynamic functions with the volume. A similar property should hold for the nonequilibrium entropy.

The book is a must for those interested in the foundational aspects of thermodynamics, in the relationship between microscopic and macroscopic descritpion of matter and in the origin and nature of irreversibility. A knowledge of the abstract framework of quantum mechanics is required, however.

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