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Quanta and entropy generation

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HIGHLIGHTS

- Irreversibility is the fundamental characteristic of real systems.
- Quanta exchange is the fundamental of any physical interaction.
- The thermodynamic processes are interpreted as quanta exchange.

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ABSTRACT

Is there a link between the macroscopic description of the irreversibility and microscopic behaviour of the systems? Transfer of the exergy, i.e., consumption of free energy will keep the system away from a stable equilibrium. So entropy generation results from the redistribution of energy, momentum, mass and charge. Moreover, irreversible consumption of free energy was underlined to create time's arrow. This concept represents the essence of the thermodynamic approach to irreversibility. The analysis developed in this paper points out that the principle of maximum of entropy generation and the least action can be recognized as the only single law. Quanta are exchanged between a system and its surroundings. Each quantum carries energy. The natural behaviour of the open systems is ascribed to the decrease of free energy in the least time, which can be related to the extremum entropy generation theorem. Irreversibility is the result of the interaction between systems and their environment with the consequence time symmetry breaking. The fundamental result of this paper is to introduce a link between the global analysis of irreversibility and Noether's results.

1. Introduction

In thermodynamics there are many topics of investigation with in particular regarding the second law. Consequently, several schools of scientists and engineers have arisen during the past two centuries [1]. One of the fundamental questions can be summarized as follows: how does macroscopic description of irreversibility link to microscopic behaviour of systems?

Indeed, entropy generation occurs as a consequence of the redistribution of energy, momentum, mass and charge [1], as is modelled by Fick's law, Fourier's law, in the Navier law, in the Smoluchowski correction to the Fick law, in the Einstein–Smoluchowski relation, in the Ornstein–Uhlenbeck process, in the Kossakowski–Lindblad equation, in the Bogoliubov–Born–Green–Kirkwood–Yvon hierarchy, etc. [2–6]. From a modern thermodynamic point of view [7–33] the interactions between system and environment maintain the system in a non-equilibrium stationary state by the transfer of exergy.

The concomitant entropy generation can be evaluated [34–41]. The entropy generation is nothing but the natural tendency of systems to progress towards the stable distribution of energy or momentum [42–47,12,48–52,48,53–76].

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Moreover, as Annila and Salthe have underlined the "irreversible consumption of free energy creates time's arrow in the fundamental physical sense" [77].

Time's arrow represents the essence of the thermodynamic approach to irreversibility and it is associated with the transitions between physical states; consequently, the concept of time is strictly related to the concept of states [77,78]. Consequently, the state can be defined by using the concept of action and the transition between states can be described by using the principle of least action [77,79–83] accompanied with Noether's theorem [77,79–82]. In this context, Annila and Salthe showed how the time's arrow is related to the change in the number of quanta [77].

The aim of this paper is to introduce the Annila and Salthe [77] conclusions in the entropy generation extrema theorem [60] in order to obtain a unified approach to irreversibility and a physical explanation of the mathematical relation obtained. To do so in Section 2 some considerations on the thermodynamic transformations as interactions will be developed, in Section 3 an analytical thermodynamic approach will be developed and in Section 4 a discussion on the results obtained will be carried on.

2. Thermodynamic interactions

A thermodynamic system is a physical system which interacts with the environment by different transfer of heat and work [84]. The fundamental concept in this definition is interaction: quanta carry energy either as free photons or as bound material entities [45]. As a consequence, the first law, which is the conservation law of energy, should be expressed as the conservation of the number of quanta [77].

Now a thermodynamic analysis of a thermodynamic system will be developed. For such system, it is possible to write the kinetic energy theorem as [13,37–40,85]:

$$W_{es} + W_{fe} + W_i = \Delta E_k \tag{1}$$

where W_{es} is the work done by the environment on the system. This is the work done at the border of the system by external forces. These comprise both the action of an external device which operates on the system and the reaction of the environment to the operation of the system itself, W_{fe} is the work lost due to external irreversibility, E_k is the kinetic energy of the system, W_i is the internal work, such that [13,37–40,85]:

$$W_i = W_i^{rev} - W_{fi} \tag{2}$$

with W_i^{rev} the internal work done on an equivalent reversible path and W_{fi} the work lost due to internal irreversibility. W_{fe} represents the irreversibility of the interaction between the system and the environment, which is the quanta of thermal waste [77] transferred (dissipated) from the high energy density (the system) into the low energy density volume (the environment). But [13,37–40,85]:

$$W_{se} = -W_{es} - W_{fe} \tag{3}$$

with W_{se} the work done by the system on the environment, the work done from internal forces on the border of the system, so, it is possible to obtain the following expression for the first law [13,37–40,85]:

$$Q - W_{se} = \Delta U + \Delta E_k \tag{4}$$

being U the internal energy. The variation of the kinetic energy can be evaluated respect to a reference state E_{ki}, in quite ($E_{ki} = 0$) without loss of generality, so that $\Delta E_k = E_{kf} - E_{ki} = E_{kf} = E_k$. This relation can be written also as follows:

$$\int_0^\tau E_k \,\mathrm{d}t = \int_0^\tau (Q - W_{se} - \Delta U)\,\mathrm{d}t = (Q - W_{se} - \Delta U)\,\tau \tag{5}$$

where τ is the time and the thermodynamic quantities are the mean time values for each process, as usually considered in applied thermodynamics [13].

Now, following Annila and Salthe, the Noether approach is introduced. The stationary system can be defined in terms of the action as [77]:

$$2\int_0^\tau E_k \mathrm{d}t = nh \quad \text{with } n \geq 1 \tag{6}$$

with n multiples of quanta and h Planck's constant. But, considering the relation (5) it follows:

$$(Q - W_{se} - \Delta U)\,\tau = n\frac{h}{2} = n\pi\hbar \tag{7}$$

with $\hbar$ the reduced Planck constant or Dirac constant. This relation represents a first link between the Annila and Salthe results and the irreversible thermodynamic approach; indeed, the balance of forces and processes between the system and the environment and the processes inside the system are the result of the flows of the quanta. In accordance with Annila and Salthe, the action is a powerful approach to stationary states since the "symmetry of action represents all motional modes" [77].