On the Microscopic Origin of the Second Law

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In: Quantum Limit to the Second Law. Ed. D.P. Sheehan. American Institute of Physics. 2002. V. 643. P. 367-372.

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Abstract. The main essence of the Second Law is the irreversibility of real processes introducing the "arrow of time" into dynamics of any natural processes. To justify the significance of this statement it is necessary to discover the genesis of "arrow of time" on the microscopic level and introduce an image of adequate information for characterizing the main features of the irreversible evolution of a considered system on every space-temporal level of its hierarchal organization. We relate the genesis of the irreversibility with the inevitable structural non-equilibrium of real materials that determines the absence of ideal thermostats in Nature and stipulates an actual openess of any real system. For solving the information problem we introduce a new image of *Information of Dynamic Distinguishes* which is formed by a set of parameters (dimensional and dimensionless) and describes "*distinguishable features*" of definite irreversible evolution in accordance with the "abstract information theory". A set of experiments for testing the above statements is proposed.

INTRODUCTION

According to Planck, the Second Law of thermodynamics expresses the irreversibility of real processes, i.e. introduces the "arrow of time" in the consideration of any natural processes. This statement could have an absolute status. Obviously, the understanding of the "arrow of time" may be achieved only due to revelation of the genesis of irreversibility of real systems evolution at a microscopic level because the basic equations of both the classical physics and quantum mechanics are reversible with respect to time inversion. It is also necessary to introduce an adequate information image to obtain a possibility for revealing and describing quantitatively the "arrow of time" in any real phenomenon. In this paper a solution of the both mentioned problems is proposed.

ON MICROSCOPIC ESSENCE OF "ARROW OF TIME"

We relate the genesis of "arrow of time" and such irreversibility of real processes (see also [1, 2]), and consequently, the microscopic essence of the Second Law, to the inevitable structural non-equilibrium of any real system, including any bodies inside a thermostat as well as the thermostat itself. In other words, contrary to standard models of solids as a passive continuum, a model of the medium in a form of an active discrete hierarchically structurally metastable system is introduced. Its main difference from a classical model of a passive continuum is that the medium can actively redistribute and release the energy kept in it and coming in from outside. At the same time, its elements may be sated to a different extent with a heat, elastic and metastable “structural” energy [3]. Obviously, the internal dynamics of such medium with local reorganizations of submicroscopic fragments of the non-equilibrium structures takes place inevitable during arbitrary evolution of any macroscopic system in thermostat. But how much such effects taking place on the macroscopic level are responsible for universality of the Second Law? The proof of such opportunity and a “witness” of the time property of real systems were obtained by Voss and Clarke [4] in the 70th. These authors studied voltage fluctuations across electron-conducting samples of various nature (semiconductor films, metals, carbon resistors) in thermostat in the absence of external sources of electric current. Voss and Clarke did not find equilibrium thermodynamic fluctuations – “white noise” in these systems. The measured fluctuations demonstrate the flicker-noise behavior. It is naturally to relate this phenomenon to the structural non-equilibrium of actual systems [3] which never are as ideal monocrystals under condition of the thermodynamic equilibrium. In such systems, direct heat fluxes between the structurally non-equilibrium fragments of the thermostat and solids arise. It means that thermostat should be considered as an open dynamic system, which may involve rearrangements of its structurally non-equilibrium fragments when someone analyzes heat fluxes. According to this statement, along with the equation describing the evolution of an object in the thermostat, we should additionally solve the equations describing the thermostat and write expressions for the fluxes of energy and entropy between the considered thermostat and outer thermostats as far as the cosmological one having the temperature 2.73 K presently. Of course, it is impossible to correctly estimate the heat flux between real objects under study and these thermostats, mainly because it is impossible to control thermostats’ microstructure.

The proposed logics could help in understanding Nature of time arrow (irreversibility of natural processes, although the equations of dynamics are reversible), one of the fundamental problems of natural science which was first recognized by Boltzmann more than a century ago. In this case the flicker-noise which is appeared in real systems could be considered as an indicator of such irreversibility. To justify this statement, much more ambitious analysis of fluctuating signals in solids is needed, because natural fluctuating signals contain considerably more information as compared to one-two parameters that are usually extracted from power spectrum. Below we present a suitable method for chaotic signal analysis.

FLICKER-NOISE SPECTROSCOPY AS A TOOL FOR GETTING INFORMATION FROM CHAOTIC NATURAL SIGNALS: INFORMATION OF DYNAMIC DISTINGUISHES

Flicker-Noise Spectroscopy (**FNS**) [5-8] is a new general phenomenological method of extracting information contained in the chaotic series of different nature (time series, space relief sections (profiles), energy spectra of complex molecules). The core of the method is a representation of the chaotic signals (the dynamic variables of the system under study) as sequences of different irregularities (the spikes, jumps, discontinuities of derivatives of different orders) that are considered to have distinguishable information value. Information distinguishability is due to the fact that the "passport data" characterizing "aggregative" properties of each type ("color") of irregularities are obtained in different ways by the analysis of both the power spectra $S(f)$ (f is a frequency) and difference moments ("structural functions") $\Phi^{(p)}(\tau)$ of order p (p = 1, 2, 3, …) where τ is a delay parameter. The dependencies characterizing difference moments are formed exclusively by "jump-irregularities" whereas power spectra formation is due to the both types of main irregularities – spikes (bursts) and jumps. The "passport parameters" of chaotic signals are introduced for various fixed time intervals. These parameters are obtained by fitting the calculated experimental curves by general phenomenological dependencies. Some of the parameters characterize an extent of correlation links (the "correlation lengths") of the measured dynamical variables separately by irregularities' "colors". Other parameters give information about the rate of loss of the correlation links inside the correlation length intervals. The term "stationarity" means that information contents is the same for each spatial-temporal level of hierarchical organization of the system under study in the considered range of time scales. Note that the use of averaging time interval and overlapping time windows processing procedure reveal factors characterizing the non-stationarity of real processes. All the "passport information" revealed by FNS method forms an information set (dimensional and dimensionless parameters), which demonstrates the "*distinguishable features*" of the signal under study which we define as *Information of Dynamic Distinguishes* - I_{DD}. The number of introduced parameters is determined by considered concrete problem: one can extract from real signals as much information as one needs.

In the FNS formalism, unlike the standard theory of fractals and renormalization group, a concept of multi-parameter self-similarity is introduced as the power spectra and difference moments corresponding to the real signals are fitted by multi-parameter dependencies, and, unlike the theory of deterministic chaos, a multi-parameter representation of the Kolmogorov entropy (as an information loss rate) is actually introduced because all the totality of the "passport parameters" play its role.

The "passport parameters" obtained during the processing of primary data of "one-point" measurements characterize univocally the current local state of the system. On the basis of "multi-point" simultaneous measurements a dynamics of interrelations could be studied in the system with a "redistribution flows" of different nature on different scales of spatial-temporal system organization. In the frame of FNS, for obtaining links in a "distributed system", a new type of multi-point correlation functions is introduced. For example, the double correlation function $q_{ij}(\tau;\theta_{ij})$ for dynamic variable $V(t)$ measured in the ith and jth "points" has a form: $q_{ij}(\tau;\theta_{ij}) = \left\langle \left[\frac{V_i(t) - V_i(t+\tau)}{\sqrt{2}\sigma_i} \right] \times \left[\frac{V_j(t+\theta_{ij}) - V_j(t+\theta_{ij}+\tau)}{\sqrt{2}\sigma_j} \right] \right\rangle$ where τ is a delay, θ_{ij} is a parameter, σ_i is the variance of the measured dynamical variable. The θ_{ij} parameter is determined having that $q_{ij}(\tau;\theta_{ij})$ is positive and has a maximum value among possible ones. The sign and value of this parameter determine the velocity and direction of the "flow" between the *i*th and *j*th "points". The similar analysis with introduction of the double, triple and other "multi-point correlation functions" gives a possibility of obtaining the needed "many-parametric inner links" in the system under consideration.

Previously the method was applied for analysis of dynamics of different physico-chemical and natural processes: the fluctuations of voltage in electrochemical and electromembrane systems, fluctuation dynamics of solar activity, magnetospheric dynamics, fluctuations of velocity components in turbulent flows. The FNS methodology was used to analyze of geodynamic activity prior to large earthquakes. It was shown that high frequency terms of the measured dynamic variables have the main informative essence for looking for an indicator of self-organized criticality of the considered geophysical medium and predictor of catastrophic changes in it. As an example, data of multi-point simultaneous digital medical measurements (EEG, ECG, etc.) are analyzed. The tentative investigations have shown a high individuality of local parameters obtained by analysis of EEG of different patients, definite sensitivity of the parameters to the change in external conditions.

CONCLUSION

Below there are examples of possible experimental tests of main statements. Suppose that we are going to use the Voss-Clarke method [4] for measuring dynamic fluctuations of the electric potential $V(t)$ in different solids in a thermostat as well as in the thermostat walls. Let these solids be samples of the gray and white tin, i.e. the α-Sn and β-Sn allotropic modification, and let the thermostat temperature T be around of $T = +13.2^0$C which is the temperature of the α–β-phase equilibrium. Obviously, the equilibrium image of the T value in this case is not an adequate indicator of the state of the samples under consideration because of the allotropic transformations taking place in the α-Sn and β-Sn samples. The additional positive and negative heat fluxes are produced in these samples due to the transformations. The measured dynamic fluctuations of the $V(t)$ values and calculated the FNS-parameters would be different for the both samples and thermostat walls. It means that there would be nonzero heat fluxes between the all "participants" of the experiment, namely, the α-Sn and β-Sn samples and thermostat walls. It would be useful to conduct this experiment for evaluating the considered heat fluxes and finding the corresponding variations of FNS-dependences. It would be an experiment which will lead to the conclusion: the absolute temperature is not an adequate parameter which can be used in formulations for the Second Law of thermodynamics. Realization of the multi-points measurements in these experiments and FNS analysis of the corresponding correlation links might enhance the conclusion.

Nonzero heat fluxes between any bodies in any thermostats must be realized in any events, although the resulting flux values can be considerable lower in comparison with the case of the above experiment. This is why in every case when there is a macroscopic evidence that the Second Law is violated (see cases [9, 10], for example) it is necessary to study dynamic fluctuations in the system under consideration and perform the FNS analysis of the data.

The experiments of such a kind are extremely important for solving another principal problem: to understand the origin of the indeterminism in quantum mechanics. Evidently, the internal dynamics with local reorganizations of submicroscopic structural fragments of the solids also takes place in a measuring device used in the investigations of quantum mechanical phenomena. These processes inevitably result in a known phenomenon of uncertainty of simultaneous measurement of the conjugated dynamic variables. In accordance with the developed ideology, the experiments are proposed to reveal explicitly the effects due to an "evolution device." FNS method could be used as a method of the analysis of the noise registered by the measuring device simultaneously with a signal related to the transitions in a quantum subsystem. FNS analysis gives a possibility to quantitatively evaluate the corresponding contribution to the "uncertainty principle" in quantum mechanics.

Here we would like to pay attention to one more factor determining the genesis of "arrow of time" and essence of the Second Law at a microscopic level which is an opportunity of irreversible interaction of quantum subsystems with energy-saturated physical vacuum which is considered as yet another "state of matter" [11] from the viewpoint of the last cosmology achievements. The presence of the energy-saturated substance is supported by new results on the gamma-ray bursts and supernova I*a* explosions in the distant [~ $(4 – 9)\cdot 10^9$ light years] galaxies and taken into account by the introduction of the Einstein cosmological term Λ ($\Lambda > 0$) in the general relativity theory. The specified "material content" of the physical vacuum, with which quantum objects may interact irreversibly, is also based on available experimental proofs of essence of the Casimir forces showing that any positioning of a material body in the physical vacuum results in local rearrangement of the "vacuum electromagnetic field" in the body's bound area [12, 13]. Carrying out the experiments on detection of macroscopic manifestations of the Casimir effect with the simultaneous measurements of transitions in quantum subsystems will allow to reveal the irreversible effects of interaction of such subsystems with energy-saturated physical vacuum and to estimate the corresponding contribution to the Second Law. Such a concept of physical vacuum will allow one to understand qualitatively a genesis of the aprioristic restriction of velocities of moving material objects with the nonzero rest mass up to the value of light velocity c in the physical vacuum, equal to $3\cdot 10^8$ m/s. This restriction is due to the rate of rearrangement of the physical vacuum, adjacent to the object, which should be caused by any moving material body, and is limited by the light velocity c.

In the frame of such logic it is natural to suppose also that light velocity in vacuum is determined by its state that can be different in the very distant galaxies (the regions of "anomaly explosions" of supernova I*a*), i.e. in the early stages of the Universe evolution. This is evident from the temperature (~ 6.0 – 14 K) of the Microwave Background in these distant regions of Universe. This temperature which exceeds the value 2.73 K in our epoch, is evaluated over the relative populations of atomic fine structure levels, which are excited by the background radiation in an isolated cloud of gas [14]. In this case, if we consider the general relativity theory to be valid for the whole Universe, there must arise the dependencies $c = c(R)$, $\Lambda = \Lambda(R)$ and $P = P(R)$ where R and P are the scale factor and pressure, respectively, entering the equations of general relativity theory, under the conditions $\Lambda \cdot c^2$ = const and P/c^2 = const. The above statements allow one to accept the Habble law validity for the whole expanding Universe. The problem of coordination of the data on energy emanation from the supernova I*a* explosions with a measured value of "redshift" for the corresponding galaxies is reduced to introduction of mentioned dependency $c = c(R)$.

Postulated consistent patterns of such a type can be a subject of comprehensive experimental checks when analyzing the fluctuation phenomena in the "device" in the course of investigations of transitions in quantum mechanical systems and distiguishing the pure "solid state" noise components.

ACKNOWLEDGMENTS

Author thanks Dr. Grigory Vstovsky for fruitful discussion and advises. This research was supported by the Russian Foundation of Basic Research, grant number 02-05-64340.

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