APPLICATION OF THE GENERAL ANALYTIC APPROACH USED FOR MODELING TRANSIENTS IN OPEN THERMODYNAMIC SYSTEMS TO NUMERICAL EVALUATION OF SOME BASIC QUANTUM AND ASTROPHYSICAL PARAMETERS

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Abstract. Based on the fundamental physical notions and the early developed general approach for analyzing a transient development in an open thermodynamic system, equivalence of the two formulations of the uncertainty principle in general physics was shown. Necessity of time quantum introduction proceeding from the uncertainty principle combined with the approach was grounded and an analytical formula to evaluate its numerical value was derived from the relation connecting uncertainties of energy and time. Using the approach, two ways for the obtained formula justification were proposed and numerically verified. Mandatory existence of the time quantum at beginning stages of the thermodynamic system evolution and its disappearing at the finishing ones was noted. Reciprocal dependence of the time quantum value on the energy of an open thermodynamic system is also emphasized that is in accordance with general physical notions. Coincidence was shown of the numerical data for some fundamental characteristics evaluated using the derived relations with

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the known literature astrophysical data. Applicability of the approach to modeling the basic quantum and cosmology phenomena was emphasized.

Keywords: uncertainty relations, transient processes, an open thermodynamic system, time quantum, basic quantum and astrophysical characteristics.

INTRODUCTION

Nonequilibrium stochastic processes are objects of intensive investigations for some last decades [1–4]. The main challenge there is wide spreading and the defining role of such processes in nature, industry, social and economical phenomena [5, 6]. However, the most of the investigated processes are the stationary industrial ones or close to stationary stages of the nonstationary natural processes. At first, it relates to so-called transport phenomena, such as diffusion and heat transfer, which in general are transient processes in nature, as they have the beginning and finishing points. So, the most of nonequilibrium stochastic processes, being in fact the transients are practicaly not theoretically considered yet within full time range of their development. On the other hand, a general approach to analysing the full range of a transient development in open thermodynamic systems was proposed recently [7–9]. It considers a system comprising huge amount of subsystems which are at a finite temperature under an action of equal external, regarding the system, energy gradient. Each of the subsystems able to be in two energy states, separated by an energy barier, overcoming which is possible due to the action of external force aided by thermal fluctuations. Based further on some commonly accepted and well physically grounded assumptions, a constitutive differential equation was derived, describing the full range of time evolution of an open thermodynamic system being as a whole under an external "driving force". Analytical solving the equation showed existence of two different types of time dependences for the introduced system energy paramer. The dependences were attributed to the two modes of the energy carriers motion within any open thermodynamic system: highly ordered (military–like) movement and disordered (diffusion -like) one. Besides, some additional features of the motion modes development were also revealed, namely: inevitable generation of new energy transferring objects (subsystems) during one of the modes and existence of such potential possibility, but not actually realised during the other one; increasing the average energy carrier velocity with time in the finishing stage for one of the transient development modes and – decreasing – for the other one etc. The developed approach was applied to quantitative modeling the macroplastic deformation in FCC metal polycrystals and successfully predicts their tensile true stress – true strain curves. Preliminary analysis has also shown, some tight analogies of the revealed features of the thoroughly investigated transient with other ones observed, particularly, in quantum physics and cosmology: stimulated emission of radiation; superconductivity; accelerated inflation of the Universe, etc. Regarding the cosmology it should be noted complex mathematical character of the models having been developed by now and difficulties to reveal physical meaning for their predictions. This situation, probably, corresponds to the commonly known words of Albert Einstein: "Mathematics is the best way to lead oneself by nose.".

So, taking into account the clear physical background of the early developed general approach for modeling a transient in an open thermodynamic system, it is important to define applicability of the corresponding successfully used notions to analyze some basic processess developed in quantum and astrophysical systems.

Aims of the article: to show applicability of the early developed general approach [7–9]: to analyze quantum processes relevant to the uncertainty relations; to show possibility of the discrete space-time existence and evaluate the time quantum numerical value; to predict basic features of the spatial distributions of astrophysical objects considering them as the energy carriers in a thermodynamic system.

2. MAIN RESULTS PRESENTATION

Uncertainty relations are basic ones in quantum mechanics and have reliable theoretical and experimental backgrounds. However, one of the relation types, particularly, that which connects the energy and time uncertainties, has complex quantum mechanics based physical justification. [10]. Besides, as it was shown in numerous works [11], the quantum mechanics principles are applicable to describe many macro-scale and planetary phenomena. Additionally, despite, particularly, the known quantum character of the possible energy changes during a measurement process, the corresponding uncertainty relation doesn't allow to specify relevant the time and space changing detailes.

Let us consider the uncertainty relation of the type: $\Delta E \cdot \Delta t \geq h$. It maybe derived from the other complementary one: $\Delta p \cdot \Delta x \geq h$ which, as a rule, is widely used and has clear physical interpretation in terms of the particle-wave dualism. Meantime, the derivation of the relation within the frame of quantum mechanics [10] is rather complex and not physicaly clear. Besides, the phenomena, mostly similar to quantum ones are observed, particularly, in planetary scales [11]. So, as it known from the classical mechanics:

$$m \cdot a = F; \quad m \cdot (V_2 - V_1) \approx F(t_2 - t_1); \quad m \cdot \Delta V \approx F \cdot \Delta t; \quad F \approx \Delta E/\Delta x;$$

$$\Delta p \cdot \Delta x \approx \Delta E \cdot \Delta t \tag{1}$$

where m is a mass of an object being under an action of force F and having resultant acceleration a;

$V_{1(2)}$ –velocity of the considered object being in the initial (1) and final (2) state, respectively;

$$\Delta V = V_2 - V_1;$$

$t_{1(2)}$ – moments of time corresponding to the being the object in the initial (1) and final (2) state, respectively;

$$\Delta t = t_2 - t_1;$$

It should be noted here that for any transient, an analysis of its full range development (from the very beginning at the time $t_1 = 0$ to an arbitrary time point $t_2 > 0$) in general case requires to fulfill the conditions: $V_1 = V(t_1) = 0$ and $V_2 = V(t_2) > 0$, respectively. Hence, during the further analysis we will use the relation: $\Delta V = V_2 - V_1 = V_2$

So, the above formula (1) represents equivalence of the both uncertainty principle formulations and then allows to write by replacing the left inequality site:

$$\Delta E \cdot \Delta t \geq h.$$

Besides, using the basic Planck relation $E = h\omega$, where we denote $\omega = 1/t$ and based on the above inequality, we should write

$$h \cdot \Delta\omega \cdot \Delta t = h$$

and finaly arrive to an indentity.

So, despite the commonly accepted quantum character of the energy changes in a quantum system it is impossible within the frame of quantum mechanics to make any conclusion about possibility of the space-time quantisation: it may be allowed as well as – prohibited.

Let us consider further a measurement process as an interaction between two objects. On the other hand, according to [12] any interaction process may be referenced to as a transient, providing energy transfer between the involved objects. Then, based on the dependence $\sigma = \sigma(t)$, where σ is density of an energy supplied to a thermodynamic system, it may be written using the approach (considering definite variations of the physical quantities and the maximal possible speed of a material object as the speed of light):

$$\sigma \approx \Delta E/(\Delta x \cdot S); \quad \Delta E \approx \sigma(\Delta x \cdot S); \quad \Delta x = \bar{V}\Delta t; \quad \bar{V} = P_2 V_{\max} + P_1 V_{\min};$$

$$\Delta E \approx \sigma \cdot P_2 \cdot \Delta t \cdot Const_1;$$

$$\Delta E \cdot \Delta t \approx \sigma \cdot P_2 \cdot \Delta t^2 \cdot Const_1,$$

where: $Const_1 = S \cdot V_{\max}$;
- S – external surface square for a thermodynamic system which an energy is supplied to;
- Δx – average distance of an energy carrier motion in a thermodynamic system;
- $\bar{V}$ – average velocity of an energy carrier moving in a thermodynamic system;
- $V_{\min} = 0$ – minimal velocity of an energy carrier motion in a thermodynamic system;
- $V_{\max} = c$ – maximal velocity of an energy carrier moving in a thermodynamic system;
- c – speed of light;
- P_2 – probability for an energy carrier in a thermodynamic system to be in a long distance;
- moving state with $V = V_{\max}$;
- P_1 – probability for an energy carrier in a thermodynamic system to be in immobile state with $V = V_{\min}$.

Additionally, it may be written:

$$\Delta E \approx \sigma \cdot P_2 \cdot \Delta t \cdot Const_1 = h\Delta\omega; \quad \Delta\omega = 1/\Delta t; \quad \Delta t^2 \approx h/(\sigma \cdot P_2 \cdot Const_1)$$

as well as

$$\Delta E \cdot \Delta t \approx \sigma \cdot P_2 \cdot \Delta t^2 \cdot Const_1 \geq h$$

$$\Delta t^2 \geq h/(\sigma \cdot P_2 \cdot Const_1).$$

From the last relations one can concude that the quantity ?t should be considered as the minimum possible time interval able to be used as physicaly accepted value which should be associated with the quantum of time δt:

$$\delta t^2 = h/(\sigma \cdot P_2 \cdot Const_1).$$

Based on the above results it is possible to evaluate a numerical value of the quatum of time as:

$$\delta t = \sqrt{h/(\sigma \cdot P_2 \cdot Const_1)}. \tag{2}$$

Further, it is necessary to take into account the equal numerical values of the time quantum for each transient mode in the same thermodynamic system being under a given arbitrary energy gradient. Then, we shall have for the first and second modes, respectively:

$$\delta t_1 = \sqrt{h/(\sigma_1 \cdot P_{21} \cdot Const_1)}, \quad \delta t_2 = \sqrt{h/(\sigma_2 \cdot P_{22} \cdot Const_1)}$$

$$\sigma_2 \cdot P_{22} = \sigma_1 \cdot P_{21}, \tag{3}$$

where: σ_1 and σ_2 – external energy gradient acting on the each subsystem during its motion in the course of, respectively, 1-st and 2-nd mode of a transient development in a thermodynamic system

$P_{21}$and P_{22} – probability for an energy carrier (subsystem) to be in a long distance moving state with $V = V_{\max} = c$ in the course of, respectively, 1-st and 2-nd mode of the transient development in a thermodynamic system.

On the other hand, for the moving carrier during the full range of a transient in an open thermodynamic system, one may write for each developed transient mode:

$$\Delta p \approx (\Delta E/\Delta x) \cdot \Delta t, \quad \Delta p/S \approx \sigma \cdot \Delta t, \quad \Delta p \approx m \cdot \Delta V, \quad \Delta V \approx V_2 = \bar{V},$$

$$\bar{V} = P_2 \cdot V_{\max}, \quad (m \cdot c/S)P_2 \approx \sigma \cdot \Delta t,$$

$$Const_2 \cdot P_2 \approx \sigma \cdot \Delta t. \tag{4}$$

Taking into account the above relation (3) and equality of $?t$ for each of two early revealed modes of a transient, proceeding from the above formula (4), one should specifically write:

$$Const_2 \cdot P_{21} \approx \sigma_1 \cdot \Delta t_1, \quad Const_2 \cdot P_{22} \approx \sigma_2 \cdot \Delta t_2, \quad \Delta t_1 = \Delta t_2,$$

$$P_{21}/P_{22} = \sigma_1/\sigma_2, \sigma_1^2 \approx \sigma_2^2 \tag{5}$$

It should be noted that the above relations (3) and (5) were derived to verify coincidence of the approach with basic quantum mechanics notions. So, it is important to examine the relation (4) and (5) fulfillment numerically that will give ground to the approach further application to describe some basic quantum phenomena and evaluate numerically the value of δt . Corresponding calculated graphs are shown on Fig.1

As it seen, the rather accurate coincidence of both relations is reached within the time interval from 0 to ~ 500 in arbitrary units at various values of the transient modeling parameters. In other words, the relations are accomplished at a beginning stage of transients development, meantime there is no coincidence of the relations at the later, especially finishing, stages of such a process.

Hence, at least three general conclusions flow from the above results of the numerical simulation: – the assumption about the time quantum existence is in a principle accordance with the early developed approach describing basic features of transients in an open thermodynamic systems; – the assumption is incorrect i.e. the time quantum is not exist, on finishing stages of the processes; – the structure (discrete or continuous) type of the real space-time is dependent on evolution features of an open thermodynamic system, specifically, – characteristics of transients taking place in the systems. It should be noted the agreement of the last conclusion with some basic results of the modern particle physics models, particularly, – general relativity theory [13]. So, after the above confirmation of consistency of the early proposed approach with itself and the modern physical notions, it is possible to give numerical evaluation of the time quantum value based on the formula (2). Before we proceed, lets consider the above $Const_1$ value from the formula (2). As it was written, $Const_1 = S \cdot V_{\max} = S \cdot c$. Lets assume for simplicity that the subsystem involved within the above whole open thermodynamic system is an object having a volume $v \approx a^3$ and then: $S \approx a^2$, where a is the subsystem size in one dimension. So, one may write:

$$\delta t = (1/\sqrt{(\Delta E/a)}) \cdot \sqrt{h/(P_2 \cdot c)}.$$

Assuming for simplicity that $P_2 \approx 1$, we shall have:

$$\delta t \approx 10 - 21/(\Delta E/a) \ , \quad \text{sec.} \tag{6}$$

As it seen, the formula (2) shows analytical dependence of time quantum numerical value δt on energy state ΔE of the considered here an open thermodynamic system. This result is in accordance with the modern physics notion about relative nature of the space-time i.e. connection of the space-time characteristics with properties of material objects involved in the system [14].

Assuming that time quantum may be associated with the Planck time, i.e. $\delta t \approx t_p \approx 10^{-43}$ sec. [15] we shall obtain, for the maximum possible energy gradient: $\Delta E/a \approx 10^{44}$ J/m, that is in accordance with the force value in the Planck scale: $F_p = 1.2103 \cdot 10^{44}$ N. Furthermore, considering a as equivalent to the Planck length $l_p = 1.62 \cdot 10^{-35}$ m, i.e. $a \approx l_p \approx 10^{-35}$ m , we shall have: $\Delta E \approx 10^9$ J that is accordance with the Planck energy: $E_p = 1.96 \cdot 10^9$ J and the energy value corresponding the Bing Bang occurrence time moment: $\sim 10^{19}$ GeV [16].

Besides, it should be noticed that according to the used in this paper general approach [8], development one of the two modes of a transient is inevitably accompanied by formation of periodically arranged specific configurations made of the energy transfer objects. For the particular case of the polycrystal plastic deformation considered in [7–9], the configurations are the dislocation groups, tangles and networks. As it was showed recently [17], the analogous spatial configurations, particularly, galaxies clusters, voids and networks are also observed.

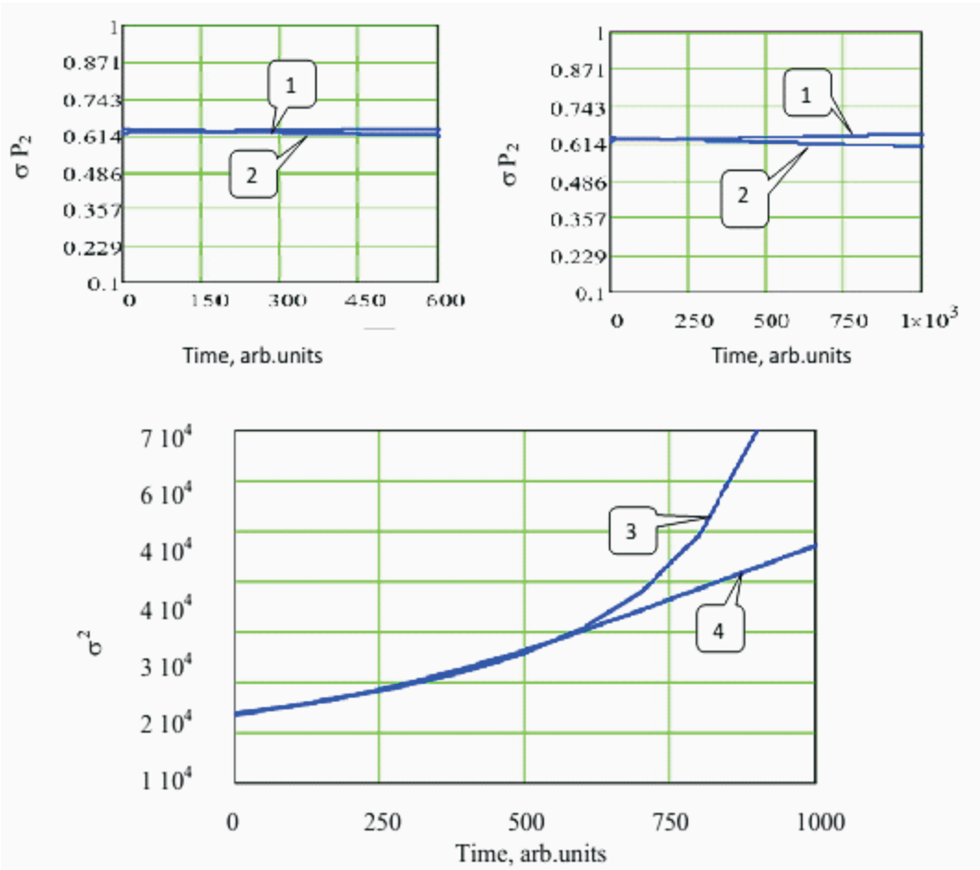

Fig. 1. Calculated time dependancies of the quantities: $\sigma_1 \cdot P_{21}$ (curve 1) at the constant values: $A_1 = 2.1$, $t_{01} = 8.10^4$, $s_{01} = 1.2$; $\sigma_2 \cdot P_{22}$ (curve 2) at the constant values: $A_2 = 10^{4.9}$, $t_{02} = 10^4$, $s_{02} = 9.5.10^4$; σ_1^2 (curve 3) at the constant values: $A_1 = 2.1$, $t_{01} = 1200$, $s_{01} = 130$; σ_2^2 (curve 4) at the constant values: $A_2 = 10^3$, $t_{02} = 400$, $s_{02} = 700$

So, proceeding from the above, we may conclude that using the early developed general approach to model a transient in an open thermodynamic system [7–9], together with commonly accepted physical notions (uncertainty principle, Newton motion laws etc.) and numerical values of the relevant fundamental parameters: Plank time, length, force, energy etc., it is possible to reach close coincidence of various experimental data and obtain results, being in a good numerical accordance with the independent evaluations, particularly, of the total energy of the outer space, [16].

3. CONCLUSIONS

1. Application of the early developed general approach to modeling a transient development in open thermodynamic systems consisting of quantum interacting objects, leads to obtaining a wide variety of self-consistent numerical results being in accordance with the basic quantum mechanics notions.
2. Quantum structure of space-time for open thermodynamic systems is theoretically predicted in wide ranges of the approach modeling parameters and time evolution of the structure characteristics is analyzed.
3. Existence of the time quantum is theoretically shown at the beginning stage of transients in an open thermodynamic system together with absence of the discrete time units at the finishing stage of the system evolution.
4. The revealed evolution of the space-time quantum structure characteristics in an open thermodynamic system is in accordance with the physics modern notions about relative (non absolute) nature of the space-time.
5. Application of the approach to numerical evaluation of the initial energy of the Universe (just after the Big Bang) based on the space-time quantum existence which have the Plank size values, together with the available data on the energy carriers spatial structures, particularly, in deformed FCC polycrystal, leads to good agreement of the current evaluation results with well known relevant modern cosmology data.
6. Similarities are shown for the basic features of the energy carriers behavior in the course of the transients development in such open thermodynamic systems as: metal policrystals under a load (dislocation multiplication, tangles and networks formation) and the observable part of our Universe (new stars formation, galaxies clusters, voids, networks existence).

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