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THE ROLE OF ORDER AND DISORDER IN THERMAL AND MATERIAL SCIENCES *PART 1: HEAT AND SOCIETY*

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Abstract

The notion of heat is thoroughly analyzed and its historical links are searched particularly with relation to both the Greek philosophy (Milesians, Pythagoreans, atomists, etc.) and in the present day thermal physics. Fluctuation, spontaneity and chaos are discussed. Thermodynamics is reviewed in the relation to both the traditional development and the modern description of disequilibria (open systems). Effect of dissipation is shown often to provide new, self-organized structures. Exploitation of fire and its conscious use as a manufacturing power are analyzed in terms of generalized engines to act in the sense of the information transducers.

Keywords: Greek philosophers, energy, entropy, thermodynamics, non-equilibrium, dissipation, self-organization, free will and space, spontaneity, fluctuations, fire as industrial and analytical tool, exploitation of fire, history of mathematics

1. Introduction - portraying of materials

Materials [1] have constantly played an important position in formation and progress of civilization, always associated with the relevant level of communication and information. We can learn about its history from archeological sites as well as from recent dumps and waste-containers. Applicability of materials is traditionally based on working up their starting (casted) clump to shape final structure. Today's science, however, tends to imitate natural processing by precise and wastes less positioning definite parts to appropriate places (e.g. nanotechnologies). Tremendous growth of species of individual materials will slowly be restricted in favor of those materials that are capable of recyclation to least harm the nature. The living structures are yet becoming more and more observable example particularly assuming synergy of various components in combined materials. Such composites are common not only in nature but also known within human proficiency: from Babylonians (3000 BC) resin impregnated papyrus or tissue to the recent icy airfields of the Greenland literally applying sandwich composites made from brittle ice strengthened by layers of newspaper. We still have to follow the models of most efficient natural composites, as are hollow fibrils in cellulose matrix forming wood or collagen fibers in hydroxyapatite constituting bonds. In the reproducibility of technological processes the artificial production of glass and cement (originally volcanic glass and slag) and iron (primarily meteoritic) have plaid a decisive role in the progress of civilization - the production is nowadays amounting for each of them to tremendous 10^{11} kg per year. They were primarily worked to produce desired wares and thus could be secured only by experienced knowledge (information) as well as by the resulting accustomed measuring techniques. Their development could only take place after people learnt to think in abstract categories such as are used in mathematics whose beginning reach as far back as the fourth millennium BC. Production became feasible only after it matured to be conscious determining and latter keeping the constant and optimal values, such as mass proportions of input raw materials. Thus, among the others, the Egyptians new the double-arm balances as early as 3000 BC. Man had acquired the techniques of producing high enough temperatures and applying controlled heat not only by using the closed kilns but also by sitting kilns or smelters in regions subject to high winds. The role of air had to be understood to get the process of burning coordinated. It was also vital to keep certain temperatures constant; hence it was necessary to introduce some early-experimental temperature scales.

Relation between input mixtures, mode of fire treatment and resulting properties were necessarily recognized and experimentally verified even in the preparation of other compounds such as drugs, dying materials and, last but not least, in culinary arts. After all there was an early recognition of three principles of early thermal treatment and analysis [2], i.e., *amount of fire (temperature) can be level-headed, applied fire affects different materials in different ways and materials compatible at ordinary temperatures can react to give new products on firing*.

However, until the middle of the seventies century the notions of heat and temperature (*temper-temperament*, first used by *Avicena* in the 11th century) were not distinguished (*Black* [3]). It took another 150 years until the consistent field of thermal science was introduced on basis of *Maxwell's* work and named by *Thompson* as '*thermodynamics*' [4,5] according to the Greek terms '*thermos'* - heat and *'dynamis'* - force. The contradiction of its dynamic 'notion' against its 'static' applicability is also the subject of my further story. Only the statistical thermodynamics (*Boltzmann)*, however, interconnected microcosms of matter with observables, i.e., our phenomenological viewed parameters. It was *Einstein* and *Debye* who associated temperature with the distinguishable micro-particles (atoms) oscillating around their lattice sites where all degrees of freedom correspond to the vibrational modes (assumed either as independent harmonic oscillators or an elastic continuous medium exhibiting different frequencies). Vibrational nature (as that of heat) is the most valuable inspiration and would accompany us throughout the following text.

The Universe, including our planet, has been shaped by the impact of heat, i.e., traditional but yet somehow curious way of energy transfer and distribution, as well associated with its manufacturing power. It has been physically processed by nature itself on all levels (including non-living and living eyesight). Humans have experienced this world in its dependence on this integrative notion of fire/light/heat/power/energy that is recognized as an element [6] rudimentary in the pathway of ordering matter and society. It was possible through specific characteristics of human cognition resulting from our capability to abstract [7] - a key feature of human consciousness enabling to gradually understand fire from its visible wholeness down to its imaginary composition of internal vibrations and capacity to be a life backer. Within periods of generations it became gradually evident that for obtaining a useful work one needs to apply not only fire but also cognition (attached know-how as today's information [8,9]). In accordance with the exercise done in electromagnetism our understanding of heat turned necessary to be encapsulated into an auxiliary field called thermodynamics the development of which became curiously distant from the traditional method adopted in more fundamental mechanics. The difference is not related to the difference of subject matter but it arises largely out of tradition. Mechanics has reached long ago the status of rational science while thermodynamics has reached similar rationality state until recently. It is customary related to the notion '*thermal equilibrium'* [5] where all processes came to halt and any organism would become dead [10,11]. We do not live in such a *thermostatic* equilibrium state we actually reside in particular self-organization processes laying evidently outside of equilibrium steadiness (*disequilibria* [10]), corresponding thus to a delicate interplay between chance and necessity, between fluctuations and deterministic laws. It was also reflected to our gradual development of the understanding of our Universe, from the statically view up to the present complex world of novelty and variance diversity, the description of which is the modest aim of this assay. For instance, on a larger scale we came to know that the 2.8 K thermal (cosmic microwave background) radiation that fills the universe is not a thermal equilibrium with the matter in the galaxies. On a smaller scale, the Earth (atmosphere, biosphere, life, etc.) was experienced to be all in non-equilibrium due to the constant influx of heat delivered from the Sun, the process which has also earmarked our entire history.

We can mention that even within a rather short chronicle of interactions of society with heat we can roughly distinguish about four periods. Perhaps the longest age can be named the period *without fire* as the first human being were afraid of fire/blaze (like wild animals) but gradually gained their first sensation of warmth and cold. First man-made fire place is old about 300 000 years but the purposeful use of fire can be even associated with the prehistoric *homo erectus* dated back one and half million years ago (*Koobi Fora, Kenya*). Another extended era was associated with growth of the continuous experience of *using fire*, which helped, in fact, to definitely detach human beings from animals (fire as weapons or as a conscious source of warmth, heat as a substantial aid in cooking meet making it more easy digestible). A definite advance came with the recent but short period of *making fire* up to the recent brief *exploitation of fire* including domestication of fire together with its employment as a manufacturing tool and energy source. The present use of heat as an instrumental reagent (recently generalized in the field of thermal analysis [2] as treated in my previous papers [8,9]) is worth considering as an integrating approach suitable of a more detailed examination.

2. Greek philosophers and the concept of fire

All nations of the world have their own mythology [12-14]. Myths, in the sense of the Greek term '*mythos'* which meant speech (tale or story), brings poetic views of the world around us although customarily considered synonymous to something widely spread and not often true. For Greek philosopher *Hesoid* (about 8th century BC), the universe was a moral order close to the idea of an impersonal force controlling the universe and regulating its processes of change. The notion *philosophy* (joining image of fondness with knowledge, likely introduced by *Pythagoreans* similarly to the term *mathematical* meaning conception or theorem '*mathema'*) came probably into existence when people were no longer satisfied with supernatural and mythical explanations. It sounded '*some are influenced by the love of wealth while others are blindly led on by the mad fever for power and domination, but the finest type of man gives himself up to discovering the meaning and purpose of life itself. He seeks to uncover the secrets of nature. This is the man I call a philosopher for although no man is completely wise in all respects, he can love wisdom as the key to nature's secrets'*. The Greek word philosophy is actually derived from the notion love ('*philia'), which* marked (or better explained) the attraction of different forms of matter, and of another opposing force called strife, hate (*'neikos'*) to account for separation. Together with wisdom (*'sophy*') they appeared first in the fifth century BC primarily concerning with the problem of „the One and the Many". Simply stated it involved the explanation of the infinity of things in the Universe (the Many) and the early Greeks believed that the single unifying thing (the One) was some material substance, like water, stone or fire. They were concerned with finding the unchanging principle of substances that lay behind all changes, and the stable unchanging component of the Universe the Greeks called '*arche'* and living nature was associated with *'physis'*. *Xenophanes* was a celebrated teacher in the *Pythagorean* school and took the Gods of mythology and reduced them one-by-one to meteorological phenomena, especially to clouds. God was in his view an immaterial eternal being spherical in form like universe and even modern believing scientists often understand God in the spirit of *Xenophanes*, identifying God with something very abstract, with some principle of Universe ('*pantheistic'* approach of *Alleatic* school). *Empedocles* taught that originally All was One. The elements of things were held together in indistinguishable confusion by Love. In a portion of this whole, the force Strife was accounted for the separation, but the separation was not ever complete and each part of the whole contained portions of the others arising the multiplicity of things. The Greek philosophers [12-14] played an important role in developing the early concept of heat, which is worth of a more detailed recollection, and study of idea penetration to our modern world of science. The four basic elements (*fire, air, water* and *earth*) were mingled in assort of solution by Love, while Strife surrounded the Sphere on the outside (*Xenophanes'* concept of the world). When Strife began to enter the Sphere, Love was driven towards its center and the four elements were gradually separated from one another. The elements alone are everlasting, but the particular things we know are unstable compounds. They are mortal just because they have no substance of their own, their birth is mixture and death is separation. Fire was held as the rarest, scared and most powerful, a kind of a chief, assuming the souls of all sentience and intellectuals are issue from a central fire, or the soul of the world. *Anaxagoras* (middle of 400s BC) postulated a plurality of independent basic elements, which he called seed (*'spermata'*) citing „*all things ('chremata') were together, infinite both in quantity and smallness; for the small too was unlimited. Science of all things were together, nothing was clear by reason of the smallness. For air and ether contained everything, both being unlimited. For these are the greatest items present in all things, both in quantity and in magnitude"*. He thought that it was mind, intelligence or pure reason *('nous')* that was a source of all motions as well as of knowledge in us. At the very beginning the seeds mixed without order but under the effect of a „cosmic starter nous" the non-arranged matter set into motion - orderly world and '*cosmos*' was created out of the initial *chaos*. Nowadays this idea represents „*deism*“, a way of explaining the operations of a supernatural cause and became popular among believing scientists, too. *Leucippus* (a teacher of *Demokritos)* assumed immense worlds that we can see resulting from the endless multiplicity of moving atoms, even soul consisted of smallest and roundest atoms. These atoms were more subtle and globular in shape and could be identified with atoms of fire. Sensation was due to atoms from outside knocking up against the soul-atoms. Latter *Democritos* (about the turn of 3rd century BC) introduced the hypothesis of active and passive *affection* (almost modern concept of forces) of motion, endless multiplicity of moving atoms and hypothesis of images or idols ’*eidola*’ as a kind of emanation from external objects, which made an impression on our senses. He believed on the shape and related arrangements of elementary particles-atoms. He used the idea of determinism’s saying that the universe is neither animate nor governed by purpose, but by a sort of irrational nature (*‘physis alogos’*). The term ‘*ananke’* was used to mean that there is no casualness or chance all governed by foolish nature. Another type of physical explanation, agreeable with the notion of fire may be termed as „materialistic, mechanistic“ or even „reductionism“ and there still remains a basic tension between the emphasis on „parts“ and „whole“ (the whole now accounted by holistic, orgasmic or even ecological views). Such a hypothesis for the action of the loadstone was advanced in the century following *Plato* by the Greek philosophers *Epicurus* (as based on the doctrine of *Democritus*) regarding the universe to consist of two parts, matter and free space.

3. Fluctuation, spontaneity and chaos

The concept of primordial rotary movements of the atoms led to the formation of innumerable worlds, separated from each other by empty inter-mundial spaces called *‘metacosma’*. In more advanced time *Epicureanism* had many theoretical and practical adherents to follow its popular sense of the distinctions of things. Such a world stands, in fact, for a refined and calculating selfishness, seeking not power but the senses. Recalling the motion of atoms they can move according to a natural tendency straight downward supposing that the atoms in falling through empty space collide by virtue of a self-determining power. This power causes certain in-determination owing to which atoms can swerve a little from the vertical direction. This deviation was termed '*parenclisis'* and enabled to explain the existence of objective chance and also of free will. This has had a direct impact to present-day thermal physics where we describe the system by a set of so called phenomenological qualities (e.g., temperature, pressure) that are not directly connected with the detailed microscopic structure of matter, but are manifested by (in) directly measured values. Any such a system exhibits small spontaneous deflections from the predicted overall state called '*fluctuations'* being caused by the particular structuralization of matter. Under standard condition fluctuations play a negligible role or their effect is averaged. Only under certain circumstances they, however, become perceivable (often at the vicinity of '*bifurcations'* a novel notion of present science) and can even play a crucial function of „*spontaneity*", a self-ordering commencement of above-mentioned free will. That was followed along modern thesis saying that quantum uncertainty can have the same roots but it was rejected by some important physicists who never accepted the probabilistic spirit of quantum mechanics and adhered to a *Democritean* access of the order of necessity ('*ananke').*

The term „*free will*" can lead to a confusing pleonasm because the only freedom concerns the possibility to do what we wish but not the subject that we wish, best interpreted by German philosopher *Schopenhauer* citing „*If I wish I could give away my property to the poor, but I cannot wish to wish".* It is related to the *Chew's* formulation of so-called '*bootstrap*' hypothesis (1970s) of a continuous dynamic transformation taking place within themselves relating thus the composition and interaction of sub-nuclear particles. It may even sound similar to the *Marutana's* concept of '*autopiesis*' (i.e., self-making) [15] for a distinctive organization of (mostly living) systems (sharing the same Greek roots of the world '*poetry'*- creating). Although autopiesis (analyzing phase portraits or fractals within the framework of topology) appears similar to the action analysis of strongly interacting hadrons within the network of high-energy collisions where each particle helps to generate other particle, bootstrap, however, does not form any desirable boundary as the living systems do.

Earlier the *Milesians* tried to explain things by reduction to one simple principle (*'arche'*) somehow viewing everything from a single point (*'monism'*). *Anaximenes* (about 5th century BC) introduced the important idea that differences in quality are caused by differences in quantity citing „*when it is dilated so as to be rarer, it becomes fire; while winds, on the other hand, are condensed air. Clouds are formed from air by felting; and this, still further condensed, becomes water. Water, condensed still more, turns to earth; and when condensed as much as it can be, to stones*“. On contrary the *Pythagorean school* (about 550 BC) was a more religious society cultivating secrecy speculating that the power could be reached through knowledge. They developed a theory that gives a form or limit (numbers) to the „unlimited“ saying that things consist of numbers. Numbers (*'arithmos'*) were in character natural and represented bounds (*'peras'*) their ratios was called *'logos'*. In medicine, the *Pythagorean* saw the principle of harmony at work (body as a musical instrument). It was grown-up by the most influential mathematicians, father of planar geometry, *Euclid* (about 3rd century BC). His textbook *Stocheia*) often considered as one of the greatest mathematical works) logic up thinking to the middle of nineteen's century when *Riemann* introduced his generalized description of curved space that was latter used by *Einstein* to formulate the modern physics of gravitation. *Philaos* created teaching about the central fire in the cosmos and located the home of the chief God *Zeus* there. Latter *Zeno of Alea* introduced proof by contradictions (well-known „Achilles and tortoise“) teaching thus that space and time were immanent in our conceptions. The concepts of space and time are not things as they were in themselves (*'noumena'*) but rather our way of looking at things (*'phenomena'* - nowadays phenomenology).

Heraclitus again redirected his attention to the change substituting dynamic *'pyr'* (as fire) for the static *'arche'* of the *Milesians.* He said that water, air and even '*apeiron'* are some substances or even material objects, but fire is a process or becoming. Fire cannot be static, it is not a „thing”, and it is the primary form of reality. Fire itself exhibits the tension of opposites and indeed depends upon it. The world is ever-living fire citing „*this world, which is the same for all, no one of the Gods or humans has made; but was ever, is now, and ever will be an ever living fire, with measures of it kindling, and measures going out*“. Nor the Gods neither themselves nor the souls of human beings can escape final destruction citing „*all things are an exchange for fire, and fire* *for all things, even as wares for gold and gold for wares. Fire lives the death of air, and air lives the death of fire; water lives the death of earth, earth that of water".* The circular process was called *'akpyrosis'*. *Heraclitus* taught that all changes in the world arise from the dynamic and cyclic interplay of opposites, and saw any pair of opposites as a unity. This unity he called *'logos'* used even for „awake people" they could make themselves understood. Who avoid public life of their city states (*'polis'*) were strangers ('second-rate' citizens who were restricted by their own ideas - *'idos'*). The existence of opposites depends only on the difference of motion, the principle of the universe is flux (change or becoming) and all things are at the same time identical and non-identical, „*the way up and the way down are one and the same"* and famous „*you cannot step twice into same river".* The process of change is unity and diversity rising the problem of identity, which is not self-evident *„it is impossible for fire to consume its nourishment without at the same time giving back what it has consumed already. This presents a process of external exchange like that of gold for wares and wares for gold".* Fire was traditionally a part of limitless *'apeira'*, sacred and self-referenced *'apeiron'* (indefinite, boundless) primordial beginning, a non-material being, and subsistence. Fire (*'pyr' - flamma)* delivers light (~ eyesight), that is transmitted (~ hearing) by air *('aer'- flatus),* reflected (~ appetite) by water (*'hydor' - fluctus)* and absorbed (~ tactility) by earth *('ge'- moles)*.

3. Fire as a manufacturing tool

Fire has always played a significant role as the explicit *tool* either in the form of an *industrialized power* (applied for working materials by men long ago in the process of manufacturing goods) or as *an instrumental reagent* (for modern analyzing the properties of materials) [6]. The consequences of a better understanding of heat led to the formulation of a consistent science of thermal physics, developing the related domain of thermal analysis touching on any adjacent field of science where temperature is taken into account. In fact, it was based on early erroneous premises of a non-material notion '*thermogen'* or '*caloric*' although we should better say that it was the application of *different* premises regarding the manner of individual approach of theoretical modeling. The caloric theory supplied, in fact, an obvious solution to the problem of thermal expansion and contraction because if the only known force of gravitational attraction would not be compensated every particle of matter would be attracted towards each other, resulting in a single solid homogeneous mass. To prevent this collision a repulsive force was postulated which was considered to be the self-repulsive caloric. Such an early fluid hypotheses became important in the formulation of modern laws and was common to the way of thinking of *Archimedes, Epicureans* latter used in the *Carnot's* and *Clausius* concept of thermodynamics [16] up to the present day truly dynamic theories of non-equilibrium, introduced by *Prigogine* [17-19]. Even our everyday use of heat flow equations applied in thermal analysis bears the "caloric" philosophy. The thermodynamic story was yet complicated by the introduction of an artificial quantity called *entropy* (after the Greek '*en*' – internal and *'trepo'* - turn), which has factually eliminated heat from its mathematical framework. Actually the first law of thermodynamics gives the quotation of energy conservation law but only under specific conditions for heat that is not fully equivalent with other kinds of energies. Heat cannot be converted back to mechanical energy without changes necessarily affiliating heat with entropy via the second law of thermodynamics intuitively stating that heat cannot be annihilated in any real physical process. It may somehow be felt that the domain of thermodynamics was originally situated to a level of *esoteric* ('those within') doctrine.

Let us repeat that for an unidirectional (ordered) motion of a piston, there arose the validity of the notion that the change in internal *energy* U defines the *state variables* of pressure P and volume V. Similarly for multi-directional (disordered) heat motion (flow) we can analogously write U as a product of T and S which leads to the physical definition of entropy, S. It naturally completes the pair of extensive (deformation) and intensive (fields) variables. Consequently it follows that any such dependent thermal engine can work only between two heat reservoirs (having definite input and output at different temperatures T_1 and T_2) and the transformation between these two states are less than ideal. It forevermore needs some non-equilibrium 'encouragement' and thus the thermal discontinuity ($T_1 > T_2$) is needed to push a heat flow through the $T_1 \rightarrow T_2$ interface. Such'disequilibria' coincides with the irreversibility of the reverse heat flux dQ. Equilibrium thermodynamics, however, has only one way to describe such a disequilibria - that is to split the system into two (often many) subsystems each one being in equilibrium providing the efficiency, ξ, is not exceeding $(T_1 - T_2)/T_2$. In such a reversible process entropy is conserved. How we can move from equilibrium to the situation of more subsystems in mutual disequilibria? We have to produce it by operating from the outside, W^{source} , at the expanse of some energy and this way of reasoning appealed suitable to *Gibbs* who, a century ago, defined the concept of minimum work, W^{min} , necessary to take a thermodynamic state out of equilibrium. Considering the rate $W^{source}/ W^{min} > 0$ we get for its limit $W^{min} \rightarrow 0$ above mentioned definition ratio $dS/dU = 1/T$. This equation is important saying that the arrow of thermodynamics goes in the direction of increased entropy or dissipated energy. If there is a change in the system driving it away from equilibrium, such a change can occur only at the expense of the displacement of another system towards equilibrium. If such a system proceeds in a given direction while opposed continuously by a force field tending to reverse it, the system can produce *useful work* done at the expense of entropy, which is frequently expressed in terms of the traditional Gibbs energy, G. Although these changes can be measured, entropy itself appears as an abstract mathematical quantity whose reality is difficult to visualize because entropy is somehow outside the range of our common sense and experience. Entropy should be understood, however, as a function of internal make up (inward structure) of the system, its organization and disorganization, rather than merely a phenomenological function of the system heat content and temperature (Q/T). If entropy is assumed reversibly proportional to order (organization) a ratio between the actual, I, and initial, I_o , information (where $I \rightarrow I_o$ when $S \rightarrow 0$) can be even used to account for an information gain by employing the relation: $I_{gain} = \log (1 - \xi_{actual}/\xi_{maximum})$ [9].

Let us look at the term entropy, which was proposed by *Clausius* (in a sound analogy with the term energy). Entropy is a measure of ordering *chaos* both in the physics and in everyday life (e.g., how effortlessly a laboratory can become a mess and how difficult it is to force everything back to order illustrating humorously the irreversibility of entropy). In fact, we can never know where an electron is positioned in the atom and the sub-particles quarks are still just „strange“. Religions, on the other hand, seem to ideally manage to emanate desirable order, with the Bible and moral rules, trying to have everything in its right place. Similarly we can elucidate symmetry looking at the Eastern religions' thoughts (Buddhists, Taoist, Hindu) and their philosophical view of the Universe comparing this view with the actual scientific facts of, e.g., crystallography or quantum mechanics. Let us mention that the general meaning of chaos is an empty space or not yet formed matter (*Theogony,* about 700 BC). It was derived from Greek '*chaskó'* – drifting apart, opening and '*chasma'* -abyss, chasm, gap and was associated with the primeval state of Universe (also associated with '*apeiron'*). In the Chinese tradition chaos was apprehended as homogeneous space that was preceding the constitution of directions/orientation (i.e., separation of four horizons) in the sense of a great creation. In the Egyptian cosmology chaos ('*nun'*) represented not only the state preceding the great creation but also the present state of a coexistence with the world of forms/structure, which serves also as a limitless reservoir of field forces where forms dissolve under infinitesimal time. In alchemy chaos was associated with primeval matter ('*nigreden')* capable to create 'big masterpiece'. Chaos was a symbolic representation of the internal state of alchemists who first needed to overcome their unconsciousness to become ready for transmutation study. In *Genesis* chaos is understood as a symbol of paltriness and non-distinctiveness but also a source of feasibility. The word chaos is sometimes taken to mean the opposite of *'kosmos'* and in that latter term has connotation of order and Arabic meaning of '*chajot'* is also closely regarded with life. For the Epicurean conception chaos was a source of a progressive transformation. Chaos thus became a definite domain of present day science showing by law that disorder can disclose windows of order (order through fluctuations) and that, *vice versa,* order bears inherent minutes of disorder (disorder as information noise). The theory of chaos provided the bases for various progressive specialties of numerous branches of knowledge seemingly important for any further advancement of science in the 20th century, see Part 2.

5. Equilibrium or disequilibria

By the end of the nineteenth century, there were available two different mathematical tools [20,21] to model natural phenomena - exact, deterministic equations of motion and the equations used in thermal physics, based on statistical analysis of average quantities present in complex systems. Whenever any non-linearity appeared, it was liberalized so that instead describing the phenomena in their full complexity, the equations dealt with small quantities (changes of temperature, oscillations, etc.) only. In linear system small changes produce small effects and large effects were due either to large changes or to a sum of many small changes. On the other hand, in non-linear systems small changes may have dramatic effects because they may be amplified repeatedly by self-reinforcing feedback being thus basis of instabilities and of the sudden emergence of new forms of order that is so characteristic for *self-organization*. With the concept of entropy and the formulation of the second law, modern thermodynamics introduced the idea of irreversible processes including the arrow of time. It says that that some mechanical energy is always dissipated into heat that cannot be completely recovered and literally the entire ‘world-machine’ is running down and will eventually grind to halt because thermal and chemical equilibrium predestinate stop of all processes, to end being, continuation and evolution of living organisms.

During 1960s, when *Prigigine* has developed such a new form of non-linear thermodynamics it became a wished vehicle to help to describe curiosity of self-organization phenomenon that we experience to takes place out of equilibrium. Classical thermodynamic concepts lead to *equilibrium structures* (crystals and other static structures) and dissipation energy (heat transfer, friction, etc.) is always associated with wastes. Non-equilibrium thermodynamics of a completely open system enables structure formation, too, but of a quite different nature (turbulence, vortices) showing that *dissipation can become a source of order*. It is often exemplified by the well-known *Bernard-Raleigh instabilities*, a very striking ordered pattern of honeycomb (hexagonal) cells appearing under certain conditions of heating a thin layer of a liquid, in which hot liquid rises through the center of the cells, while cooler liquid descents to the bottom along the cell walls. It happens only far from the equilibrium state (originally represented by the uniform temperature throughout the liquid) and emerges in the moment when a critical point of instability is achieved. A constant flow of energy and matter through the system is necessary condition for this self-organization to occur. Physically, this non-linear pattern results in a mutually co-ordinate process because molecules are not in random motion but are interlinked through multiple feedback loops, mathematically described in terms of non-linear equations. Farther from equilibrium, the fluxes become stronger, entropy production increases, and the system no longer tends towards equilibrium. However, this does not contradict the second law of thermodynamics because the total entropy of the open system keeps increasing, but this increase is not uniform increase in throughout disorder. In fact, the dissipative structures are the islands (fluctuations) of order in the sea (background) of disorder, maintaining (and even increasing) their order at the expanse of greater disorder of their environment. Particularly in the living world, order and disorder are always created simultaneously in the moment when the transfer of heat becomes to play a crucial role. Foreshadowing the work of Prigogine's self-organization there in 1920s was introduced the *science of structures* as pioneered by *Bogdanov's tektology* (from the Greek '*tekton'* - builder) being the first attempt to arrive at a systematic formulation of principles of organization operating in non-living and living systems. It was followed by *Bertalanffy's general system theory* [22] aimed to develop self-guiding and self-regulating machines, trying to solve the problems of interactions and regulation, which lead to an entirely new field of investigation which had a major impact on the further elaboration of the system view of life. It inspired *Wiener* to invent a special name *cybernetics* (derived from the Greek *'kybernetes'* - steersman) as to describe the science of control and communication in the animal and the machine. Its important part became the theory of information developed by *Shannon* when trying to define and measure amounts of signals (information) transmitted through telegraph lines. It is worth mentioning that the clockworks of the seventies century were the first autonomous machines and for the next three hundred years they were the only machines of their kind. Recently invented computers is a novel and unique machine as it moves autonomously, too, once it is turned on, programmed and kept ongoing by sufficient energy supply. Computers, however, do something completely new - processing of information. As *Descartes* used the clock as a metaphor for body *Neumann* used the computer in his cybernetic believe as a metaphor for brain introducing there the human relevant expressions as intelligence, memory or language.

Going further, there are some other restrictions for obtaining a useful technical work provided by mankind. It is often regarded to the limits in critical flux density of energy as presented by *Kapiza* at the beginning of 20th century. This borders the speed of energy transfer between systems, which is very important to construct advanced heat engines, such as turbines, etc., and their practical applications (e.g., the altitude at which the jet-airplane can fly). It certainly cannot be separated from other conditioning such as the level of technology (suitable material availability) and the possible impact on the *environment* (due to the finiteness of the earth's surface and its biosphere in which we live). No less important is the description of the organization of the human race itself - although not yet well developed, progress is beginning on a very simplified mathematical level. Recently there arose a remarkable idea that all of human society can be regarded as a kind of many-celled super-organism [23], the cells of which are not cells, but rather us, the human beings. The Internet might represent a kind of embryonic phase of the neural system of our '*if-as organism*' in which a '*global brain'* may facilitate the linking up of partial intelligence of the individual users. Later on perhaps, it may develop its own ideas, strategies and even a consciousness of an unknown order. From a systematic point of view such a '*cyber-space'* is in a similar category as language (the system) but differs in many important respects such as the temporal scale. All relevant levels in such a cyber-space are similar, the system has a body (neural network), some participants (system programmers as well as hackers) may deliberately influence the system at all levels, etc. It may become as common a property as 'fire' [1] and it may develop a systematic framework such as the theory of thermal physics (thermodynamics). We just need to look for some basic links between mathematical description of particles (strictly controlled by laws of thermodynamics in reaching lowest energy) and human beings (affected by their feelings in achieving maximum happiness [9,23,24]).

6. Conscious exploitation of fire

A most cognizant employment of fire (proposed by *Newcomen*, *Watt* and

Stephenson at the turn of nineteen's century while constructing a *steam heat engine* and latter a functional *locomotive)* gave a practical dimension to thermodynamics. Otherwise it actually interconnected the three forms of the basic elements: heating *water* by *fire* to get a thick *air* (steam) capable of providing useful work (moving piston and turning a wheel). Latter on *Lenoir's* gas-engine and particularly *Ott's* and *Diesel's* combustion engines imprisoned fire into the cylinder (forming thus the shaped *earth*) introducing thus a four stroke engine fully restricted by the laws of thermodynamics and controlled by the four cycle sequence essential to starting and ending in the same originating point. The encircled loop for the given pair of associated intensive (e.g. temperature, pressure) and extensive parameters (heat/entropy, volume) provides then a convenient estimate (*Carnot*) of the net gain of energy (or more generally assumed as 'assets, goods' [24]). Latter this idea has developed to wide variety of engines, turbines, pulse-jets and other power cycles all still governed by the same principles of thermodynamic efficiency for the external and/or internal utilization of heat/fire often misunderstood by devoted but naive ecologists. We should remain that a combustion engine (similarly to any assemblage such as hydroelectric turbine) is an open system - it consumes fuel (often together with oxygen) at a higher potential energy and consecutively is exhausting excess heat (and combustion products) at a lower potential energy. Such a desired pattern activity produces, however, disorder and thus is fully compliant with the second law of thermodynamics. *The useful liveliness produced by an automotive open system of any engine is kept alive on the production of excess amount of heat depleted to its surroundings*. The earth's based/assembled mechanism (engine) can thus be understood as an *information transducer,* that factually does not change itself during this work-producing thermodynamic process (except its wearing out). It implies that for producing useful work, it is necessary to apply not only energy but also cognition (information derived from the Greek '*in-formare'* in the sense of ether as internal shape). It is evident that any applied energy must include information within itself (alternation of electric current) to ease the interaction with some (proportionally to the information content less complex) transducer (alternator as a motor). However, for the originally information-vacant fire/heat we need to employ a more sophisticated engine (combustion engine or power plant) or should enrich (transform) heat to the other form of energy now to contain certain information within itself. A variety of useful machinery has been developed through the human cognition (purposeful mind) but have a relatively short history, just a couple of thousand years. The evolution of life, on contrast, exhibits the history several orders longer, on billions of years, and even a *live cell can be understood as a precision ally fine-tuned machine* gradually constructed through the evaluator ages as an extraordinary sophisticated set of interrelated parts (molecules) that harmoniously act together in predictable ways insuring thus the progressive development, variability and selective survival of more of its kinds and efficient use of energy. Its "know-how" experience record [7] is coded in the DNA memory that posses a capacity of creative incorporation within its structure changes (internal development of certain 'cognition') that would permit further evolution of its machinery cell into forms needed to prosper successfully upon the Earth's continuously changing face. It is clear that its space-time structures do not remain stable and some of the subsequently mentioned principles, such as chaos/entropy, order/information and generalized course of cycling (that makes a repeated process in such a reliable way as to exhibit coequally of the initial and final points necessary to retain the procedural capacity for continuous periodicity) penetrated to other fields such as humanities, sociology, economics, etc.

Theoretical progress became possible through a more comprehensively developed field of *non-equilibrium thermodynamics* [25-27] making possible to generalized laws for all almost arbitrary "open" systems. In contrast to aspects of the classical thermodynamics these newly included "*true flow*" features (which ought to be taken into account in any actually studied thermal processes that take place away from stationary equilibrium) helped to unlock an important scientific insight for a better understanding of chaos as a curious but entire source of order necessary for any systems to ever undergo evolution. As the main step it was necessary to introduce differential equations describing the *local flows*. Assuming the hypothesis that every particle is subject to a random *Brownian motion* to posses a characteristic diffusion coefficient and acting under an external field according to the Newton's law it may lead in natural way to the formula equivalent to the quantum-mechanical form [28,29] of *Schroedinger equation* (with a Hamiltonian structured like for a charged particle in an electromagnetic field) yet having its physical interpretation classical just troubled by the square roots of minus one. Its inventors *Euler* and *Gauss* declared that '*an objective existence can be assigned to these imaginary beings'* extending thus *Leibnitz's 'that amphibian between being and not-being'.* In fact, elementary physics has already gone a stage beyond the complex numbers in order to describe weak and strong interactions and temperature can be seen to play the role of concentration of the diffusing substance. Complex number can also be avoided by applying a more general diffusion coefficient based on hyper complex (multivector) mathematics capable to describe even life processes taking place within solid matter.

Nevertheless both these flows of mass and heat perform an important function in non-equilibrium processes [30] associated with the production and/or absorption of heat. For any reaction we can generally assume that at a some distance from a reacting zone the neighboring fluid undergoes irregular turbulent motion caused by intimate heat and mass transfers. It naturally creates a mushy zone consisting of cascade of branches and side branches of *dendrites* (from the Greek *'dendros'* - tree) of products (often crystals). Resulting microstructure is highly irregular (heterogeneous morphology of a final product) which is responsible not only for alternative properties but also for increased sensitivity to small input changes taking creditability for the course of localized and non-steady mass and heat diffusion, effected by temperature fluctuations, surface tension, interface curvature, etc. These circumstances altogether determine whether the growing solid looks like a snowflake or like seaweed (fractal geometry [31]) but never follows simple integral geometry (circles or balls often assumed in our theoretical modeling). If the heat extraction is isotropic such a dendritic growth is epitaxial, short parabolic tip being responsible for directional outgrowth while perturbations appear on initially smooth needles as well as in the case of inceptive breakdown of the originally planar interface (the theory of which was developed by *Sekerka* in 1960s [32]*).* This statute occurs (and should be applied in study of) not only in most reactions but also during our every day's conditioning of weather (shaping snowflakes or forming cyclones).

The "scale symmetry" has here the implication that the objects look the same way on many different scales of observation. Natural fractals in physics often belong to random. Nonrandom fractals can be created upon geometric assemble constructed by simple interactions to obey a certain growth rule. In such an aggregation process we can define the density, r, to be a ration of mass (M) and the edge length (L). Then $\rho(L) = M(L)/L^2$ that decreases with L monotonically (so that we can achieve an object of limitless low density) and in a predictable fashion (according to a simple power law, $y = a x^n$). Power laws are generally the solution to the functional equations and are also well known in a double-logarithmic form as alometric functions (often applied when studying evolution processes). There is an association with unbiased random walk identified with a characteristic displacement $L_{dis} = {}^k\sqrt{(x^k)}$. Regardless of the definition of the characteristic length, the same scaling exponent describes the asymptotic behavior and is defined by $\sqrt{t}$ analogous to parabolic law of diffusion limited aggregations (electro deposition, dendrite solidification and growth, viscous fingers in porous media, etc.). A single site is assumed occupied at the beginning. All its empty neighboring sites are then identified as possible growth sites, but only one is chosen at random. The remaining empty neighboring sites are now labeled as growth sites and the procedure is iterated. Modifying growth probability of sites we arrive to a percolation related models. Such a generalized approach to processes analyzed within random conception can even change the traditional structure of thermal physics.

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This article is a condensed part of my newly written book „Heat, Temperature, Science and Society", which is in the course of preparation for the year 2003. The text was written in a compressed form and in a more popular way. It is also based on my recent experience with university courses directed to the novel program of cross-disciplinary education brought about under the project GA CR No 401/02/0579. The theme is the extension of our long lasting research directed to the study of non-equilibrium processes (related also to the projects No 522/01/1399 and GA CR, A 4010101 GA AV CR and 23000009 MSM). Most of the involved (but in this article purposefully omitted) mathematics (as well as detailed literature references) can be found in the author's (related) articles, such as current „Irreversible thermodynamics and true thermal dynamics in view of generalized solid-state

reactions“ by Sestak and Chvoj, and „Diffusion action of waves occurring in the Belousov-Zhabotinsky kind of chemical reactions„ by Stavek, Sipek and Sestak, both recently submitted for the publication in Thermochimica Acta (to the Brown and Galwey’s special honorary issue edited by Ozawa and Vyazovkin to appear by the year 2002). The theme and (particularly mathematical background) is also a subject continuation of our 1991, widely cited book „Kinetic phase diagrams; Non-equilibrium phase transitions“ (Z. Chvoj, J. Sestak and A. Triska, edits), Elsevier, Amsterdam 1991, and factually was preceded by my 1974 NATAS/Mettler award lecture „Rational approach to the study of processes by thermal analysis“ presented as early as during the 4th ICTA in Budapest 1974. The author expresses his gratefulness to the journal Editor-in-chief, Prof. Zivan Zivkovic, and to the Co-Editor, Dr. Dragana Zivkovic, (both from the Technical Faculty in Bor, University of Belgrade) for their kind scientific and technical assistance.

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