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TO WHAT EXTENT DO WE UNDERSTAND CHEMICAL REACTIONS?

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Chemical courses are fundamentally based on the study of chemical equilibrium.

For the chemical reactions out side of equilibrium, in a open system interchanging energy and matter, «chemical thermodinamics» can only give some qualitative predictions to know if a particular reaction can evolve spontaneously, but not gives any information about the speed of such chemical reaction. A number of phenomena, that are included on the kinetics of each chemical reaction as well as, catalytical effects, chemical activities and chemical affinities, are known only as suitable approximate interpretations, that do not fit on the quantitative approach that is referred only to the chemical equilibrium.

Following the above considerations on the limits of contemporary chemistry knowledge, we are looking up to investigate how it will be possible develop a new way of thinking, with the aim to better understand how the «*auto-organization*» of a reacting chemical systems, during the process that works out side of equilibrium.

A good experimental example of such a general systems capable of «auto-organization», is delivered by the series of chemical reactions, so called «oscillating reactions» (1).

The chemist William Ostvald, was the first that observed travelling electochemical pulses, with an oscillating behaviour, during the reaction of oxidation of metals in acids; he described this phenomenon as well as a nerve-like «excitability» in chemical reactions (2). The first systematic approach about the general phenomenon of oscillating chemical reactions, was studied in 1951 by Boris Pablow Belousov, a biochemist at Moscow State University. Belousov begins from the idea that, before to understand circadian rhythms on time of cellular metabolisms in biology, we need to understand more simpler chemical analogue. Subsequently he thought to simulate the «Citric Acid Cycle», (named in biology Krebs Cycle), by oxidising citric acid, not with catalytic complex enzymes, but merely with metallic ion catalyst, that enzymes commonly carry in their active sites. Belousov discovered that his citric acid solution, really cycled periodically, as well as an internal clock works in the liquid to generate the rhythmic behaviour, typical of a system that iteratively produces neg-entropy. The paper of Belousov, at those times, was rejected by different chemical journals, because the referees usually do not accept, that the science understanding of thermodynamics was so superficial, that do not gives any prevision that chemical system can oscillate yielding neg-entropy. The abstract of the scientific work of Belousov, so important to understand the chemical foundation of living systems, we can find in the International Bibliography, only written in the proceedings of a Meeting of Medicine in U.R.S.S. (3).

In spite of the nature of human creativity, it is now not difficult to illustrate the resistance of traditional academic science, to interpret observations that do not fit into existing theories and it is generally depending from the fact that scientists today are not trained to improve creative ideas in the field of the philosophy of science (4).

Sincerely looking with carefully recognition to the international bibliography it was possible to recognise, that before Belousov, precisely from 1828, some «oscillating reactions» are experimentally well known. One of this very nice reaction is named «chemical core», this reaction show an oscillating periodic contacts between a drop of mercury and an iron wire in an acid solution of potassium bichromate. Therefore, by means the reproduction a very large amount of «clock-(or oscillating-) reactions», people today can easily investigate the behaviour of the temporal evolution of the chemical transformation far from equilibrium conditions.

But in spite of the facility to reproduce this kind of experiments, also today it remains the difficulty to interpret, the system of «auto-organisation» of such chemical phenomena. As a matter of fact, what we see, looking at «oscillating reactions», seems truly a «magic alchemy». Actually, we observe unexpected rhythmic changes in time/space organization that are evidenced by appropriate colour indicators (5).

Recently Ilya Prigogine (Nobel prize of chemistry 1977) has opened an large debate on that problem of chemistry that works out side of thermodynamic equilibrium (6). Substantially Prigogine has proposed that for a not isolated chemical system, we need to consider the difference of the gradient of entropy between the internal production of entropy (Si) of the considered system of chemical transformation and the contribute of entropy (Se) that it is due to the interchange of energy and matter with external environment.

In that conditions the gradient that is relative to the external entropy (Se) can be greater that the speed of production of internal entropy (Si) so that the balance of the flux of the total entropy, exchanged into the «in/out door frame» during the transformation can be negative; this means that the system can produce neg-entropy (- S), or in other words, a new order oriented to find new equilibrium conditions can be realised (7). Prigogine describes such phenomena of production of a new molecular order as a dynamical process regulated by means of *«dissipative structures»* that support the «auto-organization» processes of chemical transformation during the reaction flow development.

Hence the description of Prigogine of the auto-organisation of «order by means dissipative structures fluctuation», is a way to understand *«order in space without regularity in time»*, because such kind of interpretation do not clarify the aspect of the irreversibility of time evolution. In fact the above is a good approach that give an extension of thermodynamic to the chemical processes working far from the equilibrium conditions, but it is not difficult to understand that in this way of thinking, we obtain only a qualitative justification about the possibility to obtain as a result a production of neg-entropy during a chemical reaction. Therefore without any additional theory, that include «time» as a physical parameter, also the Prigogine interpretation remains inadequate to forecast the process of *«auto-organization of matter»*, that provide the possibility to get *«order from the chaos»* generating a symmetry on space organization of dissipative structures but also regularity in time rhythms of the oscillating chemical reactions.

It is important to underline that the order that we observe on the energy-matter auto organisation it is not only a «order in space» due to the geometry of «dissipative structures»; as a matter of facts the procedure of any oscillating reactions is synchronised by means a regularity of time.

Ilya Prigogine is very conscious about this fact, and in many reports and books puts in evidence that the limit of his interpretation fundamentally is a consequence of the fact that any explanation of science, from the

traditional «mechanical» point of view, always has considered «time as a reversible entity».

As Prigogine was pointed out (8), into the paradigm of normal science related to the energy/matter interactions (the old E/M paradigm) the dynamics of events, like in a film simulation, is completely reversible in relation to the time (t); in fact, if we introduce into the fundamental equations of science, (like f = ma, or, E = mc2) time's data (+ t or – t), we obtain a symmetrical reversible development of the dynamics of the considered event, that it is in fact wholly equivalent in each the two directions of the time's arrow or oriented to the future or addressed to the past. This means that, the physical reality, calculated into the traditional paradigm (E/M), is described by «a-temporal model».

Knowing that the «mechanical paradigm» of traditional science is a model that do not fit the reality of the time irreversibility, as a result of some philosophical reflections our group of research in chemical education, more in general, conceive, that not only we are not able to understand the dynamics of chemical process, that are developing far from the equilibrium conditions, but more widespread, we think that the contemporary scientific knowledge is dramatically remote by any interpretation of *«life phenomena in nature»*. Living systems in fact, also can be included into «not-equilibrium» phenomena. Our conclusion is that today science is near to a turning point of change of the general paradigm of reference of mechanical origin and consequently, we have need of urgent creative development of scientific conceptions.

NEW TOOLS FOR SCIENCE THOUGHT

Now I will summarise the research in philosophy of science of my group of Educational Research, that is mainly oriented towards developing with a constructive methodology of cognitive science growing, a new general paradigm of natural science. We begin to reflect about the need of introducing the general concept of *«Information»* instead of the meaning of «neg-entropy», and subsequently, we challenge to investigate the conceptual associations that correlate *«energy, matter and information»* conceptions in science, with the aim to introduce, into a new paradigm of science understanding (named E/I/M/ paradigm), a coherent meaning for all the processes of communication of the information, that allows the occurrence and the evolution of «auto-organised dynamical processes» in nature.

On our current view, the introduction as a general variable the «Information» is necessary for overcoming the reductionism of mechanical point of view of traditional science understanding. The traditional science paradigm in fact is dominated by the Cartesian cutting between the thinking subject and the independent external objectiveness of reality. The classic conceptualisation of Cartesian paradigm of mechanical science, substantially was acquired by the Kant philosophy, that considered space and time as «a priori» ideas, not derived by other previous notions; in that traditional cognitive dominion «space» is a concept referred to the environment, instead the notion of «time» is a psychological artefact of the mind.

Remembering that it will be no knowledge of anything, if something it will be in common between the subject and the object, consequently the time concept, not properly can be considered as a part of knowing as well as remains a subjective entity; therefore we prefer reconsider the concept of time as a concrete consequence of the *«time of information»* of observable reality, obtained by means our bio-chemical brain's system interaction with the environment.

Consequently, into the new proposal of (E/I/M) paradigm of science, space and time interactions are emerging as secondary conceptions, derived from the relationships among Energy, Information and Matter (See Figura 1).

Reducing the complexity of this philosophical problem about the general issue of the possibility of knowledge, to a short syno-

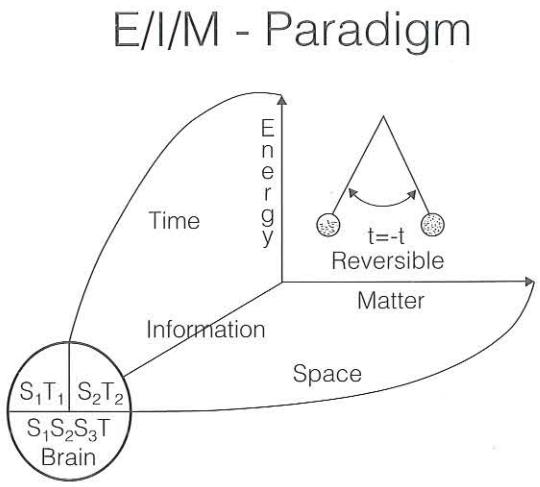

Figura 1.

psis, we can simply mention some general considerations as follows: from the one side, the conceptualisation of time is principally derived from Energy/Information relationships, that include the sensible experience of observer into the description of the global reality, from the other side, the space concept is an essential consequence of the Information/Matter interactions. As we point out in some precedent papers (se bibliography from n.° 9 to n.° 25) this two kind of interactions giving time/space relationships can be correlated with the working difference of the two halves of the human brain that are working as a bio-chemical structures.

In synthesis in our reasoning on (E/I/M) paradigm where we have introduced «Information» (I) as a general variable, we think that this new paradigm of science get a more complete comprehension of the dynamics of an evolutive system. In fact the assumption of *«three general variables»* (i.e. energy, information and matter), is a need for a global description of the system that is comprehensive of the brain system of understanding, whereas in a mechanical of traditional (E/M) paradigm of Cartesian origin, any event into the space/time, can be described referring only to «two» general conceptions of classical science interpretation: i.e. energy and matter. We remember that intraditional science understanding, «information» is carefully thought as a parameter reserved «ad hoc», referring to some especial cases of explanation in biochemistry, like brain-chemistry or DNA expression of protected genetic information.

In the E/I/M paradigm we have generalised the concept of information because as a matter of facts the «oscillating reactions» show an auto-organised action, that is the global behaviour of the out side of equilibrium processes, that need the supposition that the interacting particles can *«communicate information»* among themselves to establish regularity in synchronising time and to order space symmetry of dissipative structures during the transformation of the chemical reaction. In agreement with the above remark, we need to assume *«Information»* as a generalised appropriate parameter to interpret the global coherence of the system that we observe in any case in which a chemical transformation is oriented to diminishing the entropy of the process to give a new molecular products .

As an example of this widespread problematic of the need to introduce a general concept of information in science understanding, we can take into consideration for example that, the biological activity of the proteins is depending from the particular folding-conformation; we remember that, without any doubt, we know that the folding-conformation of the proteins of living systems is not depending from DNA-RNA bonding system of amino-acids linear sequences (26).

Who is it that expresses the necessary information for the «invisible-loom», that produces different proteinic folded frames giving different kinds of biochemical activity to the proteins of the living system, since the folding-reactions are independent from the genetic-code?

Another example of independence from the genetic code of chemical information is coming from some recent studies of biological processes generating life. Experimentally was found that the regulation of cell's division during the process that transform

«meiosis» in «mitosis» is not depending from DNA (in fact in this experiment the DNA of the cell was previously destroyed); in fact the reproduction of the cells depend from a complex «clock reaction», immediately visible from the oscillating contractions of the «ovum». This periodical oscillation is regulated by cyclic-protein (quickly named: cdc2) that presents a clear intermittent change of its concentration during the process of division of living cells; at the same time all the other proteins involved into the process of «mitosis» grow up with exponential conduct of their concentrations until the cell splits in two segmentation (27).

What is the principle by means a biological clock reaction, regulated by the protein «cdc2», can provide the necessary information for the development of the process of mitosis of living matter, forecasting forinstance, the decision about the choice of the exact time in which the duplication of the «ovum» can start?

What kind of concepts can be used to reply to this asking questions?

Those dilemmas surely are out side of any possibility to reply recurring to mechanistic approach in science; in fact in relation to the first example, contemporary science is able only to limit the range of the problem and to refine the close-packing possibility of the different protein-folding, searching for the minimum of potential energy and reducing in this way all the proteinic configurations into a generic probability to assume a spherical shape; in respect to the second example, contemporary science is able only to hypothesise an improbable generation of order coming out from chaos, without any conjecture concerning the time that need to be exact for the proper survival of borning life.

We note that the fundamental images considered as referring symbols of mechanical interpretation regards only two extreme conditions of the dynamical reality, suitable to grow up the models of traditional science: one of them is a «crystal» in which the motion is similar to a «Galileian pendulum» clock-dynamics, the other is the «Brownian motion», that like in a smoke's cloud, give only a model of probabilistic dynamics, because the particles are totally independent one from the other.

Crystals and Brownian motion are respectively fitting, ordered or completely disordered mental-images of traditional science understanding, and therefore are stimulating our thought, to elude any need to give a description of the rules that in nature are restricting the chaotic dynamics into a coherent procedure in the space/time. But for understanding what is the function that transform the divergence of the increasing entropy in a spontaneous convergent process of transformation finalised, to the goal of a stoichiometric realisation of chemical products, rationally speaking, we need to assume that the reacting particles can *«communicate information»* with a long range action, to regulate in space and synchronise in time their developmental behaviour; this therefore is a pre-requisite for giving a significance to the «auto organisation» of the oscillating action out side of equilibrium, in each chemical reactions.

Looking to support the above consideration we remember that also recent studies on heterogeneous catalysis clearly exhibit, how the entropy of the catalysed reaction can decrease, by means a system of spatial auto-organisation that shows, by photo emission electron microscopy, a rhythmic cadence of oscillations of expanding concentric spirals on the surface of the catalyst, like in the case of «oscillating» reactions mentioned earlier (28).

Therefore knowing that also the catalytic-systems under considerations exhibit a rhythmic spatiotemporal self-organization, very ordered in space symmetry and in regularity of time during the catalytic reaction, we need to recognise that the all chemical systems out side of the equilibrium, auto-catalysed like an orchestra, need to get self-accordance by means of some form of signal communication; this means, as a consequence, that to understand the above physi-

cal behaviour, we need, as we have chosen for the E/I/M paradigm, to introduce the variable «information» as a new general parameter to interpret the phenomena of the chemical reaction during the transformation realised far from the thermodynamic condition of equilibrium.

Therefore looking to the limited referring models of «mechanical» (E/M) paradigm that do not give a complete explanation about such general problem of «oscillating chemical transformation», we realise evidently the cognitive limits and the approximations by which traditional science has avoided the introduction of «information», as a general parameter of description of experimental phenomena. Hence at the same time we understand, that in all not extreme cases of the dynamics of natural phenomena, as well as, auto-catalytic or enzymatic processes in chemistry, body/anti-body recognition, proteinic reproduction in living systems, neurotransmission into the synaptic bridges of the brain etc..., we need to introduce as a general variable «I» to interpret all communication and hence elaboration of information natural phenomena, that only in the extreme cases (i.e. «pendulum» or Brownian motion), of mechanistic science traditional models, can be respectively approximated as: I = null, or indefinite.

Forever on our present view «clock-reactions» can be seen as space/time transformations that generate oscillations from a spatial order to a regularity on time, working on a transformation of informational codex of chemical affinity.

So that *«information and transformation chemical processes»* can be creatively revised in the view of the new E/I/M paradigm.

THE FUTURE OF SCIENCE NEED FOR A CREATIVE PHILOSOPHY

Before we have seen that, reasoning about the need of a new paradigm of science, we consider useful to introduce directly the general concept of «Information» instead of the concept of «neg-entropy» to understand the general character chemical transformation far from equilibrium conditions (29). But now reflecting into a more large world view, we are convinced that, we need to introduce a cognitive strategy oriented to develop creative education in «Ecology of Mechanical Science Epistemology», to obtain, in a short time, the intellectual pre-conditions to generate new conceptual tools to understand the living system in nature.

<E/I/M> paradigm is in fact, (in our conceptualisation that insert also the thinking brain into the physical reality), a «global objective paradigm», i.e. a conceptual context that overcoming the Des Cartes traditional world-view, gives a new meaning of physical objectivity, because the E/I/M paradigm proposes an extension that includes the subject, that is observing and interpreting reality, into the global description of science. The above way of reasoning about the global objectivity that integrate the subject and the object of the observation in a single reality, can be initiated considering the fundamental postulate that the whole energy cannot be destroyed or create; therefore the total energy (E) must be equal to one at any time. The above means that if we considered the information as a parameter of description of any one energy-matter transformation, (including those active in our in brain understanding), at any time the global variation (d) of the addition of free-energy (Ef) and codified-energy, like matter (Em) and Information energy (Ei = energy used for the transformation of observation in meaning into the brain of man, or in other receptive structures of information in nature), can be equalised to zero.

$$E_{tot} = 1 \text{ \{i. e. \} -at any time- } d(Ef) + d(Em) + d(Ei) = 0$$

Because each variation of a constant is zero for definition.

$$\text{\{i.e. \}/at any time/ } d[(Ef)+(Em)+(Ei)]=0$$

Therefore:

$$+ d(Ei) = - d(Ef) - d(Em) \rightarrow (A)$$

Henceforth from equation (A) the general criteria of the evolution can be seen as a

program in which nature progressively transforms energy and matter interaction, to develop an increase of energy linked to the process of information (Ei).

The increase of (+ Ei) that we can indicate as the principle of *«fertile evolution»*, correspond to dissipate (– Ef) and/or decrease (– Em), because the principle that regulate the increase of Energy linked to the information's procedures of natural evolution, is complementary to the equivalent principle, of the «minimum of action», settled by J.B. d'Alembert, that governs the motion of particles.

The *«fertile evolution»* equation, that is a working principle in spontaneous reactions, can also gives reason of the irreversible direction of the «arrow of time»; time in fact is a dimension linked to the evolution of the relationships among «energy matter and information» that are regulated by the general criterion of evolution, previously described by (A) equation. Hence the «irreversibility» of natural phenomena, can be described into the new (E/I/M) paradigm, as a fundamental consequence of the evolutive asymmetrical character of the dynamics of Matter/Information/Energy, transformations in nature.

To close the present short dialogue, we would like to express our belief that, starting to introduce a cognitive strategy oriented to develop creative philosophy of science, it will be possible in the next future to induce a new way of system science thought, changing the conceptions that link the man to the nature into a global system of co-evolution, following a more deep understanding of the rules that are developing the «intelligent life» as a natural process of our universe.

CONCLUSIONS

As was established by international organisations, the decade of «Environment» is at the same time the decade of the «Brain» development (1990-2000). Therefore the next 90's years, are very important intellectual challenges in philosophy of science, getting a new focus on our criteria of understanding the science of nature, for a revision of our antiquated mechanistic ideas; following this decade's enterprise, we initiate to promote an innovative interpretation of «auto-organization of matter», starting from a simple curiosity in chemistry, i.e. looking for understanding that beautiful and amazing *«oscillating reactions»*.

The above dialogue about advanced educational research on some hypothesis for the construction of a new paradigm of science we think can be useful for students, to understand a plausible way to construct alternative scientific meanings through an interactive process to examine new underlying assumptions in science understanding, to analyse criticism about the old knowledge, to formulate and to test hypothesis of creative theory building, looking to the aim to argue and to dispute alternative construction of scientific knowledge, more suitable to comprehend the communication of information in nature and to achieve in the future advanced scientific understanding of living systems evolution.

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(*) Memorandum -CLOCK-REACTION- Prepare a flash containing 850 ml of distilled water, and add: potassium iodate (13.0 g), manganese sulphate monohydrate (1.0 g), [$CH_2(COOH)_2$] malonic acid (5.0 g), sulphuric acid (27 ml 2M) and fresh prepared solution of soluble starch (2.5 g); when all the solids are dissolved, transfer 300 ml of (H_2O_2) Hydrogen peroxide (100 vol, 70 ml). Quickly transfer again the obtained mixture in a cylinder. Clear, gold and blue sections in the cylinder, that change with a regular dynamics, can be observed for about 15 minutes.