American Research Journal of Humanities & Social Science (ARJHSS)
E-ISSN: 2378-702X
Volume-09, Issue-01, pp-29-38
www.arjhss.com

Research Paper Open Access

Biological Information Theory: From Molecular Interaction to Communication in Living Things

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Abstract: In this article we attempt to investigate and describe the fundamental mechanisms underlying the communication of the fundamental elements that make up matter.
The thesis we support is that matter exists and transforms thanks to the mutual interactions of its constituent elements, and we present the ways in which these interactions occur.
This is the same thesis I have argued in other articles, and it is the key principle that extends the fundamental interactions that occur in matter, according to quantum mechanics.
The sequence of transformation phenomena of material elements transported by the various types of waves (mechanical, electromagnetic, gravitational, etc.) can be schematized as follows: 1) Communication, 2) Interaction, 3) Transformation and, when the transformation can be recorded and stored, it becomes 4) Knowledge.
The article highlights the similarity of the transformations that occur in matter with language; both are forms of knowledge.

Keyword: Interaction, Perception, Knowledge, Electromagnetic waves, Molecular conformation, Language.

I. Introduction

The intrinsic characteristic of material bodies is their ability to modify their physical state and their energetic content in response to the interactions and stresses they receive.
And it is the ability that transversally pervades all inanimate and living matter, including man, with the difference that man, when stimulated by external events, is able to recognize them and becomes aware of his own uniqueness with respect to the world around him.
Taking this hypothesis as a starting point, in this work I hypothesize that the transformations produced by the mutual interactions between material substances, and between these and their environment, are acquired in the form of knowledge.
Starting from this assumption, I define Knowledge as the capacity that matter has to maintain the modifications of its physical and energetic conformation in response to external stimuli.

Transformation of a particular steric conformation refers to how atoms rearrange themselves in space within a molecule, without chemically changing the substances.
For example, rotation around C-C bonds in organic molecules creates different conformations that influence the physical and chemical properties of the molecule.
If the modification is stable and traces of it remain within the molecules, it means that they have acquired new information about their state, and in systems capable of recording the new condition, new knowledge is acquired.

The analysis of the information mechanism described in this article follows a mechanistic logical process to conclude that knowledge is the intrinsic manifestation of matter. Furthermore, a hypothesis regarding its origin and expression is presented. With the advent of man, matter itself becomes capable of investigating itself and its own intimate essence.
Knowledge can thus be conceived as a virtuous ontological short circuit that originates from matter and, after each stimulus received, returns to itself, modified in form and enriched with content.
In this article I present a personal conception of the meaning of communication/information and its characteristics, relating it to the intrinsic properties of material bodies that naturally interact with each other.

I have dedicated some articles to the topic of communication/information, to its expressions, to its meaning, to its raison d'être, because I consider it the essential phenomenon through which matter manifests itself, and at the highest level of organization, can know itself.
Thus, for communication to become knowledge, it presupposes the presence of material elements that are capable of interacting and producing mutually perceptible and recordable modifications of their state, in a defined space-time context.

II. Communication/information

The phenomenon of communication presupposes the presence of material bodies, which by their very presence have the property of modifying the conditions of the space-time they occupy.

In this manuscript we want to avoid the ontological philosophical approach, and that of linguistic semiotics, to remain on the rigorously materialistic ground of science.

Interaction occurs between material bodies when they can produce effective reciprocal stimuli that temporarily or permanently modify their condition or state of aggregation, and the space-time that contains them.
The description of the entire process requires the introduction of some fundamental preparatory concepts.
Let's break down the individual events by describing them in their elementary mechanisms:
Stimulus : Material bodily event capable of determining changes in matter and/or the environment (Space-time).
Interaction : event produced by energetic phenomena that occur between material bodies, with or without direct contact, capable of temporarily or permanently modifying their condition or state of aggregation.
Perception: The ability of matter to temporarily or permanently change its state of aggregation in response to stimuli received from the outside.
Communication: The mutual transfer of information about their morphological-energetic characteristics between material bodies present in a space-time system.
The mere presence of a material body in space-time is sufficient to communicate to the environment, and to any other bodies present, its **"ergonomic** " characteristics, which are all the intrinsic properties that characterize them.
We can assign a teleological/finalistic meaning to this primordial event, with the aim of testing the optimal reciprocal energetic-conformational adaptations that best respond to the distinctive demands of the system's components.
Knowledge: It is the complex of information acquired and recorded as traces by a material element following interaction/communication with other bodies, and which can be used in adaptive behaviors to events already encountered or in evolutionary improvement.
The morphological-energetic-informational content of material bodies

We have already expressed the concept of the informational content of material bodies, which by their mere physical presence modify and communicate with the external space they occupy.

Communication is a sensitive topic and plays a fundamental role in any type of natural activity, whether spontaneous or intentionally produced. I have dedicated several articles to this topic [1-4].
Nothing can happen in the real world unless there is first communication in the matter present in it and before that, a mutual interaction occurs.
Any event that modifies the stationary state of the universe, which is the locus of possible events, or to use Einstein's term, space-time, is immediately signaled and perceived by it and secondarily by the other material bodies present in it.

Each material substance leaves its own "material imprint" on the surrounding environment with its presence, like a body immersed in water, which is the result of the space occupied by its steric conformation, and is typical and distinctive with respect to any other, Fig.1.

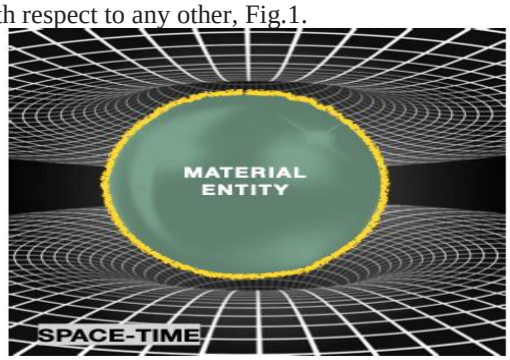


Figure 1- SCHEMATIC REPRESENTATION OF THE EFFECT OF MATERIAL BODIES ON SPACE-TIME

If we consider an atomic element isolated in its environment, we can say that it is characterised by the volume it occupies and by its energy content, which is the energy it manifests if it comes into contact and binds with other bodies or if an atomic explosion occurs Fig.2.

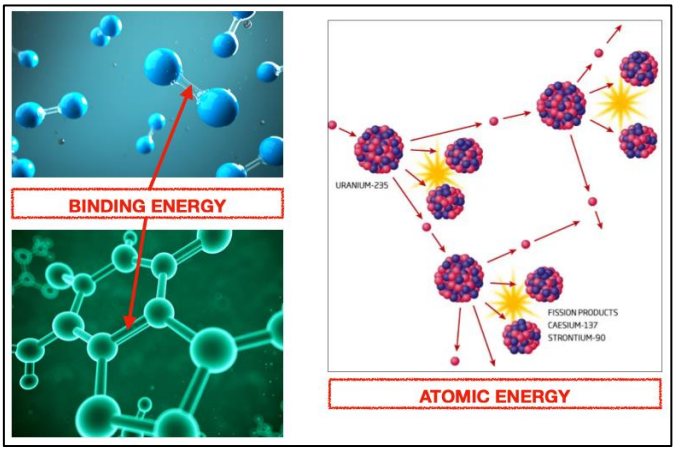


Figure 2- Binding and Atomic energy

The double articulation in interaction

It expresses the concept that interaction occurs on two levels and expresses a double effect:

Intrinsic structural interaction : It is the type of intramolecular interaction that occurs between atoms and molecules that form and bind material masses in their aggregate state;

Extrinsic steric interaction : Interaction that occurs between material masses separated in space,

and is based on the wave/electromagnetic frequencies they emit in the propagation that leads to their encounter. The comparison of their steric conformation is the second level of interaction.

Molecules recognize each other based on the specific frequencies emitted by the materials they are made of. As a result of the steric-energetic adaptation that distinguishes and characterizes them from one another, they recognize each other as compatible, enter into resonance, and collapse, forming new structures.

Living organisms have developed specialized receptor systems to recognize the different types of stimuli carried by wave frequencies: vision: for electromagnetic waves, hearing: for acoustic waves, smell, taste and touch: for the contact vibrational frequencies that occur with natural substances Fig.3.

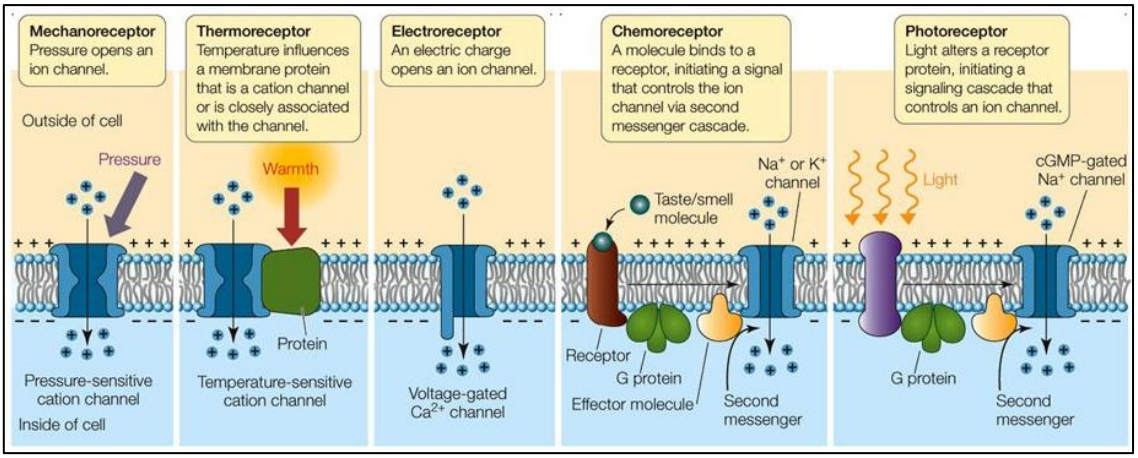


Figure 3- Schematic diagram of specialized receptor molecules to respond to various stimuli

Throughout the natural universe, the common denominator of interaction is based on the modulation and type of wave frequencies produced by bodies, which express the spectrum of specific frequencies emitted by them, and through which they can be recognized from each other or examined individually with appropriate instruments (spectrometry).

Given this premise, we can hypothesize that different types of interaction/communication are present in nature: which can be direct or mediated.

The first form of direct interaction/communication is that which occurs between material bodies through direct contact, without intervening elements, and is capable of producing or not producing a change within the system

Fig.4, and is produced by the encounter which can be casual (A) or selective and guided by some form of affinity (B).

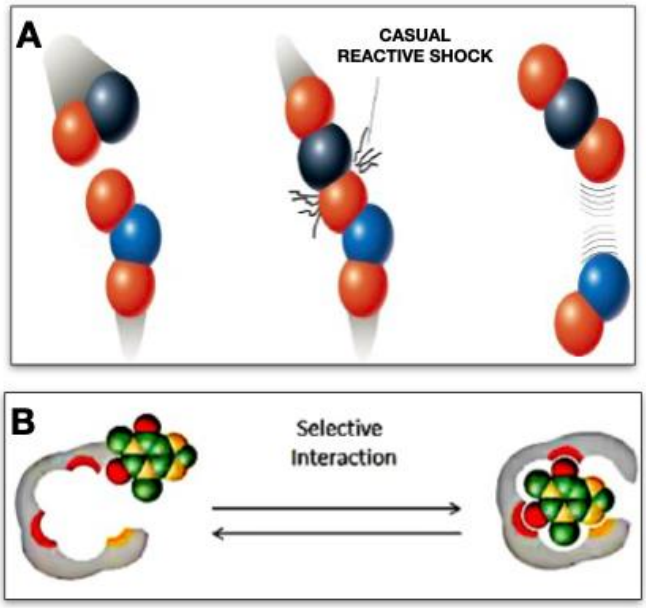


Figure 4- The main mode for which chemical transformations is explained through shock theory. Molecules of reagents can exchange atoms and give rise to the products only if , bumping , come into contact with each other .

Direct interaction is the most common interaction in the material universe and in chemical reactions that bring molecular structures into contact and lead to an exchange of matter and information. Through contact, their components are exchanged or fused, resulting from the breaking and reformation of the chemical bonds that form them.

Note that during the interaction, the interacting constituent elements (atoms) do not change; only their conformation and state of aggregation change, which requires energy consumption. This is the evolutionary mechanism in its most intimate essence.

The second type of interaction occurs when material bodies are separated in time and space and cannot come into contact with each other. In this case, the interaction must occur through changes that are transmitted through space-time and are of a wave, mechanical, or electromagnetic nature.

The change in molecular structures occurs independently of the cause that produced it and is mediated by the intervention of multiple entities in the sequence of the communication process.

The newly formed intermediate material entities participating in the interaction can modify their informational structure and transfer it to subsequent entities.

Thus, indirect communication occurs through the succession of structural changes produced at each interaction between the molecular entities participating in the global process.

This communication modality is capable of transferring an infinite amount of information and modulating it at each intermediate transformation, based on the needs imposed by environmental adaptation and the requirements that must be satisfied for the final result.

In living organisms, the communication processes that lead to the transformation of matter do not normally occur in a single step, but are divided into many small events that lead to the final result.

Here, communication is fragmented and changes appearance, becoming an organized set of interactions. Each substance used must undergo a series of steps to make it suitable in terms of morphological and energetic content before being transformed in the next sequential step, until the definitive, effective result is obtained.

Living organisms have adopted this type of communication which has established itself in the biological and metabolic cycles selected by evolution.

Let us remember, for example, glycolysis, the Krebs cycle, oxidative phosphorylation, etc.

By doing so, living organisms have the ability to modify, as they go, the molecular structures involved, their informational content, and their modes of interaction based on the feedback they exchange. All these processes allow for the production of a biologically effective and useful end result, which occurs in the aforementioned metabolic cycles in which information is translated from one system to another.

Let's cite some examples:
Protein synthesis, despite the central dogma of biology formulated by Watson and Crick, which later proved inadequate, consists in the transformation of a message contained in DNA into the structure of proteins, Fig.5.

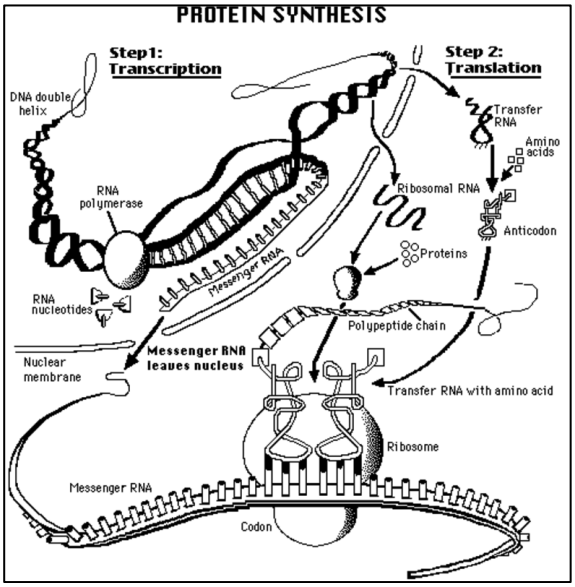


Figure 5-

In this case, the message and the communication to be transferred are written in the sequence of nitrogenous bases of DNA, which in itself has no direct information content, except that represented by the three-dimensional structure and steric disposition present in the double helix.

To transform the message contained in the sequence of nitrogenous bases into functional biological activity, the intervention of other molecules is necessary, which are messenger and transfer RNA, which first transcribe and then translate the original message into a sequence of amino acids.

Other examples include hormonal activity and nerve transmission. In these cases, communication occurs through the synthesis of special substances, hormones, and neurotransmitters, produced by specific cells, hormonal glands, and neurons. These substances are then sent to other target cells. Along the way, the message undergoes further modifications before reaching the intended target molecules.

These few examples indicate how important the role that molecules play in the direct or indirect transfer of information is. In both cases, there must be physical contact between molecules for the biological effect to be produced.

In summary, interaction is a primary mechanism for the transformation of matter;

- It involves substances that are in the same state of aggregation or in different states;
- It involves an exchange of information through direct contact of their respective steric and energetic conformations, and the breaking and formation of intra and intermolecular chemical bonds;
- The breaking and forming of bonds occurs through an intermediate transition state called the activated complex Fig.6.

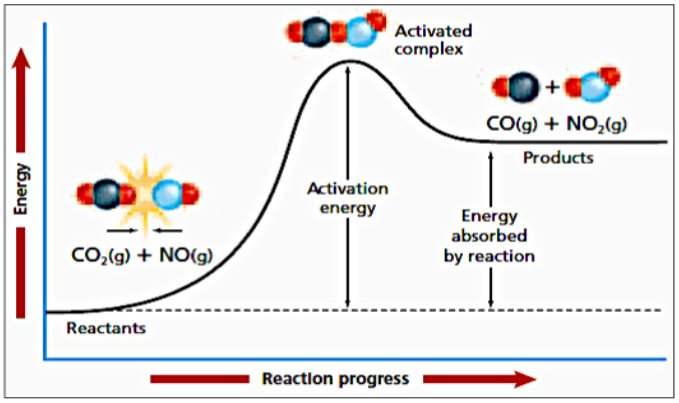


Figure 6- Formation of new compound

With the double articulation system that occurs with communication, the particles, atoms or molecules, produce the energetic-functional effect through mutual contact and the wave or physical medium that transports them has the kinetic role of enabling the contact.
They are both essential, they cannot exist separately.
It is the mechanism that allows the transformation of the material world and the transfer of energy carried by waves and material bodies.
And it is the same mechanism that is reproduced in the metabolism of living things, during which the energy content of the bonds that unite molecules is released in chemical interactions.
Throughout space-time, transformations occur thanks to the contact communication between material bodies transported by their wave systems, together they form universal energy.
Molecules have a functional role, the bonds that hold them together have an energetic role.

A special case of interaction.

In nature there are other examples of transmission for communicative purposes between material bodies.
Wave transmission is the universally adopted one.
The ways in which material bodies interact and contact each other depend on the intrinsic characteristics of the interacting materials, as we have identified above, but in any case it is essential that they adopt the same code or language, otherwise no interaction and communication is possible.

As for the structure of matter, we must recall the theories of quantum mechanics, to understand its properties.
If we stick to these theories, we must admit that the structure of matter is made up of equal or different atomic particles that can contain electrical charges in equilibrium, and are in constant motion in their environment.
We can then assume, as quantum mechanics itself informs us, that moving charges can generate a particular form of energy that has been defined as electromagnetic energy, and has both electric and magnetic properties.
In essence, we know that this energy is expressed and transmitted in wave form, which, due to its intrinsic properties, is capable of transferring numerous pieces of information through a single transmission medium.

Particles carried by electromagnetic waves modify space-time with their very mass and are therefore capable of transferring information and communicating. Mechanical waves share the same information-carrying capacity. With the infinite magnitudes that wave motion can assume, it is capable of transmitting a wide range of information.
Waves can be divided, as a first approximation, into elastic or mechanical waves and electromagnetic waves.
Both are characterised by a shape and energy content that can assume an infinite number of values, represented by the acoustic and electromagnetic spectrum, Fig.7.

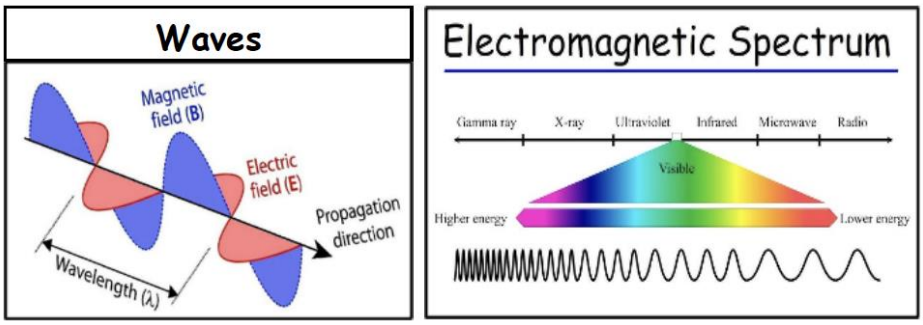


Figure 7-

The difference between mechanical waves, which produce sound, and electromagnetic waves is that the former do not transmit energy and, to propagate, require movement in a physical medium, regardless of its state of aggregation—gas, liquid, solid, or plasma—through which they transmit the wave motion. In this case, communication requires special reception systems capable of transforming the frequencies of mechanical oscillations into other forms of transmission.

High-frequency mechanical waves (sound) can also reproduce and transmit the shape and position of objects they come into contact with, as in bat sonar and ultrasound instruments.

Unlike sound waves, electromagnetic waves have the dual nature of waves and associated particles, and can be transmitted in any physical medium.

The evolution of communication

Previously, we saw that interaction and communication are linked to the very presence of matter, and we said that interaction is a two-way process that informs interacting materials of the physical-chemical properties they possess.

We also add that it is impossible not to communicate.
But why does matter communicate, and what does it communicate?
The answer cannot be derived from our subjective interpretation of the phenomenon, an interpretation that would introduce hypotheses linked to our knowledge and culture, but must be sought objectively and detachedly in the purely mechanistic, or if you prefer, quantum mechanical, effect that the interaction produces, without seeking teleological ends.
Molecular interaction is the way molecules interact with each other to form bonds, which can be weak or strong, giving rise to new structures. These interactions can occur through various mechanisms, such as chemical bonds, noncovalent forces, and hydrophobic interactions.

If we analyze the phenomenon in detail from a chemical point of view, we observe that the elementary substances, atoms, that interact with each other do not change their structure; what changes is their state of aggregation and the modalities and geometry of the bond that unites them.
In accordance with the law of conservation of mass, according to which: " *Nothing is created, nothing is destroyed, everything is transformed* ", Lavoisier, 18th century, the elementary particles remain the same, only their conformational binding energy that they assume in the newly formed structure changes.
It is interesting to note that the same atoms, recombining with each other in different ways, present infinite ways of expressing their energy content, which once again, depends on their spatial arrangement, and on the type of bond that unites them Fig.5.
Normally, atoms are joined by bonds, which involve the sharing of electrons in the outermost shell of their respective orbitals. This type of bond is called covalent.
By doing this, both atoms reach a more stable energy configuration and therefore the nuclear and electronic charges balance each other out and form a system in equilibrium.
The same phenomenon occurs between molecules, when they share the electrons that are part of their molecular structure and exchange the distribution of bonds Fig.8.

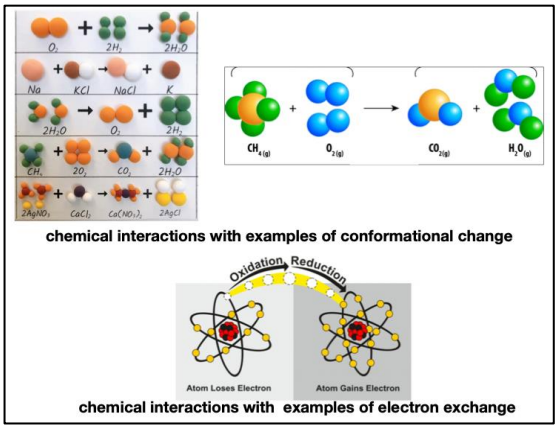


Figure 8- Example of chemical interactions

In some cases, molecules can exchange electrons in their outermost orbitals, so there are atoms that lose electrons (reducers) and atoms that gain them (oxidizers), as in oxidation-reduction reactions, or as in the formation of ionic and metallic bonds Fig.9.

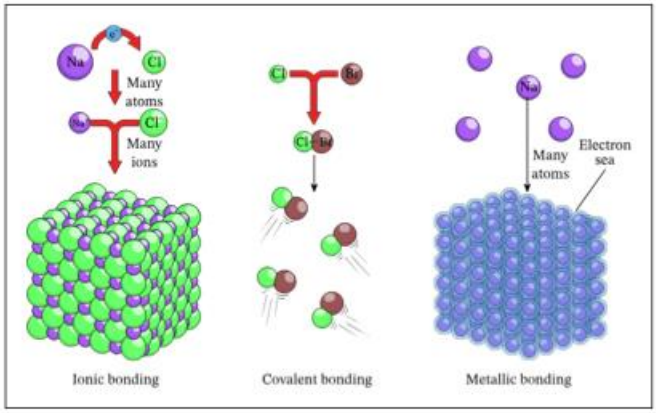


Figure 9- Ionic and Metallic bonds

This has a fundamental scientific significance, the energy of a molecular aggregate depends not so much on the elements that constitute it, but on their bonding modes and mutual interactions, Table 1.

guest	calculated ΔE	calculated $\Delta H_{298.15}$	calculated ΔH_{318}	experimental ΔH_{318}
(Fe3opt0–guest)				
methane	7.8	6.8	6.7	4.8
ethane	8.8	7.6	7.5	6.0
ethylene	12.3	11.0	10.9	10.8
acetylene	12.3	11.8	11.8	11.2
propane	9.9	8.6	8.6	7.9
propylene	14.3	13.0	13.0	10.5
(Fe3opt1–guest)				
methane	6.7	5.6	5.6	4.8
ethane	8.3	7.1	7.0	6.0
ethylene	11.9	10.8	10.7	10.8
acetylene	12.7	12.4	12.4	11.2
propane	9.8	8.6	8.5	7.9
propylene	14.2	13.0	12.9	10.5
(Fe3opt12–guest)				
methane	6.6	5.5	5.4	4.8
ethane	8.5	7.3	7.3	6.0
ethylene	15.1	14.0	14.0	10.8
acetylene	14.5	14.3	14.2	11.2
propane	9.0	7.6	7.6	7.9
propylene	16.5	15.4	15.3	10.5

(A)

Chemical Elements	E	L
H-H	432	74
H-B	389	119
H-C	411	109
H-Si	318	148
H-Ge	288	153
H-Sn	251	170
H-N	386	101
H-P	322	144
H-As	247	152
H-O	459	96
H-S	363	134
H-Se	276	146

Chemical Elements	E	L
N-Cl	313	175
P-P	201	221
P-O	335	163
P=O	544	150
P=S	335	186
P-F	490	154
P-Cl	326	203
P-Br	264	
P-I	184	
As-As	146	243
As-O	301	178
As-F	484	171

(B)

Tab 1 Bond energy between the same atoms, Carbon and Hydrogen, bonded differently **(A)** And between different atoms **(B)** : **E** Bond Energy - **L** Bond Length

We've seen that interaction is followed by steric recognition, the process by which molecules recognize each other based on their shape and three-dimensional structure. This can occur through the interaction of specific functional groups, binding sites, or molecular conformations that fit together in a complementary fashion.

Molecular interaction and structural recognition are essential in various biological processes, such as the regulation of enzymatic activity, cell signaling, antigen-antibody binding, and so on.

Recognition through molecular adhesion allows for the distinction and selection between different competing molecules, through mechanisms that involve mutual recognition and subsequent conformational variation.

As molecular complexity increased during evolution and primitive ancestral living species (prokaryotes) were formed, they then differentiated into multicellular organisms. In these organisms, the task of communicating with each other and the external environment passed to the receptors present in their sensory cells, [20-22].

We hypothesize that as the molecular and structural complexity of living organisms increased, the need to maintain contact between all the components of the structure became pressing, and to maintain overall homeostasis, they had to form a widespread communication network regulated by continuously active feedback.

If we add to this that the structural multiplicity we observe in nature required functional specialization, with the formation of dedicated cell groups, we understand how difficult it must be to maintain even the simplest multicellular organism in synergistic and synchronous balance.

Attempts have been made to simulate this network of interactions using modern computers, but they have failed to come close to natural models.

III. Conclusion

These last considerations lead us to conclude that the long evolutionary journey that has populated our planet with an infinite number of living forms would not have been possible without the fundamental mechanism of interaction and communication between the multiple material entities of their constituent elements.

At this point we can try to answer the question we posed previously: why does matter communicate and what does it communicate?

Matter communicates by the very fact of its existence and thus informs the space-time environment and the other substances it encounters of its properties and characteristics.

The aim is to exchange their energetic-conformational contents that produce modifications in matter, in search of increasingly complex forms that can ultimately give meaning to their evolution.

One interpretation could summarize the intrinsic meaning of the molecular exchanges that occur in chemical transformations: that what is important is not the type of interacting molecules, but the informational content of the energy and the bonding modality that unites them.

These processes are encoded in the metabolic systems of all living organisms; the molecules are more or less always the same. What fuels life is the energy exchanged through the transfer and transformation of the same molecular groups. Fig. 10.

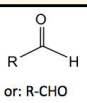
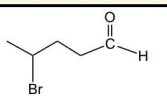
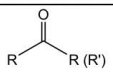
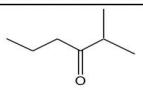
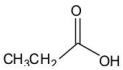
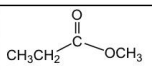
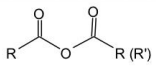
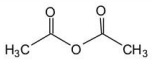
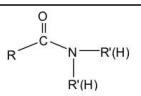
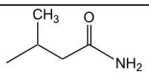
Class of Compounds	General Structure	Specific Example	Notes
Aldehyde	 or: R-CHO		C=O double bond is usually called as a **"carbonyl"** group. The function groups on this page all contain carbonyl group.
Ketone			
Carboxylic acid	 *or:* R-COOH		Reaction with base gives salt of carboxylic acid, $RCOO^-M^+$
Ester			Carboxylic acid derivative.
Anhydride			Carboxylic acid derivative.
Amide			Carboxylic acid derivative

Figure10- Functional groups of organic molecules

It is thanks to these contents that we can define life as energy in transformation,
The analogy between material communication systems and language, which is the highest expression of communication, comes naturally.
Language, too, is made up of distinct and unique elements, the character signs and phonemes that identify a particular language and culture, and it is to the logical and sequential interaction of these elements that we owe it if we can communicate effectively, or write this article.

We are surprised and amazed by the astonishing spectacle that insignificant material elements, if correctly and harmoniously interacted with each other, can present to us.
Yet, incredibly, we are unable to express the amazement and emotions that these manifestations evoke in our common feeling.

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