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From Photosensitive Molecules to the Evolution of Living Been

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ABSTRACT

All our knowledge leads us to believe that the origin of life was the formation of photosensitive molecules, which then contributed to the birth of primitive living organisms, such as cyanobacteria and cyanophyceae. Once these archaic organisms were able to feed and reproduce, other organisms would have acquired the ability to enter into symbiosis with them, taking mutual advantage of continuity and metabolic efficiency. In this article we try to trace the possible paths of this intriguing story, presenting hypotheses that are plausible, or that are a stimulus for further investigation.

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Introduction

The description of the singularity postulated by quantum physics at the origin of the universe, when it expressed its explosive energy content, did so in the form of light and gave rise to the first clusters of elementary atoms, originally super-compressed at very high energy. Even when the incandescent masses expanded, according to the Big Bang theory, they did so while maintaining a mutual interaction, necessary to promote the evolution of matter. Because only with the interaction between all particles in the universe, change is possible.

There must be a common denominator in the molecular mechanism of the receptor systems with which living beings, plants and animals, are equipped, since they are essential for their behavior in response to environmental stimuli. All living organisms have developed the ability to adapt to sidereal variations in Earth's illumination and to the succession of the seasons. Solar radiation played a decisive role in the birth and evolution of life on Earth. All organisms in the animal and plant kingdoms depend on the sidereal circadian rhythm, the light and dark cycle that inexorably marks their vital rhythms [1-3].

This is a very efficient and sensitive molecular mechanism, which has remained unchanged over millions of years of biological evolution, and has changed according to the particular environmental conditions to which individual organisms have adapted [4-6].

In the different chlorophylls of autotrophic cyanobacteria and of cyanophyceae, in the visual purple and in the suprachiasmatic nucleus of mammals, the same photosensitive molecular mechanism is present, capable of responding to light stimuli, which represent the primary energy of all vital functions. And it is the first and most powerful system of environmental conditioning, which has demonstrated a superior efficacy even to that exerted by food needs or reproductive stimuli and behaviors.

The mechanism of the circadian rhythm is fundamentally the same in all living things, and is based on the modifications imposed by the light and atmospheric conditions present on earth. Only the protein apparatus containing the photosensitive molecules changes, which have adapted to the particular conditions of exposure to environmental lighting. The complex cotyloid discs of plant chlorophylls, the photoreceptors of the retina in vertebrates, the ommatidia of insects, and the suprachiasmatic nuclei respond with the same molecular mechanism to photon stimuli, which represent the trigger system for activating cellular metabolism. This is the analogous molecular process that occurs, for example, in the light phase of plant chlorophyll and continues in the dark phase with the metabolism of photosynthesis.

Molecules and Receptor Systems

Before entering into the heart of the discussion of the photoreceptor mechanism, the subject of this article, it is necessary to introduce the fundamental concepts and properties of receptor systems. Receptor systems have played a key role in the development of life on our planet. They are present in all living organisms and are the indispensable tool for interaction and adaptation with the environmental system [7-10].

The main characteristics of the receptor systems are the following [11]:

1. They are systems linked to specific sense organs that form the receptive structure of living beings;
2. They are formed by macromolecular protein complexes capable of modulating their steric conformation, in response to the stimulus received and of transducing it to the rest of the target organs;
3. They contain within them ionic complexes or organic molecules that have the capacity to respond to specific stimuli within their competence: they are electromagnetic, mechanical, thermal, gravitational stimuli, and therefore they are the true regulatory and activating centre of the receptor

system;

4. The protein macromolecules from which they are formed are rigidly associated with the plasma membrane that contains them, and occupy a precise arrangement within it, determined by the metabolic role assigned to them with protein synthesis;
5. The exposed portion of the protein structures protrudes inside and outside the membrane, so as to interact with effector molecules present inside and outside the membrane itself;
6. Because protein complexes are bound to the plasma membrane and are immobile, they must use carrier molecules to transmit the received energy to metabolic intermediaries.

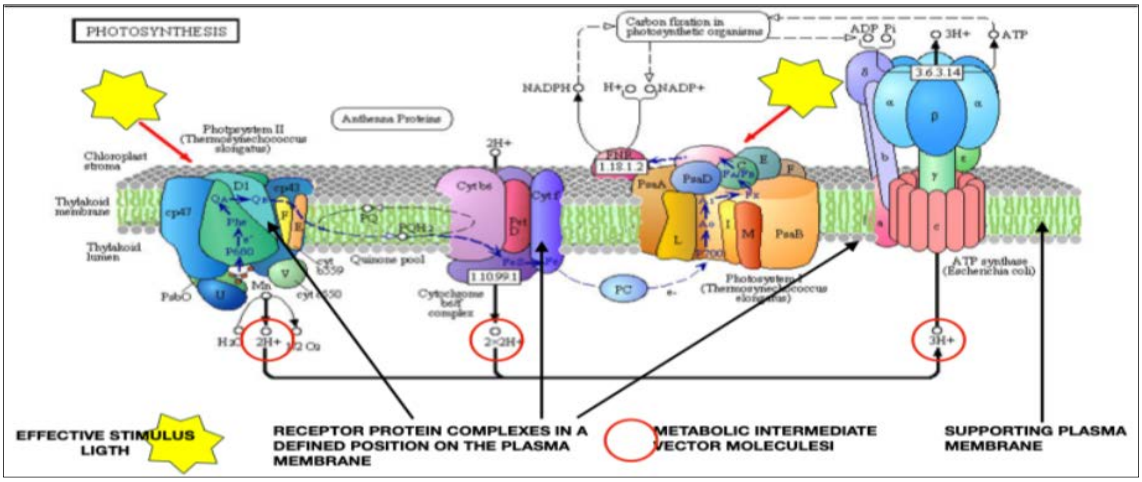

Figure 1: Schematic of the Photoreceptor System Present in the Thylakoid Membranes of Plants

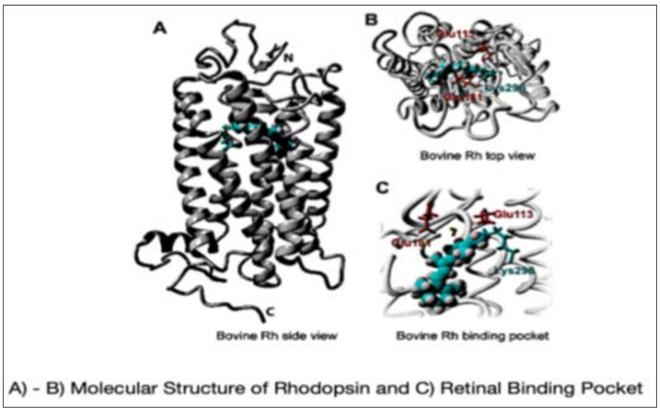

Figure 2: Molecular Structure of Rhodopsin and Retinal Binding Pocket

The system that associates the protein centers of energy transport in a defined arrangement on the plasma membranes has had a great success in the evolution of living beings, and we find similar arrangements also in the membranes of mitochondria, in the endoplasmic reticulum, in the Golgi apparatus, etc. universally used for metabolism and to obtain energy in the form of ATP Figure 3.

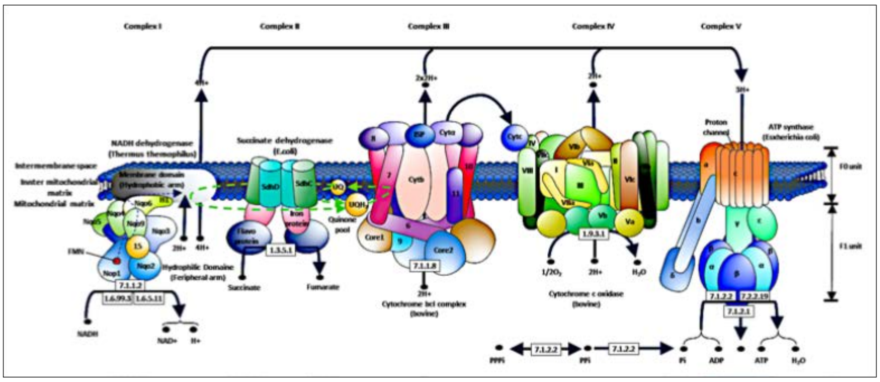

Figure 3: Scheme of Oxidative Phosphorylation, or Respiratory Chain, demonstrating the Sequential Arrangement of Electron -Carrying Molecular Complexes on the Mitochondrial Membrane

Let us see how this molecular mechanism has been realized in the photoreceptor complexes of plants and animals.

The Photoreceptors

To understand the mechanism of light excitation it is necessary to know the properties of light and photosensitive molecules, that is, those molecular complexes capable of capturing energy from light sources and transferring it to metabolic systems.

These photosensitive molecules have marked the processes of the evolution of life, since they were able to transfer the absorbed solar energy, the only energy available in the primordial Earth's atmosphere, into vital energy, by modifying their conformational state. These molecules had to be able to [12-13]:

- Use the energy of the various radiations coming from the sun and transform it into nutritional molecules,
- Adapt to the intensity and wavelength of solar radiation,
- Adapt to the circadian and seasonal variations of radiation itself, dependent on the cycle of rotation and revolution of the Earth in its orbit around the sun.

Over the course of millions of years, the composition of the Earth's atmosphere has changed, from the initial presence of gaseous molecules such as methane CH4, ammonia NH3, carbon dioxide CO2, water vapour H2O and hydrogen sulphide SH2, it has transformed into a gaseous composition capable of filtering solar rays, and allowing only the passage of electromagnetic waves with a narrow range of frequencies, between ultraviolet rays and infrared rays.

The crucial step that gave rise to life on Earth was precisely the genesis of photosensitive molecular complexes with the properties we have described. Subsequently, the specialization of photosensitive biopolymers occurred with the adaptation to various degrees of ambient lighting, and to the inorganic molecules available in the environment, to use them as food resources. All this was achieved with a series of photosynthetic oxidation-reduction reactions. The aggregation of these photosynthetic molecules into complex systems gave rise to primordial autotrophic organisms.

We must now outline the fundamental properties of light and photosensitive molecules.

Electromagnetic Energy Gave Rise to the Universe and Life

Light waves are produced by fluctuations in the electromagnetic field that propagate through space. They represent a form of radiant energy and are responsible for what the human eye and other photosensitive systems perceive [14-15].

One of the fundamental properties of light waves is their electromagnetic nature. They are composed of electric and magnetic radiations with their own energies and fields, which oscillate in orthogonal directions to each other, synchronized and coordinated, as they move through space Figure 4.

Light waves have an undulatory and corpuscular nature, represented by photons, and are defined by their physical quantities: ***wavelength, amplitude, frequency, intensity***. They are therefore physical entities capable of transferring multiple pieces of information along their path and with a single vector. Figure 4.

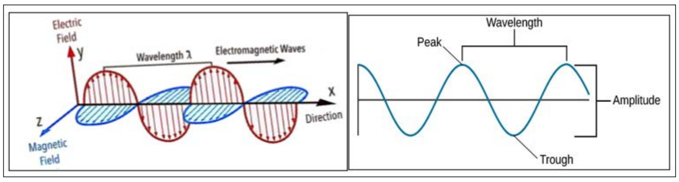

Figure 4: Electromagnetic Waves

According to quantum mechanics, the light phase of photosynthesis represents the consequence of a mechanical, rather than energetic, effect induced by ***photons (Ps) or light quanta*** when they interact with the electrons of the photosynthetic pigments.

Although photons are much smaller than electrons, since 100,000 trillion photons travel per second in a beam of visible light, or 1014 quanta, this enormous quantity of photons would produce, at the electronic level, a mechanical collision phenomenon rather than a purely energetic action.

Therefore, the photons in the mechanism of photosynthesis would behave like corpuscles that determine the release of two electrons from the water molecules (photolysis of water) which trigger all the photochemical and biochemical processes necessary for the construction of organic molecules (sugars and others) essential for the life of the plant.

The Electromagnetic Frequency Spectrum

Waves are divided into: Sound waves, Electromagnetic waves and Gravitational waves, based on their intrinsic physical properties, the ways in which they are transmitted and the effects they produce on the matter that receives them.

The waves on which we will focus our attention are electromagnetic waves, with particular reference to those of the visible spectrum Figure 5.

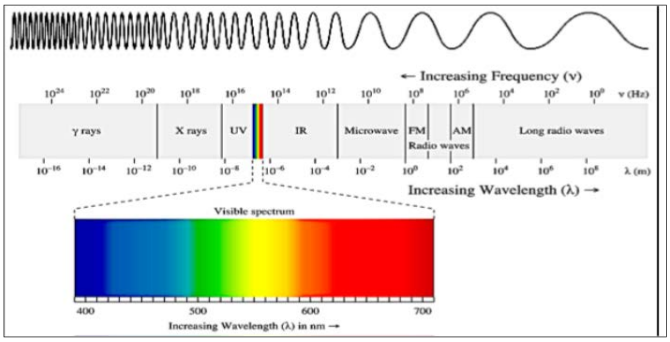

Figure 5: Electromagnetic Spectrum

There is a close correlation between the frequency of the waves and the photosensitive molecules capable of collecting them and modifying their conformation and energy content based on the frequencies received.

Light radiation is the pivotal event that initiates all processes essential for life. In this sense there has been a selection and adaptation of photosensitive molecules, in the course of evolution, to the succession of different climatic conditions, and to the different available frequencies. Generally, frequencies that emit long wavelengths have photons with lower energy content than those that transmit shorter waves. The intuitive explanation is that high frequencies have shorter wavelengths; therefore, they produce a greater number of collisions per unit time on the photosensitive molecules than do those with low frequencies, Figure 5.

Hypotheses on the Origin of Photosensitive Systems
The primitive photosensitive molecular complexes, called Photosystems, were formed by a backbone of protein macromolecules that contained organic compounds, or photosensitive prosthetic groups [16-17]. Together they could carry out the basic steps of photosynthesis, with the absorption of solar radiation and the transfer of energy and electrons to other molecules. Originally these photosystems were isolated, later they associated with the primitive lamellar structures, which would constitute the **thylakoid membranes** of primitive unicellular organisms. Thylakoid membranes are found inside the chloroplasts of plants and algae, and in the cytoplasmic membrane of photosynthetic bacteria, Cyanobacteria. There are two types of photosystems: PSI and PSII.

The functional unit of the thylakoid membrane is formed by the membrane itself, which contains the complex of photosensitive molecules, arranged in a precise order that respects their increasing redox potential, Figure 6 [18-20].

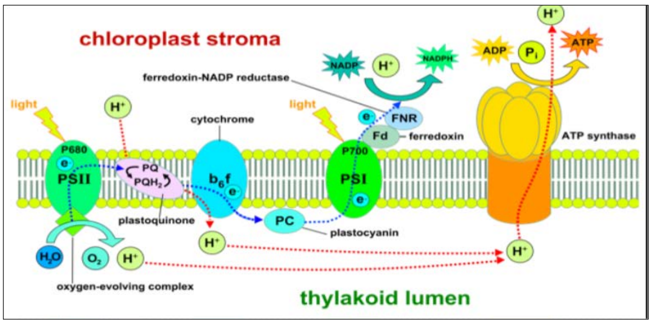

Figure 6: Schematic Structure of the Thylakoid Membrane and Photosystems I and II: PSI (Photosystem I), PSII (Photosystem II)

The diagram in Figure 6 represents the flow of electrons starting from Photosystem II, from the hydrogen ions that derive from the splitting of water and through Plastoquinone, Cytochrome and Photosystem I, to arrive at ATP Synthase which generates ATP.

To understand the fundamental mechanism that regulates the functioning of these systems, we must describe their salient properties, ask ourselves why they have these properties, and give logical answers, starting from the scheme represented in Figure 6.

The photosensitive systems, in their basic scheme, follow the same arrangement already described for the receptor systems:

1. They have a supporting structure, a sort of scaffolding, of a protein nature.
2. They are proteins with high molecular weight and complex polymeric conformation.
3. Each protein carries a different reaction center, made up of photosensitive organic molecules, reactive to light rays.
4. They have a rigidly defined spatial arrangement on the various membranes to which they are anchored.
5. The various membranes to which they are linked have the typical structure formed by phospholipids, repeatedly folded on themselves, with the evident aim of increasing the surface area exposed to light radiation.

The organic molecules, which form the photosynthetic reaction centers, although they present different structures and are recognizable and distinct from each other, must necessarily bind to proteins as prosthetic groups, because if they were isolated, they would be distributed randomly within the photosensitive organs. By binding to proteins, they follow the fate of these, they are formed with protein synthesis according to their typical structures (primary, secondary, tertiary, quaternary) and are transported to the specific recipient membranes, according to the order and exact spatial arrangement assigned to them, Figure 3 and Figure 6. Once settled in their positions, they will form a functional unitary center, which is repeated several times on the same membranes.

All the membranes of the various photosensitive receptor systems fold on themselves, but with a characteristic arrangement, as in the thylakoid lamellae or in the retinal discs which contain the photoactive molecules, Chlorophylls and Rhodopsin's.

In nature there are various photoreceptor systems, specialized to receive distinct light frequencies.
The first major distinction to make is between plant photoreceptors (Chloroplasts) Figure 7 and animals Figure 8.

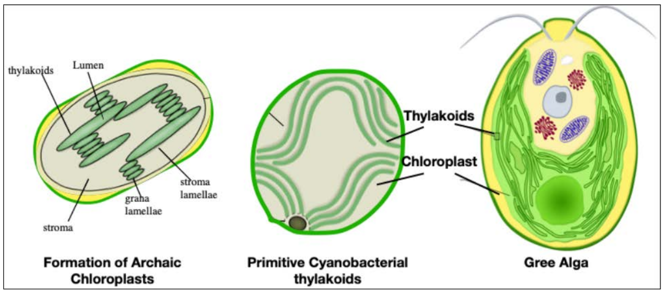

Figure 7: Thylakoid Membranes and Chloroplasts

The first photoreceptors to appear in the evolutionary history of photosensitive molecules were the photosystems of cyanobacteria, single-celled algae and later plants.

Photosystem II (PS2) (water - plastoquinone redox) is the first protein complex involved in the energy reactions of oxygenic photosynthesis. It is found in the thylakoid membrane of plants, algae and cyanobacteria. The system captures photons from sunlight that energize electrons that are then transferred to coenzymes and cofactors to reduce plastoquinone to plastoquinol. The energized electrons are replaced by water to form hydrogen ions and molecular oxygen.

With the electrons obtained from the splitting of water, Photosystem II provides electrons for all photosynthesis. The protons **H+**, generated by the oxidation of water create a hydrogen ion gradient that is used by **ATP synthase** to produce ATP. The thus energized electrons are transferred to plastoquinone, and are finally used to reduce NADP+ to NADPH or are used in noncyclic electron flows Figure 6.

Photosystem I (PSI, or Plastocyanin-Ferredoxin Oxidoreductase) is the second membrane protein complex that uses solar radiation to activate the transfer of electrons across the thylakoid membrane, from Plastocyanin to Ferredoxin. The electrons transferred from Photosystem I are used to produce the energy compound NADPH, and also produce a chemiosmotic force that is used to generate ATP, Figure 6.

We find the same architecture also in other photoreceptor systems, such as in the visual purple, the **Rhodopsin** of the retina of many vertebrates, with the arrangement in lamellae and photosensitive molecules Figure 9.

But the real revolution occurred when these molecular complexes were equipped with membranes organised in lamellar structures and with a membrane separating them from the external environment [21].

The organization in primordial lamellar structures, folded on themselves and in membranes separating them from the outside, gave rise to the first forms of cyanobacteria and unicellular algae Figure 7.

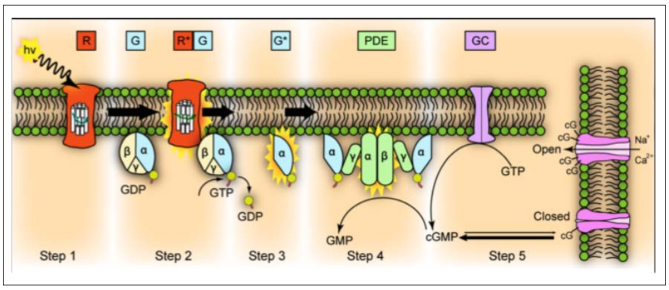

Figure 8: Schematic of Reactions in the Visual System of Vertebrates

If we examine the level of organization present in the photosensitive systems of plants and animals we are amazed by the degree of perfection and efficiency they have achieved over the course of evolution.

Returning to the observations made previously regarding the arrangement of the cotyloid membranes and lamellar discs of the retinal rods and cones and their folding on themselves, it can be seen that this type of structure occurs very often in nature.

The success and diffusion of such architectures depends on the possibility of arranging complex organizations in very small volumes Figure 8, in which a functional unitary scheme is repeated over the entire surface to be covered.

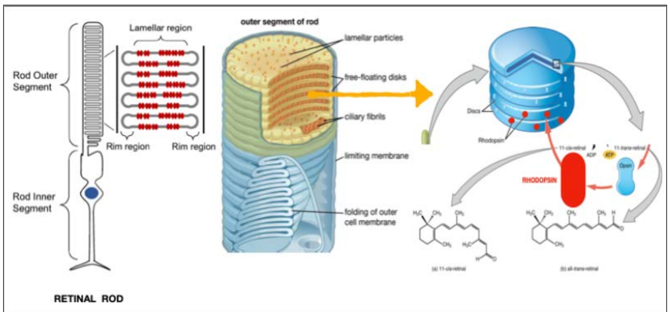

Figure 9: Scheme of Lamellar Arrangement of Photoreceptors

We find an infinite number of other similar examples within the cellular organization.
The membrane system present in the cells of living organisms presents notable advantages:
the separation of metabolic functions into isolated environments and compartments, organized by type of activity, allows the system to function in a coordinated and simultaneous manner, without interference or hindrance between different metabolic pathways Figure 10.

The spatial arrangement of the enzymatic systems and metabolic steps, on the respective membranes, follows the sequential order in which they must occur, it is also useful to verify, with feedback systems, that each metabolic step occurs in the correct order. This sequential system has a crucial role in protein synthesis and DNA replication, and in many other sequential metabolic systems. The separation between different environments does not have an absolute value, however, there is still the possibility of contact between them, which occurs with chemical messengers, necessary to coordinate the overall metabolism.

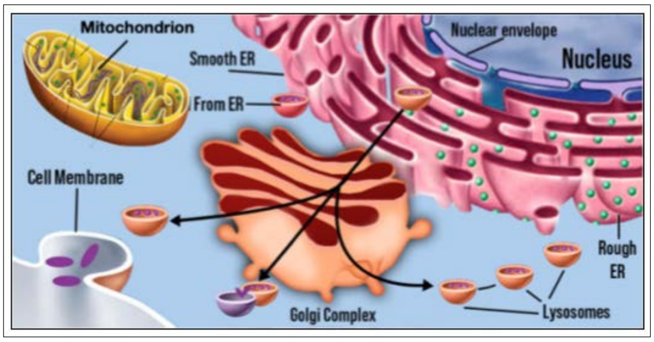

Figure 10: Division of the Cell into Metabolic Compartments Separated by Membranes

FROM: Probing the biogenesis pathway and dynamics of thylakoid membranes

Let's define cell photoreceptor: any cell That contains proteins photo exciters in the plasma membrane, which I am able to start a cascade of phototransduction reactions When exposed to the light. Several strategies have been developed to optimize the energy supply bright in photosynthetic membranes capable of responding even under lighting conditions floating.

The photoreceptors they need large amount of membrane to contain proteins sensory and transduction and, as in other sensory cells, the membranes are formed from modified microvilli or cilium. In photoreceptors from the vision, form the **photoreceptors microvillari,** the microvilli are products from evaginations of the plasma membrane, and they are collected in structures calls **rhabdomers**, which contain photopigment and other proteins essential for transduction [22-23].

In photoreceptors ciliary, invaginations of the membrane yes form above the body basal of an eyelash, Figure 11.

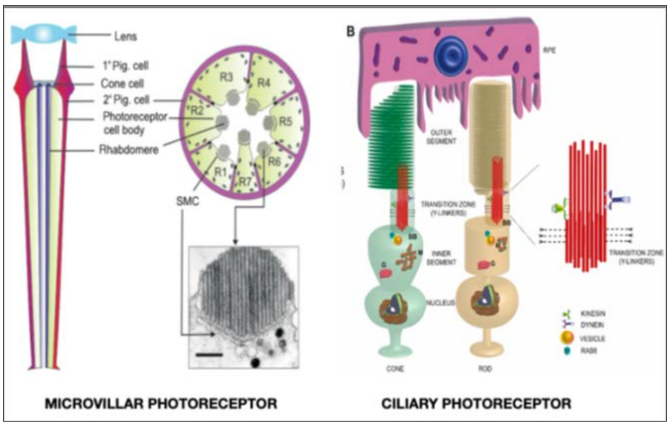

Figure 11: Photoreceptors

As we have Already mentioned, the task of the membranes is to house the complex photoreceptor protein That contains the molecules photosensitive, which is the real one transduction center from the energy bright in flow of electrons.

Photosensitive molecules are chemical compounds that can absorb light energy (especially visible, UV, or infrared light) and convert it into chemical energy, resulting in photochemical reactions. These molecules are able to change their energy state when exposed to light, often from a resting electronic configuration to an excited state.

At the nanoscopic level, molecules react with light when they absorb particles of light energy (known as photons) and enter an excited energy state. To regain energetic stability, molecules react with surrounding particles or undergo conformational changes [24-25].

Light is the primary source of energy for all plants and for most living organisms that feed on plants. And it is essential to understand how the light-plant relationship is established and how plants convert light into usable/available and efficient energy.

Macromolecules photoreceptors contain within them molecules with structure cyclical unsaturated, in which the bonding electrons they can move from one orbital to the other When I am hit from appropriate light frequencies, Figure 12 [26].

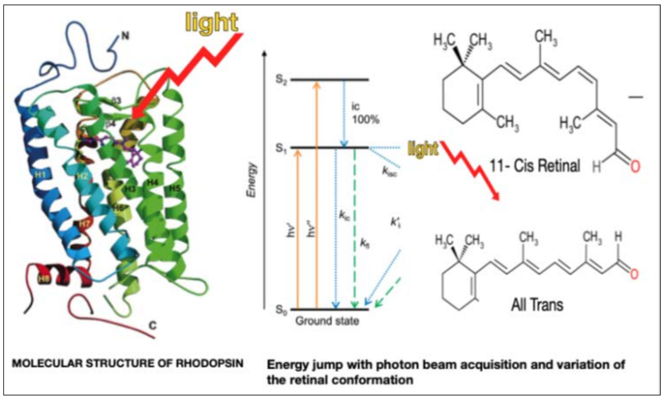

Figure 12: Plants with their nutrient content I am used from animals' herbivores, which from their consumption they draw energy. So yes, closes the circle vital and energetic Figure 13.

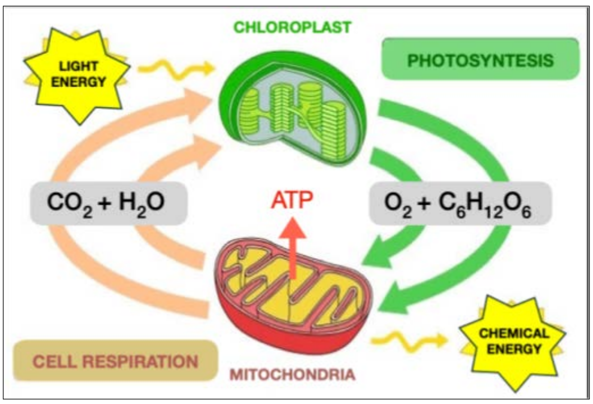

Figure 13: Observing Organic Molecules

That they form the center motor photosensitive, yes can note how many, if not all, have a structure chemistry made up of dienes married, in which Yes alternate long their entire structure, single and double bonds, and are called resonance forms, and they are they find in aromatic molecules. We report some examples Figure 14.

Aromatic chemical bonds are typical of molecules that present ring structures with a high degree of stability, as in the case of aromatic hydrocarbons. The main property of these bonds is the **delocalization of electrons** within the ring, which gives them a series of particular characteristics [27-28].

Molecules that exhibit the phenomenon of resonance have a bond structure that is not fixed but represents an average between different structures (called resonant), all equivalent to each other. For example, in benzene, the positions of the double bonds alternate between the carbons.

Aromatic compounds tend to participate in specific chemical reactions, such as **electrophilic aromatic substitutions**, rather than addition reactions, which would be destabilizing for the aromatic system, which consists in the overlapping of p orbitals to form the π-electron system, Figure 14. These characteristics make aromatic compounds very stable molecules with unique chemical properties, compared to other types of chemical compounds.

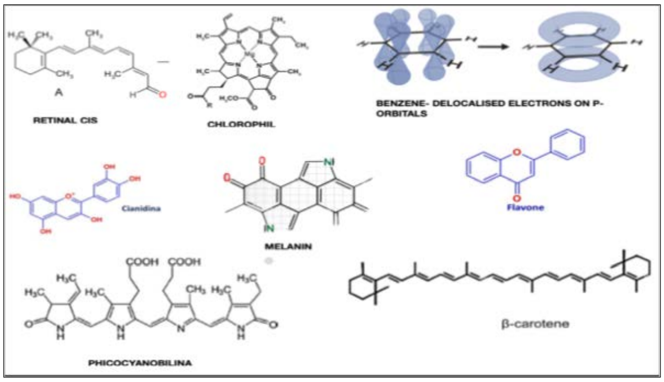

Figure 14: Examples of Structures Aromatic

A compound is aromatic if it respects these 4 **aromaticity rules**:

- Its structure is cyclical, that is, closed in itself,
- It has a planar structure in which the p orbitals are parallel to each other, orthogonal to the molecule itself.
- The structure is completely conjugated, that is, there is a p orbital in each joint of the ring,
- Has **Huckel 's number**.

The molecules complex present in nature have Often a structure cyclic type aromatic, this structure facilitates the passage of electrons from a molecule to the other, until to the final acceptor, which It is usually oxygen [29].

Conclusion

We have our journey began through an imaginary path, which starting from a few elements' chemicals such as water and anhydrite carbonated and with the essential's energy supply solar, originated, in course of a millenary evolution, the construction of particulars molecules photosensitive, which they have given start to life.

Despite the studies and hypotheses of many researchers, still Today we are unable to understand which are the mechanisms elementary That they have gave rise to the extraordinary shapes living That populate our planet.

In outlining the hypothetical evolutionary process of life on earth, we cannot ignore also the role that our planet has played, not only as a substrate for mineral resources, but as an active and fundamental participant fully involved in the life cycle.
We are losing consciousness of the importance of the close bond that binds the living to our planet and the reciprocal influence that one exerts on the atres, and how this influence has shaped over millions of years the evolution of life.

In the last century, human activity has upset the balance between life and the land that hosts it, so much so that we speak of Anthropocene, to highlight the harmful effect that man has produced on our planet, which is the only one available.

The article also wants to be a witness of this complaint. Is it possible to assume an evolutionary continuity between the systems of energy transport from the planet, from plants to animals, and their necessary coexistence in the same environment? Figure 15.

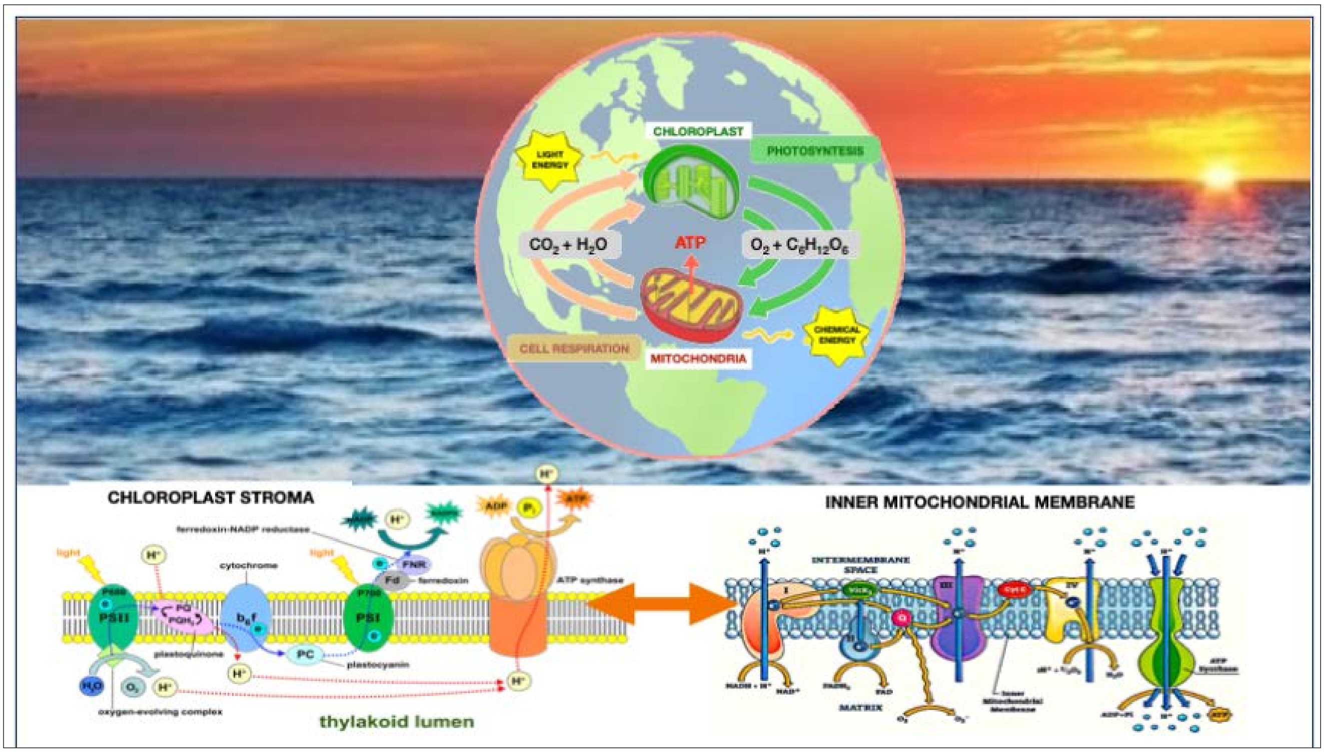

Figure 15: Flow Continuity Scheme Energetic Originated Come on Rays Solar

Disclosure

The author declares that he has no conflicts of interest in this article

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