

RETINAL PHOTONIC STIMULATION: A QUANTUM MECHANICAL EFFECT

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Abstract. The radiation pressure of light acts on retinal photoreceptors with a frankly quantum-mechanical effect. It follows that, in agreement with Feynman, to fully understand the marvelous Mechanism of Seeing in all its essence, it is necessary to consider that not only Biochemistry, but also solid-state Physics plays a major role in this phenomenon. Analyzing a rod cell under an electronic microscope, layer after layer of plane structures containing rhodopsin molecules are all aligned with each other. It may be that all of the molecules are arranged in some kind of a row so that when one is excited an electron which is generated may run all the way down to some place at the end to get the signal out, or something like it, will ultimately be used. That is, just like a domino effect! This powerful quantum-mechanical action, with which photons act on the retinal pigment molecules, can be better justified and understood if we take into account, as emerges from our calculations, that the momentum of a photon in the optical band carries a mass-energy density equal to $1.325 \cdot 10^{-22}$ grams per centimeter per second, that is, over 100,000 times greater than the rest mass of an electron.

Keywords: *photon, retina, electromagnetic radiation, chlorophyllose photosynthesis, energy, Adenosine Triphosphate (ATP)*

Introduction

Light stimulates the retina through the so-called phototransduction process, through which retinal photoreceptors (rods and cones) affected by photons (Ps), thanks to photosensitive pigments, trigger a biochemical reaction (hyperpolarization), converting the light energy of the Ps into electrical signals. These signals are immediately processed by the layers of retinal and subretinal neurons and, through a process of preliminary interpretation of the light signal, which already occurs in the retina, are channeled into the optic nerve and, through the entire circuit of optic pathways (OP), transmitted to the brain, where they are interpreted as images, colors, shapes and depths, movements, etc. In this regard, in fact, Feynman points out: “There is no question that one part of the surface of the retina (R) is connected to other parts, and that the information that comes out on the long axons, which produce the optic nerve, are combinations of information from many cells. There are three layers of cells in the succession of function: there are retinal cells, which are the ones that the light affects, an intermediate cell which takes information from a single or a few retinal cells and gives it out again to several cells in a third layer of cells and carries it to the brain” (Feynman et al., 1965).

Materials and Method

Nature and Constitution of Electromagnetic Radiation (EMR)

As it is known, in September 1909 Planck invited Einstein to talk to the eighty-first Meeting of the “Gesellschaft Deutscher Naturforscher und Ärzte”, in Salzburg, where Einstein presented a new research: ‘On the Development of Our Views Concerning the

Nature and Constitution of Radiation', maintaining that, as an electron, every quantum of radiation propagates in a specific direction: technically the quantum has a momentum (p) (Einstein, 1909). Moreover, the elimination of the ether implies that light propagating through empty space consists of electromagnetic fields behaving as "independent structures" ("selbständige Gebilde") (Einstein, 1909). Furthermore, "according to the theory of relativity, light has the characteristic in common with corpuscular theory of transferring inertial mass from the emitting to the absorbing body" (Einstein, 1909). In view of the presence of both wave and corpuscular terms in fluctuations of black-body radiation, Einstein argued that a new "mathematical theory of radiation" ("mathematische Theorie der Strahlung") was needed, which "can be considered as a sort of fusion of the wave and the emission theory of light" (Einstein, 1909). In this regard, we report from a Seminar of Madame Rinaudo: "What is there to understand in Planck's formula? This formula links energy (E) to frequency (ν) with a proportionality coefficient h , or quantum of action, which is a natural constant (Eq. (1).

$$E = h * \nu \quad \text{Eq. (1)}$$

Energy and frequency are concepts that belong to different phenomena, because energy is a properties that, in Classical Physics, we usually associate with a material body, well localised in space-time, to which, however, it is difficult to associate a frequency. In turn, frequency is characteristic of a periodic phenomenon, with which, however, it is difficult to associate a well-localised energy in space-time. In Classic Physics, energy often plays a marginal role (compared to to other concepts), but in Quantum Mechanics energy is the crucial quantity: energy must be traced back to its role as a 'state variable' and, as such, a fundamental and unifying descriptor of phenomena. Moreover, Planck's relationship is revolutionary because it expresses a link between energy and frequency of an electromagnetic field (EMF): energy is typical of material corpuscles, while the frequency represents a characteristic property of a wave. According to Einstein's interpretation, the energy of an EMF is quantised. The value of the elementary quantum of energy (E), of frequency ν , will be: $E = h \nu$. The quantisation of the energy does not occur at the moment of interaction with matter, but it is the EMF itself that behaves as a particle (the quantum of light, or photon), which simultaneously has corpuscular (E) and wave-like aspects (ν)" (Loudon and Scully, 1974).

Activation of retinal photoreceptors

Light strikes retinal photoreceptors, specialized cells divided into two main types: rods and cones, which contain light-sensitive photopigments. Rods are extremely sensitive: they allow vision in low light conditions (night or scotopic vision), while cones are responsible for viewing colors and sharp details in the presence of intense light (daytime or photopic vision). As Ganong reminds us, "The photosensitive pigment in rods is called rhodopsin, or visual purpura. Its opsin is called scotopsin. Light discolors rhodopsin by cleaving the bond between scotopsin and retinene" (Ganong, 1995). Well, one might wonder whether this action carried out continuously by light, rather than being of a purely chemical or electro-chemical nature, could not have been of another nature, such as, for example, of a quantum-mechanical nature, that is, of a purely physical nature. One might object: but why would it be a quantum-mechanical action? It is simple: it's a quantum mechanism precisely because it is an action

performed by a light quantum; it's a mechanical action, understood in the physical sense, since, under the effect of light, a chemical bond is instantly broken. Well, this mechanical action, in our opinion, performed by light, seems entirely analogous to the photolysis of water, a phenomenon that occurs during chlorophyllose photosynthesis (which we will discuss later). Ganong continues: "It is believed that before light strikes rhodopsin, retinene is present in rhodopsin as the 11-cis isomer. The only action of light is to convert this compound to its 11-trans isomer, thus forming lumirhodopsin. This straightens the retinene and allows the next step to occur spontaneously, which consists of a change in the shape of the opsin, forming metarhodopsin. The unfolding of the opsin likely exposes reactive groups that catalyze the reactions that determine electrical activity" (Ganong, 1995). That is, it would happen that the light energy of the Ps is absorbed, causing a chemical change in the retinal photopigments, which induces a depolarization (or hyperpolarization) of the cell, generating a nerve impulse, since it propagates through the long fibers (axons) of the neurons; it is believed that this impulse is of an electrical nature.

Chlorophyllose Photosynthesis (CP)

The chlorophyll molecules are made up of the polycyclic ring of porphyrins, from which branches of a long hydrocarbon chain. So, the mechanism of CP has been carried out mainly by algae, and even more, by plants. In short, the CP consists of transforming the luminous energy (E) of the sunlight in chemical E. There are 2 stages: Luminous Stage or Photochemistry (light reaction) and Dark Phase or Chemistry (dark reaction). While the photochemistry phase works only in the presence of light, the chemistry phase can work both in the dark and in the light. In the Luminous Phase there is a production of chemical E from luminous E, whereas in the Dark Reaction there is a production of glucose at the expense of the chemical E previously accumulated. These reactions take place in cellular organelles, chloroplasts, highly concentrated in the cytoplasm of cells of the green parts of plants (stroma) (Puccini, 2012).

Chloroplasts

Similar to mitochondria, present in the cytoplasm of animal cells, the origin of chloroplasts can also be attributed to an endosymbiosis between eukaryotic cells and cyanobacteria (photosynthetic prokaryotes). Chloroplasts are spherical, or lenticular, organelles 4 to 8 micrometers (μm) wide and 1–3 μm thick. Within their interior, or stroma, are membranous structures responsible for photosynthesis, called thylakoids. This is a system of thylacoidales membranes containing photosynthetic pigments, where it is possible to distinguish primarily the molecules of chlorophyll a and chlorophyll b, arranged to form respectively the Photo System I and II. The fundamental nature of such pigments is their absorption spectrum, which generally includes the wavelengths (λ) between 400 and 700 nanometers (nm), with absorption peaks at the extremes of the visible spectrum and low levels in the central areas. Therefore, with the Light Reaction chlorophylls b and other accessory pigments, or antenna pigments, collect a portion of the luminous energy (E), convert it into electronic excitation which migrates for inductive resonance (so an excited molecule transfers its E to a contiguous molecule, which in turn is energized, and so on. . .) until it reaches the chlorophyll a, since this is the only one which is able to pass to an excited state activating the CP phenomenon.

Indeed, there are special molecules of chlorophyll a called trap molecules, since the E collected by the Photo System II remains trapped in them. This happens because these trap molecules are characterized by energy levels lower than other molecules of chlorophyll, so they can only receive the excitation transmitted by other molecules of the photosynthesis unit, but they cannot forward it. This is the reaction center where chemical reactions are activated, including the splitting of water molecules by the solar radiation: hydrolysis, or photolysis of water (WP) (Puccini, 2012). In turn, the dark phase of CP, also known as the Calvin cycle, occurs within the stroma, allowing the fixation of inorganic carbon into organic molecules (autotrophy). In short, from a photochemical and biochemical perspective, the light phase of CP occurs within these flattened, stacked membranous discs, or thylakoids, as light energy is absorbed to generate highly energetic electrons, which are used to create a proton gradient within the thylakoid lumen.

Water photolysis

During CP, the phenomenon of water photolysis occurs. This phenomenon, in our opinion, also represents a clear quantum event, with a consequent mechanical effect. Quantum, since it is induced by a light quantum; mechanical, since the P exerts a mechanical action, a push effect generated by "the force, the 'pushing momentum', that is delivered per second by the light" (Feynman et al., 1965): in fact, a single 'quantum of light', to use Einstein's terminology (Einstein, 1989), is capable of expelling a massive particle, such as an electron, from the atom to which it was bound (Puccini, 2019). Thus, with photolysis, water loses electrons and protons, so it is oxidized to oxygen, which in turn is released into the atmosphere, while the protons accumulate in the thylakoid, to then be emitted through the membrane complex of ATP-Synthase, which uses the energy of the outgoing protons, in order to produce ATP (adenosine triphosphate) molecules.

Mitochondrial ATP-synthase

It is interesting to note that ATP synthase is also present in mitochondria, that is, in the cytoplasm of cells in the animal kingdom. As is well known, ATP synthase is a true enzymatic nanomotor, belonging to the lyase group, of fundamental importance for all cells. It is present in mitochondrial membranes (as well as in those of chloroplasts) and produces the majority of ATP (the cellular energy currency), as it converts inorganic phosphate and adenosine diphosphate (ADP), exploiting the energy of the proton (H⁺) gradient across the membrane, through a process called chemiosmosis. It is a protein complex, equipped with two domains, F₀ (transmembrane, acts as a channel and rotor) and F₁ (protrudes into the matrix, catalyzes the synthesis), where the flow of protons through F₀ rotates a central axis, deforming F₁ and allowing the synthesis of ATP.

Results and Discussion

Nature of the photon-retina impact

It is a common misconception that the photon-retina (P-R) impact is exclusively of an electrical in nature. Yet, regarding the nature of P and electromagnetic waves (EMWs), it is well known that EMWs do not carry any electric charge at all, but only energy and momentum. Specifically, electric charges are precisely and exclusively the

source of these EMWs. The P, in turn, is considered the fundamental quantum particle, which constitutes light and all EMRs. The P is a neutral particle, devoid of electric charge, insensitive to EM interaction, and does not transport electric charges. Each P carries an amount of quantized energy (E), directly proportional to the frequency (ν) of the EMR oscillation through the formula indicated in Eq. (1). This formula is also known as “the Planck’s Radiation Law” (Penrose, 1989). In our opinion, if we want to analyse the phenomenon of P-R impact in more depth and with greater investigative subtlety, i.e. the first activation of the Optic Pathways (OP) system, occurring precisely at the R level, we must keep in mind that it is first and foremost a frankly quantum phenomenon, since the retinal photoreceptors are activated exclusively by Einstein's "light quanta" (Einstein, 1989), i.e. by Planck's quanta of EMR (Planck, 1900), provided that they have appropriate wavelengths (λ). In this regard, Penrose asks: "Is there a role for quantum mechanics (QM) in brain activity? Is there some more clearly defined role for genuine quantum-mechanical control at some key location?"

Indeed, there is at least one key location where action at the single quantum level can matter for neural activity, and that location is in the retina (R). Recall that R is technically a part of the brain" (Penrose, 1989). And, in fact, Feynman adds: “The retina is really like the surface of the brain..As a matter of fact, people who study anatomy and the development of the eye have shown that the retina is, in fact, the brain: in the development of the embryo, a piece of the brain comes out in front, and long fibers grow back, connecting the eyes to the brain. The retina is organized in just the way the brain is organized and, as someone has beautifully put it, ‘the brain has developed a way to look out upon the world’. The eye is a piece of brain that is touching light, so to speak, on the outside. So it is not at all unlikely that some analysis of the color has already been made in the retina” (Feynman et al., 1965). Penrose concludes: "Experiments with toads have shown that a single P, affecting a dark-adapted R, can be sufficient to trigger a macroscopic nervous signal. It appears, however, that cells sensitive to even a single P are present in the human R" (Penrose, 1989). But beyond a phenomenon of a frankly quantum nature, it would also be a mechanical phenomenon, since it would be this same light quantum, or P, that induces a push effect on the particle struck by the light, namely an electron, thus carrying out a physical action of a purely mechanical nature on it (Puccini, 2011a).

Possible quantum-mechanical action of photons on rethynic pigments

A clear quantum mechanical effect that can be exerted by photons (Ps) seems to occur when a light quantum hits a subatomic particle, an electron for example. In this regard, Feynman states: "To observe electrons, we need a light because the light rebounding on electrons make them visible. Nevertheless the light affects the result because the result of light on is different from that of light off. We can say that the light affects electron behavior. The electrons are very sensitive. When light is sent on an electron, it makes the electron vibrate so that the electron because of light, behaves in a different manner" (Feynman et al., 1965). Well, this very sensitivity of electrons, for example, could better reveal to us the way light operates when it strikes the retina, revealing to us more likely a mechanical action, that is, essentially physical, concrete, rather than a mere and pure action exclusively of an energetic type, but without real physical correlates, since the operating particle, the photon, is considered to be devoid of even the slightest mass. Nonetheless, let's go and see with Feynman what happens when light strikes the rod cells of the retina: “Let us to examine in more detail what

happens in the rod cells. We observe an electron micrograph of the middle of a rod cell: there are layer after layer of plane structures, which contain the substance rhodopsin (visual purple), the dye, or pigment, which produces the effects of vision in the rods. The rhodopsin, which is the pigment, is a big protein which contains a special group called retinene, which is, undoubtedly, the main cause of the absorption of light. We do not understand the reason for the planes, but it is very likely that there is some reason for holding all the rhodopsin molecules parallel. The chemistry of the thing has been worked out to a large extent, but there might be some Physics to it” (Feynman et al., 1965). Well, this ‘solid state physics’ (Feynman et al., 1965) could really intervene under these circumstances. And how? In what respect? It is very likely that it is precisely the light quantum, Planck's grain, that behaves, with its momentum, like a real physical particle, in such a way as to be able to induce, on the affected particle, a real physical action, of a mechanical type, such as to make the particle splash away at sub-relativistic speed. Well, this ‘solid state physics’ (Feynman et al., 1965) could really intervene under these circumstances.

Power of the photon impact on the retina

It is interesting to highlight that this mechanical action, that is, this push effect induced by a single P on retinal receptors (essentially on their electrons), is not as ethereal, evanescent, abstract, immaterial, as one would expect from a massless P. No. From our calculations, something completely different emerges.

The Momentum (p) of Photon (P)

At this regard, Fermi writes: “The photon too, as other particles, is a corpuscle, a light’s quantum and has a its own momentum (p), through which transfers all its energy to the hit particle” (Fermi, 1926). Penrose states: “According to Quantum Mechanics, the key concept concerns the momentum (p): in all shocks, in all interactions between quantum objects, it is always preserved. Momentum must move somewhere: it cannot simply disappear, as it is preserved. The same happens for energy” (Roger, 2004). Thus, it seems clear that we are in an open contradiction, since a particle such as photon (P), considered to all intents and purposes massless, is universally recognized to possess its own momentum (Puccini, 2011b). This contradiction immediately comes to light if we examine why the concept of momentum arose. The concept of momentum was introduced to calculate how much a moving particle could weigh. In that regard, Newton writes: “Quantitas motus est mensura ejusdem orta ex Velocitate et quantitate Materiæ conjunctim”, that is, the momentum is a measure in itself, since it depends on both the speed and the quantity of matter (Newton, 1833). The only mass or speed do not therefore describe what happens in real cases. Therefore, Newton thus indicates the momentum vector (\vec{p}) (Eq. (2):

$$\vec{p} = m \cdot \vec{v} \quad \text{Eq. (2)}$$

The Eq. (2) describes the quantity of motion (p) of a body having a mass m and moving at a speed v. In other words, the momentum of a particle is the product of two quantities, the particle's velocity (v) and its mass (m). So, the linear momentum (p) is a vector quantity (Puccini, 2020). To this purpose, Feynman asserts: “That light carries energy we already know. We also know that the energy (E) of a light-particle is h (the

Planck constant) times the frequency (ν): $E = h \nu$. We now understand that light also carries a momentum equal to the energy divided by c , so it is also true that these effective particles, these photons, carry a momentum (p):

$$p = \frac{E}{c} = \frac{h \nu}{c} \quad \text{Eq. (3)}$$

Where, c is the light speed in the vacuum. The direction of the momentum is, of course, the direction of propagation of the light" (Feynman et al., 1965). As is known, in Quantum Mechanics (QM) p is described by the de Broglie form:

$$p = \frac{h}{\lambda} \quad \text{Eq. (4)}$$

where λ indicates the wavelength of the considered particle and h is the Planck's constant, equal to $6.626 \cdot 10^{-27}$ [erg·s]. In this respect, indeed, taking inspiration from Einstein's intuitions, de Broglie proposed a similar process, in reverse, to be applied to particles. So, he suggested assigning to particles, including photons, the same properties that waves possess, such as an its own wavelength (λ), depending exclusively on the momentum of the particle itself. In agreement with Weinberg, the mean wave length of a photon (P) in the optical band corresponds to about $5 \cdot 10^{-5}$ [cm] (Weinberg, 2022) and, in accordance with de Broglie formula, its p is:

$$p = \frac{h}{\lambda} = \frac{6.626 \cdot 10^{-27} [\text{erg} \cdot \text{s}]}{5 \cdot 10^{-5} [\text{cm}]}$$

As the erg value is expressed in $[\text{g} \cdot \text{cm}^2 / \text{s}^2 \cdot \text{cm}]$, that is in $[\text{g} \cdot \text{cm}^2 / \text{s}^2]$, we have:

$$P = \frac{6.626 \cdot 10^{-27} [\text{g} \cdot \frac{\text{cm}^2}{\text{s}}]}{5 \cdot 10^{-5} [\text{cm}]}$$

$$p = 1.325 \cdot 10^{-22} [\text{g} \cdot \frac{\text{cm}}{\text{s}}]$$

As shown in last equation, it is clear that the momentum (p) of a visible photon (P), expressed in grams, should carry out a significant dynamic-mass. In fact, the dynamic-mass, carried by the momentum of an optic P , is bigger than the rest mass of 100 protons. Yes, one would be surprised by these results, keeping in mind that most of the scientific community considers P s to be completely massless, although from a seminar held by Madame Mariotti at CERN in Geneva we read: "The photon is massless by definition". Moreover, we are comforted by Penrose, who says: 'The mass of photon is an impalpable type: it is pure energy' (Penrose, 1989). On the other hand, when a subatomic particle, and so P , is in motion, we will never be able to grasp its corpuscular aspect, or the values of its probable mass density: the Bohr Complementarity Principle categorically prohibits this (Bohr, 1928). In this regard, it seems interesting to highlight what Feynman writes: "Finally, associated with the Relativity Theory, there is a modification of the laws of kinetic energy, or whatever you wish to call it, so that kinetic energy is combined with another thing called 'mass energy'. An object has energy from its sheer existence" (Feynman et al., 1965). Likewise, it can be deduced, that the object itself, the moving particle, and so the P , also possesses a mass, although

undetectable, but closely related to the motion of the particle: to be precise a proportional equivalent mass energy. Feynman adds: “From now on we can say that the total energy of an object is mc^2 . Therefore we have a new idea: we do not have to know what things are made of inside; we cannot and need not identify, inside a particle, which of the energy is rest energy of the parts into which it is going to disintegrate. It is not convenient and often not possible to separate the total mc^2 energy of an object into rest energy of the inside pieces, kinetic energy of the pieces, and potential energy of the pieces; instead, we simply speak of the total energy of the particle. We ‘shift the origin’ of energy by adding a constant m_0c^2 to everything, and say that the total energy of a particle is the mass in motion times c^2 , and when the object is standing still, the energy is the mass at rest times c^2 ” (Feynman et al., 1965). It follows, of course, that this also applies to the particle of light, that is, the light's quantum, or P. In fact, the soul of electromagnetic radiation (EMR), that is, the soul of each P, of each Planck's grain, is represented precisely by the Planck constant (h), whose value, according to Plank (1900), is expressed in erg·s, i.e. in grams·sec: $[g\cdot cm^2/s]$.

Furthermore, it seems interesting to highlight what Asimov writes: “At the beginning of last century, Lenard had discovered that when light hit certain metals it caused the emission of electrons from their surface, just as the light had the power to push out the electrons from the atoms” (Asimov, 1984). And yet, we consider it appropriate and fundamental to dwell on this last Asimov's phrase, because a single quantum of light, considered to this day to be a corpuscle, but without any intrinsic mass of its own, can have 'the power' (Asimov, 1984) to move a particle such as the electron. It is truly astounding. In fact, in agreement with Mechanics, the act of 'to push out' (Asimov, 1984) an electron from its atom is first and foremost, and beyond doubt, a purely mechanical action. Yet Planck himself said explicitly: "we can use to this purpose the natural constant $h = 6.55 \cdot 10^{-27}$, expressed in erg·sec" (Plank, 1900), that is in $[g\cdot cm^2/s^2] \cdot s$. Therefore, already with Planck we have that the value of h is given in grams. And yet, it is well-know that the term gram is used to indicate the quantitative value of a mass, inherent in both an object of the macroscopic world and a particle of the microscopic world. Forget massless Planck grains. Moreover, we read from the literature: “Mass also means energies, as Einstein established through the famous equation $E=mc^2$ ”, known as Einstein's Mass-Energy Equivalence Principle (MEEP). At this regard, Einstein wrote to his friend Conrad Habicht: “It has come to my mind a consequence of the study of Electrodynamics. The Principle of Relativity, in association with Maxwell fundamental equations, requires that the mass is a direct measure of the energy contained in a body; the light carries a mass” (Wilczek and Farmelo, 2002). To this purpose, Galison specifies: “Einstein was unsatisfied: he was not satisfied of the analyses of the light. Einstein stated that to any kind of energy is associated a mass” (Wilczek and Farmelo, 2002). Thus, according to Einstein, there should be a mass associated to the photon (P).

Galison adds: “Planck stated that also the transfer of heat adds a mass” (Wilczek and Farmelo, 2002). What is heat made of? It's obvious: the heat is made of electromagnetic radiations (EMRs), that is Ps. Thus, according to Planck, “a transfer of radiation, i.e. Ps, from A to B will cause an increase in the mass of B” (Wilczek and Farmelo, 2002). But the opposite can also happen, whereby a physical system, losing energy, in perfect agreement with MEEP, also loses mass, as could occur with Black Holes (BHs). In this regard, we cannot ignore the famous hypothesis of the evaporation of BHs proposed by, Hawking. He writes: “It seems that any black hole will create and emit particles such as neutrinos or photons....As a black hole emits this thermal radiation one would expect it

to lose mass” (Hawking, 1974). Clearer and simpler than this, it cannot be: the loss over time of “thermal radiation”, that is, of photons (Ps), causes the BH to lose mass in parallel. It is a prestigious confirmation of the mass-energy equivalence (authoritatively, and without any hesitation, applied by Hawking also to Ps) and of the non-further sustainability, in our opinion, of the concept that P must be forcibly considered completely massless. A concept, moreover, never demonstrated experimentally (except exclusively through arithmetic processing). Indeed, many experimental tests, or practical applications in our daily lives, such as the Photo-Electric Effect for example, clearly show its push effects, that is, real mechanical actions, although elicited by a particle considered massless. But this goes against the primary rules of Mechanics, which deals with phenomena that can only be explained between massive physical systems.

On the other hand, that P is capable of carrying out some mechanical action, although it is considered massless, can be deduced from the literature: “Light can exert pressure by bombarding an object; this pressure is very small, but with sufficiently delicate apparatus it is measurable” (Feynman et al., 1965). Feynman points out: “When light is shining on a charge and it is oscillating in response to that charge, there is a driving Force in the direction of the light beam. This Force is called Radiation Pressure or Light Pressure” (Feynman et al., 1965). But it's no surprise; it's nothing new that light can exert some pressure. In fact, the phenomenon of light pressure, or "photon's pushing momentum" to use Feynman's words (Feynman et al., 1965), was brilliantly interpreted, from natural physical events, well over four centuries ago, and by none other than Joannes Keple. In fact, in 1619 Kepler pointed out the concept of the radiation pressure exerted by solar rays to explain the observation that a comet's tail always points away from the Sun (Kepler, 1963).

Conclusion

Well, this Radiation Pressure, exerted by solar rays, can help us better interpret and understand the marvelous mechanism of Seeing. In fact, this 'Light Pressure' (Feynman et al., 1965) can finally clarify and explain the various mechanical effects and phenomena activated by the incidence of light, the Ps, on the retinal pigments. In short, Physics also plays a role in the mechanism of seeing. Precisely in this regard, explaining the Lecture on the 'Mechanism of Seeing', this is what Feynman said to his students at Caltech: “It is a field in which both biochemistry and solid state physics, or something like it, will ultimately be used. This subject is very important, and has not been worked out...There might be some Physics to it” (Feynman et al., 1965). Well, this would emerge precisely by analyzing a rod cell under an electron microscope: layer after layer of plane structures containing rhodopsin molecules are observed. The most interesting, and at the same time intriguing, thing is that these plane structures are all aligned with each other. A possible explanation for this peculiar alignment is provided by Feynman: “It may be that all of the molecules are arranged in some kind of a row so that when one is excited an electron which is generated, say, may run all the way down to some place at the end to get the signal out, or something like it, will ultimately be used” (Feynman et al., 1965). That is, just like a domino effect. “This kind of a structure, with layers, appears in other circumstances where light is important, for example in the chloroplast in plants, where the light causes Photosynthesis. If we magnify those, we

find the same thing with almost the same kind of layers, but there we have chlorophyll, of course, instead of retinene.

The chemical form of retinene has a series of alternate double bond along the side chain, which is characteristic of nearly all strongly absorbing organic substances, like chlorophyll, blood, and so on. The reason why such a series of double bonds absorbs light very strong is also known. We may just give a hint: the alternating series of double bond is called a conjugated double bond; a double bond means that there is an extra electron there, and this extra electron is easily shifted to the right or left. When light strikes these molecule, the electron of each double bond is shifted over by one step. All the electrons in the whole chain shift, like a string of dominoes falling over, and though each one moves only a little distance, the net effect is the same as though the one at the end was moved over to the other end! It is the same as though one electron went the whole distance back and forth, and so, in this manner, we get a much stronger absorption under the influence of the electric field, than if we could only move the electron a distance which is associated with one atom. So, since it is easy to move the electrons back and forth, retinene absorbs light very strongly: that is the machinery of the physical-chemical end of it” (Feynman et al., 1965). It is a physical-chemical effect that gives rise to the Mechanism of Seeing, although, in summary, we seem to detect a prevalence of the mechanical action exerted by the quantum of light (hence: quantum-mechanical action), particularly when P acts on the electrons of double bonds. Yes, in our opinion, it is precisely the domino effect described above that demonstrates a very clear and indisputable mechanical effect triggered by light quanta in retinal pigments. Ultimately, these are complex, but truly fascinating, mechanisms.

Taking a quick overview of the Mechanism of Seeing, we first have a primary retinal processing of light, since light signals pass through various layers of retinal neurons (bipolar, horizontal, amacrine, ganglion cells) that begin to process and refine visual information: truly spectacular. After that, the ganglion cells, which have received the processed signals, form the optic nerve, until they transmit this information to the visual cortex of the brain. Just in that regard, and in conclusion, what Feynman highlights seems very interesting to us: “None of the other Senses involves such a large amount of calculation, so to speak, before the signal gets into a nerve that one can make measurements on. The calculations for all the rest of the senses usually happen in the brain itself, where it is very difficult to get at specific places to make measurements, because there are so many interconnections. Here, with the visual sense, we have the light, three layers of cells making calculations, and the results of the calculations being transmitted through the optic nerve. So we have the first chance to observe physiologically how, perhaps, the first layers of the brain work in their first steps. It is thus of double interest, not simply interesting for vision, but interesting to the whole problem of Physiology” (Feynman et al., 1965).

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Conflict of interest

The authors confirm that there is no conflict of interest involve with any parties in this research study.

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