

Next Quantum Computers and their Speeds

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ABSTRACT

As known, the Quantum Computer represents the most coveted and promising tool for transmitting information in the near future. Thus, with the next use of Quantum Computers (QC_s), instead of current computers, the means of transmitting information will be replaced: in fact we will pass from electrons and *bit*, to photons and *quantum bit*. So the main element, that is the essential and indispensable tool to make the next QC_s, will be represented by the photon, that is by the electromagnetic signal. These signals, as we know, are not all the same, but they differ in a wide range, based on their wavelength, on their energy, or even on their *momentum* (*p*). In short, the main task of our work is to ascertain whether, in this context, the photons with different frequencies transmit the information at the same speed, or not!

Keywords: Quantum Computers(QC_s); *momentum* (*p*); Electro-magnetic(EM); *kinetic energy*(*K_E*).

INTRODUCTION

As we all know the Quantum Computer (QC) represents the most coveted and promising tool for transmitting information in the near future. To this purpose, as Boncinelli reminds us, "The Information is a measurable quantity, like the Matter and the Energy. These 3 quantities are the basis of the material universe. The information has been defined and baptized recently (50 years ago). One aspect of this magnitude is related to Quantum Computers (QC_s). Behind all this lies a strong thought: science does not care so much to understand how things are, but how we can get to know it. As to say that knowledge is intrinsically a matter of information; we are at *it from bit*. Reality takes shape and body through information"[1].

Up until now the methods of information transmission are those described by Shannon Equations, they concern both the *quantity* and the *quality* of information in common cable transmission systems and in common computers work electrons [2]. In this respect, we read from Shannon: "The fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point. Frequently the messages have meaning; that is they refer to or are correlated according to some system with certain physical or conceptual entities. These semantic aspects of communication are irrelevant to the engineering problem. The significant aspect is that the actual message is one selected from a set of possible messages. The system must be designed to operate for each possible selection, not just the one which will actually be chosen since this is unknown at the time of design.

If the number of messages in the set is finite then this number or any monotonic function of this number can be regarded as a measure of the information produced when one message is chosen

from the set, all choices being equally likely. As Hartley pointed out the most natural choice is the logarithmic function. Although this definition must be generalized considerably when we consider the influence of the statistics of the message and when we have a continuous range of messages, we will in all cases use an essentially logarithmic measure.

The logarithmic measure is more convenient for various reasons:

1. It is practically more useful. Parameters of engineering importance such as time, bandwidth, number of relays, etc., tend to vary linearly with the logarithm of the number of possibilities.
2. It is nearer to our intuitive feeling as to the proper measure, since we intuitively measure entities by linear comparison with common standards.
3. It is mathematically more suitable. Many of the limiting operations are simple in terms of the logarithm but would require clumsy restatement in terms of the number of possibilities.

The choice of a logarithmic base corresponds to the choice of a unit for measuring information. If the base 2 is used, the resulting units may be called *binary digits*, or more briefly *bits*, a word suggested by J. W. Tukey. A device with two stable positions, such as a relay or a flip-flop circuit, can store one *bit* of information”[3].

In reference to this context, Lloyd writes: “Merely by existing, all physical systems register information. And by evolving dynamically in time, they transform and process that information. The laws of physics determine the amount of information that a physical system can register (number of *bits*) and the number of elementary logic operations that a system can perform (number of operations)”[4].

Therefore, the quantity of information is conveyed in bit/sec.

At this point, let's take a look at the equations of Shannon. As is well-known, the first Shannon's equation describes the *quantity of information*, (I), held in a message:

$$I = -p \log_2 p \quad (1)$$

where p is the so-called *surprise* contained in the message, that is the most or least probability to convey a news. In this regard, in fact, Aleksander states: “The less probable an event is, the more *surprising* it is and the more information it conveys”[5].

Therefore, as can be easily seen from the Eq.(1), it indicates the *quantity* of information conveyed (in bit/sec).

Now, let's to analyse the second Shannon equation:

$$C = W \log_2 \left(1 + \frac{S}{N}\right) \quad (2)$$

where W is the band-width of the channel, S is the signal strength and N the noise strength [6]. As it is clear from Eq.(2), unlike Eq.(1), the second Shannon equation indicates the *quality*, (C), of the transmission mean. In reference to this context, in fact, Faris specifies: “The second

equation is Shannon's formula for channel *capacity* (C). This gives the rate at which information can be transmitted in the presence of noise"[7].

In this regard, in its turn, Aleksander points out: "Shannon's equations are not about nature, they are about systems that engineers have designed and developed. Shannon's contribution lies in making engineering sense of a medium through which we communicate. He shares the same niche as other great innovators such as his boyhood hero Thomas Edison (who turned out to be a distant relative, much to Shannon's delight) and Johann Gutenberg"[5].

DISCUSSION

Well, so far we have only considered physical systems represented by atoms or electrons. Let's try now to analyse, in similar circumstances, the behaviour of electromagnetic waves and photons, since they are used in Quantum Computers (QCs) [8].

As we all know, photons are real particles and have a their own energy and *momentum* [9], so they are considered proper physical systems [10].

The Momentum

To this purpose, in fact, Fermi states: "The *light's quantum* is a corpuscle and has an its own *momentum* ($\mathbf{p}$)" [11]. Famously, the *momentum* was introduced in order to calculate how much a body in motion *weighs*. Newton was the first one to fully deal with this subject. He wrote: the *momentum* ($\mathbf{p}$) is a measure in itself, since it depends on both the speed ($\mathbf{v}$) and the quantity of matter (m) [12].

Therefore, as it is clear, the sole mass or speed do not describe what happens in real cases [2]. Newton then referred to what we call *momentum*($\mathbf{p}$): something that originates jointly from the speed($\mathbf{v}$) and quantity of matter(m). Thus, He defined this vector magnitude in the following way:

$$\mathbf{p} = m \cdot \mathbf{v} \quad (3)$$

Eq.(3) describes the *quantity of motion* ($\mathbf{p}$) of a body having a mass m and moving at a speed $\mathbf{v}$. Well, the *momentum* of a particle is the product of two quantities: the particle's mass and its velocity. Hence, the *momentum* is a vector quantity: it has both magnitude and direction, and direction and line coincide with those of $\mathbf{v}$. In fact, the vector $\mathbf{p}$ has the same direction and the same line of the speed($\mathbf{v}$) and its module is the mass(m) times the speed module. We therefore find it of particular value, as well as rich in meaning and potential, to point out that the *momentum* module of a particle is directly proportional to the mass of the object, and to its speed too [13].

In short, the greater p the greater the *velocity* of the considered particle, just in a directly proportional rate!, just as can be seen from the Newtonian formula, clearly illustrated by Eq.(3). Since *momentum* has a direction, it can be used to predict the resulting direction and speed of motion of particles after they collide.

Thus, in Newtonian Mechanics $\mathbf{p}$ is represented by the formula $\mathbf{p} = m \cdot \mathbf{v}$; in Quantum Mechanics, in its turn, $\mathbf{p}$ is described by the de Broglie formula:

$$\mathbf{p} = \frac{h}{\lambda} \quad (4)$$

where h is the Planck's constant and λ is the wavelength of the considered *quantum object*. It is interesting to highlight that in Quantum Mechanics the particle may be also considered as a wave. As known, in fact, de Broglie suggested, without experimental data, to give particles the same property as waves. He gave each particle a its own wave length depending only on the *momentum* ($\mathbf{p}$) of the particle itself [14].

Therefore, according to de Broglie formula, any *quantum object* (i.e. any particle) with a *momentum* ($\mathbf{p}$) seems to be something periodic, oscillating as a wave, with an universal relation between the wave length of the particle, indicated by λ , and the modulus $\mathbf{p}$ of its *momentum* [15].

In this respect, Feynman points out: "That light carries energy we already know. We also know that the energy (E) of a light-particle is h (the Planck's constant) times the frequency (ν):

$$E = h \nu \quad (5)$$

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* ($\mathbf{p}$) :

$$\mathbf{p} = \frac{E}{c} = \frac{h\nu}{c} \quad (6)$$

where c is the light speed in the *vacuum*. The direction of the *momentum* is, of course, the direction of propagation of the light. So, to put it in the vector form:

$$E = h \nu \quad \mathbf{p} = \frac{h\nu}{c} \quad (7)$$

We also know, of course, that the energy and the *momentum* of a particle should form a *four-vector*.

Therefore it is a good thing that the latter equation has the same constant (h) in both cases; it means that the Quantum Theory and the theory of Relativity are mutually consistent" [16].

The latter, in our opinion, is an important clarification made by Feynman [17].

Moreover, it seems useful to make a clarification: apparently the second of the equations (7), $\mathbf{p}=h\nu/c$, is in contrast with the *de Broglie formula* ($\mathbf{p}=h/\lambda$), as it is shown by Eq.(4).

However, from the formula of electromagnetic waves $c=\nu \lambda$ (where c is the light speed in vacuum and ν is the frequency) we get that the rate ν/c is the same as $1/\lambda$, thus the second of the Eq.(7) becomes: $\mathbf{p}=h/\lambda$, just as equation(4).

Photons and Quantum Computers

Well, with the next use of Quantum Computers (QC_s), instead of current computers, the means of transmitting information will be replaced: in fact we will pass from electrons and *bit*, to photons and *quantum bit* (Qbit). So the main element, that is the essential and indispensable tool to make the next QC_s, will be represented by the photon, that is by the electromagnetic

signal. These signals, as we know, are not all the same, but they differ in a wide range, based on their wavelength, on their energy, or even on their *momentum* ($\mathbf{p}$), since $\mathbf{p} = E/c$, as illustrated by Feynman in Eq.(6).

Just because with QC_s we operate in the field of the Quantum Mechanics (QM), it is right to examine the *momenta* of the various photons, using the *de Broglie formula* ($\mathbf{p}=h/\lambda$), as it is shown by Eq.(4).

The hidden Mass and Bohr Complementarity Principle

Thus, in line with *de Broglie formula*, let's now to analyze the $\mathbf{p}$ value of photons with different wave length(λ). As it is known, the mean wave length of a photon in the optical band corresponds to $\approx 5 \cdot 10^{-5}$ [cm] and its $\mathbf{p}$ is:

$$\mathbf{p} = \frac{h}{\lambda} = \frac{6.626 \cdot 10^{-27} [\text{erg} \cdot \text{s}]}{5 \cdot 10^{-5} [\text{cm}]} \quad (8)$$

Since $1 \text{ erg} = \text{g} \cdot \text{cm}^2/\text{s}^2$, we have:

$$\mathbf{p} = \frac{6.626 \cdot 10^{-27} [\text{g} \cdot \frac{\text{cm}^2}{\text{s}}]}{5 \cdot 10^{-5} [\text{cm}]} \quad (9)$$

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

As Eq.(10) shows, the momentum ($\mathbf{p}$) of a visible photon carries out a *dynamic-mass*, a *pushing momentum* bigger than the *rest mass* of 100 protons. No surprise! At this regard, Feynman writes:

"The *momentum*, as a mechanical quantity, is difficult to hide. Nevertheless, momentum *can* be *hidden*, i.e., in the electromagnetic (EM) field. This case is another effect of relativity"[16]. It's like saying that *momentum* carries, albeit *hidden*, a dynamic-mass.

Penrose adds: "In a conference held in Japan in 1922, Einstein said: 'If a person falls freely he will not feel his own weight'. In fact, when you are in *free fall* (like when you launch from a plane, before you open the parachute) you have the impression that the earth Gravity Interaction(GI) is *suspended*: the Earth's gravitational field seems to have *disappeared*. Where's the GI? Actually the GI has not vanished, it is *hidden*"[18].

Well, in these circumstances, we seem to be able to see a significant behavioral analogy between EM field and gravitational field. That is, it is as if in both of them something disappeared, temporarily concealed, *hidden*, during the event: 1) the dynamic-mass, transported by the *momentum* of the photon (in the EM field); 2) the GI (in the gravitational field).

To this purpose, Zeilinger wondering: "What is the deep meaning of a relationship like $E=mc^2$? What is *hidden* behind these symbols? For many physicists the equation $E=mc^2$ is to say that energy and mass are the same thing, two faces of the same medal; there is therefore *equivalence between mass and energy*: energy is just another form of mass, and vice versa, mass is another form of energy"[19].

In short, as it is known the photon is a particle too, a particle of light, so we think that the photo-kinematics does not involve only energy (as the energy of h , the Planck Constant[20]), but also mass (the *hidden mass*, the *masked mass* of the light quantum), in full respect of Einstein's Principle of Mass-Energy Equivalence[21]. Why a *hidden mass*? In order to respect the well-known Bohr Complementarity Principle [22], along with which a particle can show itself only with one of two "aspects": wave or particle, but never simultaneously. These parameters are "complementary", similarly to the *complementary parameters* of the Heisenberg Uncertainty Principle[23]: energy-time, or position and momentum of a particle. As we all know, in fact, the more accuracy we have in knowing a parameter, the more uncertain the measure of the complementary corresponding parameter will be. Thus, the more information we have about the wave aspect of the light quantum, the less, in the same moment, we have of its particle aspect. Therefore, according to Complementarity Principle, if the Planck grain (or any other particle) is in motion we can catch its *kinetic energy*, adding it to its main base energy, but we will never be able to have news, simultaneously, about its corpuscular characteristics. From the Planck quantum in motion (wave-like aspect) we can have news about its energy, but we can never check its mass, since the mass is *hidden, masked* by the wave behavior assumed by the moving quantum object(QO). Whereas when the light's particle, the QO interacts, it slows almost completely its run, however without stopping completely: Uncertainty Principle would not allow it to[24]. Thus the photon will cease to show its wavelike appearance and will show us its corpuscular one, allowing us to determine its mass (in case it has some!). Briefly, only when the motion almost stops (and its *wave aspect* disappears) the light quantum will be able to show its *corpuscular aspect*. Only then, as a corpuscle, the photon will show us, at last, its probable mass: maybe indirectly, showing us the probable mass-effects or mechanical effects [25].

One way say: it is wrong! The light quantum is always in motion, so it will never show us its corpuscular appearance, and thus its possible mass. On the contrary, we believe that the photon *wears* his corpuscular aspect, only in the very brief instant in which it interacts. In support of what we claim, there are several examples of *mass-effect*, or gravitational effects, *push-effects* induced by light quanta. At this regard, it is possible to mention the photo-electric[26] [27], Compton[28] and Raman[29] effects: these are unequivocal experimental evidences.

In short, as Feynman reminds us, "in the Einstein Relativity Theory, anything which has energy has mass, mass in the sense that it is attracted gravitationally. Even light, which has an energy, has a *mass*"[16]. He points out: "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 "[16].

To this purpose, in fact, as Klein reminds us, "Physicist have begun to understand that in the energy balance of any physical process you have to keep in mind that every body, even at rest, contains a certain *mass energy*"[30]. In other words, it is logical to deduce that the photon

cannot be considered massless; its mass is simply, to say it with Feynman: "hidden"[16], in full agreement with the Complementarity Principle.

It is very important to emphasize the fundamental role acquired by the mass-effect, i.e. the mechanical action exerted by photons in the transmission of information in the next Quantum Computers(QCs. In summary, the main task of our work is to ascertain whether, in this context, the different photons transmit the information at the same speed, or not!

Kinetic Energy Conservation Law

Famously, as d’Alambert reminds us, “The conservation of *live forces* or *kinetic energy* is a Principle in Mechanics that Mr. Huyghens appears to have been the first to notice and one of which Mr. Bernoulli and other authors have allowed for due to the pervasiveness of its usage in the solution to problems in Dynamics. Here is this principle which is contained in the two laws:

1. If bodies act one against the other, either by pulling on threads or inelastic rods, by pushing or by impact, as long as in this last case it has perfect elasticity, the sum of the product of the masses multiplied by the square of the speeds will always be a constant quantity.
2. If the bodies should be animated by whatever forces, the sum of the product of the masses by the squares of the speeds at every moment is equal to the sum of the product of the masses multiplied by the square of the initial speeds. Plus the squares of the speeds that the bodies would have acquired if they had been animated by the same forces and were able to move freely on the line that it has inscribed.

We distinguish between impulse and impact because *the conservation of kinetic energy* takes place in the movement of bodies which are being pushed, insofar as these movements change only by minute degrees or infinitely small amounts rather than if it occurs in *elastic* bodies which impact each other, even in the case where a spring would act in an indivisible time and would pass them and would allow them to continue without any gradual motion from one to the other. Mr. Huyghens appears to have been the first to notice that this Law of the Conservation of Kinetic Energy was contained in the collision between *elastic bodies*. It also appears that He was familiar with the Kinetic Energy Conservation Law during the motion of bodies which are animated by forces”[31].

To this purpose, Feynman writes: “It is possible to make the colliding bodies from high elastic materials, such as steel, with carefully designed spring bumpers, so that the collision generates very little heat and vibration. In these circumstances the velocities of rebound are practically equal to the initial velocities; such a *collision* is called *elastic*. That the velocities *before* and *after* an *elastic collision* are equal is a matter of conservation of *Kinetic Energy* (K_E). That the speeds of the bodies rebounding after a symmetrical collision are equal to *each other*, however, is a matter of conservation of *momentum*. Elastic collisions are especially interesting for systems that have no internal gears, wheels, or parts. Then when there is a collision there is nowhere for the condition as when they collided. Therefore, between very elementary objects, the collisions are always *elastic* or very nearly elastic” [16]. He points out: “As an interesting example, let us consider an *elastic* collision between two objects of *equal mass*. If they come together with the same speed, they would come apart at that same speed, by symmetry. But now look at this in another circumstance, in which one of them is moving with velocity v and the other one is at rest. What happens? We find that if a stationary body is struck *elastically* by

another body of exactly the same mass, the moving body stops, and the one that was standing still now moves away with the same speed that the other one had; the bodies simply exchange velocities. This behavior can easily be demonstrated with a suitable impact apparatus. More generally, if both bodies are moving, with different velocities, they simply exchange velocity at impact" [16].

Moreover, as we all know, the photon is a corpuscle, a "grain", a very little sphere which, just as a billiard small ball thrown with the right energy, pushes away the affected electron (the opponent ball). It could be a suitable example, since the *kinetic energy* (K_E) of the small ball is given 100% to the pushed ball. In fact, as Fermi reminds us, "when an atom is struck by a quantum of light it absorbs all its energy" [11]. He adds: "As the other particles, the photon too is a corpuscle, a *light's quantum* and has a its own *momentum* (p), through which transfers all its energy to the hit particle" [11].

A clear example of *elastic collision* is represented by the well-known *photo-electric effect*. In this regard, at the beginning of last century "Lenard had discovered that when the 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. When physicists started to make experiments on this phenomenon (*photoelectric effect*) they realized, with great surprise, that if they raised the light *intensity*, the energy of the emitted electrons did not increase" [32]. This appeared to be at odds with Maxwell's *wave theory of light*, which predicted that the electron energy would be proportional to the *intensity* of the radiation. On the contrary, Lenard observed that the energy of individual emitted electrons increased with the *frequency* (which is related to the *color*) of the light [26]. In fact, Lenard found that the calculated maximum electron K_E is determined by the *frequency* of the light. In other words, an increase in frequency results in an increase in the maximum *kinetic energy* calculated for an electron upon liberation. For example, ultraviolet radiation would require a higher applied stopping potential to stop current in a phototube than blue light. In this respect, Asimov points out: "What influenced the energy of the emitted electrons were the different colours of the wavelength of the light used: for instance, the blue light gave the electrons a bigger speed than the yellow light. A blue weak light caused the emission of fewer electrons than an intense yellow light, however the few electrons pushed out by the blue light had a bigger speed than any electron pushed out by the yellow light" [32].

This is unequivocal experimental evidence, as well as a revolutionary and totally innovative result.

In full compliance with the Lenard's experimental results, Feynman writes: "In the partial reflection from two glass surfaces the variation circle between 0 and 16% repeats more rapidly with the blue light than with the red one. In fact, the rotation speed of the hand of the imaginary chronometer changes with the colour of the light. The blue light, in the same unity of time, has formed 5 waves, whereas the red light formed only 3: that is the blue light covers a longer distance than the red light, in the same time. That is the blue light travels with a higher speed of the red light (which is less frequent of the blue light). The reflection cycles repeat with different intervals because the hand of the imaginary chronometer has to go more quickly when it follows a blue photon, than when it follows a red photon. In fact, the rotation speed of the

hand is the only difference between a red photon and a blue one, or a photon of any other colour, including X rays and radio waves”[33].

Since this is in clear contrast with Maxwell’s axioms, we tend to try to find the mistake somewhere: either in the preamble of the experiment or in the experimental technical processing. However the example presented is quite easy, it cannot conceal any mistake. The results shown and nicely put out by Feynman, one of the most experts of the light’s secrets, are incontrovertible.

In short what comes out is that electro-magnetic waves(EMW_s) released by an intense EM source will travel with a higher speed than EMW_s released by a less energetic source. We will wonder: why have we never noticed it? Just because we are talking about extremely small differences, imperceptible for terrestrial distances [34].

Surprisingly, in fact, it comes out that the blue colour travels with a higher speed than the red one, in the same time. These are experimental evidences confirmed countless times.

That is a photon with a higher frequency (the blue photon) travels with a higher speed than another photon with a frequency just a bit lower (the red one). That is the higher the frequency of a photon, the higher its speed, compared to photons with lower frequency.

To this purpose, Asimov adds: “A red light of any intensity did not cause at all the emission of electrons in certain metals. None of these phenomena could be explained by the old theories of light. Why ever the blue light was able to do something which the red light was not able to do? Einstein found the answer: an electron had to be hit by a quantum of energy higher than a minimum value in order to absorb enough energy to abandon the surface of the metal”[32], that is higher than the energy which keep the electron linked to the atom: *threshold value* or *shearing value*. At this regard, in fact, Einstein[27] wrote an equation for the photoelectric effect that agreed with Lenard’s experimental results:

$$K_E = h \nu - E_{link} \quad (11)$$

where K_E is the *kinetic energy* acquired by the hit electron, that is the speed it goes away; $h \nu$ is the energy of the incident photon, according to Eq.(5); E_{link} gives the *binding energy* of the electron, that is the necessary *energy* to free it from the metal (it is also called *extraction work*). As known, indeed, in 1905 Einstein described light as composed of discrete *quanta* (later called photons), rather than continuous waves. In short, in line with the Planck's theory of black-body radiation[20], Einstein theorized that a light quantum above a *threshold* frequency (as shown by equation 11) has the required energy to eject a single electron, creating the *effect* observed by Lenard [27]. It explained why the energy of photoelectrons was dependent only on the *frequency* of the incident light and not on its *intensity*: at low-intensity, the high-frequency source could supply a few high energy photons, whereas at high-intensity, the low-frequency source would supply no photons of sufficient individual energy to dislodge any electrons. The energy carried by each quantum of light is shown by Eq.(5).

Different Photon’s Momenta

To be more precise, speaking of the photoelectric effect, we need to state that it is just the *momentum* (p) of the incident photon which needs to have the necessary *power* to remove the

electron from the hit metal[35]. Therefore, let's analyze now why, differently from blues photons, red photons (with the exception of cesium and rubidium, where the *binding energy* of the electron is very weak) are unable to remove the electron from the metal. At this regard, we read from Asimov: "a violet light quantum has double energy of a quantum of red light"[32]. We have a confirmation if we calculate the value of the *momenta* of respective photons. Thus, let's consider a photon travelling with red light, whose wavelength (λ) corresponds to about 780 nanometers, that is $\approx 7.8 \cdot 10^{-5}$ [cm]. Let us calculate its *momentum* ($\mathbf{p}$):

$$\mathbf{p} = \frac{h}{\lambda} = \frac{6.626 \cdot 10^{-27} [\text{erg} \cdot \text{s}]}{7.8 \cdot 10^{-5} [\text{cm}]} \quad (12)$$

Since $1 \text{ erg} = \text{g} \cdot \text{cm}^2 / \text{s}^2$, we have:

$$\mathbf{p} = \frac{6.626 \cdot 10^{-27} [\text{g} \cdot \frac{\text{cm}^2}{\text{s}}]}{7.8 \cdot 10^{-5} [\text{cm}]} \quad (13)$$

$$\mathbf{p} = 8.5 \cdot 10^{-23} [\text{g} \cdot \frac{\text{cm}}{\text{s}}] \quad (14)$$

This is the *momentum* ($\mathbf{p}$) of a red photon.

Let us calculate now the $\mathbf{p}$ of a photon of the violet band, close the blue, with $\lambda \approx 390$ nanometers, that is $\approx 3.9 \cdot 10^{-5}$ [cm]:

$$\mathbf{p} = \frac{h}{\lambda} = \frac{6.626 \cdot 10^{-27} [\text{g} \cdot \frac{\text{cm}^2}{\text{s}}]}{3.9 \cdot 10^{-5} [\text{cm}]} \quad (15)$$

$$\mathbf{p} = 1.7 \cdot 10^{-22} [\text{g} \cdot \frac{\text{cm}}{\text{s}}] \quad (16)$$

Thus, as shown by Eq.(16), we have that the $\mathbf{p}$, that is the impulse, the *power* with which the violet photon hits the electron is exactly double of the power with which the $\mathbf{p}$ of the red photon impacts on the electron, as it is clear from Eq.(14).

This is why, differently from blue or violet photons, the red photon is not able to remove the electron from the target metal, since the K_E given to the electron is insufficient.

In fact, it is useful to state that the removal of the electron from a metal, by a sufficiently energetic photon, consists in a mechanical phenomenon imputable to the collision undergone by the electron, that is the mechanical impact, the *power* with which the photon hits the electron: as it is known this power is ascribable to the impulse, that is the value of the *momentum* ($\mathbf{p}$) of the incident photon. In fact, according to Fermi[11], the higher the energy, or the $\mathbf{p}$ of the incident photon, the higher the speed, or K_E transmitted to the electron. Thus, in line with Eq.(11), this value doesn't have to be lower than the *binding energy* of the hit electron. In short, why do electrons hit by a blue light quantum move away from the metal with a higher speed, a higher K_E compared to those hit by red light? We read from Asimov: "Anyway, the higher the energy of the *light quantum*, the higher was also the speed of the electron pushed out from the metal"[32]. In this respect, hence, in full disagreement with Maxwell's axioms, logical reasoning leads us to deduce that the blue light travels faster than red light, just as previously reported by Feynman: "The blue light travels with a higher speed of the red

light”[33]. Moreover, to our comfort comes Fermi. To this purpose, indeed, we learn from Fermi: “The photon too, as other particles, is a corpuscle, a *light quantum* and has a its own *momentum* ($\mathbf{p}$) through which transfers all its energy to the hit particle. Thus, if an electron is hit by a photon it absorbs all its energy($h\nu$)”[11] (as shown by equation 11), which corresponds to the speed of departure (K_E) of the electron from the atom.

However, the energy, as to say the *momentum*, of an optic photon is insufficient to elicit the Compton Effect [28]. As you know, in fact, in such circumstances it is necessary the *collision power* generated by the *momentum* ($\mathbf{p}$) of a X photon to remove the electron from the graphite atom. This is indisputable. Why?

Let’s calculate now the $\mathbf{p}$ value of a X ray with wavelength (λ) roughly equal to 10^{-10} [cm]:

$$\mathbf{p} = \frac{h}{\lambda} = \frac{6.626 \cdot 10^{-27} [g \cdot \frac{cm^2}{s}]}{10^{-10} [cm]} \quad (17)$$

$$\mathbf{p} = 6.626 \cdot 10^{-17} [g \cdot \frac{cm}{s}] \quad (18)$$

In this case, the difference compared to the $\mathbf{p}$ value of an optic photon, as shown by Eq.(10), is ≈ 5 orders of magnitude greater.

In both of these cases, indeed, the electrons are thrown out from the struck atom by a sufficient energetic photon. The only difference is that for the photoelectric effect it is necessary just the visible light, in the case of Compton effect, on the contrary, it is necessary the force, the *radiation pressure* given by X rays to throw out electrons from graphite. Why? An explanation can be found in the different electromagnetic (EM) frequencies used.

In summary, an optic photon does not manage to give the hit electron a sufficient *kinetic energy* (K_E), that is a speed similar to the one given by a X photon [36]. This may be the difference and the explanation. But this explanation seems to us not sufficient.

What is the intimate physical mechanism so that a visible photon does not elicit the Compton Effect? We can say because the electron hit by an optic photon has not been sufficiently accelerated, as a X photon is able to do instead.

We wonder then: why a X photon manages to accelerate the electron with a speed bigger than a less energetic photon as an optic photon is unable to do? It hasn’t been explained properly, however it is what happens with photoelectric and Compton effects[8].

As Lenard first pointed out, indeed, when some metals are struck by EM radiations with different wavelength (λ), electrons are pushed out with different velocities, in a rate inversely proportional to the value of λ and directly proportional to the frequency (ν) of the EM radiation [26].

This is the key, in our opinion, to trying to understand the intimate mechanism that can be the basis of these peculiar mechanical effects.

CONCLUSIONS

Therefore, what we learn from the Lenard's experiment? We learn that the EM radiations having a greater frequency of oscillation (ν), that is the more energetic radiations, transmit a greater speed to the hit particles, compared to what the less energetic EM radiations can do.

The Lenard's experimental demonstration represents an enormous leap, a revolutionary result which gives a significant turning point to Mechanics and assumes a very important role for the purpose of our work.

In brief, the more energetic photons give a greater and faster thrust to the particles they hit. It is unmistakable. In this respect, Fermi points out: "The photon too, as other particles, is a corpuscle, a *light's quantum* and has a its own *momentum* ($\mathbf{p}$), through which transfers all its energy to the hit particle"[11]. Even the Einstein's work predicted that the energy of individual ejected electrons increases linearly with the frequency of the light[27]. Hence, from the early 1900s it was known that the energy (i.e. K_E) of photo-electrons increases with increasing *frequency* of incident light and, moreover, it is independent of the *intensity* of the light.

These are the facts. That is, the more energetic photons give a greater and faster thrust to the particles they hit. Therefore, it is easy to infer that the EM waves with greater frequency transmit a greater K_E to the struck particles, compared to the less energetic EM radiations. Consequently, it is possible to indirectly infer that the more energetic photons travel faster than the less energetic ones [37].

In short, it is precisely this different K_E transmitted that can make us understand why only the electrons affected by X or gamma photons can generate the Compton effect. And yet, just the Compton and photoelectric effects, and their induction mechanisms, provide us with another very important piece of information: the particles capable of striking the electrons so violently, i.e. X or blue photons, receive at their origin, from their own EM source, a very high energy and thrust (proportionally greater than the photons belonging to the other less energetic bands) which likewise they transmit to the affected particles. In fact, as Feynman reminds us, "these collisions are *elastic* collisions and, therefore, the K_E is conserved"[16].

By concluding, and this is the milestone of our work, we believe that the deeper reason behind the different EM radiations propagation speeds (as experimentally confirmed countless times), lies in the different EM sources: the more energetic the source is the more energetic the acceleration given to the photons produced will be. Namely, every EM radiation should depend on the different EM sources. That is, according to the energetic charge released by the source, the EM signals emitted may have undergone a bigger or smaller push, that is a bigger or smaller propulsive power, which is translated in a bigger or smaller *momentum* ($\mathbf{p}$), related to the irradiated EM wave. This can be detected by the frequency the wave travels: the bigger the frequency, the bigger the energetic power of the source from which the wave itself come. Thus, the frequency of an EM wave may be considered as the "indication", an informer of the nature and the energetic charge contained in the EM source. Summing up, we notice that the frequency and the *momentum* of an EM radiation are proportionally related to the kind of EM source. Hence, the bigger the energy of the EM source, the bigger the frequency and the momentum of the emitted photon. But a bigger momentum indicates a higher speed of the photon itself, as we

can infer from the well known Newtonian formula $\mathbf{p} = m\mathbf{v}$ (as shown by equation 5) which describes the *quantity of motion* ($\mathbf{p}$) of a body having a mass m and moving at a speed v .

As a consequence the bigger the energetic charge discharged by the EM source, the bigger the propulsive push given to the EM signal released. Thus the EM radiation may travel with a frequency, momentum and speed, directly proportional to the energy freed by the EM source. That is, just as frequency and momentum are not constant, in the same way the speed of the photons should not be constant either.

In closing, let us suppose we can use a next Quantum Computer, that is computers not working with electrons but with photons also of different frequencies, that is with *light quanta* of different energy. Since we know, also from Margolus-Levitin Theorem [38], that in every physical system the speed the system operates is directly proportional to the energy available, it comes out that a future computer, operating with photons more energetic, should work with a higher speed than an identical computer operating with *Planck's quanta* less energetic. These concepts, moreover, are in perfect agreement with Feynman, who in this regard states: "Frequency and energy have some deep interrelationship, which of course they do"[16].

In short, it is precisely the $\mathbf{p}$ value that makes the difference in the behaviour and speed of the different photons. To this purpose, indeed, Feynman points out: "Velocity and *momentum* are proportional"[16].

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