Progress In Electromagnetics Research B, Vol. 8, 161–177, 2008

LIGHT WEIGHS

A. Puccini

Department of Neurophysiology
Order of Malta
Naples, Italy

Abstract—According to Einstein's Principle of Equivalence Mass-Energy ($E = mc^2$) the mass of a single photon (P) corresponds to 10^{-48} g/s and moving the P weighs 10^{-27} g/s, that is more than an electron. A light beam weighs 10^{-12} g/s, that is 1000 billiard times more than a proton.

1. INTRODUCTION

The dispute on the nature of light (wave or particle?) [1] dates back to Pythagorean, that is 2500 years ago. According to Pythagoras School light is made of corpuscles. This idea has been valid for more than 2000 years, since Descartes, Hooke, Boyle and Newton times [2–5], who imagined luminous beams made of *globules*, that is particles of different sizes propagating with *successive impulses* stimulating the optical nerve. At the beginning of the 19th century Young famous experiment showed an undulating nature of light. This idea remained valid throughout the 19th century. Around 1860 Kirkoff studying the radiation coming from the sun, understood that the ratio between the energy emitted by a heated body as electromagnetic radiation (EMR) and the absorbed energy, was a *function*, as indicated by P (1):

$$P(\lambda, T) \tag{1}$$

This function was not dependent on the material nature but only on the wave length (λ) and the absolute temperature (T). If we a body able to absorb radiation of each wave length is named *black body*, then its EM emission, when heated, coincides with a *universal function p*, indicated in (1). One of the first attempts to specify the *P function* was made by Paschen in 1886, who obtained experimentally the law indicated in the Eq. (2):

$$P = b\lambda^{-\gamma} e^{-\frac{\alpha}{\lambda T}} \tag{2}$$

where γ is a constant, while β and α are factors to be determined (today known as Paschen law). Thus "Wien" studied a cavity of the internal reflecting walls, as *black body* model, and the density of the energy, instead of he total energy. On the basis of an idea of Michelson (1887), according to which the spectra emissions of the solids can be explained only with *molecular vibrations* [6, 7], Wien postulated the Eq. (3):

$$P = b\lambda^{-5}e^{-\frac{\alpha}{\lambda T}} \tag{3}$$

The (3), known as Wien's law, fitted with the experimental data and with Paschen's law (2), if it was considered $\gamma = 5$. "At the beginning of 1900, lord Rayleigh analysed the *black body radiation*, considering it as a group of stationary waves, and determining the number of its vibration ways" [8], thus he obtained the *function* (4):

$$P(v,T)\alpha v^2 T \tag{4}$$

where T is the temperature and v the frequency. Rayleigh noted that when the frequency increased, a concentration of energy was obtained, thus he added to the function (4) the *dimming factor* $e^{-\beta\frac{v}{T}}$ for the high frequencies, obtaining (5):

$$P(v,t)\alpha v^2 T e^{-\frac{\beta v}{T}} \tag{5}$$

where β is a factor to be determined. The (5) is known as Rayleigh' law.

Anyway, in the same period, some experiments performed by Lummer and Pringsheim [9], or by Rubens and Kurlbaum [10], suggested the inadequacy, and the invalidity of the Wien's law (3). Thus, the problem remained unsolved until the end of the 1900 when "to suppress the anomalous behaviour of the *black body radiation* in presence of high frequencies, Max Planck proposed that the EMs oscillations come only like *quanta*" [11].

In particular, Planck proposed his conclusions during the Meeting of the Doich Fisic Society, in Berlin, the 14th of December 1900; he synthesized his ideas in the following formula (6):

$$P = \frac{8\pi h v^3}{c^3}\frac{1}{e^{\frac{hv}{kT}}-1} \tag{6}$$

(known as Planck's law), where P is the *function*, h is Planck's constant, c is the speed of the light in the vacuum, k is the Boltzmann constant (as Planck called it), $e^{\frac{hv}{KT}}$ is Rayleigh *dimming factor*, modified taking out the β and introducing h and k constants. To obtain this formula, Planck was forced to admit that the energy of the oscillators (i.e., the EM source: an electron, for instance) can coincide only with *discrete* values, that is discrete quantities defined as *energy quanta*, *EMR quanta*. Planck said: "Considering that — and this is the crucial point of the whole calculus — the E, oscillator energy, is made of a defined number of finished and same parts, we can use to this purpose the natural constant $h = 6.5 \times 10^{-27}$ [erg/s]. If this constant is multiplied for the normal oscillators' oscillating frequency, (v), we get the *energielement* (the *energy element)*, E, expressed in erg/s" [12]. The whole concept was already there, however it was necessary to wait until the following year [13] to have the final formula (7):

$$E = hv \tag{7}$$

This equation, known as Planck-Einstein equation tells the value of the energy of a single EMR, characterized by a determined oscillating frequency (v) [14, 15]. Not to be confused, of course, with the energetic value of a single *EMR quantum*, which is identified with h (8):

$$E = h \tag{8}$$

since h gives an energetic value which, according to present calculations ($6.6252 \cdot 10^{-27}$ erg/sec.), is very close to the original values calculated by Planck. This value is always the same for all the *EMR quanta*, it is always entire, never fractionated. Adding the frequency v, we indicated the energy of the EM wave (EMW) carrying our *EMR quantum*, which energy, and the *quantum* itself, are identified with h. Thus, Planck considers E as the element of energy: or the energy of the single *radiation quantum*, that is $E = h$ (8), or the energy of a single EMR, that is $E = hv$ (7). Planck did not confute the *energetic continuum*, on which Boltzmann had worked, he only divided it in *elementary cells*, with a hv size. As Sommerfield said: "that Dicember 14th 1900 marked the beginning of the Quantum Theory" [16], although in the first years of the century it was not considered by the scientific world. It was only when "Einstein extended the daring Plank's Quantum Theory to formulate his hypothesis of *photons* (Ps), or *light quanta*. This was the second decisive step in the evolution of Quantum Theory" [17]. Einstein said: "A monochromatic radiation with a reduced density (within the validity limits of Wien's formula on radiation) — our Eq. (3) — behaves, as far Thermodynamics is concerned, as if it was made of *quanta of energy*, independent one from the other, with a size $(R/N)\ \beta \cdot v[= hv]$" [18]. Thus, from a different way, Einstein got to Planck's same conclusions: see Eq. (7). According to Einstein the energetic value of a *light quantum*, P, corresponds to (9):

$$E = \left(\frac{R}{N}\right)\beta \qquad (9)$$

where, as Einstein specifies, R is the absolute constant of the gas equation, N is the number of molecules contained in a gramm-molecule, β is the exponential coefficient of Wein and Planck (corresponding to $4.866 \cdot 10^{-11}$) and v is the frequency of light.

The energetic value, given by Einstein (9), corresponds exactly to the energetic value of Planck's h (8). As Farmelo reminds us "Einstein was thinking of the relation between his idea of *light quanta* and Planck's previous researches. He realised that the idea of *light quanta* had already been used by Planck and that in Planck's theory also the energy of all atoms (within the cavity) was *quantised*. If each atoms vibrates a certain fixed number of times every second — that is with a fixed frequency — the energy of the vibrating atom could come only in entire multiples of Planck's constant (h), times the frequency (v). Thus the minimum energy that a vibrating atom can have is $E = hv$; besides the atom could have energy values $2hv$, $3hv$, $4hv$ etc. Einstein was saying that the equation $E = hv$ (7) can be applied to any kind of atom in a solid. Assuming that the *vibrating energy of every atom is quantised*, Einstein theorised that the mean energy of the atom in a solid decreases slowly as the temperature decreases, till to zero. His predictions were confirmed by the measures, in previously disconcerting, carried out 25 years earlier. In September 1909 Planck invited Einstein to talk to the physics congress in Salisburg where, with great surprise of participants, decided to talk about the "Nature and Constitution of Radiation". In this occasion Einstein presented a new research on the nature of light, maintaining that, as an electron, every *quantum of radiation* propagates in a specific direction: technically the *quantum* has a momentum. For the first time Einstein suggested in public that the radiation is made of particles. He also affirmed that since the Theory of Relativity had made superfluous the ether, it was not necessary any more to imagine the radiation as existing in something, *but as something existing independently, just as matter*. In that occasion Planck showed his reluctance to suppose that luminous waves were composed of particles, but he accepted the idea that, when the radiation interacts with the matter, the energy of the radiation goes, as *discrete quanta* to the atoms making that matter" [19].

2. DISCUSSION

So, as early as 1909 Einstein maintained that the light, the EMR, *is just as the matter*. Then if the light is "as the matter" the radiation can have a certain *consistency* (in a way), something real, material, as a *mass*, *hidden* in the radiation itself, that is the *radiation quanta* travelling with it. However the radiation, and the *radiation quanta*, are considered massless. In one of his papers, in 1909, Einstein had calculated the *mean quadratic deviation* of energetic fluctuations of the radiation in thermic equilibrium balance: the first term, prevalent with low frequencies, was consequent to the representation of the radiation in terms of waves; the second term, predominant with high frequencies, was consequent to the representation of the radiation in terms of particles. In normal conditions both representations existed, so the EMR had to be described as undulating and corpuscular at the same time [20]. What makes the difference, among the different EMRs, is their frequency! According to the frequency, the EMR can behave as a wave or as a corpuscle, a particle [21–24]. Along with what Einstein maintained, radio waves and microwaves have an undulating behaviour; on the contrary X and gamma rays behave as particles [25–28]. However, we have to keep in mind we are talking about EMWs which, according to their lower or higher frequency, can behave respectively either as waves, or as particles. If we talk about *quanta of light* that is *photons* (Ps), even if considered one by one they are corpuscles, particles. We quote: 1) Weinberg: "we have to renounce to the classical idea of radiation in terms of EMWs, we have used so far, and use the more modern *quantum* vision, according to which the radiation is made of particles known as *photons*. A normal luminous wave has a high number of photons which travel together" [29]. 2) Feynman: "I repeat: I want to emphasize that light comes in this form: particles. It is very important to know that light behaves like particles" [30].

Thus Ps are particles, corpuscles, however they do not always behave as such. It can happen that if they are carried by low frequency EMW, such as radio waves, because of a marked wave length they will go around the target (i.e., an electron) without hitting it: thus they behave as a wave too. On the contrary, if Ps travel with a high frequency EMW, with a X ray for instance, so very packed (even 10^{18} Ps per cm!), they will hit the electron, moving it away. In this case Ps behave as real bullets. We state again: "the EM field can carry waves. This oscillating waves can have different frequencies. The only difference from one wave to the other is the *oscilating frequency*" [24], which represents the main parameter of EMWs, since it characterizes its specific behaviour when the EMW and the Ps interact with the matter.

In 1923 de Broglie suggested that not only did the equation $E = hv$ (7) describe the EMR but the matter too. Just, or also, because the radiation itself isn't only energy, it is matter too, since with the matter it moves Ps which, as we know, are corpuscles, though of infinitesimal dimensions. As Farmelo reminds us "de Broglie thought that Einstein's discovery in 1905 could be extended to all material particles, and particularly to electrons" [19]. Also Ps are elementary particles, though they are considered massless. We learn from Penrose "de Broglie proposed that *material* particles themselves sometimes behaved as waves! Also the undulating frequency v, for particles with a mass m, meets Planck's relation. If we combine it with Einstein's equivalence $E = mc^2$, we have that v is related to m by (10):

$$hv = E = mc^2 \tag{10}$$

Thus, according to what de Broglie proposed, the nature does not respect the dicotomy between particles and fields, which had been an important element in the classical theory! Indeed, whatever oscillates with a frequency v, can only come in discrete units with a mass hv/c^2. In some ways the nature manages to make a consistent world where *particles and field oscillations are the same thing*! Or rather, the world is made of a thinner ingredient, of which the words 'particle' and 'wave' manage to give only in part an appropriate image" [8]. Thus, de Broglie added: "not only is the equation $E = hv$ applied to the radiation, but to the matter too. Hence, any particle had to be accompanied by a sort of *matter wave*" [19]. We are talking about the famous de Broglie *associated wave*, which can be mathematically expressed by de Broglie' formula (11):

$$\lambda = \frac{h}{p} \tag{11}$$

This formula tells us that the wave length (λ) of a *quantum*, both of radiation and *free matter*, is given by Planck's constant (h), divided by the size of the quantum momentum (p). It is very important the idea that a momentum (p) is associated to the P, we will talk about it later in this paper. From de Broglie formula, besides, it is clear that as the momentum increases (related both to a particle and to a *quantum* of EMR or P) the wave length shortens, and *viceversa* [31]. De Broglie conclusions were the following: "the light and the matter, can behave both as particles and as waves. Radiation and matter are both two-faced: they show their corpuscular aspect (or face) when interacting, and their undulating aspect (or face) when they propagate" [19]. This fundamental aspect was developed some years later by Bohr, in his Principle of Complementarity. According to this Principle of Quantum Mechanics, any particle, including Ps, has both aspects: the *corpuscular one*, and the *undulating* one (just as de Broglie had suggested), thus particles and EMR, can behave both as waves and as corpuscles. The importance of what Bohr stated is that these two values are *complementary,* that is *canonically conjugate*. This means that particles and the EMR, are as the same coin with two different faces. The peculiarity of the Principle of Complementarity is that these two faces cannot be shown at the same time, just as for the coins. Thus, the P, always moving, always shows his *undulating aspect*. Hence, if we intended to detect his probable mass, we should see it in his *corpuscular aspect*. When then? Just when it interacts, de Broglie would say. But we are talking about an extremely short moment, so it is very unlikely to manage to study the P in his *corpuscular aspect*. The P (just as any other particle) cannot stop completely, since this would allow us to know at the same time both his position (the place where the interaction with the matter, that is with another particle, takes place) and his speed, that is the momentum (which would be null, being it still). However, as we know, the position (x) and the momentum (p) are two more complementary parameters (*canonically conjugate* too), so we couldn't have simultaneous and accurate information, about the position and the speed of a particle. This is stated by Heisemberg Uncertainty Principle (HUP) [32, 33], as in (12):

$$\Delta x \cdot \Delta p \geq \hbar \tag{12}$$

where $\hbar$ is "Planck constant rationalised" ($= \frac{h}{2\pi}$), following Dirac formulas.

Well, we know that the P, that is the EMR *quantum*, the light *quantum*, *Planck's grain*, is a corpuscle, an elementary particle which cannot be divided. However it is considered massless. Besides even if the P had a mass (*hidden* to our eyes), it would be very difficult to detect it and measure it experimentally. But the P is not just energy, but *matter* too. Galison reminds us that Einstein wrote to his friend Conrad Habicht in May 1905: "It has come to my mind a consequence of the study of Electrodynamic. 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*" [34]. What is the light made of? It is made of a multitude of Ps. We know that Ps carry energy: the energy of a single P corresponds just to the energetic values of Planck's constant (h), that is $6.6252 \cdot 10^{-27}$ erg/sec. Thus, since the P carries energy, it should carry a mass too! Galison continues: "Einstein was unsatisfied: he was not satisfied of the analyses of the light, he stated that *to any kind of energy is associated a mass*" [34]. Thus, according to Einstein there should be a mass associated to the P. How is it possible? We know that the P is considered massless. Maybe this mass can be *hidden*, not detectable: just because of the Principle of Complementarity. Going on with our reasoning, we cannot overlook the Laws of Conservation, first of all the Law of Conservation Mass-Energy, well represented by Einstein Principle of Equivalence Mass-Energy, (13):

$$E = mc^2 \tag{13}$$

Planck stated that: "also the transfer of heat adds a mass" [34]. What is heat made of? We know it is made of EMR, that is Ps. Thus, according to Planck, a transfer of radiation, of Ps, from A to B will cause an increase in the mass of B! "It seemed that a hot pot was heavier than a cold one, although exactly the same size. It was a new idea: in Newtonian physics there was nothing suggesting a variation in mass as a consequence of the energy" [34]. Einstein himself considered (13) as "the connection between *inertial mass and energy*" [34]. Thus wherever there is a body, or particle, having energy, there should be in a way (visible or hidden, concealed) a certain mass too, and *viceversa*: this is what comes from (13). Our Ps are corpuscles, elementary particles, they have a known and defined energetic value, but they are massless. However, just according to (13) the P mass should have a minimal values; but it isn't so: the P mass is considered zero. Wilczeck says: "The Quantum Theory developed initially with Planck's researches on the radiation theory and reached its apex with Einstein's theory of Ps, which central result is that light comes in minimal indivisible units, Ps, having energy and momentum proportional to the frequency of light. This established the concept of a *corpuscular aspect of light*" [35]. Einstein wrote in the introduction to his most famous work: "Maxwell's theory of light (and in general any undulating theory) tells that the energy of a luminous ray, emitted by a luminous source, distributes continuously on a growing volume. I think that the observation about the radiation of the black body, the photoluminescence, the emission of cathode rays through ultraviolet light and other groups of phenomena related to the emission that is to the transformation of light, are much more comprehensible if considered based on the hypothesis that the energy is distributed in the space in a discontinuous way. According to the idea that I wish to propose here, when a light beam expands starting from a point, the energy doe not distribute with increasing volumes, but it remains made of a finite number of energy quanta localised in the space and which move without splitting, and which cannot be absorbed or emitted partially" [36]. Thus Ps move in some directions, that is they have a *momentum* which, for any particle, is described by (14):

$$p = mv \tag{14}$$

Thus the momentum (p) is given by the velocity (v) of the particle itself. The velocity of the P, we know, is equal to the speed of light, but its mass (m) is zero. Indeed, apparently there is something which doesn't work: we know that P is a corpuscle, a particle real, which travels at the speed of light in any direction. Thus, the P has a its own momentum (p), nevertheless, if we apply the (14) to the P, we have an unexpected result (15):

$$p = 0 \cdot 300.000\,\text{Km}/\sec. \tag{15}$$

where we have considered that the P travels in the vacuum and is massless. Of course the (15) will give zero as a result:

$$p = 0 \tag{16}$$

Hence, if we consider the P with a zero mass, its momentum will be null, so the P will be still, since to a massless P will correspond a zero momentum. We all know it is not so: the P is always in motion, and even with a very high speed, rather than still. Moreover, as we have mentioned above, just for the HUP the P will never be able to be still [33]. Hence, in order to make the (14) accounts balance, when considering a massless particle as the P, we will have to modify the value of one of the three terms of the equation. Let us try. The velocity (v) of the P is real and accurately determined: it corresponds to 299792.458 (± 0.4) Km/sec [37]. Besides, since the P is always in motion, in some directions, implies automatically that the P also has a momentum (p), which value in that case should be superimposing to the value of v. Thus it is absolutely impossible, as it comes from (16), to give a value zero to the momentum of the P. In the case of P, his value is superimposing to v's. Hence we can only think that it is the value given to m (the mass of the P), which doesn't make the accounts balance. That is, if we continue to consider that the P has a zero mass, both Mathematics and the facts, tell us we are wrong. In short, since the P has an velocity (v), a momentum (p), cannot be massless (otherwise at least the value of the momentum would be null). What is the value of this mass then? Let's precede step by step. Let us examine the (13); if we invert the factors, we have (17):

$$m = \frac{E}{c^2} \tag{17}$$

As Penrose reminds us "according to the famous Einstein relation $E = mc^2$, the energy if basically interchangeable with the mass (since c^2 is only a *conversion constant* among the units of energy and mass which are used)" [38]. In the same way, Feynman stated that "Energy and mass differ just for a c^2 factor" [24].

This should be true for any particle having a its own energy. Let us now try to apply the (17) to a single P (which is an energetic particle). In that case too, just as for the (14), we know two parameters of the P: the energy of the P, that is E, which corresponds to Planck's constant, which is just an energetic value, since $h = 6.625 \cdot 10^{-27}\,\mathrm{erg/sec}$. The second parameter we consider is the c of the (17) and the v of the (14): it corresponds to the speed of light, that is to the speed of each P. If we know two of the three parameters of the Eq. (17), we must necessary know the third one, that is the value of m, the mass of the P. If we insert these values in the (17) we have the (18):

$$m = \frac{h}{c^2} = \frac{6.625 \cdot 10^{-27}\,\mathrm{erg\,sec}}{(2.9979 \cdot 10^{10}\,\mathrm{cm\,sec})^2} \tag{18}$$

If we make the calculation with the cgs system we have (19):

$$m = \frac{6.625 \cdot 10^{-27} erg\,\mathrm{sec}}{(2.9979)^2 \cdot 10^{20}\,\mathrm{cm\,sec}} \tag{19}$$

which follows (20):

$$m = \frac{6.625}{(2.9979)^2} \cdot 10^{(-27-20)} = \frac{6.625}{(2.9979)^2} \cdot 10^{-47}\,\mathrm{g/s} \tag{20}$$

From (20) we can get (21):

$$m = 7.372 \cdot 10^{-47} g/s \tag{21}$$

and in the end (22):

$$m = 7.372 \cdot 10^{-48} g/s \tag{22}$$

This is what the value of the mass of a P should be: the value expressed in gram/sec, since the P is an *action quantum*, besides we can calculate this value from its energy, which is expressed in values (of energy) per second. With this respect Penrose says: "the energy and the momentum are both correlated to a *period*: temporal for the energy, and spatial for the momentum" [38]. That is why the P, that is Planck constant, h (which represents the P itself and its energy), is correlated to a *period*, that is to say a temporal measure, as the second. This is why the P, that is the h, is expressed in an energetic value in the time: in erg/sec. This is why if we extract the mass of the P from its energy/c^2, this mass will be expressed in mass-second, that is, using the cgs system, in gr/sec.

Of course the value coming from (22) is really infinitesimal. It is true: however it is $\neq 0$. Besides we have to add the *kinetic energy* (K) to its mass. The formula of the kinetic energy, valid for any particle is (23):

$$K = \frac{1}{2}mv^2 \tag{23}$$

it is the value of the mass of the particle times the square of its speed, all divided 2. Analysing (23), Chandrasekhar warns "we observe that as the speed doubles the energy quadruples. The energy has just one measure, expressed in erg, but it does not have a direction as the momentum: it is a *scalar*. Is it possible to mention any other scalar quantity? The mass, m. It only has a quantitative value, usually expressed in grams, but not a direction" [39]. This is perfectly congruous with the values of the mass of P: expressed in grams and seconds, since the measure of the energy is expressed in erg/sec. Talking about the kinetic energy Hawking says: "because of the equivalence Mass-Energy the kinetic energy is added to the mass of the object in motion, so the faster the object, the more his mass will increase. This effect has some relevance only when considering speeds next to the speed of light. For instance, an object travelling with a speed 10% of the speed of light, its mass will increase only 0.5%, whereas with 90% of the speed of light its mass will be more than double. As an object gets closer to the speed of light its mass increases more quickly" [40]. Starting from (23) let us try to calculate the kinetic energy of the P in motion. Adding the value of its mass indicated by (22) we get the (24):

$$K = \left(\frac{1}{2}\right)\left(7.372 \cdot 10^{-48}\,\mathrm{g/s}\right)v^2 \tag{24}$$

Adding in (24) the value of the speed of P we have (25):

$$K = \left(\frac{1}{2}\right)\left(7.372 \cdot 10^{-48}\,\mathrm{g/s}\right)\left(2.9979 \cdot 10^{10}\right)^2 \tag{25}$$

Hence (26):

$$K = \left(\frac{1}{2}\right)\left(7.372 \cdot 10^{-48}\,\mathrm{g/s}\right)\left(8.9874 \cdot 10^{20}\right) \tag{26}$$

and (27):

$$K = \left(\frac{1}{2}\right)\left(66.2551 \cdot 10^{-28}\,\text{g/s}\right) \tag{27}$$

and (28):

$$K = 33.1276 \cdot 10^{-28}\,\text{g/s} \tag{28}$$

That is the kinetic energy (K) of a single P should correspond to (29):

$$K = 3.3128 \cdot 10^{-27}\,\text{g/s} \tag{29}$$

This should be the mass with which a P hits another particle, an electron or a proton (which mass corresponds to the nucleus of an atom of hydrogen), or a nucleus with a bigger atomic weight . The mass of an electron is 9×10^{-28}gr, thus the P hitting the electron has a total mass even bigger then the electron's itself, in fact it manages to move it away, as it happens with the photoelectric effect, with the Compton effect, or the Raman effect. In these circumstances the P behaves as a real corpuscle as it is, we may say, following Newton, that the P behaves as a billiard small ball, which hits the opponent ball (the electron) moving it away. Well, this *pushing effect* the P makes on the electron seems more a *mechanic effect* (rather then a merely energetic action, which intimate action mechanism seems that hasn't been well shown, but it remains vague) [41]. We learn just from Mechanics that at the bottom of a mechanic action it is implicated a mass. That is, a mechanic effect should be induced by an object, or a particle, but they must have a mass (also in case this mass is *concealed* — respecting the Complementary Principe — *under an energetic shape*), as it may be for our P. In nature there are several examples of mechanic actions carried out by the light: one of them is the chlorophyllian photosynthesis. In that case, as we know, the mechanism of the photosynthesis is induced by the mechanic action of the light, through the Ps, which hits the electrons, moving them away from the molecules of water and setting up in the chloroplasts the series of chemical reactions which result in the sugar biosynthesis, necessary for the metabolism and the life of plants [41].

We can find another example of mechanical action induced by Ps in the action mechanism of a Geiger counter. With this respect Giacconi and Tucker say: "In 1946 Herbert Friedman and his group designed a Geiger counter sensitive to a small wave length interval, based on specific filters and on the selective ionization of the gas. The idea is the following: a gas (a mixture of argon and carbon dioxide or methane) is introduced in a box containing one or more high tension wires, called electrodes. The box has a "window" made of a thin membrane which stops the light, but allow the passage of some wave length of X and ultraviolet radiation. The thickness of the membrane determines which wave lengths can pass through the window and which are filtered. For instance a this window allow the passage of all the wave length from the extreme ultraviolet till "hard" X rays, whereas a thicker window stops the extreme ultraviolet, and one even thicker stops also the "soft" X rays, and so on. One a high energy photon has gone through the window, it is absorbed by the gas in the counter. In this process one of the atoms of the gas ejects an electron, which goes through the gas freeing other electrons from their atoms. All these electrons travel towards the high tension wire acquiring energy and ionizing other atoms. When the cloud of electrons reaches the wire, thousands of electrons have been freed so we have a strong electric signal" [42]. Thus, these high energy Ps, that is with high frequency, behave just as real bullets, which hit the electrons, taking them away from their atoms and pushing them towards the wire, so they create an electric signal. These Ps, in this way, carry out a mechanical action, rather than a mere energetic effect, which action mechanism is not very clear. In other words this mechanical action, this *pushing effect* carried out by Ps on the electrons implies that Ps have a certain *material consistence*. Apparently, Ps carried by EMWs with higher frequency behave as they carried with them a certain mass, that is as something able to produce a *mass effect* on the electrons, acting in this way as billiard balls, just as Descartes, Hooke, Boyle and Newton had imagined [2–5].

Just in passing, black holes (BHs) can give us some indications on a probable mass of the P. Hawking says "according to Quantum Mechanics, BHs are not completely *black*, but they emit particles and radiations of different types, just as incandescent bodies. The BH loses its energy, and thus mass (according to $E = mc^2$). Thus the BH would evaporate and reduce its dimensions" [43]. Hawking is literally telling us that, with the emission of EMWs (of any kind) not only is the energy lost but the mass too! In other words, not only would the EMR take away energy, from the source, but with it, through *radiation quanta*, mass too. It seems to be a very authoritative confirmation of the mass carried by EMWs, and with them by Ps. That is why the BH, with the time, evaporates and reduces its dimensions.

3. CONCLUSION

According to Einstein Equivalence Mass-Energy Principle, any particle having a its own energetic value, already at rest (that is without summing the possible kinetic energy) will have to have an *intrinsic mass* (even if concealed), and corresponding to the value of its energy, divided the square of the speed of light in vacuum. This should be true also for the P, so its *restmass* should be the same as the value indicated in the (22). Since the P is always in motion, we have to consider its kinetic energy, which values are expressed in the (29), from which emerges surprisingly that its mechanical effect corresponds to the effect of a mass bigger than the electron's.

If, then, we consider the action carried out by a light beam, we need to multiply the value of the kinetic energy of a single P for the number of Ps carried, each second, by that beam. If we consider a light of a mean frequency 5×10^{14}, we have the (30):

$$\left(5 \cdot 10^{14}\right)\left(3.3128 \cdot 10^{-27}\,\mathrm{g/s}\right) = 16.564 \cdot 10^{-13}\,\mathrm{g/s} \tag{30}$$

that is (31):

$$1.6564 \cdot 10^{-12}\,\mathrm{g/s} \tag{31}$$

This is the mechanical action, we may say the *mass effect* carried out by a common light beam, each second. It is just this mechanical effect which, for instance, after some hundred seconds, makes flowers bloom every morning.

If we decided to consider the radiation of the extreme red, that is with a frequency about $4 \times 10^{14}\,\mathrm{c/s}$, we would have the (32):

$$\left(4 \cdot 10^{14}\right)\left(3.3128 \cdot 10^{-27}\,\mathrm{g/s}\right) = 13.2512 \cdot 10^{-13}\,\mathrm{g/s} \tag{32}$$

that is the (33):

$$1.3251 \cdot 10^{-12}\,\mathrm{g/s} \tag{33}$$

On the other side of the visible light there is the violet, with a frequency about 8×10^{14}, which gives (34):

$$\left(8 \cdot 10^{14}\right)\left(3.3128 \cdot 10^{-27}\,\mathrm{g/s}\right) = 26.5024 \cdot 10^{-13}\,\mathrm{g/s} \tag{34}$$

that is (35):

$$2.6502 \cdot 10^{-12}\,\mathrm{g/s} \tag{35}$$

It comes that the visible light carries out a mechanical effect, on the matter it interacts, probably induced by a *mass-equivalent* (carried by the light beam, second after second), which is 1000 billiards times bigger than the mass of a nucleus of hydrogen (as to say: the mass of a proton), since this weights *only* 1.67×10^{-24} gr.

REFERENCES

1. Zu, D.-L., "The classical structure model of single photon and classical point of view with regard towave-particle duality of photon," *Progress In Electromagnetics Research Letters*, Vol. 1, 109–118, 2008.
2. Descartes, R., *Dioptrique*, 84, Adam-Tannery eds., Paris, 1637.
3. Hooke, R., *Micrographia*, Martyn-Allestry eds., 58–59, London, 1665.
4. Boyle, R., *Experiments and Considerations touching Colours*, 58–59, Birch T. ed., London, 1664.
5. Newton, I., *Phylosophical Transactions of the Royal Society*, Vol. 7, No. 80, 3075–3087, London, 1672.
6. Censor, D., "The Mathematical elements of relativistic free-space scattering," *Journal of Electromagnetic Waves and Applications*, Vol. 19, No. 7, 907–923, 2005.
7. Jung, B. H. and T. K. Sarkar, "Analysis of transient electromagnetic scattering with plane wave incidence using MOD-FDM," *Progress In Electromagnetics Research*, PIER 77, 111–120, 2007.
8. La Teana, F., *Introduction of 'Die Hypotese der Lichtquanten' by Hermann Armin*, 1965; 10–14, Newton-Compton eds., Roma, 2005.
9. Lummer, O. and E. Pringsheim, *Verhandlungen der Deutschen Physicalischen Gesellschaft*, Vol. 2, No. 163, 237, 1900.
10. Rubens, H. and F. Kurlbaum, *Sitzungsberichte der Koniglich Preussischen Akademie der Wissenschaften zu Berlin*, 929, 1900.
11. Penrose, R., *The Emperor's New Mind*, 1989; 295–297, Oxford Univ. Press, RCS ed., Milano, 1997.
12. Planck, M., *Verhandlungen der Deutschen Physikalischen Gesellshaff*, Vol. 2, 237, 1900.
13. Planck, M., *Annalen der Physik*, Vol. 4, 553, 1901.
14. Ruppin, R., "Scattering of electromagnetic radiation by a perfect electromagnetic conductor sphere," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 12, 1569–1576, 2006.
15. Wang, L.-F., J. A. Kong, K. H. Ding, T. Le Toan, F. Ribbes, and N. Floury, "Electromagnetic scattering model for rice canopy based on Monte Carlo simulation," *Progress In Electromagnetics Research*, PIER 52, 52, 153–171, 2005.
16. Sommerfield, A., *Atombau und Spektrallinien*, 39, Braunschweig, 1931.

17. Hermann, A., *Die Hypotese derLichtquanten*, 1965; 42–43, Newton-Compton eds., Roma, 2005.
18. Einstein, A., *Jahrbuch der Radioaktivitat und Elektronik*, Vol. 4, 443, 1907.
19. Farmelo, G., *It Must Be Beautiful. Great Equations of Moderne Science*, Granta Publications, London, 2002; 39–41, 48–51, Il Saggiatore ed., Milano, 2005.
20. Einstein, A., *Physikalische Zeitschrift*, Vol. 10, 817, 1909.
21. Lindell, I. V., "Class of electromagnetic bi-quadratic (BQ) media," *Progress In Electromagnetics Research B*, Vol. 7, 281–297, 2008.
22. Ghunlem, A. M., "Modes of electromagnetic wave propagation in circular concrete tunnels," *Journal of Electromagnetic Waves and Applications*, Vol. 19, No. 1, 95–106, 2005.
23. Lindell, I. V. and A. H. Sihvola, "Reflection and transmission of waves at the interface of perfect electromagnetic conductor (PEMC)," *Progress In Electromagnetics Research B*, Vol. 5, 169–183, 2008.
24. Feynman, R. P., *Lectures on Physics*, 1965 California Institute of Technology; Vol. 1, 2–7, 2–6, 7–7, Zanichelli ed., Bologna, 2001.
25. Mahmoud, S. F., "Modal propagation of high frequency electromagnetic waves in straight and curved tunnels within the earth," *Journal of Electromagnetic Waves and Applications*, Vol. 19, No. 12, 1611–1627, 2005.
26. Pan, W.-Y., K. Li, and H.-Q. Zhang, "Lateral-wave electromagnetic field generated by a horizontal electric dipole below the spherical-earth surface," *Journal of Electromagnetic Waves and Applications*, Vol. 19, No. 7, 953–972, 2005.
27. Popov, A. V. and V. U. Kopeikin, "Electromagnetic pulse propagation over nonuniform earth surface: Numerical simulation," *Progress In Electromagnetics Research B*, Vol. 6, 37–64, 2008.
28. Lindell, I. V. and A. H. Sihvola, "Perfect electromagnetic conductor," *Journal of Electromagnetic Waves and Applications*, Vol. 19, No. 7, 861–869, 2005.
29. Weinberg, S., *The First Three Minutes. A Modern View of the Origin of the Universe*, 1977; 65–66, Mondadori ed., Milano, 1977.
30. Feynman, R. P., *QED. The Strange Theory of Light and Matter*, 1985; 30, Adelphi ed., Milano, 1989.
31. Okazaki, T., A. Hirata, and Z. Kawasaki, "Time-domain mathematical model of impulsive EM noises emitted from discharges," *Journal of Electromagnetic Waves and Applications*, Vol. 20, No. 12, 1681–1694, 2006.

32. Heisemberg, W., *Zeitschrift fur Physik*, Vol. 43, 184–185, 1927.
33. Piccini, A., "Uncertainty principle and electromagnetic waves," *Journal of Electromagnetic Waves and Applications*, Vol. 19, No. 7, 885–890, 2005.
34. Galison, P., "The Sextant equation," *It Must be Beautiful. Great Equations of Moderne Science*, Granta Publ., London, 2002; Vol. 119, 107–114, Il Saggiatore ed., Milano, 2005.
35. Wilczeck, F., "Something Magic," *It Must be Beautiful. Great Equations of Moderne Science*, Granta Publ., London, 2002; 218–219, 221, Il Saggiatore ed., Milano, 2005.
36. Einstein, A., *Annalen der Physik*, Vol. 17, 132, 1905.
37. Achenbach, J., *National Geographic Italia*, Vol. 10, 8, Milano, 2001.
38. Penrose, R., *The Road to Reality*, 611, 503, Rizzoli ed., Milano, 2005.
39. Chandrasekhar, B. S., *Why Things Are the Way They Are*, Cambridge University Press, 1998; 58–59, Il Saggiatore ed., Milano, 2004.
40. Hawking, S., *A Briefer History of Time*, 47, RCS ed., Milano, 2005.
41. Puccini, A., *Progress In Electromagnetics Research*, Vol. 55, 133, 2005.
42. Giacconi, R. and W. H. Tucker, *The X-Ray Universe. The Quest for Cosmic Fire from Black Holes to Intergalactic Space*, 1985; 32, A. Mondadori ed., Milano, 2003.
43. Hawking, S., *The Universe in a Nutshell*, 196, A. Mondadori ed., Milano, 2001.