WAVES AND PARTICLES OF LIGHT

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A description of the wave-particle duality of the electromagnetic radiation is presented, in which explanations are advanced to some statements of the standard quantum mechanics. In this description the free light is only a wave and the photons appear by interaction. The generation of photons is explained, using the idea of the existence of a nonlocal field.

1. INTRODUCTION

The usual standard conception on the wave-particle duality is given today by quantum mechanics in the Copenhagen interpretation, which we shall call conventional quantum theory (CQT).

CQT has been remarkably successful in handling many phenomena in atomic, molecular, macroscopic and technological domains. However CQT is embarrassing in some problems, and it has been criticized by many physicists, and also alternative interpretations have been proposed, e.g. [1-9]. Reviews up to 1977 and 1986 in refs. [10] and [11]. Yet the experiments performed so far to decide between different interpretations seem to incline in favour of CQT.

But there need to be no constraint on the question asked in physics. Popper said [12]: "...there are no scientific benefits in assuming that quantum mechanics is a complete and finished theory, the <end of the road>. That would be a non-scientific and even dogmatic attitude".

In the present paper we shall examine the wave-particle duality of the electromagnetic radiation, light in short, and advance a description which preserve those statements of CQT confirmed by experience, but introducing, contrary to CQT, conceptual realism and determinism. Also an explanation of the so called "collapse" phenomenon will be advanced. Our description is a lax interpretation (LI).

2. THE FORM OF THE WAVE-PHOTON DUALITY

According to CQT a microentity, in particular light, is at all times either a wave or a particle, namely a photon, and the doubt is resolved only when some measurement is made of it. This effect of a measurement (or in general any interaction with some other system) is to "collapse" the state of the entity. Particle and wave are never the two simultaneously, they are complementary descriptions.

The LI point of view resemble in some way to that of CQT. Light is sometimes photon. The existence of photons has been sustained by several phenomena, as the photoelectric effect, the Compton effect, etc.[13], all proved be interaction of light with some devices.

On the other hand the wave character of the light has been proved long time ago by the interference and diffraction phenomena [13]. It has been shown that these phenomena occur even with no matter haw small intensities of light [14-19]. Yet the diffraction patterns on a screen, or other detectors, are obtained by agglomerations of highly localised effects, i.e. by action of individual photons. Panarella [6] speaks of "photon clumps".)

According to LI light is a complicated wave, composed of several fields, a combined fields wave (CFW). The "free" light is only a wave, in agreement with CQT: between the interactions one can say nothing observationally. Yet CFW is not a probabilistic but a real wave; this is a potential reality in the sense that comprises real electric and magneticfields, and also contains elements to produce in certain conditions entities that can be detected, that is photons.

The idea of associated waves originates, of course, from the theory of the double solution of de Broglie [2], and was adopted in various forms also by other authors, e.g. [20-25]. But in these theories the combined waves are attached to the particle, while in the LI version there is also a "free" CFW without particles.

Further on, LI states, as CQT, that photons are evidentiated only by interaction, by measurement or observation. However LI states that there is not a "collapse" in the sense of CQT, but it is a formation, or generation of photons from the wave, a real physical phenomenon.

3. GENERATION OF PHOTONS

In order to explain the formation of photons by interaction LI adopts the idea of nonlocality, alike CQT, but associated with realism and determinism. Bell [26] discovered a proof that any deterministic model that assumes realism and reproduces CQT results must be explicitly nonlocal. Nonlocality has been corroborated by some experimental tests [27, 28]. In the frame of LI the nonlocality is displayed as follows.

It has been advanced in former paper [29] the hypothesis that a universal nonlocal field – say *W*- does exist. This is not a form of ether, or a kind of medium, but a fundamental entity conceived as expression of a background nonpreferentiality. The field obeys a nonlinear equation with higher derivatives, which in compact form reads [30]

$$\sum_{n=0}^{2z+1} C_n \partial^n W + \mathcal{N} = 0 \qquad (1)$$

where $\mathcal{N}$ is the nonlinear part. (The formalism with higher derivatives in [31,32].) This field manifests itself in all physical phenomena in different countenances. Mark the words of Bohr [33] that the Universe is coupled together. We express this idea by the field *W*.

Now, according to LI when light is in interaction with another system the following components of CFW are envisaged. One component – say *w* – "activates" the field *W* in the interaction zone in the form of oscillating "peak" solutions "sweeping" the whole area; another component –say v_1 – is a simple linear wave with the frequency of the light wave and with intensity proportional with the intensity of the light wave; the third component – say v_2 – is nonlinear and gives rise to some kind of "solitons" or "singular regions" in number proportional to the intensity of the wave v_1 i.e. of light

$$N = aI \tag{2}$$

The three waves can be represented by three equations, emerging from eq. (1). Making in that equation *Z*=2 a decomposition according to refs. [34, 35] yields

$$\sum_{\lambda} A^{\lambda}\partial_{\lambda} w + Bw + \eta_w \mathcal{N}(W) = 0 \tag{3}$$

$$\sum_{\lambda} \partial_{\lambda}^{2} v_1 = 0 \tag{4}$$

$$\sum_{\lambda} \partial_{\lambda}^{2} v_2 + \eta_{v_2} \mathcal{N}(v_2) = 0 \tag{5}$$

where

$$\begin{cases} w = f(\partial^l W) \\ v_1 = g_1(\partial^l W) \\ v_2 = g_2(\partial^l W) \end{cases} \tag{6}$$

(l=0~5). $\mathcal{N}$ contains in general the interaction with other systems and selfinteraction. One can see from (6) that the three fields in eqs. (3), (4), (5) are in connection through the field *W*.

In the conception of LI, the "singularities" appearing from the nonlinear eq. (5) become detected photons only if they "meet" the oscillating "peaks" of *W*; this hypothesis is justified by the mentioned character of the field *W*. There are several theories e.g. [36, 37, 38] which presume interaction between the behaviour of particles and a subquantum medium; but LI introduces instead the field *W* and goes further asserting that the very formation of photons is assured by the intervention of this field.

From the above one can see that the number of photons appearing is proportional with the number of the "singularities". On the other hand for each period of the light wave a number of "peaks" occur. For a longer period greater number of “peaks”, greater number of “coincidences” with the “singularities”; therefore one can consider the number of photons generated also proportional with the period of light, thus

$$n=bNT \tag{7}$$

Keeping in mind (2) we have

$$n=abIT \tag{8}$$

thus the intensity of light results

$$I=n\ .\ const\ .\ T^{-1}=n\ .\ const\ .\omega \tag{9}$$

which allow to consider the energy of the photon as

$$\varepsilon=\ const\ .\omega=\hbar\omega \tag{10}$$

The way in which this result was obtained is in support of the above hypothesis.

Due to the fact that the frequencies of the “singularities” and of the “peaks” differ, the conditions of coincidences between them are at random, therefore the apparition of the photons seems probabilistic. As the number of photons is proportional to the intensity of the light wave, i.e. of the v_1 wave, it results that the v_1 wave can be related to the ψ probability wave.

However the apparition of the photons is in fact deterministic, because it is well determined by the frequencies of the “singularities” and of the “peaks”, through the last one is unknown for now. This is an open question.

For the “free” light, in absence of all interactions, equations (3), (4), (5) are

$$\sum_{\lambda} A^{\lambda}\partial_{\lambda} w + Bw = 0 \tag{11}$$

$$\sum_{\lambda} \partial_{\lambda}^{2} v_1 = 0 \tag{12}$$

$$\sum_{\lambda} \partial_{\lambda}^{2} v_2 = 0 \tag{13}$$

one can see that v_2 is analogous to the u wave of de Broglie and v_1 is analogous to the de Broglie v wave. According to de Broglie [2] “...ces deux equations puissent être considerées comme étant presque partout dans l’espace pratiquement identique”.

On the other hand, considering that v_1 and v_2 have four components, one can introduce from (12) and (13) the magnitude

$$kv_1 + kv_2 = F_{\mu\nu} \tag{14}$$

and one can write the equation

$$\sum_{\lambda} \partial_{\lambda}^{2} F_{\mu\nu} = 0 \tag{15}$$

Interpreting the components of $F_{\mu\nu}$, with $\mu\neq\nu$, as the components of the electric field $\vec{E}$ and of the magnetic field $\vec{H}$, eq. (15) represents the wave equation for the electromagnetic field.

In view of the above description, the phenomenon of the electromagnetic radiation runs as follows. A source emits photons as consequence of a change of energy; departing from the interaction with the source the photons disintegrate remaining only a wave; entering in interaction with another system photons reappear; leaving the system they again disintegrate; the process takes place as a continuous propagation of a wave. Eventually the photons can be absorbed by a system, for example in a detector, where they can be observed

4. CONCLUSIONS

The present description of the wave-particle duality of light is in agreement with the statement of CQT that light is wave or photons; yet for LI photons and waves are not complimentary descriptions but specific realities which transform in each other.

LI is a realist and conceptual determinist interpretation of the quantum phenomenon, leading to the same experimental results as the CQT interpretation, and gives an explanation for some aspects of CQT as the probability propagating as wave and the “collapse” phenomenon.

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