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Some comments on the matter wave-light wave hypothesis

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From the de Broglie matter wave hypothesis and Planck's energy quantization law, and assuming conservation of energy in the absorption of a photon and its consequent conversion to kinetic energy of motion by a material particle initially at rest, one can deduce a simple mathematical relationship between the wavelength λ (or frequency ν), of the photon absorbed by the particle at rest, and the resulting de Broglie matter wave length, λ_D, of the particle with kinetic energy of motion of $mv^2/2$. The relationship so deduced, $\lambda_D \propto \sqrt{\lambda}$, suggests that visible wavelengths of light, from about 4000 Å, in the violet, to beyond about 7000 Å, in the red, on absorption by an electron at rest, lead to material electron wavelengths, λ_D, of the order of the size of the electron transfer proteins seen in the photosynthetic reaction centers of photosynthesizing organisms, at about a size of 50–100 Å. In addition to understanding the mechanism of photosynthesis as a material wave mediated phenomenon, further areas of importance of the relations pointed out in this paper are in the design of experiments to gain a deeper understanding of the basic tenets of wave mechanics, and in the use of tunable lasers to probe various properties of material waves, and to precisely control their properties for applications including lithography.

KEY WORDS: Planck energy quantization, de Broglie matter wave hypothesis, photon, wave mechanics, photosynthesis, tunable radiation

1. Introduction

Planck introduced the concept of the quantum of energy in 1900 [1]. This idea revolutionized physics and changed the nature of the physical understanding of the universe. The fundamental equation of the quantum hypothesis is shown as equation (1).

$$E = h\nu. \tag{1}$$

The well-known Planck constant, h, has the dimensions of an action, or an energy multiplied by a time, it is given in units of Js. We see in (1) that a photon

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of fixed frequency, ν, has a very specific energy mandated by the product $h\nu$. Later in the 20th century, De Broglie made the fundamental contribution of the matter wave hypothesis in 1924 [2], this relation is shown in equation (2).

$$\lambda_{\mathrm{D}} = \frac{h}{mv}. \tag{2}$$

Here, De Broglie employed Planck's quantum hypothesis, by making use of Planck's constant h, in the relation shown in (2) describing the wave nature of material particles. The corresponding mass, m, and velocity, v, of a particle in motion, which are contained in the denominator of the right-hand side of (2), lead to, by simple dimensional analysis, the computation of a length, the so-called de Broglie wavelength, λ_{D}, in dimensions of m, that a particle of mass m, in dimensions of kg, characteristically possesses by virtue of its velocity v, in dimensions of m/s. De Broglie's wave-particle duality hypothesis has been verified for electrons, and other material particles like neutrons, in scattering experiments by Compton and Allison [3] and diffraction experiments by Davisson and Germer [4] and other investigators.

Assuming a particle of mass, m, initially at rest, can be excited by a photon of frequency, ν, and through conservation of energy convert the photo energy, as given by equation (1), entirely into classical kinetic energy of motion, given simply by the expression $\mathrm{mv}^2/2$, one can state the following expression (3) for its velocity, v.

$$v = \sqrt{\frac{2h\nu}{m}}. \tag{3}$$

Subsequently, from simple algebraic substitution of equation (3) into (2), for the velocity of a material particle with corresponding de Broglie wavelength, λ_{D}, one gets a relation, shown in (4), between the de Broglie wavelength of the material particle of mass, m, and the frequency of the light photon, ν, absorbed by the material particle, and which it has entirely converted into kinetic energy of motion.

$$\lambda_{\mathrm{D}} = \sqrt{\frac{h}{2m\nu}}. \tag{4}$$

From considerations of dimensional analysis equation (4) is internally consistent. It represents a purely algebraic relation between the de Broglie wavelength of a material particle, λ_{D}, and the kinetic energy of motion acquired by that material particle upon excitation from rest by a photon of frequency ν. It is hereafter called the matter wave-light wave hypothesis.

2. Nature of matter wave-light wave hypothesis

Equation (4) can be rearranged, with the use of the physical identity $\nu\lambda = c$, into a direct relation between the square root of the wavelength of light absorbed

Table 1
De Broglie wavelength, λ_D, and corresponding absorbed light photon wavelength, λ, for an electron acquiring kinetic energy $mv^2/2$.

λ_D, De Broglie Wavelength in Å	λ, Light photon absorbed with wavelength in Å	Color of absorbed radiation
1.1014	1.0000	Hard X-ray
3.4829	10.000	Mid X-ray
7.7880	50.000	Soft X-ray
11.014	100.00	Hard ultra-violet
24.628	500.00	Mid ultra-violet
34.829	1000.0	Near ultra-violet
69.659	4000.0	Violet
77.881	5000.0	Green
85.314	6000.0	Yellow–orange
92.150	7000.0	Red
110.14	10,000	Near infra-red

by a material particle at rest, $\surd\lambda$, and the corresponding de Broglie wavelength it acquires in motion, λ_D. Such a relation is shown in equation (5).

$$\lambda_D = \sqrt{\frac{h}{2mc}} \cdot \surd\lambda. \tag{5}$$

The term to the immediate left of $\surd\lambda$, on the right-hand side of equation (5), is a collection of natural constants given by the expression $\surd(h/2mc)$. Here, h is Planck's constant with the value of 6.626×10^{-32} Js, m is the mass of the particle considered in kg, and c is the speed of light as 2.998×10^8 m/s. By dimensional analysis, one can see indeed this factor has the dimensions of $m^{1/2}$, this is the dimensions it must have for the equality in 5 to hold. By inserting into this factor the mass of the electron, m_e, as the particle of interest, where m_e is 9.109×10^{-31} kg, the resulting factor takes on the constant value of $1.1014 \times 10^{-5}\, m^{1/2}$. This constant is characteristic of the matter wave-light wave hypothesis as presented here in equation (6).

$$\lambda_D = (1.1014 \times 10^{-5}\, m^{1/2}) \cdot \surd\lambda. \tag{6}$$

One can thus use equation (6) to calculate a simple spectrum of de Broglie wavelengths of a material electron particle across the electromagnetic spectrum. The first column of table 1 gives specific values of the de Broglie wavelength, λ_D, of an electron excited by the corresponding electromagnetic radiation of wavelength, λ, given in column 2 of table 1. One can see from equation (6) that the algebraic correlation of the two wavelength quantities is, practically speaking, given by the elementary algebraic function $y = C \cdot \surd x$, where C is just a small numerical constant with the value given above as $1.1014 \times 10^{-5}\, m^{1/2}$, while y, in

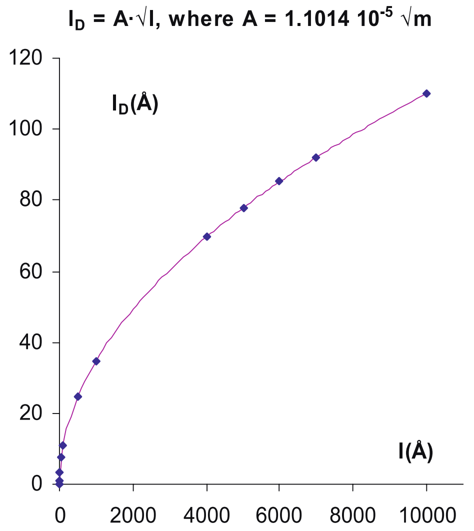

Figure 1. Plot of de Broglie wavelength of particle, λ_D, against a function of the wavelength of light photon absorbed by it, λ.

this instance, would be given by λ_D and x would be just λ. Thus, figure 1 shows a graph of equation (6) from photon frequencies in the X-ray region of the electromagnetic spectrum, through the visible region and out to the near-IR part of the electromagnetic spectrum.

It is interesting from the data given in table 1, and the graph in figure 1, to trace the de Broglie wavelengths, λ_D, of the excited electron with the wavelength of its excitation photon, λ. The correlation is almost a direct one initially, with photons of X-ray wavelengths in the neighborhood of Ås yielding electron material wavelengths also in the neighborhood of Ås. The curve flattens out abruptly, though, and we see photons in the visible region of the electromagnetic spectrum, with wavelengths in terms of 1000s of Ås, yielding corresponding electronic material wavelengths in the 10s of Ås. This occurs all the way out to the near-IR part of the electromagnetic spectrum, and beyond, where we see a photon of $\lambda = 10,000$ Å, drives an electronic material wave of just about 110 Å.

3. Implications of matter wave-light wave hypothesis: photosynthesis

A direct and broad interpretation of equations (5) and (6) and the data contained in table 1 and plotted in figure 1, would be in an attempt to explain the ubiquitous photosynthetic reaction scheme, shown in equation (7), in terms of electronic transport via de Broglie waves.

$$2\,H_2O + h\nu \rightarrow 4\,H^+ + O_2 + 4e^- . \tag{7}$$

The data contained in table 1 suggest that material electrons that are excited from rest by electromagnetic photons of wavelengths in the range given by $\lambda =$ 4000–7000 Å, acquire corresponding de Broglie wavelengths in the range from 69.659 to 92.150 Å, respectively. If the path length over which the electrons in photosynthesis travel is in the neighborhood of about 70–90 Å, or some higher harmonic of this wavelength, λ_D, then it is entirely reasonable to expect that the mechanism of the photosynthetic reaction center involves a material electron de Broglie wave as the long-range electron transport process. Given the dimensions of the photosynthetic reaction center in plants from protein crystallography studies [5] as on the order of 50–100 Å, we see the matter wave-light wave hypothesis is an entirely consistent basis for an explanation of the photosynthetic process in terms of material electronic de Broglie waves.

4. Conclusions

Simple constructs of quantum theory, including the fundamental postulate of Planck that energy is quantized, as $E = h\nu$, and the postulate of de Broglie of wave-particle duality, as $\lambda_D = h/mv$, have been employed, in this communication, to establish a further simple and fundamental wave mechanical relation between the material wavelength a particle acquires, λ_D, on absorption of a photon of frequency ν, upon the subsequent conversion of this photon energy into kinetic energy of motion of the material particle, given by the simple classical expression $mv^2/2$, assuming the conservation of energy principle holds in the process.

This simple relation is shown, in terms of the frequency of the photon absorbed, ν, as equation (4), and in terms of the wavelength of the photon absorbed, λ, as equation (5). It is a simple, yet fundamental, relation that is derived from pure algebraic manipulation of some of the most fundamental relations of wave mechanics [1,2]. Evidently, this particular relation has not been pointed out previously by the originators of the wave mechanical theory, at least not to the limited knowledge of the authors of this paper.

Equations (4) and (5) potentially have implications for the understanding of some fundamental chemical and physical phenomena, including possibly the mechanism of the chemical physical process of photosynthesis, where it is understood that a visible light photon causes an H_2O molecule to split apart into H^+ ions and O_2 accompanied by the long range ($\approx$50–100 Å) transfer of electrons (see equation (7)). Equation (5) predicts that the de Broglie wave length, λ_D, of an electron excited by a visible light photon with a wavelength, λ, in the range of 10^3 Å, will be in the corresponding range of the dimensions of the photosynthetic reaction center proteins at $\approx$50–100 Å in size [5]. Therefore, from relation (5) it is plausible to expect the mechanism of the photosynthetic process to be mediated by a material electron wave at its core. Such a matter wave interpretation of photosynthesis may help advance work directed at designing artificial photosynthetic systems, or in exploiting existing photosynthetic organisms for the benefit of solar energy conversion. Indeed, the reaction equation shown in (7) is the basis of the world's food and energy economies, and a more thorough understanding of its mechanism as essentially wave mechanical, as provided by the relations shown in equations (4) and (5), may be important in the further exploitation of this basic resource.

From the point of view of understanding the physical nature of matter waves and their generation, one could turn to equations (4) and (5) and carry out predictive calculations in order to design productive experiments. With the advent of tunable lasers in chemistry and physics, it is entirely conceivable to produce material waves, on the basis of equations (4) and (5), of a precisely controlled wavelength λ_D. The generation of precisely tuned material waves could involve electrons, protons, neutrons or any other particles, including atoms and molecules, for experiments designed to test the basic tenets of the quantum theory of material waves, or to study matter wave mediated diffraction phenomena, or quite possibly to control the lithography process, used to create computer components, at a more fundamental, wave mechanical level. These are just a few of the applications of these new wave mechanical relations.

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