Research Open

Nanotechnology and Advanced Material Science

Volume 6 Issue 1

Review Article

A Reappraisal of Einstein's Light-Quantum Hypothesis

Bernardo Gut*

Peter Merian-Straße 2, CH-4052 Basel, Switzerland

Corresponding author: Bernardo Gut, Peter Merian-Straße 2, CH-4052 Basel, Switzerland; **Tel:** 0041 77 431 31 29

Received: December 30, 2022; **Accepted:** January 06, 2023; **Published:** January 13, 2023

Abstract

Einstein published his light-quantum hypothesis (LH) 1905, suggesting that a light ray transmits discrete energy quanta *h.fi*, emitted at speed *c* from their source, where *h* refers to Planck's constant - and *fi* to the frequency of a ray of light *Lx* in accordance with the wave equation $c=\lambda i.fi$ – with λi indicating the wavelength of *Lx*. Now, let *fv* and *fr* stand for the frequency of violet and red light, respectively, assuming that $fv=2.fr$. Following these premises, a source of light *Qv* emitting *h.fv* light-quanta would transmit an energy amounting to (*h.fv.fv*) per second, whereas a source *Qr*, releasing *h.fr* light-quanta would only emit an energy equivalent to (*h.fr.fr*). In other words: The LH implies that the energy a ray of light transports per time-unit corresponds to the square of its frequency. This stands at odds with the experimentally established view that the energy carried by different light-rays per time-unit is linearly proportional to their (respective) frequency.

Introduction

Einstein introduced 1905 the *light-quantum-hypothesis* (LH) in his paper «Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt» [On a heuristic point of view concerning the production and transformation of light]. With the help oft he LH he aimed to interpret the photoelectric effect - as well as other phenomena related to it – in a consistent, straightforward way.

In the present paper, I shall

1. Consider the LH as a purely theoretical system, based on a number of explicit and implicit postulates;
2. Check whether the postulates underlying the LH are self-consistent and mutually compatible;
3. Analyse certain implications of the LH, and compare them with the generally accepted interpretation of the experimental findings.

*An earlier version of this paper was published in *GALILEAN ELECTRODYNAMICS*, Volume 30, Number 5, September/October 2019, p. 95-97.

Explicit and Implicit Postulates Underlying the LH

P1: Let sources of light *Qx* emit homogenous, mono-frequent rays of light *Lx*.

P2: Let the wave-equation

(1) $c=\lambda i \,.\, fi$

be valid for every light-ray *Li* emitted by a source *Qi*, with λi referring to the wavelength of a ray of light *Li*, and *fi* to the frequency of *Li*.

P3: Let *Lv* be of a higher frequency than *Lr*, i.e. $fv > fr$, with 'v' standing for "violet", 'r' for red.

P4: Let every source of light *Qi* which emits rays of light of a given frequency *fi*, emit these rays as bundles of light-quanta or photons *Phi* having the energy *h.fi*, i.e.

(2) $Ei=h.fi$,

where '*h*' refers to Planck's constant (elementary quantum of action), and '*fi*' to the frequency.

P5: Let the light-quanta (=energy quanta, photon) *Phi*, which are emitted by *Qi*, move through space as indivisible entities, and let them be absorbed as such by adequate targets.

P6: Let each light-quantum *Phi* move with speed *c* in relation to its source *Qi* – if mutual conditions of rest are given between source, receiver, and medium (insofar a medium needs to be taken into account).

A short explanation of the foregoing postulates reads as follows:

Postulate *P1* is seldom assumed explicitly. Einstein, in his introductory remarks, observed that he would consider the energy transmitted by a light-ray emitted by a «*Lichtpunkt*» (i.e. a very small source of light). With respect to the following analysis, I'll assume the existence of « quasi-linear » rays of light, i.e. tiny bundles of light the cross-sections of which are so small that only one light-quantum per unit of time can hit and perforate an adequately placed perpendicular plane. Said in other terms, and in accordance with Einstein: I'll consider rays of light in which light-quanta move in a linear row.

Postulate *P2* is very rarely formulated explicitly. Nevertheless, it is implicitly taken for granted as soon as one:

(a) alludes to the frequency *fi* of a given light-ray, and distinguishes rays of light of different frequencies;

(b) introduces *c* as the constant speed of every light-ray *Li* in relation (i) to its source, (ii) to the medium (insofar a medium has to be considered), (iii) the receptor, and (iv) the « external

observers » - albeit on the premises that source, medium, receptor, and « external observers » are at rest with respect to each other;

(c) assumes that the fronts of the rays of light – *e.g.* of violet and red light – proceed from their respective sources at equal speeds *c*.

Postulate *P3* is generally accepted and needs no further comment.

Postulates *P4* and *P5* comprise the main, central, statements of Einstein's LH [1]. Strictly speaking, *P4* and *P5* contain three separate assertions, concerning:

(i) the *emission* of light-quanta (see: *P4*);

(ii) the *propagation* through space of indivisible light-quanta (see: *P5*), and

(iii) the *absorption* of indivisible light-quanta (see: *P5*).

However, since I am dealing in the present paper only with the *emission* and the *propagation* of light-quanta, I have subsumed propagation and absorption to the same postulate *P5*.

Postulate *P6* is seldom stated explicitly. In a configuration stating mutual rest of source, receiver, medium (insofar a medium needs to be considered), and observers – *P6* is self-evident. Furthermore, *P6* can be derived from *P2* in conjunction with *P4* and *P5* [2-5].

Discussion of the LH

We shall start by considering the postulates *P1 – P6* independently of one another: As far as I can see, there are no ambiguous demands being made, and nothing otherwise untenable can be discerned. Thus, every single postulate *P1 – P6*, taken on its own, is free from contradictions [6,7].

We must now look at several combinations of these postulates:

(i) It follows from *P3* and *P4* that *Lv*-photons consist of a larger amount of energy than *Lr*-photons. In other terms:

(Ev=h.fv) > (Er=h.fr).

(ii) According to *P4* in conjunction with *P5*, the light-quanta spread from their respective sources as indivisible entities, in their respective frequencies *fv* and *fr* – which is a constitutive factor of the light-rays we are considering.

(iii) With regard to *P2*, it follows that every frequency *fi* is univocally correlated to a corresponding wavelength *λi*, so that any kind of event belonging to *Li* (e.g. its wave-peaks) will be repeated with the corresponding frequency *fi* at any well-defined point along the path of *Li* that continues to move forth with speed *c*.

(iv) According to *P4*, source *Qv* emits light-quanta of energy *h.fv*, whereas a source *Qr* will release light-quanta of energy *h.r.*

(v) Now, following *P3*, *'fv'* refers to the frequency of violet light-rays and *'fr'* to the frequency of red light-rays, with *fv > fr.* On the basis of *P2*, we will then, reciprocally, have to infer that *λv < λr.*

This assertion implies that source *Qv* will not only emit light-quanta *Phv* which excel in energy the light-quanta *Phr* emitted by source *Qr* by the factor *(fv – fr)*, but *also* that source *Qv* is due to propagate its light-quanta *Phv* with a frequency which surpasses the frequency with which source *Qr* releases its light-quanta *Phr* by the same factor *(fv – fr).*

In other words: On the basis of *P1 – P6*, we are compelled to deduce that if we – for instance – compare a ray of light *Lv* of wavelength *λv=4000 nm* with a ray of light *Lr* of wavelength *λr=8000 nm*, the former one (i.e. *Lv*) must transmit *four* times (and *not* twice) as much energy per unit of time than the latter (i.e. *Lr*).

It is hard to see, how this unexpected implication could be avoided: The frequency *fi* is a firmly bound variable of equation (1) *[c=λi.fi].* – As soon as we use the symbol *'fi'* to point at the energy of a light-quant *h.fi*, we are forced to accept that these quanta are linked to equation (1) and are, therefore, emitted *fi* times per unit of time.

(vi) Einstein *believed* that the amount of energy contained in a single light-quantum *h.fi is linearly proportional* to ist frequency, i.e. to the *fi*. However, *on the basis of his premises – i.e. of his postulates P1 – P6* – we are logically compelled to infer that Einstein's premises do not support what Einstein *believed to be true, but -on the contrary* – supported the erroneous assumption that the amount of energy contained in a single light-quantum *h.fi* is proportional to the *square* its frequency.

(vii) In 1916 [8]: Millikan pointed out: "The hypothesis [i.e. Einstein's LH] was apparently made solely because it furnished a ready explanation that when an electron is thrown out of a metal by ultra-violet light or X-rays it is independent of the intensity of the light while it depends on its frequency ." However, if one *correctly argues – based on the experimental findings established by Millikan* - that the amount of energy being transported by a ray of light *Li* per unit of time is *linearly proportional* to its frequency – one is compelled to dismiss as erroneous the core of Einstein's theoretical *premises and his reasonings based on them.* In short: Einstein's theoretical premises and his reasonings based on them stand at odds with his belief and with the experimental findings established by Millikan.

Conclusion

Einstein's *light quantum hypothesis* (LH) prescribes that every ray of light *Li* transports and transmits discrete *energy-light-quanta* of magnitude *h.fi.*If every source of light *Qi* emitted discrete *light-quanta* of a specific, frequency-dependent magnitude *h.fi*, it would also have to release these *energy-quanta* with the corresponding frequency *fi*. This would, in turn, imply that the energy *Qi* emitted per unit of time with a ray of light *Li*, had to be proportional to the square of its frequency, *i.e.* the amount of the propagated and transmitted energy would have to be equivalent to *fi.(h.fi)* per unit of time.However, if we hold to the generally acknowledged – and by Millikan [9] experimentally established - view that every ray of light transports and transmits an amount of energy per unit of time which is linearly proportional to its frequency, Einstein's premises and his reasonings cannot be maintained.

References

1. Einstein A (1905) Über einen die Erzeugung und Verwandlung des Lichtes betreffenden heuristischen Gesichtspunkt. *Annalen der Physik*. 17: 132-148.
2. Einstein A (1905) Ist die Trägheit eines Körpers von seinem Energieinhalt abhängig ? *Annalen der Physik*. 18: 639-641.
3. Einstein A (1906) Zur Theorie der Lichterzeugung und Lichtabsorption. *Annalen der Physik* 20: 199- 206.
4. Einstein A (1909) Zum gegenwärtigen Stand des Strahlungsproblems. *Physikalische Zeitschrift* 10: 185-193.
5. Gut B (1996) Einstein's Lightquantum Hypothesis. Analysis, Implications-and an Alternative. *The Toth-Maatian Review* 13: 5925-5929.
6. Kaase H, Scrick F (2004) Optische Strahlung und ihre Messung. Bergmann, Schaefer. *Lehrbuch der Experimentalphysik*. *De Gruyter* 633-668.
7. Kane JW, Sternheim MM (1988) Physics. John Wiley. 3rd ed.
8. Millikan RA (1916) Quantenbeziehungen beim photoelektrischen Effekt. *Physikalische Zeitschrift* 17: 217-221.
9. Millikan RA (1916) A direct photoelectric determination of Planck's 'h'. *Physical Review* 7: 355-388.

Citation:

Bernardo Gut (2023) A Reappraisal of Einstein's Light-Quantum Hypothesis. *Nanotechnol Adv Mater Sci* Volume 6(1): 1-3.