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What is a Photon: Particle or Wave?

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Part 1

The question I try to answer herein is, how long is a photon? What I have uncovered is that there is a general time τ that appears to be characteristic for the emission of a photon (or the absorption of a photon), from the beginning of the process until the end, and in that time, the energy (hf) of one photon is emitted. If a photon was a point particle, the emission time should be no longer than its physical length. So how long is it? This depends on its frequency - an RF photon can be many kilometres in length. The characteristic length of a visible light photon is on the order of cm's to meters. This should pose a serious problem to anyone considering a photon a "point particle", or a particle of any kind for that matter.

Evidence:

1) How a photon is created or absorbed.

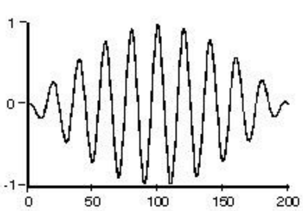
Henderson et.al. (1) describes how during a transition from the 2S to the 1S orbital, the charge density oscillates back and forth between the two orbitals at the Bohr frequency, which is:

Fig.1:

$$\omega = [E(2s) - E(1s)]/(h/2\pi) = 2\pi f = 1.546 \text{ E } 16 \text{ Hz, where } f = 2.46 \text{ E } 15\text{Hz}, \lambda = 1.22 \text{ E} -7 \text{ M.}$$

This periodic fluctuation is called “transient nutation”. The number of cycles from start to finish is between 10^6 and 10^7. The oscillations begin small, are strongest in the middle, and then die off, as shown below:

Fig.2:



This should effectively be the form of a photon in space. The effective length for a S2 to S1 transition photon should be approximately: 12.2 cm to 122 cm (average = 61cm) based on their estimates.

The above authors (1) also discuss how physics students are taught that the transition is effectively instantaneous - quote:

" The state of affairs has been greatly influenced by over 40 years of popular belief that since a bound system exhibits only certain discrete energies and a transition from one to another cannot proceed through any observable intermediate levels, then the corresponding wave function must also evolve in a similar discontinuous manner. This interpretation has been shown to be incorrect. "

They go on to say:

At this point, the natural questions of the student are, "How is a photon created or absorbed? What is the mechanism of this process and how long does it take?" The usual instructor response may be that a transition involves a quantum jump, which is an instantaneous process and the

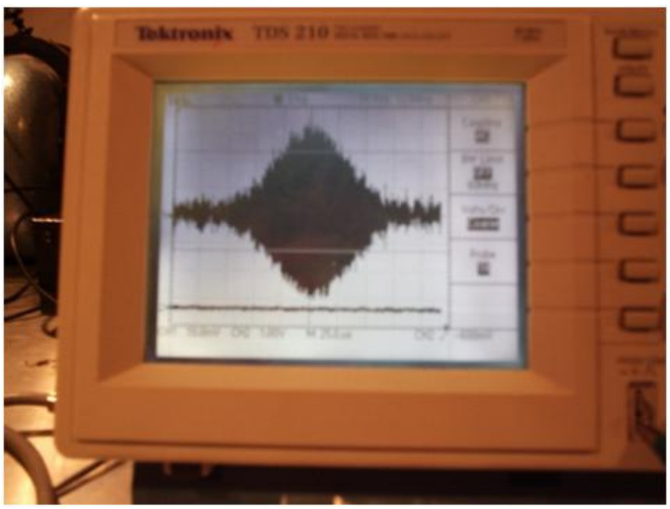
Uncertainty Principle prohibits us from observing or describing in classical terms the details of the transition, or he/she may evade the question by claiming the concepts are beyond the scope of an introductory course and will be developed later in quantum physics or physical chemistry. After completing a bachelor's degree, our student has been exposed to a lot of the prescriptive formalism of quantum mechanics with heavy emphasis on finding eigenvalues and solutions to the time-independent Schrödinger equation and possibly modest exposure to the time-dependent equation and perturbation theory for the purpose of developing transition probabilities. However, to her/his great disappointment, freshman questions probably still remain unanswered."

They then explain how the actual transition has been observed in detail:

The first experimental measurements of bulk samples undergoing spectroscopic transitions were obtained from nuclear magnetic resonance observations of the transient nutation effect (5) and spin echoes (6, 7) using coherent radiation produced by a single radio frequency oscillator. More recently, the analogous transient nutation effect (8, 9) and so called "photon echoes" (10-12) have been observed in molecular spectra using pulsed coherent laser radiation. These experiments confirm that there are no "quantum jumps" in the non-stationary state; rather there are smooth, continuous periodic changes in the magnetic and electric properties of a system undergoing a transition.

Fig. 3 is a spin echo of a glycerol H1 sample (10mV resolution, 25uS per division) , from the home-built NMR (18 MHz) described on this website (2). Notice that the transient nutation (spin echo) is around 125 us in duration. This puts the length of the EM emission from the relaxing ensemble of protons in the glycerol sample at greater than 37,500 meters, since 125 us x the speed of light = 37.5 km travelled from the start to the finish of the transition. Another paper (3) discusses the length of a stimulated nutation echo from a microwave transition electron spin echo at 5.95 GHz. This is found to be around 40 us long (or around 12 km from start to finish).

Fig.3: Spin Echo from a glycerol H1 sample at 18 MHz.



2) Radiative Lifetime:

The radiative lifetime of an excited electronic state e.g. in a laser gain medium is the lifetime which would be obtained if radiative decay via the unavoidable spontaneous emission were the only mechanism for depopulating this state. It is given by the equation.

Fig. 4:

$$\frac{1}{\tau_{\mathrm{rad}}} = \frac{8\pi n^2}{c^2}\int \nu^2 \sigma_{\mathrm{em}}(\nu)\,\mathrm{d}\nu = 8\pi n^2 c \int \frac{\sigma_{\mathrm{em}}(\lambda)}{\lambda^4}\,\mathrm{d}\lambda$$

which shows that high emission cross sections and a large emission bandwidth inevitably lead to a low radiative lifetime. This is because the cross sections describe not only the strength of stimulated emission but also that of spontaneous emission. Another important aspect is that **a shorter mean wavelength of the emission implies a shorter radiative lifetime.** This results from the increased mode density of the radiation field. A consequence is that ultraviolet lasers tend to have a higher threshold pump power than infrared lasers.

The radiative decay rate of a classical electron oscillator is given by :

Fig.5:

$$\gamma_{\mathrm{rad,ceo}} = \frac{e^2\omega_a^2}{6\pi\epsilon m c^3} \approx 2.47\times 10^{-22}\times n f_a^2,$$

where n is the refractive index of the medium in which the oscillator is embedded, and the oscillation frequency is measured in Hz. A useful rule of thumb is that the purely radiative lifetime of a classical oscillator is approximately given by:

Fig. 6:

$$\tau_{rad,ceo}(\mathrm{ns}) \approx \frac{45 \times [\lambda_0(\mathrm{microns})]^2}{n},$$

where n is again the refractive index of the medium, and λo is the free space wavelength in um. By way of example, if at λo = 500 nm (visible region) , the classical oscillator radiative lifetime is about 11 ns (about 3.3 meters from start to finish). .

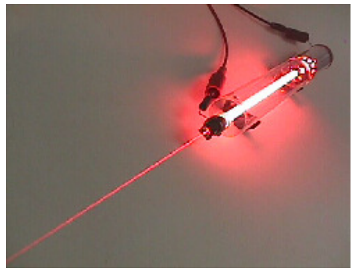
The Fig. 6 equation is used to calculate the photon length at different classical oscillator emission wavelengths as shown in the table below:

Wavelength (m)	radiative lifetime(s)	Photon Length (m)	Photon Energy		spectrum
9.93609E-07	4.44267E-08	1.33E+01	0.001	KeV	IR
4.96805E-07	1.11067E-08	3.33E+00	0.002	KeV	VIS
2.48402E-07	2.77667E-09	8.33E-01	0.005	KeV	UV
1.24201E-07	6.94167E-10	2.08E-01	0.01	KeV	UV
6.21006E-08	1.73542E-10	5.21E-02	0.02	KeV	UV
3.10503E-08	4.33854E-11	1.30E-02	0.04	KeV	UV
1.55251E-08	1.08464E-11	3.25E-03	0.08	KeV	UV
7.76257E-09	2.71159E-12	8.13E-04	0.2	KeV	UV
3.88129E-09	6.77897E-13	2.03E-04	0.3	KeV	UV
1.94064E-09	1.69474E-13	5.08E-05	0.6	KeV	x-ray soft
9.70322E-10	4.23686E-14	1.27E-05	1.3	KeV	x-ray soft
4.85161E-10	1.05921E-14	3.18E-06	2.6	KeV	x-ray soft
2.4258E-10	2.64804E-15	7.94E-07	5.1	KeV	x-ray soft
1.2129E-10	6.62009E-16	1.99E-07	10.2	KeV	x-ray hard
6.06451E-11	1.65502E-16	4.97E-08	20.5	KeV	x-ray hard
3.03226E-11	4.13756E-17	1.24E-08	40.9	KeV	x-ray hard
1.51613E-11	1.03439E-17	3.10E-09	81.9	KeV	x-ray hard
7.58064E-12	2.58597E-18	7.76E-10	163.8	KeV	x-ray hard
3.79032E-12	6.46493E-19	1.94E-10	327.6	KeV	x-ray hard
1.89516E-12	1.61623E-19	4.85E-11	655.1	KeV	x-ray hard

For the values shown, the length of a photon from the start of the emission to the finish varies from around 13 meters long in the IR region, to around the size of an electron orbital in the hard x-ray region. The higher one goes in x-ray frequency, the more compact and discrete the EM emission, and the closer it will fit into the space occupied by the electron orbital.

The Length of a Photon considered in relation to the laser emitting it:

Now consider a photon being emitted by a HeNe laser at 632.8 nm wavelength. If we assume a distance between the laser mirrors of say 20 cm and that the atom emitting the photon is near the back mirror, we would be forced to conclude that the photon, being 5.4 meters long by the time the atoms has completed its emission, would have changed direction by reflection off the laser mirrors about 27 times! How can we consider a photon in this laser to be a particle when it is travelling simultaneously along opposite directions in 27 different paths?



Conclusions on the Length of a Photon

The above discussion suggests that because of the finite time required for the emission of an EM wave of energy E = hf from an oscillating source that the length of this putative photon must be so long as to make it ludicrous to consider it a point particle. In the RF region, a photon would be many kilometres in length. In the IR region, a photon would be several meters in length, and in the visible region it would be many cm to meters in length. It is only in the hard x-ray region that the "photon" would approach the dimensions of an orbital, but would still be about 1000x longer than the "point electron" that it interacts with. This evidence calls into question the assertions in the literature that a "photon" should be considered a particle in any real sense. Wave-particle duality is a common feature of modern physics - even though these two concepts are mutually exclusive. A wave is a form of motion, a particle is an object. You can have a wave in a population of particles, but a single particle can't be a wave in and of itself. As has been said elsewhere on this website, one needs to take a stand - either light is a wave and space is a medium, or light is a particle and space is empty. Feynman at least took a stand when he said that light is a particle-

"I want to emphasize that light comes in this form - particles. It is very important to know that light behaves as particles, especially for those of you who have gone to school, where you were probably told something about light behaving as waves. I am telling you the way it does behave, like particles."(4) This must be the wrong stand, since the shear length of the photon should rule out a particulate nature. If there is a contradiction, it is symptom of the inadequacy of the theories that have been offered to us.

Footnotes:

1) Henderson, Giles,et.al., "How a Photon is Created or Absorbed" http://jchemed.chem.wisc.edu/JCEWWW/Articles/

2) Home-built 18 MHz Nuclear Magnetic Resonance(NMR)Spectrometer (2008)

3) http://arxiv.org/ftp/physics/papers/0203/0203039.pdf

4) Feynman , QED, P. 15.

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