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Planck's constant 2

This note will really make physicists laugh. Ah, well.

This note conveys my ignorance of the wave function and ideas about the "collapse of the wave function". See other note on wave packet.

How many quanta (units of h) are in one complete EM wave, or in one complete "f" of EM? I cannot get a clear answer to what seems like a fundamental and simple question. I might be able to calculate it out for myself given the energy jumps that are associated with some actions, such as the jump from one orbit to another of an electron in a well-known atom. But before trying to work through numbers, I want to muse about the question. We should be able to say something about the issue from basic principles.

Energy Equation

For here, f is the frequency of a wave. I use "f" rather than "v" because it is too hard to put "v" in italics and because it is not conducive to memory like "f" is. f = v. I use "w" for "wave length", rather than "l", for similar reasons even though "l" is conducive to memory. I want to remind myself that we are dealing with waves and that waves cannot be fractional.

The energy equation for EM radiation is usually written E = hf. It is useful to think of it in the following terms, which might be more in line with Planck's original derivation. w = l = wavelength. F = 1/w. When using the form with "1/w", make a mental adjustment so that you don't use a fractional wavelength, or a wavelength less than 1.

$$E = \sum_{1}^{f} h$$

$$E = \sum_{1}^{1/w} h$$

Questions

I take as given that there cannot be less than one quantum h in any EM wave.

Is there ever more than one quantum h in one EM wave?

Is the number of quanta h in an EM wave constant for all waves or does it vary?

If the number of quanta h varies, does it vary in a regular way such as according to f or w (wavelength)?

Is it useful to think about quanta in terms of particular small waves in a larger wave packet? There are two ways to do this:

(A) One quantum is one wave packet. Inside the quantum are smaller waves that make up the wave packet that is one quantum, and stabilize it. See below.

(B) Quanta are grouped into wave packets. Each quantum is a small wave inside a larger wave packet. How are quanta grouped into a wave packet? How many quanta are in one small wave within a wave packet? How are wave packets of multiple quanta grouped into a wave or particle?

Both ways have problems.

In either case, we have to avoid the idea of fractional quanta in an EM wave.

The Energy Formula and "Beats".

In an earlier note about Planck's constant, I said that the formula for energy from a wave made it easy to overlook the fact that energy can come only in discrete units. "f" and "l" (wavelength or "w") are discrete integers, not any parts.

The energy formula counts bits of energy (h) in terms of whole waves. Each "f" is a whole wave, or one whole wave length. I find it useful to think of it in terms of music. One f is one "beat" as in one whole note, one whole half-note, one whole quarter-note etc. Later we will see that a group of f is analogous to a measure or a phrase. The energy formula measures energy in terms of whole beats, never partial beats.

The energy formula strongly implies, to me, that energy comes one-unit-per-beat, or one-unit-per-f, or one-unit-per-wavelength. "h" is counted in "f" units, which implies that there is one h per f unit. I am not sure if this is the general understanding of physics. For now, assume it is true, and go on.

Electrons

How many quanta h are in a standing electron that is not in "orbit" in an atom?

An electron has many quanta. For here it does not matter exactly how many, so let's say 1000.

The electron also has a wave function, a wave length, and frequency. Sometimes it is a little odd to think of a standing electron as having a wavelength and frequency, but that is not the issue here. Because it has more than 1 quantum h, it has a frequency that is greater than 1, and so it has more than one wave. Exactly how many wavelengths and what f should be calculable from the energy equation and the mass of the electron, but, again, the exact figures don't matter. How are the h distributed in the electron? Is the electron a whole bunch of little waves, each of which is 1 h?

If the electron was a bunch of little waves, each of which is 1 h, then it seems the difference between orbits for the electron would be very small. Each orbit jump would be hardly more than 1 h. That does not seem to be the case.

An electron might be made up of several waves, each of which is composed of a bunch of quanta. I can call one of these waves a “contributing wave”. The quanta support each contributing wave much as the small waves inside a wave packet support the big wave that is the wave packet. How many quanta are in each of these contributing waves? What determines this relation? How many contributing waves make up one electron? What determines this relation?

Electrons in Orbit

Assume we can find a real physical event that depends on exactly one “h”. I am not sure there are any real physical phenomena like this, but there could be in theory. Later I will get to the case where we need multiple h per physical event. Maybe the jump of one electron from one orbit energy level to another level takes only one h of energy. Assume that is true for now.

In this case, all the energy in the jump is taken up in exactly one wave, and one wave carries exactly this energy and no more. The entire energy of the wave is given over to the electron, with nothing left over in any way. The entire wave, and only this one wave, without requiring anything else, collapses, and it conveys just exactly enough energy to the electron to make one minor jump. Think of this as a basic scenario from which to understand other scenarios.

Companion query: We understand the electron’s “orbit” around a nucleus as a standing wave, made of component waves that just come together in phase to make one standing wave. If the standing wave is made of just one component wave, then the “head” of the wave just comes to the “tail” of the wave. If the wave has more than one cycle (more than one wave length) then the cycles are exactly in phase when they meet head-to-tail. It is not possible to tell one cycle (component wave) from another. This is pretty much the definition of a standing wave. In this case, each wave in the total standing wave (packet) and the standing wave as a whole (the whole wave packet) has to be composed of exactly a whole integer amount of energy. If they were not, then the whole standing wave would entail a fractional “h” of energy, and I think that is not possible. So how many quanta h are in each wave in the standing wave (packet)? How many quanta h are in the whole standing wave (packet)?

This way of looking naturally raises problems with Uncertainty, but I let those go for now.

If the standing wave represents the total energy that it takes to make up the electron including its energy of angular momentum, then the total number of quanta in the standing wave is equal to the total number of quanta that it takes to make up that energy. (Some quanta could be in the system of the electron, the nucleus around which it “orbits”, and the intervening space; but I discount that alternative here.) In this case, each individual component wave in the standing wave packet has the total energy divided by the number of individual waves in the standing wave. In this case, given what I know about the amount of energy in electrons and the likely number of waves in the total standing wave (packet), it seems there is more than one quantum in each wave that composes the standing wave (packet).

In any case, only orbits that depend on (represent) exact integer amounts of quanta are allowable. Only jumps that go from one such discrete orbit to another such discrete orbit are allowed.

If each component wave in a standing wave takes exactly 1, 2, 3 etc. of quanta, that seems allowable. Each component wave has to take up exactly as much as any other component wave as long as each component wave is symmetric to the others. Even if they are not symmetric, each component wave still has to take up an exact integer amount of quanta.

N is the number of component waves in the whole orbit. If the total number of quanta in the whole orbit, including the electron (rest mass), is x, then each component wave of the standing wave takes x/n. x/n has to be an integer. So there has to be a precise integral relation between the number of waves and the total quanta of energy in any orbit. It is not clear if the number of quanta that can enter into a component wave (in the standing wave) constrains the total orbit, or if the total orbit constrains the number of quanta that can enter into any component wave.

Now bump the electron up by one quantum h so that it is in another orbit. Where does that quantum go in the standing wave (packet) and in the waves that compose the standing wave (packet)? Which wave component gets the one quantum in preference to the other waves? Does the one quantum somehow distribute itself over the whole standing wave (packet) without being in any particular component wave? That result seems odd to me. This same line of questions holds even if we add more than one quantum of energy to the standing wave (packet), with the exception described just below.

Suppose an electron is in orbit, and the standing wave that is the orbit requires 4 component wave lengths (cycles) to make the standing wave. The electron jumps to an orbit that requires 8 component wave lengths to make the standing wave, for a difference of 4. These figures are made up and unrealistic so as to make a point. The 4 additional quanta of energy could be shared among the 8 waves in the standing wave (packet) if we can accept that each standing wave can somehow get half a quantum of energy. I don’t know about this.

The electron begins with 3 component waves in the standing wave (packet), gets 4 more, and jumps to a new orbit that requires 7 total component waves in the standing wave (packet). I find it hard to imagine how 7 waves could share 4 quanta of energy, but maybe this situation is no harder to swallow than 8 waves sharing 4 quanta.

The electron begins in an orbit that has 6 component waves with 6 quanta of energy total, then moves to an orbit that has 12 standing waves with 12 quanta of energy total. This seems allowable.

The electron begins in an orbit that has 6 component waves with 6 quanta of energy total, and then moves to an orbit that has 12 standing waves with 24 quanta of energy total, or 2 per wave. This too seems allowable.

Quanta in a Wave

In this section, I do not try to solve wave-particle duality.

Imagine that 1 wave length, 1 beat, 1 f, has exactly 1 quantum h of energy. This is not hard to imagine. This picture goes along with an intuitive sense of a wave, and it goes along with the idea from above that the energy equation ascribes 1 quantum to 1 beat. With 1 quantum per beat, the question "where is the energy" does not really come up. It is all over the wave all at once. It need not be distributed evenly over the wave. Whether it is evenly distributed over the wave, I can't say.

With 1 quantum per beat, it makes sense to ask about the energy density. The wave has a length. Assume the wave is basically 1 dimension. Still, the wave has a length, and the energy density is the amount of energy over the wave length. If the wave is 1 centimeter long, then the energy density is 1 quantum h per centimeter. If the wave is 100 centimeters long, then the energy density is 1 quantum h per 100 centimeters. If the wave is 10^-30 centimeters long, then the energy density is 1 quantum per 10^-30 centimeters, getting close to the "Planck length" and something like a "Planck density".

Now imagine 2 quanta per wave. This is harder to imagine but doable. More interesting are questions of the location of the energy and the energy density. With 2 quanta per beat, we can imagine 1 quantum on the downbeat and 1 on the upbeat. 1 quantum is in one whole loop of flux in one direction while the other quantum is in one whole loop of flux in the other direction. With 1 quantum per wave, it is easy to think of the energy being distributed over the whole wave at once but with 2 or more quanta per wave, it is harder to think that way. We start looking for where the quanta might be. The energy density goes up as the numbers of quanta go up. Eventually, with very high frequency waves, with short wave lengths, we run into situations where the energy density is more than 1 quantum h per Planck length. I don't know what to do with those situations. I have speculated on high energy densities in another note.

Now imagine 4 quanta per wave. While it is easy to imagine 1 quanta per directed flux (half the wave length) when there are only 2 quanta for the whole wave, it is harder to imagine 2 quanta per directed flux (have the wave length). It can be done with 2 per flux, but why does one quantum go in one part of the flux while the other quantum goes in the other part of the flux?

Now imagine 7 quanta per wave. With odd numbers of quanta, it is hard to imagine how the fit into the wave and how they relate to the flux. Do they fit proportionally into parts of the wave? Why? Are all the quanta somehow spread out over all the wave? How?

Go back to 1 quantum per 1 wave. When the wave was less than a centimeter long, it is easy enough to imagine the whole quantum coinciding with the whole wave all at once. Now imagine the wave 10^10 meters long. How does the quantum coincide with the whole wave all at once? It is harder to imagine.

Getting Energy from the Wave to the Electron

Think about how the energy gets from the photon or the EM wave to the electron in orbit.

Suppose it takes exactly 1 quantum h to move the electron into another orbit, and the EM wave carries exactly 1 quantum h per wave. This case seems intuitively acceptable even if we don't know exactly how the wave gets its energy to the electron.

What if the electron needs more than 1 quantum to change orbits, say X quanta, or 100 quanta? If there is only 1 quantum per beat (wave length or f) then 100 waves have to strike the electron. The electron is (kind of) moving around in “orbit” so it is unlikely 100 waves in a wave “ray” would sequentially strike the electron. Even if the electron was not moving, its location is uncertain and variable. It might be possible to lessen problems of location if we keep in mind that the electron is being hit with waves, which are not strictly localized. If we overcome problems of location, the electron has to “hold” one quantum after another until it has accumulated all the quanta necessary to move its orbit. If the electron can do this in the brief time that it is being hit by incoming waves, why couldn’t it to it for a longer time? Why couldn’t it hold 99 quanta for a couple of years? Of course, if it did so, it would have too much energy to be in its present orbit, but not enough to be in another orbit. The additional energy now would change the mass-energy of the electron and change its orbit too, but not to anything stable.

What about the photoelectric effect, the relation between frequency (f) and threshold for changing orbit? Recall energy density. If the electron needs a certain minimum energy density to accept a quantum, then the f would have to be high enough, or the wave length short enough, to have any effect at all. The electron waits to absorb 100 beats (waves) of EM waves of sufficiently high energy density or frequency or short wave length.

Even though the energy equation seems to imply that each wave (beat) has one quantum, in fact, if the electron is to get enough energy from the wave, that relation cannot be simply the case.

What if each beat (wave) had multiple quanta? I think this is essentially the way that physics looks at the situation.