Re: The time it takes to emit one photon

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- *From*: Igor Khavkine <igor.kh@xxxxxxxxx>
- *Date*: Thu, 25 Aug 2005 08:44:31 +0000 (UTC)

On 2005−08−21, Eugene Stefanovich <eugenev@xxxxxxxxxxxx> wrote:
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\> Igor Khavkine wrote:
\>
\>>>And the best way to see it explicitly is to use the
\>>>"dressing transformation" which eliminates bare and virtual particles and
\>>>reduces QFT
\>>>to a theory of real particles interacting at a distance.
\>>
\>>
\>> Non sequitor. The way to see it is psi(x,y,..) = <psi|phi(x)phi(y)...|0>.
\>
\> 1. I am not sure how your formula challenges what I wrote about the
\> "dressing transformation". Could you please elaborate?

This formula is a direct reversal of the procedure of second quantization, which can be checked by direct calculation. It is mentioned not only in Weinberg, but in other books as well, mostly in more old fashioned treatments of second quantization. Dirac is a prominent example. Also, this formula is used in disguise in the Green function or correlation function formalism. What I challenge is your introduction of unnecessary steps into the equivalence, such as "dressing". QFT is applicable to many theories, some of which don't require renormalization.

\> Now, I fail to see what is the difference between "quantum theory with
\> finitely many particles (wave functions of as many arguments)" and
\> "quantum field theory (Fock space with field operators)". I though we
\> agreed that they are equivalent. Let me remind you:
\>
\> I wrote: "I agree completely: QFT is equivalent to a quantum theory of a
\> variable number of particles."
\>
\> You wrote: "So far so good."

Notice the important adjective "variable". If I fix the number of particles to N, my Hilbert space is composed of wave functions of N arguments, psi(x_1,...,x_N). If I allow the number of particles to vary,

my Hilbert space is composed of linear combinations of wave functions
with different numbers of arguments, 1, psi(x), phi(x,y), chi(x,y,z),
....

Many, but fixed, number of particles is not the same as a variable
number of particles. It is only when the number of particles is allowed
to vary that the theory can be made equivalent to a field theory (Fock
space + field operators). The equivalence is through second
quantization.

This is an important, but perhaps subtle difference.

> > This has been known for 70+ years. And when I say "known", I don't
> > mean in the sense of folklore. The calculations are there for anyone
> > to see, check any book on QM or QFT.
>
> If you want to substitute discussion by pointing to books,
> then I would like to draw your attention to my book
> physics/0504062 which tells a different story.

My comment was regarding the construction of the classical limit. I've
outlined this construction several times previously. If a citation is
not sufficient, you're welcome to ask specific questions. As to book
thumping, one would have to establish the credibility of the author
before doing so.

> I thought that if we take the limit hbar −> 0, then undeterministic
> wave functions are replaced by trajectories. In this limit, photons
> should be described in terms of Newtonian light rays.
> No diffraction, no interference.

Again, trajectories arize in the classical limit of QM with a *fixed*
number of particles. Photon number is not conserved. When that happens,
the classical limit does not yield trajectories, it yields fields.

> ?? Do you dispute the fact that in Maxwell's theory fields
> E(x,t) and B(x,t) play two roles:
>
> 1) they describe the intensity distribution
> in the radiation field.
> 2) they determine the forces acting on charged particles
> (via the Lorentz force law)?

The E(x,t) and B(x,t) fields play a *single* role, to determine the
force on a test charge at any point in space and time. The fact that
they carry energy and momentum (radiation) stems from their equations of
motion and their coupling to matter. Radiation and the Lorentz force law
are two manifestations of the same phenomenon.

> I think that hbar −> 0 limit does not apply to the description of
> light in Maxwell's theory. If you think otherwise, then you should

> come to the conclusion that there are two different sources of
> the interference effect. One source is purely quantum (as in Feynman's
> double−slit experiment), another source is due to "classical waves"
> (as in Young's experiment). Can these two contributions to the
> interference be distinguished experimentally? I don't think so.

Yes, there are and yes they can. But Feynman's double slit example does not describe a quantum effect here. What we call interference fringes are a generic phenomenon common to all linear wave equations. This includes both Schroedinger's and Maxwell's equations. So what's quantum about it? A state with one electron is described by a wave function (of one argument) obeying the Schroedinger equation. When we consider the hbar −> 0 limit, only a single particle trajectory remains. The single argument of the wave function becomes a dynamical variable of the particle and no interference is seen. This limit can be reversed by simultaneous consideration of many trajectories for the same particle and by assigning phases to these trajectories. This is Feynman's description of the double slit experiment, it shows how to recover the wave function and the interference fringes with it.

For the sake of argument, suppose we want to apply the same treatment to a state with a single photon. Everything is fine, the same argument applies, with a few differences. We have to use Maxwell's equations instead of Schroedinger's, and we have to use a multi−component wave function. There will be one distinct kind of photon for each independent polarization. Each independent polarization of the wave function will describe the probability amplitude for the corresponding photon particle. This implies that the values of the photon wave function are not the same as the electric and magnetic field (or rather the vector potential) amplitudes.

But that is not what we see when it comes to light. In most situations, the photon number is very large. This implies that we have to use the classical hbar −> 0 limit. But unlike the electron case, we do not recover trajectories, rather we recover the electric and magnetic fields. The big surprize is that they satisfy the same Maxwell equations as the single photon wave function! Coincidence? No, it is a consequence of second quantization. Note however, that the single particle (photon) equation is always linear, while the classical field equation may be non−linear. Any field non−linearities get translated into into interactions when multi−particle (multi−photon) wave functions are considered. So, simply because Maxwell's equations are linear, we automatically get interference fringes completely within the classical regime.

But what if we increas hbar, do we get any actual quantum effects? The answer is yes, but the detection is more subtle. When we increase hbar, we now have to consider multiple *field configurations* at the same time and assign phases to each of them (cf. "multiple particle trajectories at the same time"). One example of this is a cavity containing a QED state of the form a|1 photon> + b|2 photons>. Each state |n photons>

(more or less) describes a classical field mode, with the number n parametrizing the amplitude of the classical field. Depending on the geometry of the cavity, the classical field mode may already exhibit interference fringes. But at the same time, quantum mechanically the state is in a superposition of two different classical field configurations (different intensities). Wherever we see superposition, we will see interference. However, in this case, it will not be as visual as in the electron double slit experiment. So, yes, there are two kinds of detectable interference here.

\>> Again, belief is no substitute for calculation. See Sakurai's _Advanced
\>> Quantum Mechanics_. There he explicitly relates the strong field limit
\>> (many photons) to the classical limit (hbar −> 0). Unfortunately, I
\>> don't have the book handy, so I can't give a more precise reference.
\>
\> Thanks for the reference. I'll check that out. It looks suspicious to me
\> that in the weak field limit (when individual photons can be discerned)
\> Maxwell's theory gives continuous predictions incompatible with
\> experiment. This forces me to believe that Maxwell's fields are
\> some surrogates for multi−photon wavefunctions, rather than their proper
\> hbar −> 0 limits.

Take |psi> to be a several electron state. <x,y,...|psi> = psi(x,y,...) is the corresponding several electron wave function. X = <psi|x|psi>, Y = <psi|y|psi>, ..., are the "classical" expectation values of the individual position operators x, y, ... The wave function psi(x,y,...) satisfies the multi−electron Schroedinger equation. The expectation values X, Y, ... satisfy Hamilton's equations of motion, this is Ehrenfest's theorem.

Take |phi> to be a several photon state. <0|e(x)e(y)...|phi> = phi(x,y,...) is the corresponding several photon wave function, with e(x), e(y), ... being the field operators (which are also decorated with polarization indices). E(x) = <psi|e(x)|psi> is the expectation value of the classical field amplitude. The wave function phi(x,y,...) satisfies the multi−photon "Maxwell equations". The expectation values E(x) satisfy Maxwell's equations, in the usual sense of the term, which is also a consequence of Ehrenfest's theorem. The fact that the single photon wave equation is the same as the linear part of the classical field equations is a theorem of second quantization.

Igor

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- ***Follow−Ups***:
    - ***Re: The time it takes to emit one photon***
        - *From:* Eugene Stefanovich
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    - ◊ *From:* Eugene Stefanovich

- ***References***:
    - ♦ ***Re: The time it takes to emit one photon***
        - ◊ *From:* nightlight
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