Re: The time it takes to emit one photon

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- *From*: Igor Khavkine <igor.kh@xxxxxxxxx>
- *Date*: Sat, 27 Aug 2005 07:23:12 +0000 (UTC)

On 2005−08−26, Eugene Stefanovich <eugenev@xxxxxxxxxxxx> wrote:
>
>
> Igor Khavkine wrote:
>
>>>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.
>
> So far so good. The only thing is that quantum fields are not necessary
> for describing the systems with a variable number of particles in the
> Fock space. Such a description can be formulated entirely in the
> language of "composite" wavefunctions, where each fixed−particle−number
> function 1, psi(x), phi(x,y), chi(x,y,z) enters with its own
> coefficient, and the sum of squares of all such coefficients is 1.

Necessity is a subjective notion. Necessary to whom? To yourself, who
does not use the field formulation? Or to the hunderds (thousands?) of
physicists who do? Equivalence is what it is. You either either

contradict it or you don't. If you do, I suggest you avail yourself of
the references I cited numerous times and follow the proof yourself. If
you don't, you've said nothing to change other people's opinions of QFT.

> Such a description is not fundamentally different from the particle
> description in ordinary (fixed particle number) quantum mechanics.
> The only difference is that the particle number is not fixed.
> In my view, this minor difference does not warrant the complete
> change of the paradigm suggested by the field theory.
>
> In my view, quantum fields are fine if you interpret them as
> formal technical constructs that aid your calculations.
> They are not fine when you start to consider them as
> "basic ingredients of the universe" and particles as
> "bundles of energy and momentum of the fields" (Weinberg's words).
>
> This is not a purely philosophical debate. Particle picture is
> essential to make the "dressing transformation" in QFT and to
> eliminate "bare particles" and "ultraviolet infinities" for good.

Yes it is. The ultraviolet infinities have been eliminated long before
your philosophy or "dressing transformation" existed. Old news. We've
been there.

>> 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.
>
> I thought that in a classical theory with a variable number of
> particles there should be trajectories that can start and terminate at
> some points. I don't see how you can jump from a variable (but still
> finite) number of degrees of freedom in the particle theory to the
> plain infinite number of degrees of freedom in the field.

That's the same statement that I've alread answered above. You may think
what you like, but that's not what actually happens. Read the following
carefully:

THERE IS PROOF THAT WHAT YOU THINK IS WRONG.

> The number of particles (including photons) in the Universe is finite.
> Field theories seem to disregard this important fact. They use infinite
> number of degrees of freedom to describe even one electron
> with its field.

Your objection is void. Any normalizable state in Fock space has a
finite expectation value for the number of particles. Just like,
classically, any physical field configuration has finite energy.

>>> 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.
>
> Do I understand you right? Are you saying that Maxwell's theory can be
> applied to the weak−field regime? I don't think so.

I don't think so. I don't think you understand what I'm saying.

> Take the Young's double−slit experiment. Maxwell's wave theory describes
> the light intensity on the screen by continuous functions E(x) and
> B(x). This is all fine while the intensity of light is high: there are
> many photons, and the light intensity appears continuous on the screen.
> At low intensities, when we can distinguish individual
> photons on the screen, the field description doesn't work anymore.
> The light intensity produced by one photon is more like a
> delta−function. One can reconsile these two contradicting
> descriptions in the tradition
> of quantum mechanics.

This situation is handled no differently than single electron
diffraction. The distribution pattern of detections is predicted by the
amplitude of the single photon wave function. As I illustrated above,
this wave function satisfies the wave equation for a relativistic vector
particle. There aren't that many wave equations that have this property.
In fact, there is only one, we call it "Maxwell's equations".

> One can say that E(x) and B(x) are "sort of"
> photon wave functions, and when the photon reaches the screen these
> wavefunctions collapse to produce a single observable dot.

> This is my interpretation of Maxwell's theory: the fields E(x) and B(x)
> there are some surrogates of multi−photon wavefunctions that remained
> after we took the (incomplete) classical limit from QED to the theory in
> which electrons are treated classically, while photons (due to their
> zero mass) are treated in a "sort of" quantum way.

What would be really nice is if you could give an even "sort of" precise and quantitative statement of this correspondence. Something like a formula relating these many−photon states to the electric and magnetic fields, perhaps?

Igor

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

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