Are virtual particles really constantly popping in and out of existence? Can laser make them real?

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Abstract

This article is summary of discussion in researchgate.net concerning possibility to use laser to create real particle from virtual particles (Schwinger effect).Virtual particles are indeed real particles. Quantum theory predicts that every particle spends some time as a combination of other particles in all possible ways. These predictions are very well understood and tested. Quantum mechanics allows, and indeed requires, temporary violations of conservation of energy, so one particle can become a pair of heavier particles (the so-called virtual particles), which quickly rejoin into the original particle as if they had never been there.

Introduction

Virtual particles are indeed real particles. Quantum theory predicts that every particle spends some time as a combination of other particles in all possible ways. These predictions are very well understood and tested. Quantum mechanics allows, and indeed requires, temporary violations of conservation of energy, so one particle can become a pair of heavier particles (the so-called virtual particles), which quickly rejoin into the original particle as if they had never been there. (see Scientific American, Oct 9 2006, http://www.scientificamerican.com/article/are-virtual-particles-rea/)

Recent methods claim that lasers will be able to make virtual particles real:
"Next-generation lasers will have the power to create matter by capturing ghostly particles that, according to quantum mechanics, permeate seemingly empty space. The uncertainty principle of quantum mechanics implies that space can never be truly empty. Instead, random fluctuations give birth to a seething cauldron of particles, such as electrons, and their antimatter counterparts, called positrons. These so-called "virtual particles" normally annihilate one another too quickly for us to notice them. But physicists predicted in the 1930s that a very strong electric field would transform virtual particles into real ones that we can observe. The field pushes them in opposite directions because they have opposite electric charges, separating them so that they cannot destroy one another."
(see New Scientist 2010,http://www.newscientist.com/article/dn19327-lasers-could-make-virtual-particles-real.html)

Answers

[1] **Gert Van der Zwan**

On the popping-in-and-out-of-existence time scale the electric field of laser light is the same as a static field. So, if a static field can pull the particles apart, a laser should also make this possible. It is also easier to create very high electric field strengths in short laser pulses than in static fields.

[2] **Alexander Nozik**

The first statement of your question about that virtual particles are the real particles is only partly correct. The virtual particle is indeed interacting as a real particle, but it does not propagate as a real

particle because it is not on the mass surface. In fact, you do not have a particle in a corpuscular sense, but rather some wave front with complicated features.
You can not simply make such particle "real" because it would violate principles of conservation of energy and momentum, but you probably can create such conditions, that due to interactions with the field, the conditions of "reality" are satisfied.

[3] **Gert Van der Zwan**
Alexander, that is what I assumed. If you create an electron positron pair, you can easily have momentum conserved, and by pulling apart the particles, the electric field performs work, which takes care of energy conservation.

In the mean time I followed some links, for instance to http://arxiv.org/abs/1004.5398v1, which points to the 1930's physicists, Sauter and Klein, who basically showed that there is a limit to the strength of an electric field, apparently because when it becomes too strong it starts producing particles, something conjectured by Bohr, according to the archiv paper. If you are interested I can attach copies of the Z. Phys. papers by Sauter and Klein if you have no access. The archiv paper itself is also an interesting read. Apparently the effect has already been observed. Funny idea, if you pull hard enough you can tear vacuum apart, and all kinds of particles start popping out. Well, maybe just electrons and positrons, but that's already quite something.

Interesting question, Victor.

[4] **Alexander Nozik**
Gert, it is indeed possible to "create" electron-positron pair from vacuum if you put sufficient energy to it. For example, the high energy charged particle passing through the matter usually creates a lot of such pairs. If it is possible to make such pairs with the static field is a complicated question, because in order to create particles there should be some inhomogeneity or fluctuation in that field. I am not sure that I am competent enough to discuss this possibility.
Returning to the initial question, you can consider the creation of the electron-positron pair as a decay of some virtual photon, but still you can not make such virtual photon real - it should be massive, and it is not.
I think the problem is what to call a virtual particle. As I was tough it is just a very short-lived (and short flying) particle without fixed mass, which could exist (as a particle) only because of uncertainty relation.
The laser pulse definitely can create a lot of electron-positron pairs, but i do not understand what connection does it have with virtual particles.

[5] **Gert Van der Zwan**
Alexander, regarding your first remark I would like to know what Bohr said about this. The abstract of Fedotov's paper suggests that Bohr was thinking of a static uniform field. Unfortunately Fedotov et al. only give a reference to a book by Sommerfeld, which is not available in the library I have access to, and I can only find on sale for $150 which I am not willing to pay. The papers by Sauter and Klein have a simple linear potentials of the type V=bx as a barrier and give a solution to the Dirac equation in the presence of that potential. No fluctuations or inhomogeneities.

The Fedotov paper more or less describes the process opposite to electron-positron annihilation which leads to two gamma rays, but not quite, since the wavelength of the laser is much longer. But in the way they do the experiment, by having two opposite circularly polarized light beams collide, momentum and angular momentum are conserved, and look likes the creation of a strong static field (on the time scale of particle production) in the focus. I don't understand your remark about the photon mass, mass itself is not a conserved quantity, it also disappears in electron positron annihilation, not leading to massive photons.

Cascades of particles are also observed in the atmosphere when high energy cosmic rays enter. I am not sure if this would qualify as the vacuum process the original question was about.

I agree that it is unclear that what you are doing is creating pairs, or pulling virtually created pairs apart, but I assume you could take that latter point of view. At first I thought the process could be similar to Hawking radiation, where the creation takes place close to the event horizon of a black hole, and of the produced pair one particle gets drawn in, and annihilation is no longer an option. But now I am not so sure.

Since I am also not an expert in this field myself, I would not mind hearing from one. Or we could just ramble on for a while.

[6] **Alexander Nozik**
Indeed mass is not a conserved quantity, yet each particle has some certain mass and it can't be made "real" with different mass.
I am not arguing about possibility to create particle-antiparticle pairs from vacuum in some either static or dynamic fields. It is just a question of terminology whether to connect this process with virtual particles or not.
When one high energy proton hits the other proton there is a vast cloud of different particles. Of course you always can say that before the collision there was a cloud of virtual particles which were virtual before the collision and are made real after, but in my opinion it is a bad use of the term.
Still, I just looked up over the internet and found that that meaning is also in use, so there is no point to argue.

[7] **Victor Christianto**
@Gert and Alexander. Thank you for your comments. Btw, i just found an interesting paper by Karimaki from finland, where he discusses a madelung fluid model of virtual particles, see http://arxiv.org/pdf/1206.1237v2.pdf. But alas, he does not discuss possible interaction with laser. Best wishes

[8] **Gert Van der Zwan**
Victor, you are right in concluding that the papers by Klein and Sauter are not really looking at pair production, although their results can now be interpreted as such. At the time they were still struggling (and so apparently was Dirac himself) with the relativistic theory, and these papers were attempts to come to terms with some of the difficulties. Concepts like pair production and the way we now look at vacuum are probably from a much later time. Let me give you an attempt to translation of the introduction of Klein's paper, which states so explicitly:

"As was indicated by Dirac, it is a serious problem for his relativistic quantum theory that an electron in a force field can attain negative eigenvalues, which are in general connected with the physically useful positive eigenvalues by transition probabilities. Also in his new, from other points of view successful treatment of relativistic quantum dynamics did he not succeed to overcome this difficulty. In the next pages an elementary example will be worked out, in which this difficulty comes out very clear (sharply)" [p. 11. My German is not very good, and I hope this is close enough].

Klein then proceeds to do the calculations for a potential jump, and shows that these transition probabilities become very large for high jumps, and the Sauter papers are for the slightly more complicated potential V=bx, where the ramp can later be adjusted, but in the end give similar results. Both papers make the difficulty obvious, and show that for an at that time impossibly high barrier the transition electron->positron will indeed occur. I wonder if there is a historical treatment of this problem, and what the old and new versions of Dirac's theory were. I only have Dirac's "Principles of Quantum Mechanics" in which he does not treat the barrier problem.

[9] **Yónatan Calderón Pérez**
I believe you are refering to the Schwinger effect. I heard that the most promissing way to see this effect is in graphene where the quasi-electrons have zero mass. However, I'm not an expert on this field.

[10] **Gert Van der Zwan**
Yónatan, thanks for the reference. You're correct: there is a webpage by Dunne http://www.phys.uconn.edu/~dunne/dunne_schwinger.html, which mentions that Schwinger's work was based on Sauter's. It does not give a reference to papers, but I'm sure I can find those. If you read the first two paragraphs of the Dunne link, you'll notice that it points to some very interesting topics. Here is a quote of the second paragraph, which relates to Victor's original question:

"Theoretically, this is a non-perturbative effect, as the virtual particles tunnel out of the Dirac sea. This makes this elusive effect of great interest for other theories, such as quantum chromodynamics (QCD), where non-perturbative effects are known to be significant but are not directly accessible, and also in gravitational physics, in particular for the phenomena of Hawking radiation near a black hole, and Unruh radiation of accelerating mirrors. It is also closely related to the dynamical Casimir effect of atomic physics."

[11] **Gert Van der Zwan**
I don't think that is possible on the basis of the paper you linked. The first line of the abstract is: "An interpretation of non-relativistic quantum mechanics is presented...", and pair production, Dirac sea, and concepts like that are only possible in relativistic quantum mechanics. The paper looks more like a reformulation of Bohm's interpretation of quantum mechanics. You note that in section 7, where QFT is supposedly discussed the author has a lot of ifs and maybes, and suggestions for possibilities. The current version of the theory presented definitely does not allow it. Although I did study Bohm's theory a long time ago, I never was very happy with it, and never looked at the relativistic extensions. Therefore I could not say if Nicolic's approach could be applied and the suggestions of section 7 followed. I also don't see what you would gain from it.

[12] **John Scales**
Slightly tangential, but Hawking radiation is a good example of the production of real radiation from virtual particle pairs. There are several examples in superconductivity in which real photons are created from virtual pairs. One involves the Casimir effect, e.g.,
http://www.sciencedaily.com/releases/2011/11/111118133050.htm

[13] **Stanislav Kuzmin**
Hi Victor
The hole situation is very similar to Dynamical Casimir effect where vacuum fluctuations take energy from laser
Let us estimate the laser intensity needed for particle-antiparticle generation.

Energy of mass of rest E=2mc^2 should be spend during uncertainty time t=h/E in the region comparable with Compton's wavelength l=h/(mc)
Thus, the laser intensity should be not less than
I=4E^2/(hl^3)=4(mc^2)^5/((h^4)(c^3))
For electron neutrino the minimum laser intensity is 4.2e9 W/cm^3.
The common femtosecond laser have intensity nearly
10e30 W/cm^3. So, regular lasers already generate neutrino.

Though, the minimum needed laser intensity for generation of
electron-positron pair is nearly 4e150 W/cm^3
This intensity cannot be attended in nearest future.

[14] **Victor Christianto**
@Gert, John and Stanislav. Thank you for your answers. I think Stanislav is correct that the present laser technology may not be able to create real particle from virtual particles. Btw, just fyi, there is a good introduction on Schwinger effect, at: http://www.qgf.uni-jena.de/gk_quantenmedia/Texte/hebenstreit090623-p-61.pdf. best wishes

Concluding remarks
While the Schwinger pair production concept seems interesting, creating particle from virtual particles is beyond the reach of present laser technology.

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Reference:
[1] http://www.qgf.uni-jena.de/gk_quantenmedia/Texte/hebenstreit090623-p-61.pdf