# Pair production and annihilation

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## Abstract

The creation and annihilation of matter-antimatter pairs is usually taken as proof that, somehow, fields can condense into matter-particles or, conversely, that matter-particles can somehow turn into lightlike particles (photons or neutrinos), which are nothing but traveling fields (electromagnetic or, in the case of the neutrino, some *strong* field). However, pair creation always requires the presence of a nucleus. We, therefore, wonder whether pair creation could not be analyzed as a nuclear process.

We argue the usual nuclear reactions involving protons and neutrons can effectively account for the process of pair creation. Conversely, we also find matter-antimatter pair annihilation can be explained by the same reactions. We, therefore, the need to invoke quantum field theory to explain these high-energy processes would need to be justified much better than it currently is.

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# Introduction

The creation and annihilation of matter-antimatter *pairs* is usually taken as proof that, somehow, fields can condense into matter-particles or, conversely, that matter-particles can somehow turn into light-particles (photons), which are nothing but *traveling* electromagnetic fields. However, pair creation always requires the presence of another particle and one may, therefore, legitimately wonder whether the electron and positron were not already *present*, somehow.

Carl Anderson's original discovery of the positron involved cosmic rays hitting atmospheric molecules, a process which involves the creation of unstable particles including *pions*. Cosmic rays themselves are, unlike what the name suggests, *no* rays – not like gamma rays, at least – but highly energetic protons and atomic nuclei. Hence, they consist of matter-particles, not of photons. The creation of electron-positron pairs from cosmic rays also involves *pions* as intermediate particles:

1. The $\pi^+$ and $\pi^-$ particles have *net* positive and negative charge of 1 $e^+$ and 1 $e^-$ respectively. According to mainstream theory, this is because they combine a *u* and *d* quark but – abandoning the quark hypothesis[1] – we may want to think their charge could be explained, perhaps, by the presence of an (extra) electron![2]
2. The neutral pion, in turn, might, perhaps, consist of an electron *and* a positron, which should annihilate but take some time to do so!

Neutral pions have a much shorter lifetime – in the order of $10^{-18}$ s only – than $\pi^+$ and $\pi^-$ particles, whose lifetime is a much more respectable $2.6\times10^{-8}$ s. Something you can effectively *measure*, in other words.[3] In short, despite similar energies, neutral pions do *not* seem to have a lot in common with $\pi^+$ and $\pi^-$ particles. We, therefore, wonder why neutral pions and $\pi^+$ and $\pi^-$ particles should be considered to be similar particles.[4]

[1] You may be so familiar with quarks that you do not want to question this hypothesis anymore. If so, let me ask you: where do the quarks go when a $\pi^\pm$ particle disintegrates into a muon-$e^\pm$?

[2] They disintegrate into muons (muon-electrons or muon-positrons), which themselves then decay into an electron or a positron, respectively.

[3] The point estimate of the lifetime of a neutral pion of the Particle Data Group (PDG) is about $8.5\times10^{-17}$ s. Such short lifetimes cannot be measured in a classical sense: such particles are usually referred to as *resonances* (rather than particles) and the lifetime is calculated from a so-called *resonance width*. We may discuss (and criticize) this approach in a future version of this paper. Just note that, even at the speed of light, these particles would only travel $(8.5\times10^{-17}\text{ s})\cdot(3\times10^{8}\text{ m/s}) = 25.5\times10^{8}\text{ m}^{-9}$. That length is about 500 times the radius of a hydrogen atom, and a particle with a rest mass of 135 MeV can surely not aspire to travel anything near lightlike. So, yes, thinking of it as some kind of local unstable resonance – something which happens *at the scale of an atom itself* – is quite appropriate.

[4] Quark theorists say they have this in common: they all consist of a quark and an antiquark. We wonder what they mean by that – not approximately, but *exactly*? What explains the *very* different lifetimes and the *very* different decay modes? Aitchison and Hey answer this question in two volumes (*Gauge Theories in Particle Physics*, 2013) but, frankly, we find such long answer rather complicated and, therefore, unconvincing. The short explanation is that the neutral pion decays via the electromagnetic force, while the charged pions decay because of the weak force. We read this as follows: the neutral pion consists of opposite (electric) charges (which do not necessarily need to be quarks for us) while the charged pions (also) involve something else, which is not necessarily some weak force (we think of a force as holding something together, rather than as something pulling something apart) but, perhaps, some strong force. Such strong force must have a different *geometry* than the electromagnetic force

Even the energy difference is quite substantial when measured in terms of the electron mass: the neutral pion has an energy of about 135 MeV, while $\pi^+$ and $\pi^-$ particles have an energy of almost 140 MeV. To be precise, the difference is about 4.6 MeV. That is quite a lot: the electron rest energy is 0.511 MeV only.[5] So it is *not* stupid to think that $\pi^+$ and $\pi^-$ particles might carry an extra positron or electron, *somehow*. In our not-so-humble view, this is as legitimate as thinking – like Rutherford did – that a neutron should, *somehow*, combine a proton and an electron.[6]

The whole analysis – both in the QED as well as in the QCD sector of quantum physics – would radically alter when thinking of neutral particles – such as neutrons and $\pi^0$ particles – not as consisting of quarks but of protons/antiprotons and/or electrons/positrons cancelling each other's charges out. We have not seen much – if anything – which convinces us this cannot be correct. We, therefore, believe a more realist interpretation of quantum physics should be possible for high-energy phenomena as well. With a more realist theory, we mean one that does *not* involve quantum field and/or renormalization theory. Such new theory would not be contradictory to the principle that, in Nature, the number of charged *particles* is no longer conserved, but that total (net) charge *is* actually being conserved, *always*. Hence, charged particles could appear and disappear, but they would be part of neutral particles. All particles in such processes are very short-lived anyway, so what *is* a particle here? We should probably think of as an unstable combination of various bits and bobs, isn't it? 😊

However, we readily admit the reasoning above is rather sloppy and general. Let us, therefore, be much more precise.

## Pair production as a nuclear process

The overview below (Figure 1) lists of all of the decay modes of a proton.

| $\pi^0$ DECAY MODES | | Fraction ($\Gamma_i/\Gamma$) | Scale factor/ Confidence level | $p$ (MeV/c) |
|---|---|---|---|---|
| $2\gamma$ | | $(98.823\pm0.034)$ % | S=1.5 | 67 |
| $e^+e^-\gamma$ | | $(1.174\pm0.035)$ % | S=1.5 | 67 |
| $\gamma$ positronium | | $(1.82\pm0.29)\times10^{-9}$ | | 67 |
| $e^+e^+e^-e^-$ | | $(3.34\pm0.16)\times10^{-5}$ | | 67 |
| $e^+e^-$ | | $(6.46\pm0.33)\times10^{-8}$ | | 67 |
| $4\gamma$ | | $< 2\times10^{-8}$ | CL=90% | 67 |
| $\nu\overline{\nu}$ | [e] | $< 2.7\times10^{-7}$ | CL=90% | 67 |
| $\nu_e\overline{\nu}_e$ | | $< 1.7\times10^{-6}$ | CL=90% | 67 |
| $\nu_\mu\overline{\nu}_\mu$ | | $< 1.6\times10^{-6}$ | CL=90% | 67 |
| $\nu_\tau\overline{\nu}_\tau$ | | $< 2.1\times10^{-6}$ | CL=90% | 67 |
| $\gamma\nu\overline{\nu}$ | | $< 1.9\times10^{-7}$ | CL=90% | 67 |
| **Charge conjugation (*C*) or Lepton Family number (*LF*) violating modes** | | | | |
| $3\gamma$ | *C* | $< 3.1\times10^{-8}$ | CL=90% | 67 |
| $\mu^+e^-$ | *LF* | $< 3.8\times10^{-10}$ | CL=90% | 26 |
| $\mu^-e^+$ | *LF* | $< 3.4\times10^{-9}$ | CL=90% | 26 |
| $\mu^+e^- + \mu^-e^+$ | *LF* | $< 3.6\times10^{-10}$ | CL=90% | 26 |

Figure 1: The decay modes of the $\pi^0$ resonance

The table shows a $\pi^0$ usually (98.8% of the time) decays into two photons. Occasionally (almost 1.2% of the time), it decays into a photon and an electron-positron pair but, according to Wikipedia, this is

or – who knows? – might act on a different charge, or both perhaps. However, we do not necessarily think of the concept of color charge here.

[5] Of course, it is much smaller when compared to the proton (rest) energy, which it is about 938 MeV.

[6] See our short history of quantum-mechanical ideas or our paper on protons and neutrons.

actually also a two-photon decay with one of the photons decaying into an electron-positron pair. Once in a million (see the $10^{-6}$ fractions), or once in a billion (see the $10^{-9}$ fractions), it decays into something else. We will come back to those other modes later. Let us first think about the main decay mode: two highly energetic photons. How energetic? And what happens with these photons?

Gamma rays from radioactive decay (*nuclear* gamma rays) carry energies up to 8 MeV, but so here we must be talking 67 MeV photons (half of the 134 MeV energy of the pion). That is *huge*. When interacting with the electromagnetic fields inside of an atom and, presumably, within a *nucleus* itself, must rip all apart – and it does! This is probably why the naturally occurring process of pion decay in the upper layers of our atmosphere usually shows the two photons creating electron-positron pairs when interacting with other nearby matter-particles, as shown below.

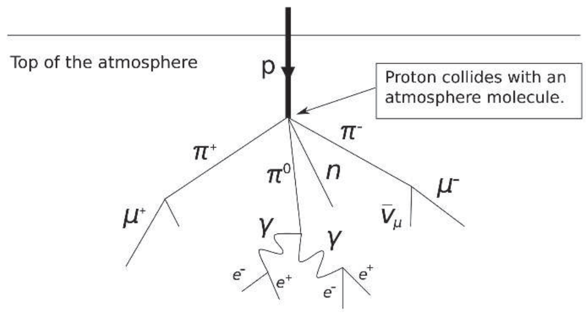


Figure 2: Pion production from cosmic rays (source: Wikipedia)

We must, of course, think of the four principal nuclear processes involving neutrinos here[7]:

1. Neutron decay: $n^0 \rightarrow p^+ + e^- + \nu^0$
2. Electron capture by a proton: $p^+ + e^- \rightarrow n^0 + \nu^0$
3. Positron emission by a proton: $\nu^0 + p^+ \rightarrow n^0 + e^+$
4. Positron emission by a proton: $\gamma + p^+ \rightarrow n^0 + e^+ + \nu^0$

The latter two processes are very different[8] but yield the same: a proton emits a *positron* and becomes a neutron. However, the process we are interested in here is, of course, the positron emission which involves the photon absorption. Perhaps we may think of a sequence like this:

1. The nucleus absorbs the gamma-ray photon by a proton-neutron *Verwandlung*.[9] We have a proton less, but an extra neutron and a positron now.
2. The nucleus returns to its original state when the extra neutron decays back into a proton, *while emitting an electron*.

[7] We denote the neutrinos as $\nu^0$ here and, for simplicity, we do not distinguish between neutrinos and antineutrinos: we think they are like photons and, hence, the difference between neutrinos and antineutrinos must be related to their spin, which we interpret as being *physical* somehow and, therefore, spin may be in one of two possible *geometric* directions. The point is this: there is no *charge* inside neutrinos which could be opposite, so we think the prefix (*anti*-) is not necessarily useful when talking neutrinos.

[8] The first is the 1951 Cowan-Reines experiment (bombarding protons with neutrinos). The second describes $\beta^+$ decay. We refer to one of our papers on this for a more detailed description.

[9] We think the German word sounds less futuristic and, therefore, more scientific, than the English: transformation.

3. The neutrinos in this process may or may not take care of themselves.[10]

You will have to admit this is a much more elegant way to explain matter-antimatter pair production out of photons than the usual hocus-pocus, isn't it?

You may think this makes some sense (probably not) but, if it does, we should also explain matter-antimatter annihilation in a way that shows *electric charge does not get magically lost somehow!*

You are right. Let us see if we can do this.

## Pair annihilation as a nuclear process

We need to think practically here, perhaps: the positron will meet an electron and there will be mutual annihilation, but *where exactly*? The positron is likely to meet an electron that is part of some atom. Will it engage with one of the electrons in the electrons shells? Maybe but – if we would think of a neutron as consisting of a proton with an electron[11] – we may imagine the positron to, perhaps, interact with the nucleus. Our positron is probably highly energetic and so it may, effectively, tear through the electron shells without any interaction with them. Hence, we might imagine a process that is the *reverse* of the positron emission by a proton. Instead of $\nu^0 + p^+ \rightarrow n^0 + e^+$, we get this[12]:

$$n^0 + e^+ \rightarrow p^+ + \nu^0$$

How does the neutron *do* this, really? If we think the neutron consists of a proton and a neutron, the incoming positron must annihilate the nuclear electron. Can we prove this? No. Can we rule out this is *not* possible? No. We think it might make some sense. That is all.

We lost a neutron and we gained a proton, but the state of the nucleus must not change! That is taken care of by the electron: we must assume this electron is highly energetic too and will, therefore, also be able to tear through the electron shells without any interaction.[13] This electron should be captured by a proton so as to restore the original nucleus state:

$$p^+ + e^- \rightarrow n^0 + \nu^0$$

Again, we did not care about the neutrinos in this process: they may or may not take care of themselves.[14] The point in this: this process explains matter-antimatter annihilation as a nuclear process too. No need for quantum field theory ! 😊

[10] If the neutrinos are anti-neutrinos of each other, they should annihilate and provide some extra (strong) energy. If not, we would need to keep track of them. We note some of the other decay modes of neutral pions involve neutrinos, so that might not be an issue.

[11] We know this sounds outrageous but we think it is justified because of the neutron decay reaction. A neutron does not decay into quarks or some other exotic thing. It decays into a proton and an electron: $n^0 \rightarrow p^+ + e^- + \nu^0$. Simple. We do not understand why it is so difficult for some to read what is written here.

[12] Again, we do not care about the neutrino being a neutrino or an antineutrino: we think both just differ because of their spin. There is no *charge* inside which could be opposite so as to justify the prefix.

[13] Note that the positron is going through a potential *well*, while the electron is going through a potential *barrier*.

[14] See footnote 10.