# Pair production and annihilation as a nuclear process

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## Abstract

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

We argue the usual nuclear reactions involving protons and neutrons can effectively account for the processes of pair creation and annihilation. We therefore argue that the need to invoke some quantum field theory (QFT) to explain these high-energy processes would need to be justified much better than it currently is.

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## Introduction

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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*.[2] Cosmic rays themselves are, unlike what the name suggests, *no* rays – not like electromagnetic 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 involves these 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[3] – we may want to think their charge could be explained, perhaps, by the

[1] The usual reason that is quoted here has to do with excess energy and momentum that, somehow, needs to be absorbed. The Wikipedia article on pair creation, which quotes or summarizes from J.H. Hubbell's 2006 overview article on electron-positron pair production by photons, says this: "*The photon must be near a nucleus in order to satisfy conservation of momentum, as an electron–positron pair produced in free space cannot both satisfy conservation of energy and momentum.*" We think this explanation does not quite cut it.

[2] The discovery of the positron is, without any doubt, to be credited to the tireless efforts of Carl Anderson in the early 1930s. In contrast, the discovery of the pion – both experimentally as well as theoretically – is a more complicated matter. Nobel Prizes in Physics were awarded to Yukawa in 1949 for his theoretical prediction of the existence of mesons, and to Cecil Powell in 1950 for developing and applying the technique of particle detection using photographic emulsions, which were effectively used to confirm the existence of what was then referred to as *charged* π-mesons in an international effort led by Cecil Powell. However, some credit a young Indian scientist at the Bose Institute in Calcutta (now Kolkata), Bibha Chowdhury, with the actual discovery. She effectively discovered traces of the heavy ionized particles using photographic plates and apparently published on these discoveries in not less than three articles for the *Nature* journal in 1941 and 1942. As for its theoretical foundations, we think Yukawa's concept of a strong force makes sense, but we never quite understood the idea of it having to be *mediated* by a 100 MeV *virtual quantum*. See our paper on the nature of Yukawa's force and charge.

[3] 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 charged pion disintegrates into a muon-electron (or positron), or into highly energetic photons? We think the invention of the concept of strangeness by Murray Gell-Man and Kazuhiko Nishijima in the 1950s may or may not have been useful as a *mathematical* concept. However, we feel this concept started a rather strange life of its own as it would effectively serve – much later – as the basis for the quark

presence of a positron (or an electron in the case of a $\pi^-$)! They effectively disintegrate into a muon-electron ($\mu^\pm$) which, in turn, will emit a neutrino[4] and morph into an electron or its positively charged antimatter counterpart ($e^\pm$).

2. The neutral pion is a very different animal: it (usually) disintegrates into two photons[5] which, in turn, somehow both *morph* into an electron and a positron – so we get two electrons and two positrons, and so that is the process which we want to think about in this paper.

The illustration below shows the (1) ingredients (the highly energetic proton and an atmospheric molecule) and (2) final products (one muon-electron/positron pair, two electron/positron pairs[6], and a neutron) of this remarkable process.

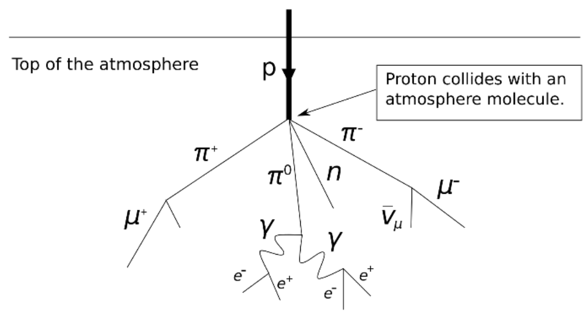


Figure 1: Pion production from cosmic rays (source: [Wikipedia](https://en.wikipedia.org))

Before we get into the nitty-gritty of it all, we should make some few preliminary remarks here:

**1.** Note that the illustration above might suggest that the whole process – from start to end – does not respect the charge conservation principle: the charge of the incoming proton is $e^+$, while the charges of the intermediate products ($\pi^+$, $\pi^-$, $\pi^-$ and a neutron) add up to zero. However, while the lifetime of a (free) neutron is close to eternity (about 15 minutes), we argue one should think of it as combining a proton and an electron.[7] Hence, the proton balance before and after is OK, but we are missing an

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hypothesis which – for a reason we find even stranger than the concept of strangeness itself – was officially elevated to the status of a scientific dogma by the Nobel Prize Committee for Physics.

[4] To be precise, the process involves the emission of *two* neutrinos: a neutrino and its so-called antimatter counterpart. We think of neutrinos as lightlike particles, so there is no opposite charge here: we think the two neutrinos differ only in their spin.

[5] There are other decay modes, of course, but this is the principal one, and so we will look at this mainly.

[6] Because the $\mu^\pm$ will disintegrate into an $e^\pm$ (the lifetime of a muon-electron is $2.2\times10^{-6}$ s), you may think of the final products as three electron-positron pairs (and some neutrinos, of course) and – lest we forget – the neutron. Note that a lifetime of $2.2\times10^{-6}$ s is considered to be (almost) an eternity in particle physics. The Wikipedia entry on the microsecond has an animated gif which gives you an idea of what such time interval actually means.

[7] 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: $n^0 \to p^+ + e^- + \nu^0$. Simple. We do not understand why some academics find it so difficult to accept what is written here or, worse, simply refuse to consider it as an alternative for the quark hypothesis.

electron. It should be added somewhere.[8] Where, *exactly*? We do not know, *yet*. It must be something with the atmospheric molecule.[9]

**2.** It is plain weird – or *artificial*, we should say – that neutral pions are, somehow, being thought of as being similar to (charged) $\pi^{\pm}$ particles. The casual lumping together of $\pi^{\pm}$ particles and neutral pions under one and the same banner (pions) is like saying protons and neutrons are nucleons, both. That is an obvious truth, of course, but we do not learn much by it: we need to get into the nitty-gritty of neutron decay and other nuclear processes to understand how *different* they actually are, right? And the difference between neutral and charged pions is even starker.

For starters, 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.[10] And then, charged pions carry charge. Neutral pions do not. Huge difference! In short, despite similar energies, neutral pions do *not* seem to have a lot in common with $\pi^{+}$ and $\pi^{-}$ particles. Historically, charged pions were discovered in the late 1930s (and further confirmed in the 1940s), while the neutral pion was discovered in very different experiments in the 1950s only. We, therefore, wonder why neutral pions and $\pi^{+}$ and $\pi^{-}$ particles are to be thought of as, somehow, being similar particles.[11]

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[8] All kinds of weird things may happen to the *number* of charged particles – especially if they are only *intermediate* particles – but the matter-antimatter pair creation of annihilation does respect the overarching charge conservation law. Charge, momentum (linear and angular), and energy are always conserved, *somehow*. The invention of a zillion weird quantum numbers does not fundamentally challenge this.

[9] There are many possibilities here. The most obvious is an ionization of the atmospheric molecule: there is a very good reason why the upper layer of the atmosphere is referred to as the ionosphere, indeed! However, such ionization may not be the *direct* result of an electron being ripped out of a shell. The highly energetic proton might, perhaps, knock out one of the neutrons in the nucleus! It could then *morph* into a neutron by capturing an electron: $p^{+} + e^{-} \rightarrow n^{0} + \nu^{0}$. Is this what happens? We do not know. The point is this: in high-energy physics, we should forget about particles being conserved – obviously – but we should not forget *total charge must be conserved, somehow*.

[10] 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.

[11] 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 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.

Even the energy difference is quite substantial (when measured in terms of the electron mass, that is): 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.[12] 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.[13]

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 such thinking cannot possibly 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 or neutral) *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 this was probably the longest introduction to a paper – *ever* – and that, nevertheless, some of the reasoning above may be considered to be rather sloppy and general. Let us, therefore, be much more precise.

## Pair production as a nuclear process

The overview below (Figure 2) 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 2: The decay modes of the $\pi^0$ resonance

The table shows what we know already: a neutral pion ($\pi^0$) usually – this means 98.8% of the time here – 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 actually also a two-photon decay with one of

[12] Of course, it is much smaller when compared to the proton (rest) energy, which it is about 938 MeV.
[13] See our short history of quantum-mechanical ideas or our paper on protons and neutrons.

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 may or may not come back to those other modes in a later version of this paper. Let us first think about the main decay mode: two highly energetic photons. How energetic, *exactly*? And what happens with these photons, then?

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).[14] That is *huge*. When interacting with the electromagnetic fields inside of an atom and, presumably, within a *nucleus* itself, such photon 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 in Figure 1, indeed). So how does that happen – not approximately but *exactly?* We must, of course, think of the four principal nuclear processes here[15]:

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[16] 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. So we think of a sequence like this:

1. The nucleus absorbs the gamma-ray photon by a proton-neutron *Verwandlung*[17]: $p^+ \rightarrow n^0 + e^+$. 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*.[18] Hence, the equation is this:

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

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[14] See the values for the momentum in the final column of the PDG table.

[15] All processes involve neutrinos, and we denote these neutrinos simply as $\nu^0$ here. Indeed, 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. We think of neutrinos as just carrying energy (and, therefore, mass). Nothing more. Nothing less.

[16] 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.

[17] We prefer this German word to the English: transformation. We admit it is not scientific. We note the proton-neutron transformation involves a neutrino. Where does that come from? We do not know: it may be energy from outside, but we think it should come from some internal *strong* field. We admit this is speculative. We put the neutrino in the final equation: the reader can verify we have it in both sides of the equation, which lends credibility to the hypothesis of using internal energy only here.

[18] The neutrinos in this process may or may not take care of themselves. We want to look at this in more detail later. Here we just note that, if the neutrinos are anti-neutrinos of each other, they should annihilate and provide some extra (strong) energy – whatever that might be. If not, we would need to keep track of them. We note some of the other decay modes of neutral pions involve neutrinos, so we do not think of our simplistic "let us examine that more in detail" approach here as a serious issue. The reader has the right to disagree, of course.

The *net* result is the $\gamma \rightarrow e^- + e^+$ equation that we needed. 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? However, science is not necessarily about elegance.[19] Science is about what makes sense and who does not. Hence, if this makes sense (which remains to be seen), we should also explain matter-antimatter annihilation in a way that shows *electric charge does not get magically lost somehow!* Let us see if we can do this.

## Pair annihilation as a nuclear process

Let us think practically here too: 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. However, if we would think of a neutron as consisting of a proton with an electron[20], we may imagine the positron to, perhaps, interact with the nucleus. Our positron is probably highly energetic and so it will, effectively, tear through the electron shells without any (meaningful) interaction with them or – more likely, perhaps – it may shear them all off without losing much energy at all.[21] 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[22]:

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

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 before and after must be the same – *sort of* at least, right? 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.[23] This electron should be captured by a proton so as to restore the original nucleus state:

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

So, yes, the two processes together yield the $e^+e^-$ annihilation process we wanted to see:

$$n^0 + e^+ + p^+ + e^- \rightarrow p^+ + n^0 + 2\nu^0$$

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[19] As Dirac famously remarked, quantum field theory and perturbation approaches are surely *not* about elegance and beauty!

[20] The reader will, in the meanwhile, have understood that we love Rutherford's original hypothesis of the neutron combining a proton with *a nuclear electron*: we think it remains relevant and extremely productive. For a short introduction to Rutherford's ideas here, see our short history on quantum-mechanical ideas, in which we analyze some of Rutherford's remarks in this regard in his paper on '*The Structure of the Electron*' at the 1921 Solvay Conference.

[21] If we take the example of atmospheric molecules, the reader should remember those molecules are mostly ionized already, so there are no electron shells to start with even!

[22] 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.

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

You will say: neutrinos are not photons, so how do we get the photons?[24]

We admit we should answer this question, and we cannot for the time being. However, we feel it is more reasonable to argue that *strong* field energy inside of the nucleus could, somehow, be converted into electromagnetic field energy. Much more reasonable than the pointblank creation of matter-particles out of field energy, in any case! Indeed, the key point is this: this process explains matter-antimatter annihilation as a nuclear process too.

No need for quantum field theory ! 😊

## Conclusions

We have been talking about protons, neutrons, electrons, and their antimatter counterparts – *real* matter-particles. And about photons and – to a very limited extent – neutrinos. Things that we know to *exist* in any meaningful way: they last for a while, or even permanently (except when they happen to be part of a high-energy event, of course). So what *are* those pions, then?

You tell me. I do not worry about them too much. They are some kind of unstable state – a *disequilibrium* state, in other words: some *transient* electromagnetic oscillation[25] with one or more elementary charges whirling around in it. When a car gets destroyed in some accident, we are usually interested in the victims – not in the exact details of what debris flies where exactly. We are not, in any case. We summed up our vision of what makes sense in several ironic rewrites of Feynman's *Lectures*. We rewrote his introduction to quantum physics, for example, as follows[26]:

> Newton thought that light was made up of particles, but then it was discovered that it behaves like a wave. Later, however (in the beginning of the twentieth century), it was found that light did indeed sometimes behave like a particle. Historically, the electron, for example, was thought to behave like a particle, and then it was found that in many respects it behaved like a wave. Hence, the challenge is to find a description that takes account both of the wave- as well as of the particle-like character of both matter- as well as light-particles. We may refer to both as wavicles but – for historical reasons – this term did not become household language.
>
> Light-particles are known as photons. Photons carry electromagnetic energy, but they do *not* carry charge. In contrast, matter-particles always carry charge. If they are neutral – think of a neutron or an atom – they will carry both positive and negative charges. We should, therefore, think of them as composite particles. Elementary particles are stable. Composite particles consist of elementary particles and may be stable or unstable. An atom is an example of a stable composite particle. A neutron is stable inside of the nucleus but unstable as a free particle: it spontaneously disintegrates into a proton and an electron. This process involves the emission of a neutrino, which ensures energy is conserved. We think of a neutrino as a lightlike particle: it also carries energy but no charge.[27]

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[24] Electrons and positrons usually annihilate by producing two highly energetic photons, indeed!

[25] You might wonder: perhaps some strong oscillation too? If you find it useful to think like that, I do not mind. Not at all, really. But I would appreciate if you could elaborate what you could possibly *mean* with that. Something neutrino-like, perhaps?

[26] See our [Lectures on Physics, Chapter I: Quantum Behavior](#).

[27] The *nature* of this energy is *not* electromagnetic, however. Electromagnetic energy is related to electromagnetic forces. We may, therefore, think of the energy of a neutrino as being related to the stronger force inside of a proton or a neutron.

Electrons and protons are elementary matter-particles. They are stable because they are *wavicles* in an equilibrium state – in the sense that their *fundamental cycle* is given by the Planck-Einstein relation: T = $1/f = h/E$.[28] They are stable but not indestructible. High-energy collisions between protons – or between protons and anti-protons – yield unstable particles which disintegrate back into stable particles. Because they are unstable, such particles should not be referred to as *particles* but as *transients* or, when very short-lived, as *resonances*.

The Higgs particle is an example of an extremely short-lived resonance: its lifetime is of the order of $10^{-22}$ seconds. Even at the speed of light – which an object with an estimated *rest* mass of 125 GeV/$c^2$ can never aspire to attain – it cannot travel any further than 0.3 *femto*meter ($0.3 \times 10^{-15}$ m) before it disintegrates. Such distance is *smaller* than the radius of a proton, which is in the range of 0.83 to 0.84 fm. Labelling it as a particle is, therefore, hugely misleading. Likewise, quarks have also never been directly observed or isolated. Their existence is and remains, therefore, a mere hypothesis, which we will not entertain in these lectures because we have no need for it: high-energy physics studies disintegration processes, which involve non-equilibrium states—and we will not study these in our lectures.[29] These high-energy collisions are interesting though because they show that protons must have some internal *structure*. We think of such structure not in terms of quarks or gluons[30], but in terms of the motion of the elementary charge. Paul Dirac wrote the following on that:

> "Quantum mechanics may be defined as the application of equations of motion to particles. […] The domain of applicability of the theory is mainly the treatment of electrons and other charged particles interacting with the electromagnetic field—a domain which includes most of low-energy physics and chemistry.
>
> Now there are other kinds of interactions, which are revealed in high-energy physics and are important for the description of atomic nuclei. These interactions are not at present sufficiently well understood to be incorporated into a system of equations of motion. Theories of them have been set up and much developed and useful results obtained from them. But in the absence of equations of motion these theories cannot be presented as a logical development of the principles set up in this book.
>
> We are effectively in the pre-Bohr era with regard to these other interactions. It is to be hoped that with increasing knowledge a way will eventually be found for adapting the high-energy theories into a scheme based on equations of motion, and so unifying them with those of low-energy physics."[31]

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[28] For a broad overview of our assumptions, which amount to a full-blown realist interpretation of particle or quantum physics, see our *Principles of Quantum Physics*.

[29] If you want to know what we think of the quark hypothesis, we think this hypothesis results from an unproductive approach to analyzing disintegration processes: Gell-Man and Kazuhiko Nishijima studied disintegration processes of K-mesons back in the 1950s, and invented new quantities that are supposedly being conserved in these processes. One of these quantities was referred to as strangeness (see the analysis of K-mesons in Feynman's *Lectures*). These strange new concepts then started to lead an even stranger life of their own.

[30] See our remarks on the quark hypothesis in footnote 29. As for gluons, these are supposed to carry the strong force. We see no need to invent new particles to carry forces: the concept of fields – electromagnetic or other – should do. The idea of force-carrying particles resembles 19th century *aether* theory: there is no need for it, so why should we entertain it?

[31] Paul A.M. Dirac, *The Principles of Quantum Mechanics*, 4th edition (1958), p. 312.

These words were written in 1958 but still ring true today. What about quantum field and perturbation theory? Dirac thought they could not be *true*.[32] We think the situation is a lot worse: no one seems to be able to clearly state why they were invented or what problem they are supposed to solve. It is probably a question to be left to the history of science: no one uses quantum mechanics in *practical* theory anyway. The study of semiconductors, for example, just takes the main results out of quantum physics and then develops more realist workable models based on these results. In a *pragmatic* interpretation of what physics should and should not be, we think that is maybe not great (because untrue), but good enough (because practically workable). In addition, as Dr. Consa usefully notes[33], it sustains large research institutions and consumes budgets that would otherwise would probably be spent on R&D in the defense sector anyway. We may, perhaps, add a final remark on Dirac. In the *Preface* to the fourth and last edition (1958) of his *Principles of Quantum Mechanics* (1930) – from which we quote above – Dirac also writes this:

> "In present-day high-energy physics the creation and annihilation of charged particles is a frequent occurrence. A quantum electrodynamics which demands conservation of the number of charged particles is therefore out of touch with physical reality. So I have replaced it by a quantum electrodynamics which includes creation and annihilation of electron-positron pairs.
>
> This involves abandoning any close analogy with classical electron theory, but provides a closer description of nature. It seems that the classical concept of an electron is no longer a useful model in physics, except possibly for elementary theories that are restricted to low-energy phenomena."

From what we wrote in this paper, the reader will understand we could not agree more with the former part of this statement. However, we do not agree with the latter part. We find Rutherford's concept of nuclear electrons (or neutrons combining a proton and an electron, *somehow*) amazingly productive and rich, and we think all that is needed to save the 'old quantum mechanics' is to think of pair creation and annihilation as *nuclear* processes – involving interactions with protons and neutrons, and also involving neutrinos. We may, therefore, qualify these interactions as *strong* rather than electromagnetic interactions, but such qualification is – for us, at least – not a license to multiply concepts by invoking color charges, quarks, gluons, or whatever other *virtual* particles one might come up with. We also think the classical concept of a field will do. The *quantization* of a field is a useful concept, but we think it has got nothing to do with fields condensing, somehow, in real or virtual (stable or not) particles.[34] We welcome good arguments on why we should think otherwise.

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[32] In regard to Dirac's skepticism, the Wikipedia article on Paul Dirac, quotes this from his last paper (*The inadequacies of quantum field theory*, 1984): "It effectively contains his last and final judgment on quantum field theory: "These rules of renormalization give surprisingly, excessively good agreement with experiments. Most physicists say that these working rules are, therefore, correct. I feel that is not an adequate reason. Just because the results happen to be in agreement with observation does not prove that one's theory is correct." The other quotes refer to the lack of a good theory, with a 'good theory' being defined as mentioned above: "a scheme based on equations of motion." See our paper on the meaning of uncertainty and the geometry of the wavefunction.

[33] See: *The Rotten State of QED*.

[34] See, for example, our analysis of quantized magnetic fields in the context of a ring current in a superconductor in our paper on the concept of a field. The quantization does not imply that we should assume that the magnetic field itself must, somehow, consist of (discrete) field quanta. Not at all. The magnetic field is just what it is: a finite quantized magnetic field.