Annihilation

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ANATATION

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Contents

1. Introduction

Annihilation is the result of the interaction of an electron and a positron. The process is physically observable, but ambiguous. Both particles are mechanically identical, but have opposite electrical charges and opposite quantum properties. Quantum properties include: relativistic rotation energy (E_r); Cherenkov radiation energy (E_h) and relativistic moments (p_r, p_h). During the interaction, the total kinetic energy of both particles is transformed into electromagnetic radiation or other short-lived, heavy particles (muons, pions, tau leptons). Annihilation generally occurs in two directions:

- Two gamma quanta are formed according to the scheme:

$$e^+ + e^- \to 2\gamma_n \ .$$

Here, n is the number of the electron energy level in vacuum. The radiation energy per electron is, $E \approx 511.026\ \pm 1\ keV$.

- Two short-lived muons are produced according to the scheme:

$$e^+ + e^- \to \gamma^* \to \mu^+ + \mu^-$$

Here, γ^* is a virtual photon, which decays into a muon and an anti-muon.

Before annihilation, electrons can temporarily form a bound pair. This state of particles is called positronium. In quantum electrodynamics, a distinction is made between Ortho-positronium and Para-positronium. The difference depends on the relative orientation of the spins.

2. Electrons

The allowed energy levels of electrons in a vacuum are defined through discrete values of the relativistic parameter, $x_n = \beta_n = v_n^2/c^2$, [1]. There are no external fields. The collision is head-on, and the particle velocities are the same. The self-energy $m_e c^2$ acts as a constant coupling coefficient between the total kinetic energy of the particle and the relativistic parameter:

$$E_e = E_{se} + [E_{re} - E_{he}]; \qquad (1)$$

$$E_{en} = \frac{1}{2} m_e c^2 \beta_n^2 + m_e c^2 \left[1 - \frac{1}{\sqrt{1+\beta_n^2}} - \frac{\alpha^2}{8} \frac{1}{\sqrt{1+\beta_n^2}}\right].$$

The number of electron energy levels in a vacuum is limited by the range $n = 0, 1, 2, 3, \ldots .15, 16$. Here n is the principal quantum number. Within one level, the particle's energy fluctuates from a metastable state to an unstable one. For an electron, at $n = 0$, the minimum energy E_{e0} is 3.402 eV, the minimum relativistic velocity v_0 is $1.09385 * 10^3\ km \cdot s^{-1}$. The electron velocity in a vacuum depends only on the quantum number "n" and is independent of mass, time, and spatial coordinates [1]. The expression in square brackets $[E_{re} - E_{he}]$ determines the relativistic nature of the particle.

For a relativistic electron in a vacuum, the Cherenkov energy E_{he} is always present, but can be emitted as a separate photon in another medium if the electron's velocity exceeds the speed of light in that medium, $v > c/n$. Here, "n" is the refractive index of the medium. The lost quantum of Cherenkov energy is compensated for by the electron's own kinetic energy.

3. Muons

According to information on the internet and accelerator experiments, the ratio of the muon mass to the electron mass is:

$$\frac{m_\mu}{m_e} \cong 206.768\ .$$

Muon mass measurements have been conducted using relativistic and **non-relativistic methods**. Therefore, the information can be trusted. Let's find a limit on the minimum muon energy:

$$E_{\mu 0} > E_{e0}\frac{m_\mu}{m_e} = 3.402 \cdot 206.768 = 703.425\ . \qquad (2)$$

It is widely believed that in its own reference frame, a muon lives for $2.2\ \mu s$ (microseconds). In a laboratory reference frame, the muon lifetime ranges from tens to hundreds of microseconds. Everything depends on the reference frames used in the experiments: stationary; moving; laboratory; After studying all the methods for measuring the muon lifetime, the author does not wish to comment on the results obtained. In the absence of motion in its own frame of reference, a material point is constantly at the origin—what kind of clock or time can we talk about! Only one thing is clear: the muon is the longest-lived particle of all short-lived particles.

4. The Cherenkov Energy Problem

For the initial electrons, the Cherenkov energy is described by the formula:

$$E_{he} = \frac{\alpha^2}{8}\frac{m_e c^2}{\sqrt{1+\beta^2}}\ . \qquad (3)$$

The energy range, according to experimental data, is between 2 and 6 eV. Calculations yield a range of 2.4 to 3.4 eV for the entire velocity range. The Cherenkov energy is the same for all charged particles. For the muon, as a heavy electron, this energy should not depend on the particle's mass. Similarities between the electron and the muon:

- Charge: Both have a charge of -1.
- Spin: Both are fermions with spin 1/2.
- Class: Both belong to the lepton family (along with the tau particle).
- Electromagnetic Properties: Their electromagnetic interactions are identical.

A hypothetical assumption arises that the muon is the same electron with an increased longitudinal mass. Then the total kinetic energy of the muon is determined by the expression:

$$E_{\mu} = \frac{m_{\mu}c^2}{2}\beta_{\mu}^2 + m_e c^2 - \frac{m_e c^2}{\sqrt{1+\beta_{\mu}^2}} - \frac{\alpha^2}{8}\frac{m_e c^2}{\sqrt{1+\beta_{\mu}^2}}; \qquad (4)$$

$$E_{\mu} = E_{s\mu} + E_{re} - E_{he}\ .$$

The relativistic energies of the muon and electron are identical in notation. The electromagnetic properties and charge of the electron are conserved. Essentially, the muon retains the electromagnetic tail of the electron or positron, taking into account the change in velocity. **This assumption** contradicts existing physical concepts of the muon. Muons can form even at annihilation energies lower than $m_{\mu}c^2$. If Einstein was right, muons with such energies should exist forever. But this is not the case! This means Newton is right: the lower threshold for muon formation is:

$$E_{\mu 0} = \frac{m_{\mu}v_{\mu 0}^2}{2} > 703.425\ eV. \qquad (5)$$

Here is the smallest relativistic velocity of a muon in a vacuum.

5. Annihilation Process

The relativistic momenta of the electron and positron act in opposite directions (the vapor-positron state). The relativistic components of the kinetic energy E_{re} and E_{he} have opposite signs. We write the formulas for kinetic energy in operator form:

$$\hat{E}_{e^-} = \frac{1}{2}m_e c^2\beta^2 + m_e c^2\left[1 < -> \frac{1}{\sqrt{1+\beta^2}} < -> \frac{\alpha^2}{8}\frac{1}{\sqrt{1+\beta^2}}\right]; \qquad (6)$$

$$\hat{E}_{e^+} = \frac{1}{2}m_e c^2\beta^2 + m_e c^2\left[1 < +> \frac{1}{\sqrt{1+\beta^2}} < +> \frac{\alpha^2}{8}\frac{1}{\sqrt{1+\beta^2}}\right].$$

For identical particles (electron and positron), the arithmetic signs of the relativistic components are replaced by mutual compensation operators, <->, <+>. We find the total collision energy of antiparticles:

$$\sum E = m_e c^2\beta^2 + 2m_e c^2. \qquad (7)$$

The expression $m_e c^2$ is the maximum relativistic energy of an electron. It is also the **maximum electromagnetic self-energy**. Some of this energy is involved in the kinematics of the electron's motion.

Considering that particles annihilate in symmetric pairs, **we will analyze their interaction processes per electron, muon, and gamma quantum of electromagnetic energy.** The velocity of muons is much less than the velocity of the initial electrons. If the velocities of the initial electrons are close to the speed of light, heavier particles may form. This article considers annihilation only before the formation of the first muons. The initial data on the velocity and energy are presented in the article "Interaction of

Relativistic Electrons with Photons" [1]. To calculate the annihilation, **the geometric mean values of the electron velocity and total energy at each quantum level are used:**

$$E_n = \sqrt{E_{max}E_{min}} = \sqrt{E'_k E_k} \;\; keV \;; \quad (8)$$

$$v_n = \sqrt{v_{max}v_{min}} = \sqrt{v'v} \;\; km \cdot s^{-1} \;;$$

$$E_{sn} = \frac{m_e c^2}{2} \beta_n^2 \;\; keV \;;$$

$$m_e c^2 = 511.026 \;\; keV \;;$$

$$E_{\gamma n} = 511.026 \, keV + E_{sn} \, .$$

The indices max and min correspond to the unstable or metastable state of the electron in vacuum. The results of calculations before the appearance of the first muons are given in Table 1.

Table 1

n	$v_n \cdot 10^3 \; km \cdot s^{-1}$	E_n, eV	E_{sn}, eV	Annihilation products, keV
0	1.09385	3.402	3.402	$e^+ + e^- \rightarrow 2\gamma_0$ $E_{\gamma 0} = 511.029$
1	1.54694	10.204	6.803	$e^+ + e^- \rightarrow 2\gamma_1$ $E_{\gamma 1} = 511.033$
2	2.18771	23.811	13.607	$e^+ + e^- \rightarrow 2\gamma_2$ $E_{\gamma 2} = 511.040$
3	3.09543	51.078	27.240	$e^+ + e^- \rightarrow 2\gamma_3$ $E_{\gamma 3} = 511.053$
4	4.38099	105.721	54.567	$e^+ + e^- \rightarrow 2\gamma_4$ $E_{\gamma 4} = 511.081$
5	6.20232	215.294	109.365	$e^+ + e^- \rightarrow 2\gamma_5$ $E_{\gamma 5} = 511.14$
6	8.78349	435.125	219.334	$e^+ + e^- \rightarrow 2\gamma_6$ $E_{\gamma 6} = 511.25$
7	12.4426	876.321	440.142	Option 1 $e^+ + e^- \rightarrow 2\gamma_7$ $E_{\gamma 7} = 511.5$ Option 2 $E_n > E_{\mu 0}$ $e^+e^- \rightarrow \gamma^* \rightarrow \mu^+\mu^-$
8	17.6314	1 761.876	883.779	Option 1 $e^+ + e^- \rightarrow 2\gamma_8$ $E_{\gamma 8} = 511.9$ Option 2 $E_n > E_{\mu 0}$ $e^+e^- \rightarrow \gamma^* \rightarrow \mu^+\mu^-$

6. Muon Velocities

6.1 For muons moving at velocities less than $10 \cdot 10^3\ km \cdot s^{-1}$, the relationship from formula (4) is valid:

$$m_e c^2 - \frac{m_e c^2}{\sqrt{1+\frac{v_\mu^2}{c^2}}} \cong \frac{m_e v_\mu^2}{2}. \qquad (9)$$

We neglect the Cherenkov energy, $E_{he} \ll E_n$. Formula (4) is transformed to a simple form:

$$E_\mu = E_n = \frac{m_e c^2}{2}\left(\frac{v_\mu^2}{c^2}\right)\left(\frac{m_\mu}{m_e} + 1\right). \qquad (10)$$

Taking the electron's self-energy in kilo electron-volts as a basis, we can write:

$$E_\mu = E_n = \frac{511.026}{2}\beta_\mu^2\left(\frac{m_\mu}{m_e} + 1\right)\ keV.$$

Numerically, the muon velocity after annihilation is:

$$v_\mu = 1.30113\sqrt{E_n} \cdot 10^3\ km \cdot s^{-1}.$$

The closest muon formation energy is $E_7 = 0.876321\ keV$. The minimum muon velocity after annihilation is:

$$v_{\mu 0} \approx 1.2180 \cdot 10^3\ km \cdot s^{-1}.$$

The electron collision is head-on, and the resulting muons fly off in opposite directions. The results of calculating the muon velocity after electron annihilation are given in Table. 2.

Table 2

n	E_n, keV	$v_\mu \cdot 10^3\ km \cdot s^{-1}$	correctness
7	0.876321	1.2180	Reliable
8	1.761876	1.7270	÷
9	3.538698	2.4476	÷
10	7.098837	3.4667	÷
11	14.147593	4.8940	÷
12	28.317378	6.9238	÷
13	55.941017	9.7318	÷
14	108.822945	13.5732	Not reliable
15	206.787062	18.7104	÷
16	382.190949	25.4367	÷

6.2 We must stop at the $n = 13$ level. Further velocity calculations can only be **made based on the assumed muon energy formula:**

$$E_\mu = E_n = \frac{m_e c^2}{2}\left(\frac{m_\mu}{m_e}\right)\beta_\mu^2 + m_e c^2 - \frac{m_e c^2}{\sqrt{1+\beta_\mu^2}}.$$

The velocity is found by successive approximations. To begin the approximations, the unreliable results of the previous calculation are used. A subsequent estimate showed: $v_{\mu 14} = 13.5735$; $v_{\mu 15} = 18.7106$; $v_{\mu 16} = 25.4373$ thousand kilometers per second. The difference is insignificant. **It is impossible to produce a muon near the speed of light from annihilation.** If a muon is accelerated to a velocity of $v_\mu \approx$ c, its maximum kinetic energy is $E_\mu \approx 52.981\ MeV$. This is significantly less than the energies obtained using Einstein's formulas.

However, not everything is so simple; the bifurcation of particle formation intervenes in the annihilation process. At levels $n \geq 8$, heavier particles can begin to form: pions, tau leptons, and even composite protons. Everything depends on the nature of the environment (vacuum, gas, water, etc.). For example, for a proton:

$$E_{p0} > E_{e0}\frac{m_p}{m_e} = 3.402 \cdot 1836 = 6\ 246\ 072\ eV\ ;$$

$$v_p \approx 0.00146\sqrt{E_n} \cdot 10^3\ km \cdot s^{-1}.$$

The closest value for the proton formation energy is $E_{10} = 7.098837\ keV$. The minimum proton velocity after annihilation is:

$$v_{p0} \approx 0.00146\sqrt{7.098837} \cdot 10^3 = 3.89\ km \cdot s^{-1}.$$

It is impossible to produce a proton near the speed of light from annihilation. With an acceleration velocity $v_p = 53\ 000\ km \cdot s^{-1}$, the proton's kinetic energy is approximately:

$$E_p \approx \frac{m_e c^2}{2}\left(\frac{m_p}{m_e}\right)\beta_p^2 + m_e c^2 - \frac{m_e c^2}{\sqrt{1+\beta_p^2}};$$

$$E_p \approx \frac{511.026}{2} \cdot 1836\left(\frac{53}{299.792}\right)^2 + 511.026 - \frac{511.026}{\sqrt{1+\left(\frac{53}{299.792}\right)^2}};$$

$$E_p \approx 14\ 662.14 + 7.803 = 14\ 669.943\ keV = 14.67\ MeV\ .$$

The maximum kinetic energy of a proton accelerated to the speed of light is approximately equal to $E_{p\,max} \approx 469.27\ MeV$.

This concludes the article. The topic is complex, and the conclusions are ambiguous. There are more questions than answers.

7. Resume

In this article, the author used a stationary laboratory reference frame. In this frame, a particle has its own clock, proper time, and proper velocity. No specific conclusions are drawn. The author's personal views do not necessarily align with generally accepted physical concepts of annihilation. Unfortunately, the modern apparatus of mathematical physics pushes all elementary particles close to the speed of light, and kinetic energy to infinity. Renormalization in quantum field theory (QFT) distorts the calculation results. This situation is hardly considered normal in theoretical high-energy physics.

Source of information

1. Haletsky M., Interaction of Relativistic Electrons with Photons, 2025/10, https://halmich.ru/wp-content/uploads/2025/10/%D0%92%D0%B7%D0%B0%D0%B8%D0%BC%D0%BE%D0%B4%D0%B5%D0%B9%D1%81%D1%82%D0%B2%D0%B8%D0%B5-%D1%80%D0%B5%D0%BB%D1%8F%D1%82%D0%B8%D0%B2%D0%B8%D1%81%D1%82%D1%81%D0%BA%D0%B8%D1%85-%D1%8D%D0%BB%D0%B5%D0%BA%D1%82%D1%80%D0%BE%D0%BD%D0%BE%D0%B2-%D1%81-%D1%84%D0%BE%D1%82%D0%BE%D0%BD%D0%B0%D0%BC%D0%B8.pdf