Scientific Research Publishing

Open Journal of Microphysics, 2022, 12, 47-54
https://www.scirp.org/journal/ojm
ISSN Online: 2162-2469
ISSN Print: 2162-2450

Theoretical Explanation of $m = E/c^2$

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How to cite this paper: Khalife, A.M. (2022) Theoretical Explanation of $m = E/c^2$. *Open Journal of Microphysics*, **12**, 47-54.
https://doi.org/10.4236/ojm.2022.122003

Received: February 15, 2022
Accepted: March 21, 2022
Published: March 24, 2022

Abstract

The aim of this theory is to study and explain the phenomena that have been predicted by Einstein in the year 1905 which affirms that the mass of a body increases with velocity; the mass of a body increases when it travels at high speed. In classical physics, it gains in the energy of motion. In relativity that kinetic energy makes itself felt as additional mass. As the object reaches the speed of light, theoretically, its mass becomes "infinite". Nevertheless, the concept of "infinite mass" is still a subject we know little about. In the following paper, I will be focusing on how and why such phenomena take place. Furthermore, we shall discuss antimatter. Antimatter is now known to shower down from the sky above us, and when a particle meets its antiparticle, both of them disappear in a burst of radiant energy, exactly in accordance with $E = mc^2$.

Keywords

Special Relativity, Particle Physics, Coulomb's Law, Pair Production and Annihilation, Infinite Mass, Constancy of the Speed of Light, Einstein's Correction

1. Introduction

Our understanding of the physical world was reformed in the twentieth century. For over 200 years the equations of motion enunciated by Newton were believed to describe nature correctly, and the first time that an error in these laws was discovered, the way to correct it was also discovered. Both the error and its correction were discovered by Einstein. He was able to develop and publish four groundbreaking papers that revolutionized the scientific understanding of the universe. The special theory of relativity was among these papers and considerably the main one. Let's concentrate our attention on, arguably, the world's most

famous equation $m = \frac{E}{c^2}$; it states that matter and energy are relatively the same things, just in different forms, matter can be converted into energy and vice versa. This equation has been done and demonstrated mathematically by the brilliance of Sir Einstein and was proven to be true experimentally. Another perspective this equation could state is that the mass of a body increases as the velocity increases. In Einstein's corrected formula m has the value

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}} \tag{1}$$

where the "rest mass" m_0 represents the mass of a body that is not moving and c is the speed of light, which is about 3×10^8 m/s [1] [2] [3]. Now we are familiar with, in simple words, the higher the velocity, the bigger the mass. Of course, we could settle down and rest but the thing is: anyone can know, the key is to understand. In addition, Einstein once said: "*The effort to strive for truth has to precede all other efforts.*" Thus, I may ask theoretically, how and why does the mass increase as the velocity increases? This question is what I'll be able to answer in the following paper.

2. Pair Production and Annihilation

Pair production is the creation of an elementary particle and its antiparticle, for example creating an electron and positron, or a proton and an antiproton. It is often referred specifically to a photon creating an electron-positron pair. In order for pair production to occur, the incoming energy of the interaction must be above the threshold in order to create the pair, both energy and momentum to be conserved [4] [5].

$$\gamma + \gamma \to \mathrm{e}^+ + \mathrm{e}^-$$

$$h\nu + h\nu = K_{\mathrm{e}^+} + K_{\mathrm{e}^-} + 2m_0c^2 \tag{2}$$

where h is Planck's constant, γ is the photon, ν is the frequency of the photon, K_{e^+} and K_{e^-} represent the kinetic energy of the positron and electron immediately after their creation and m_0c^2 is the rest energy of an electron, which is equal to that of the positron, so the factor of 2 represents the fact that two particles of identical rest mass are created.

An inverse process to pair production exists and it is called pair annihilation, in which a particle and its antiparticle collide and annihilate each other, the total energy of the two particles appears as electromagnetic radiation [6] [7].

$$\mathrm{e}^+ + \mathrm{e}^- \to \gamma + \gamma$$

$$K_{\mathrm{e}^+} + K_{\mathrm{e}^-} + 2m_0c^2 = 2h\nu \tag{3}$$

3. Transforming Pure Energy into Matter and Antimatter

A long-predicted process for generating matter directly from light has been

demonstrated in July 2021 at the time that the Department of Energy's Brookhaven National Laboratory was able to turn light particles, which are energy, into pairs of electrons and positrons, which are matter.

The experiment took place in the Relativistic Heavy Ion Collider creating matter and antimatter from pure electromagnetic was a complete success. Accelerating two gold ions (Au) in opposition to each other at 99.995% of the speed of light was effective in colliding two electromagnetic waves and producing electrons and positrons out of pure energy as **Figure 1** demonstrates [8] [9].

4. Structure of Atom and Electromagnetism

It has been well known for over a century that an atom is a complex arrangement of negatively charged electrons circulating around a positively charged nucleus. This nucleus is composed of protons and neutrons.

To begin by emphasizing on the charged particles. A charged particle produces an electric field. This electric field exerts a force on other charged particles, and this force is what is known by the Coulomb force

$$F = \frac{|q_1| \times |q_2|}{4\pi\varepsilon_0 r^2} \tag{4}$$

where q_1 is the charge of one particle, q_2 is the charge of another particle, r is the distance between the two particles and ε_0 is the vacuum permittivity [10].

An electrically charged particle has an electric field extending to infinity as shown in **Figure 2**. If this charge is accelerated, the position of the field center changes, and the information propagates out as a "kink" in the field lines. A magnetic field is also induced at the kink. This traveling kink is an electromagnetic wave, indicated in **Figure 3**.

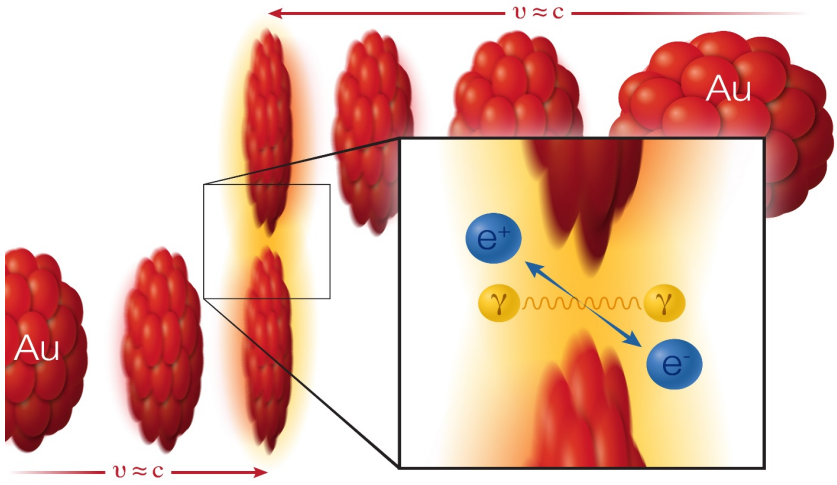

Figure 1. Making matter from light: Two gold (Au) ions (red) move in opposite direction at 99.995% of the speed of light (v, for velocity, =approximately c, the speed of light). As the ions pass one another without colliding, two photons (γ) from the electromagnetic cloud surrounding the ions can interact with each other to create a matter-antimatter pair: an electron (e^-) and positron (e^+).

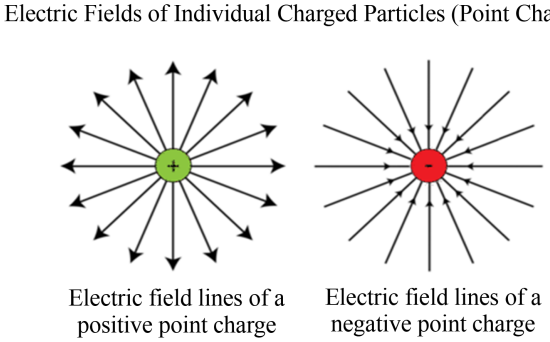

Figure 2. Electric field lines.

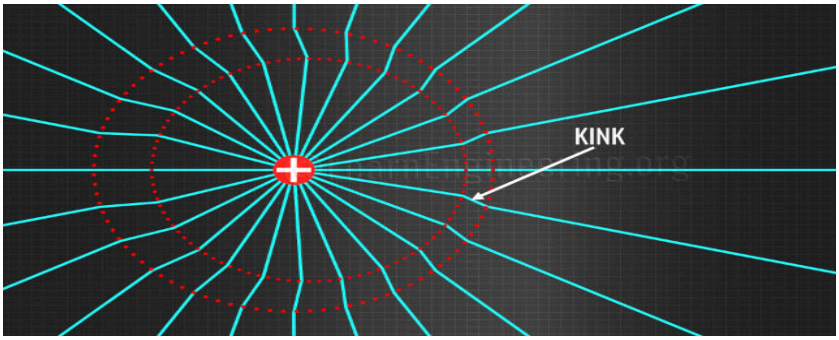

Figure 3. A charged particle (in this case positively charged particle) is accelerated and produces an electromagnetic wave which represented as kink.

5. Increase in Mass

I believe everything mentioned above is basic and introductory to what is about to be explained just now. Therefore, let's dive into the main idea of this paper and ask, how does the mass actually increase as the velocity increases? One might search enough and find multiple clarifications for this question. Every professor will explain it in his own way or try to analogue it so the students will get the idea. For me on the other hand, that's not quite enough.

Suppose a gold ion is moving at 99.995% the speed of light, the same as the one in the experiment done in the Brookhaven National Laboratory; this ion is composed of electrons, protons, and neutrons. Now to maintain such velocity, the atom must accelerate. Therefore, the subatomic particles (proton, electron, and neutron) are accelerating and marching at the same velocity. Moreover, the laws of electromagnetism state that as a charged particle accelerates it produces electromagnetic waves. Basically, an accelerated electron is producing an electromagnetic wave, another one is producing another electromagnetic wave, they then collide with each other and produce a pair of new electrons and their antimatter, positron (as predicted and demonstrated in the experiment mentioned above). Other particle pairs, such as proton and antiproton, can be produced as well if the initiating two photons have sufficient energies. This phenomenon is simultaneously happening with the proton as it accelerates and in turn, leads to the emitting of electromagnetic waves and when two waves collide, they produce a new proton and its antimatter anti-proton. This continuous production in

matter and antimatter, at a continuous accelerating ion, and contains a relatively large number of charged particles, will increase in the mass of the ion as every particle is giving triple the original mass, since it is responsible for creating two other identically massive particles. Such phenomena taking place with a great number of ions in the object will be another brilliance predicted by Einstein when he stated that the mass will continue toward infinity if we were able to reach the speed of light.

6. How Do They Not Collide?

One question must be answered when a hypothesis like that is stated; how do the matter and antimatter not collide with each other?

I shall be able to answer this in two parts: proton-antiproton and electron-antielectron.

6.1. Proton-Antiproton

After emitting electromagnetic waves and these waves collide and produce pairs of protons and their antimatter, neutrons too are able to emit electromagnetic waves. An identical process happens, and a pair of electromagnetic waves collide to indicate the existence of a neutron pair and their antimatter. Moreover, an attraction between these two electrically opposite charges (proton and antiproton) exists due to the electric force expressed in Equation (2). The electric force will not be able to attract the proton and the antiproton simultaneously because of the excessive existence of a neutron and its antimatter, the electric field will be "blocked" by these neutral charges that will be in the nucleus.

6.2. Electron-Antielectron

Moving on to the electron's case, it is evident that it differs from the proton's case. We may recall the structure the electrons float in, they circulate around the nucleus. Therefore, when electromagnetic waves are emitted and after producing pairs of electron and positron (as the experiment in the Brookhaven National Laboratory confirms), there will also be an electric attraction between the two subatomic oppositely charged particles. With that result, how do these two not collide and liberate energy?

The force of attraction is the equivalent to the Coulomb force

$$F = \frac{k|q_1| \times |q_2|}{R^2} \tag{5}$$

where k is Coulomb's constant. **Figure 4** is needed to complete the mathematical work. Matter and antimatter are known to be identical in all their properties, except that the sign of their charges (and have different magnetic moments), then q_1 and q_2 have the same magnitude ($|q_1| = |q_2| = 1.602 \times 10^{-19}$ coulombs); in this case, assuming that the attraction force is strong enough to join them together, they will both march the same distance $\frac{R}{2}$ opposite directions and

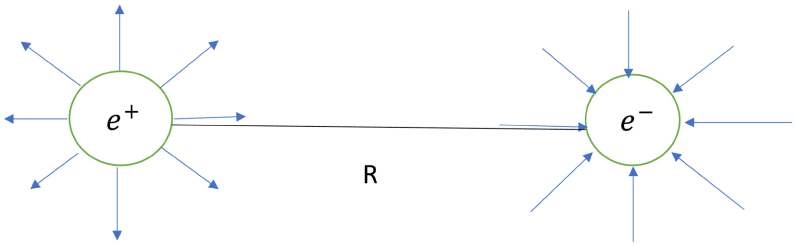

Figure 4. Representation for the electric field of the positron (e^+) and electron (e^-) distanced by R.

collide, and the reasoning for that is because of the identicality of the two particles in the magnitude of charge and mass. I would like to refer to it by the name "virtual distance" due to the fact that they will not collide together. This virtual distance could help me demonstrate how they won't collide.

q_1 and q_2 are equal in the magnitude,

$$F_1 = \frac{k \cdot Q}{\left(\frac{R}{2}\right)^2} \tag{6}$$

where Q is equal to $q_1 \times q_2$ and is a constant. F is the force that q_1 exerts on q_2.

Let's recall the concept of velocity in physics which is described by the formula:

$$v = \frac{r}{t} \tag{7}$$

r and t are the distance and the time, respectively. Equation (7) can be also written as:

$$v = r \times t \tag{8}$$

Replacing the "virtual distance" by velocity multiplies by time will get:

$$F_1 = \frac{k \cdot Q}{\left(2v \cdot t\right)^2} \tag{9}$$

Equation (9) shows that the force of attraction and the square of velocity are inversely proportional with each other, the force decreases as the square of the velocity increases. When the velocity is near the speed of light, the force of attraction will not be sufficient enough to pull and join the electron and the positron together.

One might ask, what about time? Isn't time dilated at such a high velocity? Needless to say, we have to take time into consideration here, in fact, time is squared.

Einstein's time correction is described by:

$$t' = \frac{t_0}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{10}$$

where t_0 is the time of an object in a reference frame at rest. An equation for the

correction of time must be made, (6) at such high speed, and it is crucial that there is no room for a mistake [11] [12]. However, with regard to the calculation, this time dilation will not have much effect on the results and therefore, the results will remain approximately the same.

To begin with, I will examine the numerical value of the force of repulsion between two electrons in a general case (which should be the same as that of attraction between electron and positron since they both have the exact magnitude of the electric charge). The distance $R \approx 10^{-10}$ meters is between two electrons.

$$F = \frac{kQ}{r^2} = \frac{8.99\times10^{9}\times\left(1.602\times10^{-19}\right)^{2}}{\left(10^{-10}\right)^{2}} = 2.307\times10^{-8}\ \text{C}$$

Simple calculation with the help of Equation (4) will give a value of $F \approx 10^{-8}$ Coulomb. This number describes an approximation of the force between two electrons in a shell and is also greater than the force of attraction between the positron and electron; this should not, theoretically, be great enough to allow the two particles to collide (this demonstrates how the electric field will not be great enough to attract the two particles).

Calculating the force between the positron and electron in the general case

$$t' = \frac{t_0}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{t_0}{\sqrt{1-\frac{0.99995^2\times c^2}{c^2}}} = 100.00125t_0$$

where $t_0 \approx 3.3335\times10^{-19}$ s.

Replacing the numerical values in Equation (9), we find that

$$F' = \frac{8.9875\times10^{9}\times2.566\times10^{-38}}{\left(2\times0.99995\times3\times10^{8}\times100.00125\times3.3335\times10^{-19}\right)^{2}} = 5.76\times10^{-13}\ \text{C}$$

F' is the force of attraction between positron and electron, and it is clear to say that F is greater than F'.

7. Conclusions

In summary, the infinite mass phenomenon of an object, described by Einstein, occurs when the object is nearest to the speed of light, resulting in the production of antimatter and matter, which in turn substantially increases the mass of an object. Accelerating charged particles emit electromagnetic waves that collide with each other, creating new particle/s and anti-particle/s. Owing to the fact that an object contains a large number of atoms, and due to that matter and antimatter production, its mass tends to go towards infinity at the speed of light which makes it, up to this date, impossible to reach that constant speed.

This could help us understand the concept of infinite mass and energy, as well as, allows us to better deal with speeds nearing the speed of light, and this equally lets us see improvements in particle physics, astrophysics, and engineering. In that case, it would be a major breakthrough in physics.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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