Interpretation of Cause of Mass Increase

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Abstract: It is known that the relativistic mass formula is numerically well consistent with the experiment for the charged particles. But, unfortunately, the explanation of the cause of the mass increase is insufficient. We think that the explanation of the cause and effect is very important in physics. *It is an axiom that the mass of a body could never be increased unless it absorbs an outside material, that is, the mass increase is impossible without the absorption of an outside material.* In this paper, we add the content of the special theory of relativity by the interpretation of cause of mass increase, paying attention to the idea that the mass of the particle should be taken up as much as mass of the absorbed photon. We very simply derive the mass formula only with the most basic concepts of physics at the last part of this paper.

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1 Introduction

About one century ago, it was experimentally found that masses of the charged particles such as an electron were increased during the acceleration in an electromagnetic field. The mass in terms of the speed is evaluated by the famous relativistic mass formula

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

where m, v, m_0 and c are mass and speed of the moving particle, rest mass of the particle and light speed, respectively.

Although the relativistic mass formula numerically agrees with the experiment for the charged particles, but, unfortunately, it seems that the description of the cause of the mass increase is insufficient.

Einstein writes; “If a body takes up an amount of energy E_0, then its (inertial) mass increases by an amount E_0/c^2” at p. 40 of his book [1] and “If a body gives off the energy E in the form of radiation, its mass diminishes by E/c^2 (see p. 140 of the book [2]).

We must consider not only with the equation $E=mc^2$ but also with physical intuition why the energy change E is accompanied by the mass change E/c^2, which is called the equivalence of mass and energy. Einstein writes that "radiation conveys inertia between the emitting and absorbing body" (see p. 141 of the book [2]). The above expression hints us that radiation may play a decisive role in the mass change of the body. So we will pay attention to the radiation.

Today, we know that the radiation (or light) is made of corpuscles each carrying an energy, called photons. On the one hand, the energy of a photon, ν being the frequency, is given by

$$E = h\nu = \frac{hc}{\lambda}, \tag{2}$$

where h and λ are Planck's constant and wavelength, respectively. On the other hand, the energy of a photon, m being the mass, is

$$E = mc^2. \tag{3}$$

The equation (3) could be obtained from classical electrodynamics. In the classical electrodynamics, the momentum p of the electromagnetic wave (or light), E being the energy, is given by

$$p = \frac{E}{c}. \tag{4}$$

According to the classical definition of the momentum, the momentum of the quantum of the electromagnetic field (photon), m being the mass, should be mc. Therefore, from the equation (4), the equation (3) is obtained.

The equation (2) for photon is also obtained from the special theory of relativity. The relativistic energy for any particle is expressed by

$$E = \sqrt{m_0^2c^4 + p^2c^2}, \tag{5}$$

where m_0 and p are the rest mass and momentum of the particle, respectively (see p. 123 of the book [2]). Because the rest mass of a photon is considered as zero in the special theory of relativity, for photon, from the equation (5), the equation (3) ($E=pc=mc^2$) is obtained.

Now we especially emphasize that the equation (3) is just for photons, not for any particles.

From the equations (2) and (3) for energy of photon, the mass of photon of the frequency ν is determined as (see p. 34-12 of the book [3])

$$m = \frac{h\nu}{c^2} = \frac{E}{c^2}. \tag{6}$$

Consequently, we confirm that the mass of photon, E being the energy, is just E/c^2.

Let’s think about the above mentioned equivalence of mass and energy. The fact that the mass change corresponding to energy change E is equal to the mass change of photon E/c^2 tells us that the main performer of energy change may be photon.

In fact, absorbing photons into the nuclei, they vibrate. As a result, the thermal energy arises. Photons absorbing into or emitting from the electrons constrained in the atom or molecule, the transition of the energy level is brought about. Absorbing photons into the free electrons, their kinetic energy is increased. It results in the electric current. Like this, the main source of energy in the microscopic world may be photons. This fact is mathematically expressed as

$$\Delta H = \Delta E, \tag{7}$$

where ΔH and ΔE are the total energy change and the energy of photon absorbing into or emitting from the considering system, respectively. The physical meaning of the equation (7) is that if photons are absorbed, the energy of the system is increased as much as the energy of the absorbed photons and vice versa.

Let’ check whether the expression (7) is right. The energy change theoretically calculated by quantum mechanics is experimentally checked by the energy of photons emitted from the excited electrons independent of whether the applied energy is electric, magnetic and thermal. This tells that the energy level transition may interiorly arise by photons independent of the forms of the applied energy. Therefore, we can know that the equation (7) is right in the microscopic world.

Consequently, because the main performance of energy change in the microscopic world is just photon, we have a result that the mass change corresponding to energy change ΔE should be equal to the mass of photon $\Delta E/c^2$. It is natural that if the system absorbs photon of the energy E, its mass must be increased as much as mass E/c^2 of the absorbed photon and vice versa.

Like this, the mass increase of the body may relate to the photons. In this paper, we demonstrate that the mass increase of the charged particles is due to the absorption of photon.

2 Interpretation of mass formula

As mentioned above, the mass formula (1) is experimentally verified. We'll check what conclusions come from the right equation (1). Differentiating the mass formula (1) and by some algebra, we can easily obtain (see Appendix A)

$$v^2 dm + \frac{m}{2} d(v^2) = c^2 dm. \tag{8}$$

At p. 121 of the book [2], the equality (8) was used to get the relativistic kinetic energy. The mathematical aspect of the equality (8) was only used in the book. Now, we'll investigate the physical meaning of the equality (8). As mentioned in the book [2], the left-hand side of the equality (8) is the differentiation dK of the kinetic energy of the particle whose mass and speed are simultaneously changed. As seen from the equation (3), the right-hand side of the equality (8) is the differentiation ($dE=c^2dm \rightarrow dm=dE/c^2$) of the energy of photon. As a result, we can rewrite the equality (8) as

$$dK = dE, \tag{9}$$

The equation (9) corresponds to the equation (7) in the case of the free particles.

From the equations (8) and (9), we conclude as follows.

First, the increase (decrease) of the kinetic energy of the particle is equal to the energy of the absorbed (emitted) photon. Therefore, the mass formula can apply only to the particles being driven by photons. The equation (9) is nothing but the law of conservation of energy. We note that the charged particles could be driven by photons because the interactive quanta between the charged particles are considered as photons in quantum electrodynamics (see p. 52 of the book [4]).

Second, the mass increase (decrease) dm (of the left-hand side of the equality (8)) of the particle is equal to the mass $dm=dE/c^2$ (of the right-hand side) of the absorbed (emitted) photon, which coincides with the equivalence of mass and energy (energy dE and mass dE/c^2 are changed). This tells that the mass of the total system is conserved.

3 Illustrating the model of Compton scattering

Let's consider Compton scattering model (figure 1) as an example of the system to check the above conclusions.

Compton scattering is a phenomenon which a photon is scattered by a rest electron. The frequency ν_2 of the scattered photon is less than that ν_1 of the incident photon.

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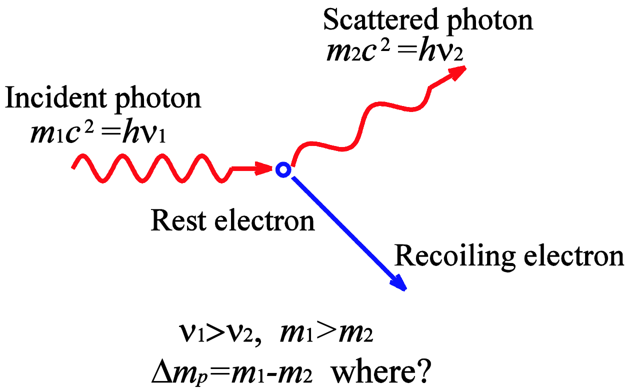

Figure1. Model of Compton scattering.

From the equations (2) and (6), the decrease of the frequency of photon by Compton scattering results in the decrease of energy and mass. Now it is necessary to investigate whereabouts of the mass difference between the incident and scattered photons
The law of conservation of energy in the model of Compton scattering is

$$h\nu_1 = h\nu_2 + (m - m_0)c^2, \tag{10}$$

where m_0 and m are masses of the rest and recoiling electrons, respectively (see p. 121 of the book [5]). In the equation (10), expressing the energies of the incident and scattered photons as masses, we get

$$m_1c^2 = m_2c^2 + (m - m_0)c^2, \tag{11}$$

where m_1 and m_2 are the masses of the incident and scattered photons, respectively. From the equation (11), we get

$$\Delta K = \Delta E \quad \text{or} \quad \Delta m_e = \Delta m_p, \tag{12}$$

with $\Delta m_e=m-m_0$, $\Delta m_p= m_1-m_2$, $\Delta K=\Delta m_ec^2$ and $\Delta E=\Delta m_pc^2$.
That the kinetic energy Δm_ec^2 of the recoiling electron has the same form as the energy (3) of photon is due to the motion of electron by the energy of the absorbed photon.
The first one of the equation (12) is consistent with the equation (9). The second equality of the equation (12) shows that the mass increase of electron is equal to the mass decrease of photon. That the mass of electron is increased means that it absorbs a material. The fact that the mass increase of electron is equal to the mass decrease $\Delta m_e=\Delta m_p=\Delta E/c^2$ of photon tells that the material absorbed into the electron is just photon. That is, the amount Δm_p corresponding to the mass difference between the incident and scattered photons is absorbed into the

electron. Like this, a portion of the incident photon is absorbed into the electron. Such a partial absorption of a photon could be brought about by the absorption of the incident photon and subsequent re-emission of the scattered photon (see p. 120 of the book [5]).

4 Simple derivation of mass formula

We showed that the equivalence of mass and energy comes from the laws of conservation of mass and energy. The laws of conservation of mass and energy are the most basic laws in physics. Paying attention to the fact that the absorption of a material inevitably accompanies the mass increase, we very simply derive the mass formula from these basic laws. It is assumed that the equation (9) could be applied to the considering particles. In other words, we deal with the particles moving by the absorption (meaning mass increase) of photons. This part gives the main result of this paper.

The differentiation dK of the kinetic energy of the particle whose speed and mass are changed, which corresponds to the left-hand side of the equation (9), is defined as (see p. 121 of the book [2])

$$dK = \frac{dP}{dt} \cdot dx = dP \cdot \frac{dx}{dt} = vd(mv) = v^2 dm + \frac{m}{2} d(v^2). \qquad (13)$$

We note that the definition (13) gives the usual kinetic energy definition $K=mv^2/2$, when $dm=0$, in other words, when there is no absorption or desorption.

The energy of photon (3) could be also obtained from the definition (13). After replacing v by c in the equation (13), considering that c^2 is a constant, the differentiation dE of the energy of photon, which corresponds to the right-hand side of the equation (9), is obtained by (see Appendix B)

$$dE = c^2 dm_p. \qquad (14)$$

According to the law of conservation of mass, the mass decrease dm_p of photon (equation 14) by the absorption into the particle should be the same as the mass increase dm of the particle (equation 13). Therefore, from the equations (9), (13) and (14), the equation (8) is obtained. Separating the variables of the equation (8), we get

$$\frac{dm}{m} = \frac{1}{2} \frac{d\beta}{(1-\beta)}, \qquad (15)$$

where $\beta = v^2/c^2$. Integrating (see Appendix C) the equation (15), we obtain the mass formula

$$m = \frac{m_0}{\sqrt{1-\frac{v^2}{c^2}}}. \tag{16}$$

Conclusions

The essential idea of this work is very simple: when the energy of a body takes up by the absorption of photons, its mass is increased as much as mass of the absorbed photons. This might be a self-evident truth that anyone can accept.
We strive to describe this concretely enough such that the broad readers can easily understand. The main result of this manuscript is described at the last part, "simple derivation of mass formula", which is shorter than one page.
It is not only important to obtain the formula consistent with the experiment in physics, but also important to clarify the cause and effect.
Because the mass is increased during the acceleration, in other words, the increase of energy, it would be more suitable description to check the energy change like this work.

Mass is a measure of the amount of material (or equivalently measure of inertia). Only when a body absorbs the other material, the mass (amount of material) of the body could be increased. Therefore, the charged particles should be also so. The phenomenon of nature would have to be explained as simply and evidently as possible for anyone to understand easily. In this meaning, this work will be popular. Because Einstein's theory of relativity is one of the two important branches of modern physics, it'll be important to add the content.

Appendix A: Obtaining the equality (9)

Differentiating the mass formula (1), we get

$$dm = \frac{m_0 v}{(1-\frac{v^2}{c^2})^{\frac{3}{2}}}\frac{dv}{c^2} = \frac{mvdv}{(c^2-v^2)}. \tag{A-1}$$

Rearranging the equation (A-1), we obtain

$$v^2 dm + \frac{m}{2} d(v^2) = c^2 dm. \tag{A-2}$$

Appendix B: Discussion of the equation (14)

Replacing v by c in the equation (13) for photon, we get

$$dE_p = c^2 dm_p + \frac{m_p}{2} d(c^2). \tag{B-1}$$

Look at the Compton scattering figure 1. Let's check the equation (B-1) for the incident photon, before it begins to interact with the electron. In this case, because both the mass and speed are not changed, the decrease (B-1) of the energy of photon should be zero. For the scattered photon, after it finishes interacting with the electron, we can say the same.

Because the mass of photon is decreased during the interaction with the electron, the first term of the right hand side of the equation (B-1) should be not zero. The second term should always be zero, because $c^2 = const$ for the incident and scattered photons. Therefore, the energy decrease of photon as a result of the interaction is given by

$$dE_p = c^2 dm_p. \tag{B-2}$$

Appendix C: Integral of the equation (15)

Integrate the equation (15).

$$\int_{m=m_0}^{m=m} \frac{dm}{m} = \frac{1}{2} \int_{\beta=0}^{\beta=v^2/c^2} \frac{d\beta}{(1-\beta)}. \tag{C-1}$$

From the equation (C-1), we get

$$ln\left(\frac{m}{m_0}\right) = -\frac{1}{2} ln(1 - v^2/c^2). \tag{C-2}$$

From the equation (C-2) the equation (16) is easily obtained.

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