Conceptual conflicts inspire new theories

(The mystery of the mass of the muon)

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Abstract

In the introduction , we recall some theories which have been brought into existence by the conflict (or disagreement) with the existing concepts . After that , we discuss the variability of the electric charge of the electron in an external field and try to explain the mystery of the mass of the muon .

I . Introduction

1/ **Einstein** postulated in the Special Theory of Relativity that the upper limit of velocity is c , the velocity of light in vacuum . Nearly all scientists rely on this postulate in their researches . But some physicists did not accept this concept ; they believed there exist particles , called tachyons , that can travel faster the c . They have spent lots of time to create a big chapter of Physics on these tachyons . (I don't know if there are any physicists still investigating tachyons)

2/ **Dirac** speculated the existence of the magnetic monopoles from his theoretical researches . Many physicists have tried to materialize these elusive particles . They searched for them in the meteorites falling from the universe ; they dug deep into the Earth to look for them , but until now physicists failed to find out these magnetic monopoles . (I think many scientists around the world are still searching for these elusive particles) .

Although these two concepts (as well as the concept of " ether ") failed to become existent , they inspired other concepts to be explored and developed into new theories . The following is the subject of this article **: the invariability of the mass of the electron leads to the new concept of varying electric charge .**

3/ **Lorentz** proposed (1904) that when the electron accelerated through the "ether " , its transverse dimension remained unchanged , but its length in the motion direction contracted and the mass varied with velocity as

$$m = (1 - v^2/c^2)^{-1/2} \; m_0 \;=\; \gamma \, m_0 \qquad (1)$$

where $\gamma = (1 - v^2/c^2)^{-1/2} > 1$ is the Lorentz factor .

The concept of mass varying with velocity became the mainstream of physics since then .
But recently , many physicists opposed this concept by confirming the invariability of the mass of a particle .

i) **Okun**[1] , " The concept of mass" , Physics Today ,1989
" In the modern language of relativity theory there is one mass , the Newton mass m , which does not vary with velocity ".

ii) **Sternheim & Kane**[2] , "General Physics " , 1991
" The correct definition of the relativistic momentum of an object of mass m and velocity v is $p = mv\,(1 - v^2/c^2)^{-1/2}$ *. In this equation , m is the ordinary mass of the object as measured by an observer in its rest frame . (Some books refer to this quantity as the rest mass and also define a velocity-dependent mass . We do not do this)" .*

iii) **Marion & Thornton**[3] , "Classical Dynamics of Particles and Systems",1995 , p.555
" Scientists spoke of the mass increasing at high speeds . We prefer to keep the concept of mass as an invariant , intrinsic property of an object . The use of two terms relativistic and rest mass is now considered old-fashioned . We therefore always refer to the mass m , which is the same as the rest mass ".

iv) **Kacser**[4]**,** " Encyclopedia of Physics " , by Lerner & Trigg , 2005, topic : "Relativity, Special Theory"
" Mass – a notational issue - yet profoundly important ... . So here I will use m as the one-and-only mass of a particle being what is often called the rest mass and written m_0 *. This mass m (by others often called* m_0 *or the rest mass) is the same as the Newtonian mass at low velocities . Most important , m is a scalar or invariant , it has the same value for all observers of the particle, and is a constant parameter for the particle " .*

As its title suggests - *conceptual conflicts inspire new theories* - this article will introduce a new concept to solve the conflict : " does the mass of a particle (e.g., an electron) vary with its velocity or remain invariant ? " .

II . New concept : varying electric charge in the ratio e / m

The new concept is to replace the concept of **varying mass** by the concept of **varying electric charge .** The reasoning is following :

In the equations of motion of the electrons in external field , e and m appear together in the ratio e / m , rather than appearing separately . The value of the ratio e / m decreases owing to the *relativistic increase in mass* as the velocity of the electron approaches c , the speed of light *. If we want to adjust these equations of motion to express the effect of relativistic mass of the electron , we write this ratio e / m in the form $e / \gamma m_0$ ($m = \gamma m_0$ from Eq(1))

Since $$e / \gamma m_0 \equiv \gamma^{-1} e / m_0 \qquad (2)$$

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* The Penguin Dictionary of Physics - Editor : Valerie Illingworth , 1990

the equations of motion do not change mathematically if we write the ratio in the second form $\gamma^{-1} e / m_0$ of Eq(2) . But physically , this means that we have chosen to express the concept of varying charge $(\gamma^{-1} e)$ instead of the concept of varying mass (γm_0) .
(If (γm_0) conveys the physical meaning of varying mass , then similarly , $(\gamma^{-1} e)$ conveys the concept of varying charge) .

These two forms of the ratio are interchangeable in the equations of motion of the electron suggesting that the concept of varying charge can replace the concept of varying mass to explain phenomena involving electrons moving in external fields .

Conclusion : if we believe that the mass of the electron is invariant (as confirmed by the above mentioned physicists Okun , ..., Kacser) , then the second form of the ratio $\gamma^{-1} e / m_0$ physically makes sense in the relativistic regime . Physically speaking , this means that it is the electric charge e $(\equiv q_0)$ of the electron that must be renormalized , not the mass m , although two forms of the ratio are mathematically identical .

From the second form of the ratio : $\gamma^{-1} e / m_0$, the renormalized (or effective) charge q of the electron can be deduced as

$$\boxed{q = \gamma^{-1} e \equiv \gamma^{-1} q_0} \tag{3}$$

where $q_0 \equiv e$ and γ^{-1} is *the inverse* of the Lorentz factor .

Therefore , the Lorentz factor γ is used to renormalize the mass ; its inverse γ^{-1} is used to renormalize the electric charge . In other words , the concept of *increasing mass* can be replaced by the concept of *decreasing charge* in relativistic regime .

III. Generalization : heuristic expression for q

In two textbooks by : 1/ **Bergmann**[5] (1976) and 2/ **Marion & Thornton**[3] (1995) we can find two *particular forms* of γ which depend on the directions of the acceleration and the velocity of the particle with respect to the external field :

$\gamma = (1 - v^2/c^2)^{-1/2}$ when the acceleration is parallel to the velocity ($a \parallel v$, in **E**)

$\gamma = (1 - v^2/c^2)^{-3/2}$ when the acceleration is orthogonal to the velocity ($a \perp v$, in **B**)

These are two particular cases : $a \parallel v$ and $a \perp v$. To generalize the Lorentz factor γ for any other case (when a and v make any angle between them) , we replace two exponents 1 and 3 in two above expressions by the real number N , we get the generalized Lorentz factor $\gamma = (1 - v^2/c^2)^{-N/2}$, where N is a positive real number representing the *features of the external field* (its type : **E** or **B** , strength, direction ...) . Hence , Eq(3) is generalized to become the heuristic expression (4) for the renormalized electric charge of the electron

$$\boxed{q \;=\; \gamma^{-N}\, q_0} \qquad (4)$$

where $\gamma = (1 - v^2/c^2)^{-1/2}$ is the Lorentz factor .

or
$$\boxed{q = (1 - v^2 / c^2)^{N/2}\, q_0} \qquad (4)$$

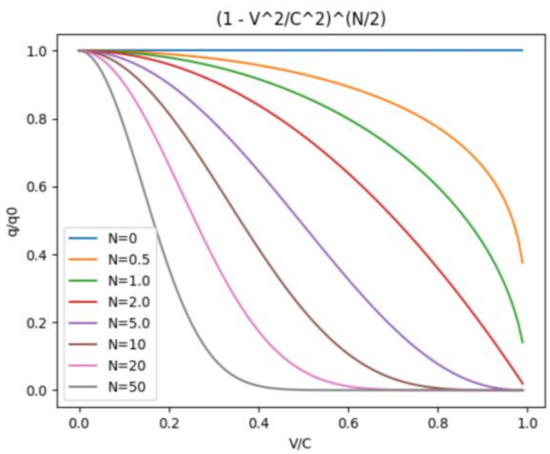

Fig.1 : $q / q_0 = (1 - v^2/c^2)^{N/2}$

Fig.1 shows the chart of Eq(4) plotted by computer programming : q / q_0 vs v/c .

It should be noted that Eq(4) or Fig.1 gives the *magnitude* of the effective charge q of the electron ; (q is negative by convention) ; q depends not only on the velocity but also on the external applying field which is represented by the real positive number N .

The graph shows that when the electron is subject to an applying field , its electric charge q drops below q_0 ($\equiv$ e) . Remarkable points are :

(i) When $N = 0$, $q = q_0$ for all velocities : this is the case when the electron travels in free space where no field is supposed to exist : the electron has constant charge q_0 ($\equiv$ e) .

(ii) **At low velocities ($v \ll c$) , $q \approx q_0$** for all values of N ; i.e., for all applying fields.

Let's note that this is the case of the oil-droplet experiments of **Millikan** [6] in which electrons (on oil droplets) fall down at low velocity of **a fraction of a millimeter per second in the electric field of 6000 volts per cm** . And as a result , Millikan experiments could only give the unique value $q \approx q_0$ ($\equiv$ e) for the electric charge of the electron (because of low velocity or low field or both) .

(iii) **At high velocities near c** ($v \to c$) , various curves in Fig.1 show that

- if $N = 0.5$ or 1.0 , q drops but does not reach zero when $v \to c$;
- if $N = 2.0 , 5.0$ $q \to 0$ when $v \to c$;
- if $N = 10 , 20 , 50$, $q \to 0$ at velocities less than c .

This means that in an intense field (e.g., in particle accelerators or in collisions between particles) , electrons could be devoid of their charge and become *free particles* ($q \approx 0$) at *velocities less than c* ; and thus they have no (or very weak) interaction with other particles .

Notes :

1/ More than 50 years ago , **Schwinger** speculated that if the charge can partially drop, it can totally drop to zero : " *The implication that physical charge are weaker than bare charge by a universal factor is the basis for the charge renormalization . But once the idea of a partial neutralization of charge is admitted one cannot excluded the possibility of total charge neutralization* ." (Schwinger 's Nobel lecture , 1965)

We notice from this quotation that Schwinger might be among the first physicists to use the term " *charge renormalization* " and he also speculated *the possibility of total charge neutralization* : that is , $q \to 0$, but he did not elaborate why or when .

2/ The immediate consequence of Eq(4) is the adjustment of the Lorentz ' s force equations for relativistic regime :

$$\mathbf{F_L} = (1 - v^2/c^2)^{N/2} q_0 (\mathbf{E} + \mathbf{v} \times \mathbf{B})$$

$$\mathbf{Fe} = (1 - v^2 / c^2)^{N/2} q_0 \mathbf{E} :$$ Fe decreases with v and tends to zero as $v \to c$.

$$\mathbf{Fm} = (1 - v^2 / c^2)^{N/2} q_0 \mathbf{v} \times \mathbf{B} :$$ Fm first increases with v , reaches its maximum at $v = c (N + 1)^{-1/2}$ then decreases and tends to zero as $v \to c$.

For $v \ll c$, $\mathbf{Fe} \approx q_0 \mathbf{E}$ and $\mathbf{Fm} \approx q_0 \mathbf{v} \times \mathbf{B}$: these are two familiar non-relativistic Lorentz ' s force equations .

3/ Different expressions for the effective electric charge :

In this article we have come to Eq (4) by a heuristic reasoning on the ratio e / m :

$$q = \gamma^{-N} q_0 = (1 - v^2 / c^2)^{N/2} q_0 ,$$ its graph is showed in Fig.1

In the literature we can find other general expressions for the renormalized electric charge :

Bekenstein[7] proposed :
" Thus every particle charge can be expressed in the form $e = e_0 \in(x^{\mu})$ *,*
where e_0 *is a constant characteristic of the particles and* $\in$ *a dimensionless universal field ."*

Rohrlich[8] proposed in the topic of renormalization :
"The effective charge e , which is the physical (renormalized) charge , is defined to be

$$e = Z_1 Z_2^{-1} Z_3^{-1/2} e_o$$

where Z_i *are renormalization constants ."*

All these expressions describe the same idea of effectiveness of the electric charge of the electron , written in different forms because they were derived from different bases .
This means that the variability of the effective charge of the electron has become a crucial and exceptional topic in the scientific research .

4/ The physical reason for the variability of the electric charge is that the electron is not a solid point particle but a spatially extended particle , filled with electrically charged elements , called dipoles . When the electron is subject to an external field , the polarization of these dipoles causes the net charge of the electron to change[9] .
A thought experiment is proposed to demonstrate the variability of the charge of the electron in a variable magnetic field[10] .

IV . The mystery of the mass of the Muon

Physicists consider the muon as a mystery . Here are some statements from prominent physicists:

i / *" Muons even today represent something of a puzzle ... Only in its mass and stability does the muon differ significantly from the electron , leading to the hypothesis that the muon is merely a kind of ' heavy electron ' rather than a unique entity ."*
(A.Beiser , Concept of Modern Physics , 1981)

ii / *" Another promising speculation , due to Dirac (1962) is that the muon mass may be associated with the radial oscillation of the surface of a nonrigid A-L-P electron . "*
(A-L-P : electron model of Abraham , Lorentz , Poincare')

(Philip Pearle , Classical Electron Models , Chapter 7 : " Electromagnetism: Path to Research " by D. Teplitz)

iii / *" The fundamental understanding of the relation of the muon to the electron must involve a theory of the value of m_μ / m_e , and this is still a central but unsolved problem in elementary particle physics ."* (Gell-Mann , 1959)
(Muon Physics , Hughes & Vernon W . , Academic Press , 1975)

iv / *" Experiment therefore confirms , to an accuracy of one per cent in the anomalous part of the g-factor, that the muon behaves exactly like a heavy electron ... The mystery of the muon mass has deepened and at the moment there are no very helpful suggestions as to where physicists can turn for enlightenment ... For the time being , however , the muon itself qualifies as a " riddle wrapped in a mystery inside an enigma ." "*
(Sheldon Penman , " The muon " Scientific American , 205,46 , July 1961)

v / " *The muon is a mystery ; it is like an electron almost every way but its mass . There is no known reason why it must exist ... A complication is introduced by the magnitude of the charge , for both the rate of energy loss and the radius of the circle depend on how much charge the particle has . "*
(Lehrmann & Swartz , Foundation of Physics , p.697 , 1969)

This last quotation tells us that the magnitude of the charge interferes in the determination of the mass of a particle . So , if we do not know how much charge the particle has , we cannot determine its mass accurately ; this is the case in the determination of the mass of the muon .

V . Explanation of the mystery of the mass of the muon .

In the determination of the mass of the muon , physicists assumed that its charge is invariant and equal to e , while its mass varies with velocity . This assumption certainly is the reason why their calculations resulted in the heavy mass of the muon relative to that of the electron .

Now , let's use the new concept of **varying electric charge** instead of the old-fashioned concept of **varying mass** to explain the mystery of the mass of the muon .

Experimental determination of the mass of the muon gave : $m_\mu = 207 \, m_e$ (5)

In the following we will search for the real meaning of the factor 207 in Eq(5) .

First , this is the Lorentz factor γ (not yet generalized) : $m = \gamma \, m_0 = (1 - v^2/c^2)^{-1/2} \, m_0$

After being generalized , the Lorentz factor γ becomes : $\gamma = (1 - v^2/c^2)^{-N/2}$
it is the renormalized factor for the mass , this is the number 207 in Eq(5)

$$\gamma = (1 - v^2/c^2)^{-N/2} = 207 \qquad (6)$$

At the end of section II , we have come to this result :

" The renormalized factor for the electric charge is *the inverse* of the renormalized factor for the mass " , which is

$$\gamma^{-1} = (1 - v^2/c^2)^{N/2} = (207)^{-1} \tag{7}$$

Hence , we have $q = \gamma^{-1} q_0 = (1 - v^2 / c^2)^{N/2} q_0 = (207)^{-1} q_0$, where $q_0 \equiv e$ (8)

<u>Conclusion</u> : The muon is the electron with reduced and varying electric charge , which , from the beginning , is equal to

$$q = (207)^{-1} e = 7.739\times10^{-22} C \tag{9}$$

Therefore , the muon differs from the electron by its reduced and varying electric charge ; its mass remains unchanged , equal to that of the electron .

When the muon is created , its charge is 7.739×10^{-22} C , then increases to $e = 1.602\times 10^{-19}$ C in 2.2 μs (this is the lifetime of the muon) . The variation of the electric charge follows a curve N showed in Fig. 1 . Since the charge varies in so short period of time (2.2 μs) that it cannot be detected ; it is taken for granted as a constant , equal to e .
As for the velocity , when the muon is created , its velocity v may be high ; it decreases and eventually stops in the detector : $v \to 0$ in 2.2 μs . At the end of the travel , it becomes identical to the electron : $\mu^- \to e^-$ (We don't pay attention to the hypothetical neutrinos) .
As for the mass of muon : it is invariant , equal to the mass of the electron m_0 .

Let' s notice that the number 1 / 207 in Eq(7) and Eq(8) is specific for the muon ; it provides the numerical value of the ratio $q / q_0 = 1/ 207$

and the relationship between N and v/c : $(1 – v^2 / c^2)^{N/2} = 1 /207$

Since the effective charge q varies from zero to e , and the velocity v and the field N are independent parameters , the renormalized factor γ^{-1} can take any value . The value $\gamma^{-1} = 1/207$ was obtained under a specific physical conditions (for v and N) when physicists determined the mass of the muon .

VI . Conclusion

The concept of varying electric charge is an innovative one , which relies on two claims of prominent physicists :

- the mass of a particle is invariant (Okun , Sternheim & Kane , Marion & Thornton , Kacser)

- the electric charge is to be renormalized (Schwinger , Bekenstein , Rohrlich) .

Since the mass m of the electron remains invariant , if experiments prove that its ratio e / m changes in relativistic regime , then the electric charge e must be renormalized .

The result is the Eq(4) (or the graph of Fig.1) which reveals that the electric charge is an effective one , depending on the velocity and the applying field .

Physics changes and has no frontier . Eliminating an old-fashioned concept is as crucial as inventing a new one : the concept of varying mass must be replaced by the new concept of varying electric charge .

This new concept leads to a new theory of *a spatially extended model for the electron* [9], which is so far considered as a solid point charge .

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