# The mass versus the electric charge of the electron .

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**Abstract**

In the physical literature there were two opposite concepts on the mass :
- the mass changes with velocity ( Section 1 ) ,
- the mass doesn't change with velocity ; it is invariant ( Section 2)

First , let 's review these two concepts in the literature .
Next , we introduce a new concept on the variability of the electric charge ( Sections 3 , 4 ).
Finally , we propose a thought experiment to show this variability (Section 5) and discussion & conclusion (Section 6).

**1. The mass changes with velocity** .

In his theory of the electron (1904) Lorentz came to this famous relation

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

Bergmann[1] , in his text book " Introduction to the Theory of Relativity " (1976)

introduced the longitudinal mass $m_l$

$$m_l = ( 1 – u^2 / c^2 )^{-3/2} m = \gamma^3 m , \quad \text{(when the velocity } \mathbf{u} \text{ is parallel to the force)} , \qquad (2)$$

and the transversal mass $m_t$

$$m_t = ( 1 – u^2 / c^2 )^{-1/2} m = \gamma m , \quad \text{(when } \mathbf{u} \text{ is perpendicular to the force)} . \qquad (3)$$

This means that the rest mass m can be modified by the factor $\gamma^3$ or $\gamma$ to describe its dependence on the velocity and the direction of its motion .

More recently , in the Encyclopedia of Physics (2005) by Lerner and Trigg , we can find the term " *relativistic increase of mass* " which implies the idea of velocity-dependent mass .

All the above expressions imply the concept of variability of mass with velocity .

**2. The mass doesn't change with velocity ; it is invariant** .

On the opposite side , many contemporary physicists maintain that the mass of an elementary particle , such as the electron , does not change with its velocity : it is an invariant .

i) **Okun**[2] , ‘ 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**[3] , ‘General Physics ’ , 1991 , p. 673
*“ 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**[4] , ‘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**[5], in the Encyclopedia of Physics by Lerner & Trigg , 2005, in the topic “Relativity, Special Theory”
*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 .*

v ) **Einstein** might be the first physicist to reject the concept of changing mass . In his letter to Lincoln Barnett , 19 June 1948 , Einstein wrote (in German) : “ *It is not good to introduce the concept of mass* $M = m / ( 1 - v^2/c^2 )^{1/2}$ *of a moving body for which no clear definition can be given . It is better to introduce no other mass concept than ‘ the rest mass ’ m . Instead of introducing M , it is better to mention the expression for the momentum and energy of a body in motion .”*

**Conclusion**

Considering these two opposite ideas , we , therefore , conclude that the variability and the invariance of the mass of the electron still remain as a fundamental issue in modern physics , awaiting to be resolved .

**3. A proposed solution : introduction to the variability of the electric charge**

I am on the same side with physicists who maintain the invariance of the mass . Hence I think the concept of changing mass should be removed from the mainstream physics .

In the following , I propose a substitute for the changing mass : the plausible candidate is the electric charge $e$ of the electron which is so far considered as a fundamental constant .

The ratio $e/m$ appears in most equations of motion of the electron in external fields ; e.g., in the particle accelerators . If we adjust the mass $m$ in the ratio $e/m$ by using the factor $\gamma^3$ as in Eq.(2) , we have the identity

$$e / (\gamma^3 m) \equiv (\gamma^{-3} e) / m \qquad (4)$$

While the term $(\gamma^3 m)$ on the left-hand side means the adjustment of the mass m , the term $(\gamma^{-3} e)$ on the right-hand side means the modification the electric charge $e$ of the electron , and in either way , the value of the adjusted ratio remains unchanged . Therefore , since the mass is invariant , we should think of the modification of the electric charge of the electron . This means that in the case of a relativistic motion , the electric charge of the electron should be adjusted ( instead of its mass ) such that its equation of motion agrees with experimental results .

Similarly , if we use the factor $\gamma$ as in Eq.(3) to adjust the mass in the ratio $e/m$ , we get the identity

$$e / (\gamma m) \equiv (\gamma^{-1} e) / m \qquad (5)$$

The term $(\gamma^{-1} e)$ means the modification of the electric charge of the electron to replace the modification of the mass $(\gamma m)$ .

From Eqs. (4) & (5) the effective electric charge of the electron can be deduced as

$$q = \gamma^{-3} e \qquad \text{or} \qquad q = \gamma^{-1} e \qquad (6)$$

In order to get a general expression for $q$ , we replace two exponents -3 and -1 of the factor $\gamma$ in Eq. (6) by -N , since -3 and -1 are two particular cases when the velocity **u** is parallel and perpendicular to the force as noted in Eqs. (2) & (3) . We come to a generalized form for the effective electric charge of the electron $\boxed{q = \gamma^{-N} e}$ (7)

where $N \geq 0$ is a positive real number representing the applying field , and e is the value of the electric charge of the electron given by the oil-drop experiment of Millikan .

With the factor $\gamma = (1 - u^2 / c^2)^{-1/2}$ , Eq.(7) is rewritten as

$$\boxed{q = (1 - u^2 / c^2)^{N/2}\, e} \qquad (8)$$

Eq.(8) leads to the following consequences :

1. Since $0 < u < c$ and $N \geq 0$ , the factor $(1 - u^2 / c^2)^{N/2}$ varies in the interval ( 0 ,1 ), and q varies in the interval $0 < q < e$ . That is , when the electron is subject to an applying electric or magnetic field , its effective charge q drops below the maximum charge e .

2. When $N = 0$ , i.e., there is no applying field , $q = e$ for all velocities . That is , when the electron moves in free space , its electric charge is always equal to e .

3. When N is a large number , i.e., the applying field is very strong : $q \rightarrow 0$ for all values of u : the electron is devoid of charge ; it becomes a free particle .

4. At low velocities : $u << c$ , $q \approx e$ for all values of N ( i.e., for all applying fields) . This is the case of the oil-drop experiment of Millikan . In this experiment , electrons ( on oil drops ) fall down at velocity of **a fraction of a millimetre per second in the electric field of 6000 volts per cm** . And thus , Millikan experiment could only give a unique value $q \approx e$ . ( We notice that in his Nobel lecture , 1924 , Millikan never said that the electric charge of the electron was invariant . He might think that the electron could have charges different from e , but his experiment could not be performed at higher velocities or higher electric field ).

5. At high velocities near c : $u \rightarrow c$ , $q \rightarrow 0$ for all values of N : the electron becomes a free particle .

**Conclusion**

By using a heuristic argument on the ratio e/m , which appears in the equations of motion of the electron in external fields , we reached a simple expression (8) for the effective charge of the electron . This is the sole expression that tells us how the electron behaves in an extremely high field : it tends to be a free particle .

## 4 . The variability of the electric charge in contemporary physics

In contemporary physics there exist experimental phenomena and theoretical researches which suggest the variability of the electric charge of the electron :
A) The running of the fine-structure constant $\alpha$ ,
B) The Rutherford's nuclear experiment ,
C) The Lamb's shift ,
D) Other expressions of the effective electric charge .

### A . The fine-structure constant $\alpha$

Nowadays , physicists consider the dimensionless fine-structure constant $\alpha = e^2 / 4\pi\varepsilon_0 \hbar c$ as a "running" coupling constant which varies with the energy at which it is measured .
**Bekenstein**[6] and **Uzan**[7] have investigated the variability of $\alpha$ and its consequences on the variation of the electric charge $e$ .

### B . The Rutherford's nuclear experiment [8]

*" Rutherford's experiment, in which he scattered alpha particles by atomic nuclei, showed that the equation* $F = qq' / ( 4\pi\varepsilon r^2 )$ *is valid for charged particles of nulear dimensions down to separations of about* $10^{-12}$ *cm . Nuclear experiments have shown that the forces between charged particles do not obey the equation for separations smaller than this ."*

The invalidity of the Coulomb's force equation at very short distances can find the explanation in the variation of the effective electric charge $q$ and $q'$ .

### C . The Lamb shift [9]

The Lamb shift is a manifestation of the invalidity of Coulomb's law at short distances .
In 1947 Lamb succeeded in measuring the small energy difference between two energy levels $2\,^2S_{1/2}$ and $2\,^2P_{1/2}$ of hydrogen atom . In his Nobel lecture (1955) Lamb pointed out the reason for the splitting of these two energy levels as follows :

*" The exact coincidence in energy of the* $2\,^2S_{1/2}$ *and* $2\,^2P_{1/2}$ *states is a consequence of the assumed Coulomb law of attraction between electron and proton. Any departure from this law would cause a separation of these levels".*

Therefore , it is the variability of the electric charge that makes the Coulomb's law inaccurate at very short distances and this causes the Lamb shift .

### D. Other expressions for the effective electric charge of the electron .

In this article we came to the expression (7) or (8) for the effective electric charge of the electron, meanwhile physicists Bekenstein and Rohrlich proposed other expressions for it :

**Bekenstein**[6] wrote : *" Since $\alpha = e^2 / \hbar c$ , where e is the electron charge , $\alpha$ variability means that e depends on the spacetime point . ... 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 ." (p. 1529)*

**Rohrlich**[10] wrote 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 ."*

**Conclusion**

All the above quotations imply that the variability of the elementary electric charge of the electron may have involved in various physical phenomena , and hence it is worth investigating further by experimentation .

**5. A thought experiment to demonstrate the variability of the electric charge of the electron in a variable magnetic field** .

If the electric charge of the electron is an effective one which varies with the applying field , we can figure out an experiment to demonstrate its variability .

In this thought experiment we keep the velocity of electrons unchanged while we change the intensity of the magnetic field **B** in the solenoid by changing the intensity of the current I .

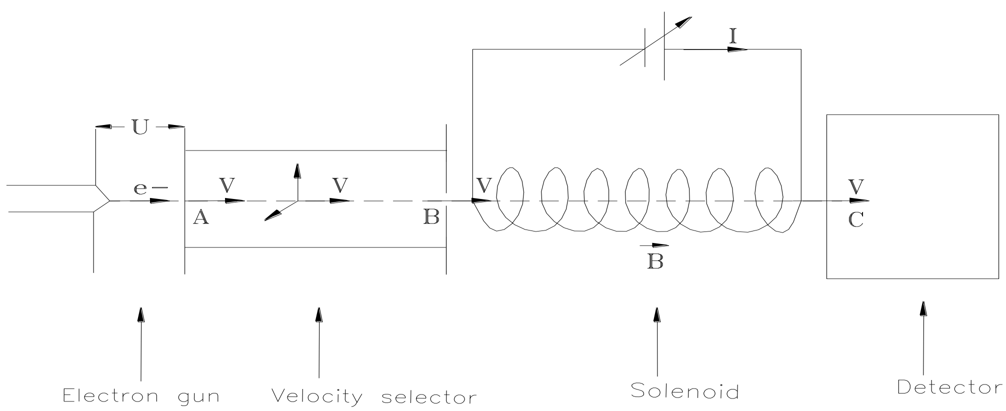


Fig 4

( Note : this is Fig.1 , not Fig.4)

- An electron gun produces electrons with various velocities at the point A .
- A velocity selector allows only electrons with velocity **v** to travel to the point B .

- A solenoid produces a uniform magnetic field **B** along its axis which coincides with the trajectory of the electron beam . The intensity **B** of the magnetic field can be regulated by the current I . Since $\mathbf{v} \parallel \mathbf{B}$ , there is no net ( magnetic ) force produced on the electron , so electrons travel with constant velocity **v** through the solenoid to the point C . And hence , there is no change in the mass and the kinetic energy of the electron with velocity .
- A detector , which can be a thick block of photographic emulsion ( silver bromide ), is installed at the exit C of the solenoid to detect the changing of the electric charge q of the electron when **B** changes its intensity .

At the entrance point C on the detector, the velocity of the electron is v , and its effective charge is q , which is expected to decrease when the magnetic field **B** increases .
Since the energy loss per unit distance[3] ( p. 827 & 850) in the medium of the detector is proportional to $q^2 / v^2$ , that is $\Delta K \propto q^2 / v^2$ . Now if we increase the intensity **B** ( N increases ) , the effective electric charge q will drop ( according to Eq.(8) ) and hence $\Delta K$ decreases , resulting in a deeper penetration of electrons into the block of photographic emulsion . In short , when we change the intensity **B**, if the depth of penetration changes in response to the change of **B** , this means that q varies with the applying magnetic field .

**6 . Discussion & Conclusion**

The reason why the electron can change its electric charge is that it is not a point charge but an extended particle . Moreover , (just for an illustrative comparison) , it is not solid as a marble , but soft as a tennis ball ! When a tennis ball is hit by a racket , it deforms and changes some of its properties , e.g., its internal pressure and temperature , while keeping its mass unchanged . Similarly , when an extended electron is " hit " by an external field , it reacts by spinning , radiating and changing its electric charge , while keeping its mass unchanged .
So , it is essential that we consider the electron as an extended particle and if we could figure out a suitable extended model for it , we would be able to demonstrate the above properties [11].
The immediate consequences of the variability of charge would be the modification of the Lorentz forces and the equations of motion of charged particles in external fields would not

remain the same as before .

Physics has no frontier , and hence there is no ultimate truth : a new reasonable concept can possibly come true . Finally , let us recall the message from the Nobel laureate, **Louis de Broglie**, that we should frequently and profoundly re-examine those physical principles which we have regarded as definitively established [12] .

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[12] Louis de Broglie ( Nobel Laureate in physics , 1929) : " L' histoire des sciences montre que les progrès de la science ont constamment été entravés par l'influence tyranique de certaines conceptions que l'on avait fini par considérer comme des dogmes . Pour cette raison , il convient de soumettre periodiquement à un examen très approfondi les principes que l'on a fini par admettre sans plus les discuter ."