American Journal of Physics and Applications
2024, Vol. 12, No. 2, pp. 21-26
https://doi.org/10.11648/j.ajpa.20241202.11

Research Article

Quantitative Investigation of Parallel Interactions Between Charged Particles

Huang Shaoshu[1, 2, *], **Feng Junjie**[3]

[1]Academic Research Center of Liupanshui No. 23 Middle School, Liupanshui, China
[2]School of Mathematics and Science, Anshun College, Anshun, China
[3]Academic Affairs Office of Liupanshui Normal University, Liupanshui, China

Abstract

On the premise that the charged particle is a normal geometry model, an expression of the migration current, displacement current and magnetic induction intensity generated by the charged particle motion is deduced according to the microscopic definition of current intensity, the total current law and the Biot-Savart law. Further calculate the electric field force between two charged particles in vacuum, give the velocity constraint relationship and velocity value criterion of the electric and magnetic field forces, and compare the consistency with the correlation results obtained considering the relativistic effect. It is pointed out that the magnetic field force is comparable to the electric field force only when the charged particle moves near the speed of light.

Keywords

Motor Charge, Migration Current, Displacement Current, Speed of Light

1. Introduction

The so-called parallel charged particles refer to the charged particles moving side by side in the same speed and in the same direction.

There are interacting electric field forces between static charges, and there are interacting magnetic field forces between moving charges in addition to interacting electric field forces. Therefore, the interactions between the moving charged particles are more complex.

According to the classical electromagnetic theory combined with the assumption of the gauge geometry model of charged particles compare detailed calculation analysis and according to the electrodynamics considering the theory of relativity results, only quantitative discuss two equally charged particles with the same speed in parallel motion interaction. At the same time, according to the comparison results, the question of whether the common overhead current-carrying transmission wires will have adverse accidents due to the interaction of current and magnetic field is simply answered.

*Corresponding author: 597015954@qq.com (Huang Shaoshu)

Received: 29 July 2024; **Accepted:** 9 September 2024; **Published:** 23 September 2024

2. The Calculation of the Classical Theory

2.1. Current Formed by the Movement of a Charged Particle

The current generated during the movement of isolated charged particles includes the migration current on the particle movement track and the displacement current in the space around the particle. Among them, migration current, also known as current current or convection current, refers to the current formed by the regular motion of the charge in the space (such as vacuum or extremely thin gas); the displacement current is the integral of the rate of change of the electric displacement vector with time over a surface, the concept of displacement current only represents the rate of change of the electric field.

2.1.1. Migration Current

Let the particle be a gauge positive cube of edge length d, with an electric charge of q, moving in a straight line with a velocity v. Consider the current path of the particle as a prismatic conductor with a cross-sectional area of d ? There is only one free charge, that is, one charged particle, in the volume of d ?

According to the microscopic definition of the current intensity

$I_Q = nqSv$ (n is the number of free charges per unit volume) (1)

The intensity of the moving current formed during the movement of a charged particle is obtained as

$$I_Q = \frac{qv}{d} \tag{2}$$

To illustrate, the same expression of the migratory current can be obtained by using different spatial models for particles. For example, If the particle is regarded as a gauge sphere with diameter d, In the case of the above motion, the current path formed by the particle motion is regarded as a 1/4πd² cylindrical conductor with a cross-sectional area, If there is only one free charge in the volume of 1/4πd³, that is, one charged particle, then the migration current expression is the same

$$I_Q = \frac{qv}{d} \tag{3}$$

2.1.2. The Displacement Current

Assume that a charged particle with a certain amount of charge is moving in a straight line with a velocity v towards o point, and the distance between the o particle and the point is x, as shown in Figure 1. Take the point o as the center of the circle to make a circle r of radius, the circle surface is perpendicular v to the particle velocity, take a ring of radius on the circle surface, the area of the ring is $\mathrm{d}S = 2\pi R\mathrm{d}R$, the Angle between the direction of the normal and the direction of the electric field is ф and the electric field intensity at the surface element is

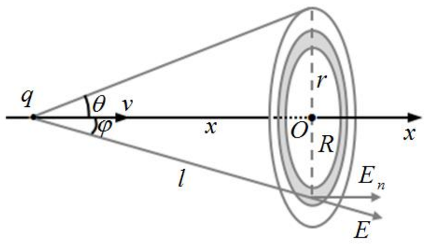

Figure 1. *Calculatin o of displacement current.*

$$E = \frac{q}{4\pi\varepsilon_0 l^2} = \frac{q}{4\pi\varepsilon_0 (x^2 + R^2)} \tag{4}$$

Among $\varepsilon_0 = 8.85\times10^{-12}\ \mathrm{F/m}$, it is called the vacuum dielectric constant (the same below).

The electrical flux through this element is

$$\mathrm{d}\Phi_E = E\cdot\mathrm{d}S = E\mathrm{d}S\cos\varphi = E\cdot 2\pi R\,\mathrm{d}R\cdot\frac{x}{l} = \frac{qx}{2\varepsilon_0}\frac{R\mathrm{d}R}{(x^2+R^2)^{\frac{3}{2}}} \tag{5}$$

Thus, the electrical flux through the loop is given at

$$\Phi_E = \int_0^r \frac{qx}{2\varepsilon_0}\frac{R\mathrm{d}R}{(x^2+R^2)^{\frac{3}{2}}} = \frac{qx}{2\varepsilon_0}\int_0^r \frac{\mathrm{d}(x^2+R^2)}{2(x^2+R^2)^{\frac{3}{2}}} = \frac{q}{2\varepsilon_0}\left(1-\frac{x}{\sqrt{x^2+r^2}}\right) \tag{6}$$

Thus, the electric displacement flux through the loop is

$$\Phi_D = \varepsilon_0\Phi_E = \frac{q}{2}\left(1-\frac{x}{\sqrt{x^2+r^2}}\right) \tag{7}$$

It can be seen that the larger the radius of the circle made at one point along the axis of the particle motion, the greater the flux of electrical displacement through the circle. Considering $\frac{\mathrm{d}x}{\mathrm{d}t} = v$, it is not difficult to conclude that the displacement current passing through the loop is

$$I_D = \frac{\mathrm{d}\Phi_D}{\mathrm{d}t} = \frac{q}{2}\cdot\frac{\mathrm{d}\left(1-\frac{x}{\sqrt{x^2+r^2}}\right)}{\mathrm{d}t} = \frac{q}{2}\cdot\frac{r^2 v}{(x^2+r^2)^{\frac{3}{2}}} \tag{8}$$

O $x = 0$ When the particle is in the center of the circle, immediately, the formula (8) becomes

$$I_D = \frac{1}{2}\frac{qv}{r} \tag{9}$$

Obviously, the displacement current generated by the motion of a charged particle at a point in the surrounding space is related to the distance from that point to the particle.

2.2. Magnetic Field Resulting from the Motion of a Charged Particle

In order to compare and explain the rationality of the charged particle model and the nature of the magnetic field generated by the charged particle motion, the magnetic field generated by the charged particle motion.

2.2.1. Calculated Based on the Migration Current

Based on the assumption of the particle model in the moving current calculation, the moving charged particle can be regarded as a current element with a length equal to the diameter of the particle, and the magnetic field generated by the current element in its surrounding space can be generated according to the Biot-Saval law [1-3] r P Find out. As shown in Figure 2, the magnetic induction intensity at a point from the moving charged particle (the velocity vertical to the particle) is

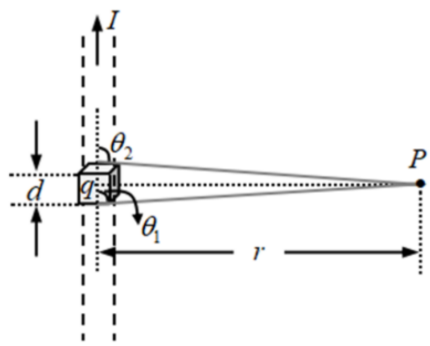

Figure 2. *Magnetic Field Generated by the Motino of Charged Particles.*

$$B = \frac{\mu_0}{4\pi}\int_{\theta_1}^{\theta_2}\frac{I_Q \sin\theta \, d\theta}{r} = \frac{\mu_0 I_Q}{4\pi r}(\cos\theta_1 - \cos\theta_2) \tag{10}$$

$\mu_0 = \frac{1}{\varepsilon_0 c^2} = 4\pi\times10^{-7}\ \mathrm{N/A^2}$ Where, it is the vacuum permeability (the same below). Considering that in practical situations, $r >> d$, $\cos\theta_1 \approx \frac{d}{2r}$, $\cos\theta_2 \approx -\frac{d}{2r}$ Therefore, formula (10) can be rewritten as

$$B = \frac{\mu_0 I_Q d}{4\pi r^2} \tag{11}$$

The electric current I_Q is determined by the formula (2). Therefore, by substituting formula (2) into formula (11), the P pmagnetic induction strength at the available point is

$$B = \frac{\mu_0}{4\pi}\cdot\frac{qv}{r^2} \tag{12}$$

2.2.2. Calculate According to the Displacement Current

According to the assumption of the displacement current calculation in Figure 1, the boundary of the circle is taken as the loop. Because the magnetic field of the circuit is the same, according to the full current law [4-10], have

$$\oint_L H\cdot ds = I_C + I_D \tag{13}$$

Due to the conduction current $I_C = 0$, the formula (13) can be reduced to

$$\oint_L H\cdot ds = I_D \tag{14}$$

That is, the relationship between the displacement current and the magnetic field strength is

$$H\cdot 2\pi r = I_D \tag{15}$$

In consideration $B = \mu_0 H$, substitute formula (8) into formula (15), the magnetic induction strength is

$$B = \mu_0 H = \frac{\mu_0 qv}{4\pi}\frac{r}{\left(x^2+r^2\right)^{\frac{3}{2}}} \tag{16}$$

When the particle is at the center of the circle O, immediately $x = 0$, the formula (16) becomes

$$B = \frac{\mu_0}{4\pi}\cdot\frac{qv}{r^2} \tag{17}$$

Obviously, formula (17) is exactly equivalent to formula (12). It shows that the two methods of calculating the charged particle motion in space according to the migration current and the displacement current are equivalent, which reflects the unity of the nature of things. That is, the magnetic field generated by the migration current and the magnetic field generated by the displacement current are, in fact, the same magnetic field, essentially produced by the specific motion of the same given charged particle.

2.3. Interactions of the Two Moving Charged Particles

For simplicity, the aforementioned model of moving current is analyzed and discussed here.

Two identical charged particles apart r move in parallel in the same direction at the same speed (the direction of movement is perpendicular to the connection of the two particles), as shown in Figure 3. Obviously, one of the particles is in the magnetic and electric fields of the other The magnetic field force for the interaction between the two particles is given by

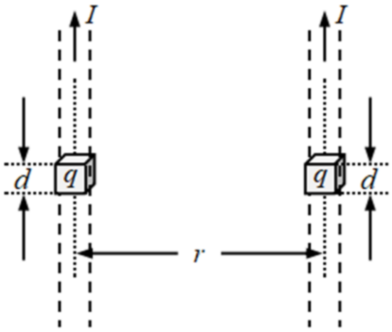

Figure 3. *Charged particles flying parallel at the same speed and direction.*

$$F_{\text{magnetism}} = I_Q dB \tag{18}$$

Where the current I_Q is determined by formula (2) and the magnetic induction strength B is determined by formula (12). Therefore, combining (2) and (12), (18) can be rewritten as

$$F_{\text{magnetism}} = \frac{\mu_0 q^2 v^2}{4\pi r^2} \tag{19}$$

It is shown that the electric field interaction between parallel charged particles also complies with the Coulomb's law, so that the electric field force between two particles is

$$F_{\text{electric}} = \frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2} \tag{20}$$

If the mutual repulsion force between the two moving charged particles is positive, the mutual attraction is negative. Then, from (19) (20), the force between the two particles can be expressed as

$$F = \pm\frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2} \mp \frac{\mu_0}{4\pi}\frac{q^2 v^2}{r^2} \tag{21}$$

For the same (different) charge, the first term on the right side of formula (21) takes the positive (negative) number and the second term takes the negative (positive) number.

It can be seen that the relationship between the interacting magnetic field force and the interacting electric field force between two charged particles flying in parallel with the same speed depends on the velocity of the particles. According to formula (19) and formula (20) or formula (21), when the force between two particles

$$F\begin{cases} >0 \\ =0 \\ <0 \end{cases} \tag{22}$$

When, have

$$\frac{\mu_0}{4\pi}\frac{q^2v^2}{r^2}\begin{cases} <\frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}\text{时}, v<\sqrt{\frac{1}{\mu_0\varepsilon_0}}=\sqrt{\frac{1}{\frac{1}{\varepsilon_0 c^2}\varepsilon_0}}=c=3\times10^8\ \text{m/s} \\ =\frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}\text{时}, v=\sqrt{\frac{1}{\mu_0\varepsilon_0}}=\sqrt{\frac{1}{\frac{1}{\varepsilon_0 c^2}\varepsilon_0}}=c=3\times10^8\ \text{m/s} \\ >\frac{1}{4\pi\varepsilon_0}\frac{q^2}{r^2}\text{时}, v>\sqrt{\frac{1}{\mu_0\varepsilon_0}}=\sqrt{\frac{1}{\frac{1}{\varepsilon_0 c^2}\varepsilon_0}}=c=3\times10^8\ \text{m/s} \end{cases} \tag{23}$$

This is an exciting and wonderful result!

Obviously, the value of velocity (the speed of light c) expressed by formula (23) is a criterion for the correlation between the magnitude of the electric field force and the magnetic field force between the charged particles. That is, the electric field force between particles with the same electric properties (opposite) is mutual exclusion (attraction), and when the two particles move side by side in the same direction, the magnetic field force between them is mutual attraction (repulsion). The details are as follows:

$v<\sqrt{\frac{1}{\mu_0\varepsilon_0}}=c=3\times10^8\ \text{m/s}$ $F_{\text{magnetism}}<F_{\text{electric}}$ At that time, the effect between the two particles was repulsion (attraction).

$v=\sqrt{\frac{1}{\mu_0\varepsilon_0}}=c=3\times10^8\ \text{m/s}$ $F_{\text{magnetism}}=F_{\text{electric}}$ At that time, the effect between the two particles behaved as zero. According to the current support theory, this situation is difficult or even impossible to achieve.

$v>\sqrt{\frac{1}{\mu_0\varepsilon_0}}=c=3\times10^8\ \text{m/s}$ $F_{\text{magnetism}}>F_{\text{electric}}$ At that time, the action between the two particles appeared as attraction (repulsion). Of course, according to the current support theory, this situation does not exist.

c In practice, because the particle speed is always less than or even much less than the speed of light. Therefore, the electric field force between two parallel charged particles is always greater or even greater than the magnetic field force.

3. Results of the Relativistic Effect

According to the electrodynamics [11-16]. The principle of electromagnetic field transformation can obtain the electric field between two charged particles, one particle at the other particle (consistent with the connection) is

$$E' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \tag{24}$$

The magnetic field generated by one particle at another particle (perpendicular to the connection) is

$$B' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \frac{v}{c^2} \frac{1}{4\pi\varepsilon_0} \frac{q}{r^2} \tag{25}$$

So, the electric field force of the interaction between the two charged particles is

$$F'_{\text{electric}} = qE' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \frac{1}{4\pi\varepsilon_0} \frac{q^2}{r^2} \tag{26}$$

The magnetic field force for the interaction between the two charged particles is given by

$$F'_{\text{magnetism}} = qvB' = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} \frac{v^2}{c^2} \frac{1}{4\pi\varepsilon_0} \frac{q^2}{r^2} \tag{27}$$

Thus, by combining both in (26) (27), the interaction force between the two particles is

$$F' = F'_{\text{electric}} - F'_{\text{magnetism}} = \sqrt{1-\frac{v^2}{c^2}} \frac{1}{4\pi\varepsilon_0} \frac{q^2}{r^2} \tag{28}$$

Considering that formula (28) is meaningful, i. e

$$\sqrt{1-\frac{v^2}{c^2}} \geq 0 \tag{29}$$

that is

$$v \leq c = 3\times10^8 \text{ m/s} \tag{30}$$

This suggests that the parallel charged particles cannot move faster than the speed of light c, or that the magnetic field force interacting between the parallel charged particles cannot be greater than the electric field force between them. Therefore, the interaction between two charged particles is always the electric field force, and the magnetic field force between them is comparable to the electric field force only when the speed of their motion is infinitely close to the speed of light c.

This method of reasoning is used in the relevant journal literature [17]. There is a similar statement in it.

4. Conclusion

(1) The same charged particle in a given same motion, the magnetic field generated by the migration current and the magnetic field generated by the displacement current are the same magnetic field. Therefore, the effect between the migration current and the displacement current is the same unified effect, and only one of these can be quantified when studying the macroscopic magnitude of the magnetic field interaction between such charged particles.

(2) Comprehensive comparative analysis of the formula (30) and formula (23), the results of considering the corresponding effect are consistent with the conclusion drawn by adopting the classical electromagnetic theory. This shows that the unity between classical electromagnetic theory and relativity exists in a certain range of fields, and the speed of light is the bridge between them. c

(3) parallel two charged particles, indicating that the electric field force and magnetic field force constraints or the (23) force and (30) are independent of the charge of the two particles. Therefore, the charge equivalence of two charged particles does not affect the relevant conclusions and discussion.

(4) The usual overhead current transmission wires, in which the free charge directional movement rate (10^{-5} m/s order of magnitude) is very small, and the distance between the wires (usually about 1-3m) is relatively large. Therefore, the current and magnetic field forces between them are very weak, and their unit length is generally only 10^{-7} N/m ~ 10^{-1} N/m, and they will not have adverse accidents because of the current and magnetic field between each other.

Abbreviations

No abbreviation.

Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Zhao Kaihua, Chen mou. New Concept physics tutorial on Electromagnetism (second edition) [M]. Beijing: Higher Education Press, 2006. 12(2): 109-113.

[2] Miao Zhongying. Discussion of electromagnetics issues [M]. Anhui: University of Science and Technology of China University Press, 2018 (1): 239-240.

[3] Zhang Sanhui. University of Physics (Mechanics, electromagnetism) [M]. Beijing: Tsinghua University Press, 2009. 2(3): 343-344.

[4] Available from: https://baike.baidu.com/item/%E5%85%A8%E7%94%B5%E6%B5%81%E5%AE%9A%E5%BE%8B/7202859?fr=ge_ala- [On May 23, 2024]

[5] Available from: https://wenku.baidu.com/view/77ad05f9f142336c1eb91a37f111f18582d00c5e.html?_wkts_=1725867003986&bdQuery=%E5%85%A8%E7%94%B5%E6%B5%81%E5%AE%9A%E5%BE%8B%E5%85%AC%E5%BC%8F%E5%8F%8A%E7%89%A9%E7%90%86%E6%84%8F%E4%B9%89&needWelcomeRecommand=1 [On September 9, 2024]

[6] Available from: https://www.eefocus.com/baike/1518246.html [On September 9, 2024]

[7] Available from: https://zhidao.baidu.com/question/1808749723296596747.html [On September 9, 2024]

[8] Availablefrom: https://zhidao.baidu.com/question/1650406998265661260.html [On September 9, 2024]

[9] Available from: https://www.docin.com/p-2066621658.html [On September 9, 2024]

[10] Availablefrom: https://wenku.baidu.com/view/5602b1a8be64783e0912a21614791711cd797970.html?_wkts_=1725868629929&bdQuery=%E5%85%A8%E7%94%B5%E6%B5%81%E5%AE%9A%E5%BE%8B%E5%85%AC%E5%BC%8F%E5%8F%8A%E7%89%A9%E7%90%86%E6%84%8F%E4%B9%89&needWelcomeRecommand=1 [On September 9, 2024]

[11] Guo Shuohong. Electrodynamics (Third Edition) [M]. Beijing: Higher Education Press, 2008. 6(3): 217-222.

[12] Cao Changqi. Electrodynamics [M]. Beijing: People's Education Press, 1962. 7(2): 281-289.

[13] Li Yuanjie. electrodynamics [M]. Beijing: Machinery Press, 2014. 7(1): 136-144.

[14] Wang Zhi shi. A concise tutorial of electrodynamics [M]. Chengdu: Sichuan University Press, 1996. 8(1): 152-163.

[15] Ding Mingxin. Electrodynamics [M]. Shenyang: Liaoning Education Press, 1986. 11(1): 512-530.

[16] Ren Yi Zhi. A concise tutorial of electrodynamics [M]. Tianjin: Nankai University Press, 2003. November (1): 223-245.

[17] Cheng Jinglong, Wu Xiaosong. On charge attraction or repulsion and related issues [J]. Physical Bulletin, 2017. 2: 110-112.