Magnetic force on a current that not flowing through the magnetic field

Yannan Yang

(Shanghai Jinjuan Information Science and Technology Co., Ltd.)

Abstract: From the distribution characteristics of the magnetic field created by a current wire, we speculate that a current wire will experience force from a magnetic field nearby even if the current does not go through the field. From the same analysis, a similar effect should also exist for a moving charged particle, i.e., a moving charged particle will experience force from a nearby magnetic field, although the particle does not cut across the magnetic field. To prove the existence of this force, two experiments are performed and the results support our speculation. Considering the experimental results of this paper, if the relativistic transformation of field is universally valid, a motional electromotive force should be created in a neutral conductor moving through a space where there is no magnetic field, as long as there is a magnetic field around. Experimental designs are proposed to prove this motional electromotive force.

Keywords: Force on electric current; Lorentz force law; Charge in magnetic field; Motional electromotive force.

Introduction

When a straight wire carrying an electric current is placed in a magnetic field, it experiences a force. The force experienced by a wire of length L carrying a current $\boldsymbol{I}$ in a magnetic field **B** is given by [1, 2],

$$\boldsymbol{F} = \boldsymbol{I} \times \boldsymbol{B} L \qquad (1)$$

The force is perpendicular to the plane formed by the current and the magnetic field.

It is widely believed that the physical origin of the force is from the resultant Lorentz force of the charge carriers in the current. Each of the moving charges, which comprise the current, experiences the Lorentz force, and together they create a macroscopic force on the wire [1, 4].

According to Ampere's circuital law, a current wire produces a magnetic field around it. The magnetic field lines around a long straight wire which carries an electric current form concentric circles around the wire [1, 2, 3, 5]. The magnetic field is perpendicular to the wire. For a long wire carrying a current $\boldsymbol{I}$, the expression for the magnetic field is,

$$\mathbf{B} = \frac{\mu_0 \boldsymbol{I}}{2\pi r} \qquad (2)$$

Where, *r* is the distance to the wire and μ_0 the permeability. This magnetic field stretches away from the wire and the strength is inversely proportional to the distance from the wire.

Theoretically, the circular magnetic field of a current wire can interact with an external magnetic field nearby. From this respect, the force on a current wire in a magnetic field can be thought originated from the interaction of the circular magnetic field of the current wire and the external magnetic field. Because the circular magnetic field stretches away from the wire, the current wire can interact with not only a magnetic field which it is in, but also a nearby magnetic field which it is not in. How the interaction works are shown in figure1 and figure2.

In the case of figure1, the force experienced by the wire is still given by equation (1). But in the case of figure2, because the wire is not in the magnetic field, the magnitude of this force should decrease with distance to the magnetic field. Due to the strength of the circular magnetic field of the current wire is inversely proportional to the distance away the wire, the force may be expressed as,

$$\boldsymbol{F} = \frac{I \times BL}{r} \qquad (3)$$

To prove existence of this force, we did following two experiments. The experimental results confirm that a current wire really experiences a force from a nearby magnetic field which the wire is not in.

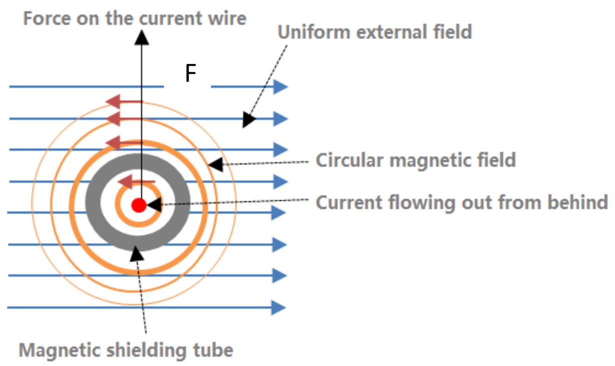

Fig.1. A magnetic shielding tube is placed cross a uniform magnetic field and inside the tube there is a current wire. The electric current flows out from behind. The external uniform magnetic field is completely kept free from the space inside the tube.

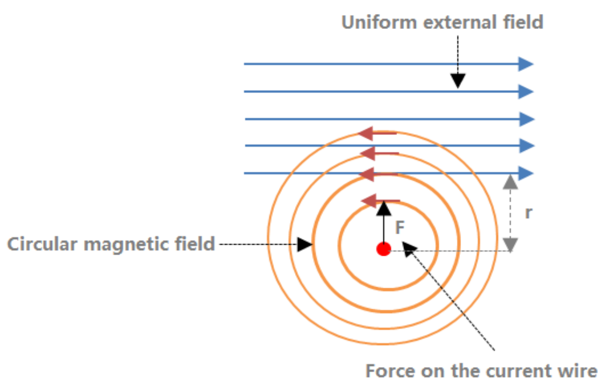

Fig.2. A current wire is placed beside a uniform magnetic field. The electric current flows from behind. The value of the external magnetic field is zero within a certain area around the current wire.

Experiments

Experiments1: This experimental design is to simulate the situation of figure1. As shown in figure3, a hollow cylinder made of magnetic shielding material is placed cross a uniform magnetic field. A straight current wire passes through the cylinder. Because of the magnetic shielding function, the magnetic field inside the tube is almost zero. When an electric current flows through the wire, the current does not cut across the magnetic field. According to the Lorentz force law, the wire will not experience a force from the uniform magnetic field. However, according to the Ampere's circuital law, there is circular magnetic field outside the cylinder, which produced by the current wire. It has interaction with the uniform magnetic field and the result is that the wire will experience a force from the uniform magnetic field. So, by observing if the wire moves to right when a current flow through, we can prove if a current wire really experiences a force from a nearby magnetic field which the wire is not in.

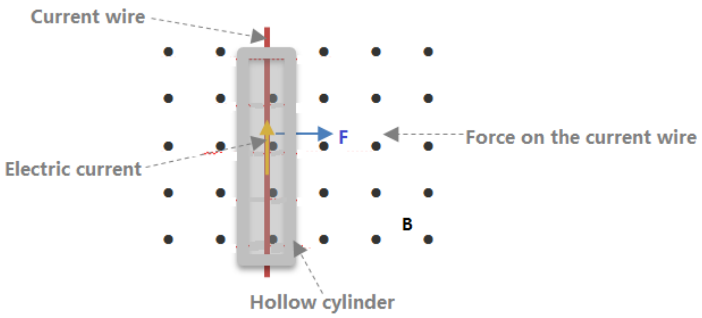

Fig.3. A hollow cylinder made of magnetic shielding material in a uniform magnetic field. Inside the cylinder there is a straight current wire. The magnetic field is zero inside the cylinder

In our experiment, two round magnets was used to form a magnetic field space. The hollow cylinder was made of 18 layers of permalloy film. One layer's thickness is 0.5 mm.

In the inner area of the cylinder, the magnetic field can be neglected compared to that when without the hollow cylinder. A straight thin copper wire is suspended from a beam above and passes through the hollow cylinder, as shown in figure4.

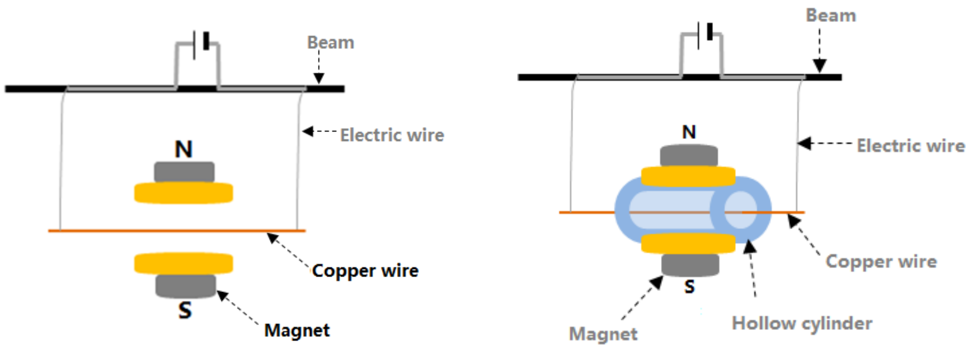

Fig.4. Two round magnets form a magnetic space. A thin copper wire, which suspended from a beam above passes across the field. In the right diagram, a magnetic shielding hollow cylinder is placed between the two magnets and the copper wire passes through the hollow cylinder.

When passing electric current through the wire, we compare the force on the copper wire in two conditions, having or not having the magnetic shielding hollow cylinder. We estimate the force by swinging magnitude of the wire. In this experiment, we found that swinging magnitude of the wire was no difference under the two conditions. This means that the force on the current wire is same in the two situations, having or not having the magnetic shielding hollow cylinder. So, the result supports our speculation that a current wire experiences force from a surrounding magnetic field that the current does not cut across.

Experiment 2: This experimental design is to simulate the situation of figure2. A hollow cylinder made of 18 layers of permalloy film is placed beside a magnetic field formed by two magnets and a current wire pass through the cylinder, as shown in figure5. The magnetic field inside the cylinder is almost zero. When an electric current flows through the wire, we observe if the wire moves. Again, the result is positive. The wire moves to right, which proves that a force is exerting on the current wire. The force direction is the same as if the wire were in the magnetic field.

In order to confirm that the force on the wire is not from the residue magnetic field of the two magnets within the hollow cylinder, we did a contrast experiment, as shown in figure6. In this design, the magnetic shielding hollow cylinder is removed. We found that the force on the wire has no difference in the two experimental designs. This proves that the force on the current wire in figure5 is not from the residue magnetic field within the hollow cylinder.

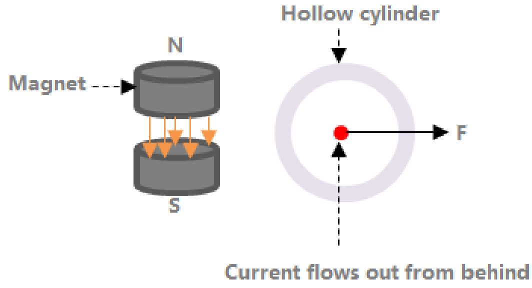

Fig.5. a magnetic shielding hollow cylinder is placed beside a magnetic field formed by two magnets. A current wire passes through the cylinder.

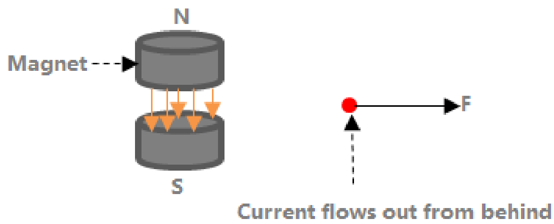

Fig.6. a current wire is placed beside a magnetic field formed by two magnets.

Results and discussion

From the above experimental results, we see that a current wire experiences force from a nearby magnetic field even if the wire is not in the magnetic field. So, a magnetic field exerts force not only on a current wire within it, but also on a current wire nearby.

By the same analysis, the same effect should also exist for a moving charged particle. That is to say that a moving charged particle will experience a force from a nearby magnetic field, although it does not cut across the field. The force direction is the same as if it were cutting across the magnetic field.

From these experimental results, it looks like that Lorentz force is not the physical origin of the force on a current that cuts across a magnetic field. The essence of the force is more likely originated from the interaction between the circular magnetic field of the current and the applied magnetic field.

Now, we may ask a question. As shown in figure7, when a neutral conductor bar moves beside a uniform magnetic field and there is no magnetic field in the vicinity of the conductor, will an electromotive force (EMF) be created in a conductor bar?

Unlike a charged particle, a moving neutral conductor does not produce a magnetic field around it. In this view, a moving neutral conductor has no interaction with a nearby magnetic field which it does not go through, so an EMF will not be created in the conducting bar of figure7.

According to relativistic transformation of electric and magnetic field [1], in the reference of an object moving in a magnetic field, it will experience an electric field perpendicular to both directions of moving and the magnetic field. From the experimental results of this paper for current wire, if replacing the conducting bar with a charged particle in figure7, there will be a transferred electric field in the reference where the charged particle is motionless. As to such logic, if the relativistic transformation of field is universally valid, there should be a transferred electric field in the reference where the conduction bar is at rest in figure7. Otherwise, it will conflict with relativistic transformation of fields and cause the following problem: In the same inertia reference, there is an electric field for a charged object but no for a neutral object. In order to avoid the problem, there must have a transferred electric field in the reference where the conductor bar is at rest in figure7. So, an EMF will be created in the conductor bar in figure7.

Instead of a conductor bar, if it is a U shape frame with a moving bar to form a loop as shown in right side of figure7, an induced current will be produced in the loop while there is no magnetic flux change and even no magnetic field through the loop. This is will be a very typical case violating Faraday's law of induction.

Let’s think this way. Around a moving neutral object, the magnetic fields, which created by the positive and negative charges within the body of the object, are always existed. The reason that we cannot feel them is due to the two magnetic fields cancel out each other. But when being placed close to an external magnetic field, they will respectively interact with the external field, which cause the positive and negative charges within the neutral object move to opposite direction. This produces an EMF in the moving neutral conductor bar of figure7. The mechanism is described in figure8. Just like there are always electric fields of positive and negative charges around a neutral object, but they cancel each other out. By this way, the EMF in the moving conducting bar of figure7 can be explained.

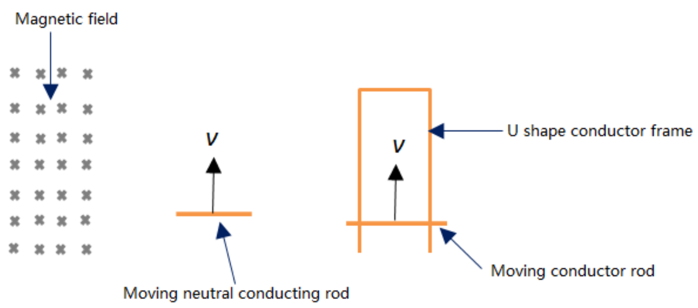

Fig. 7. A neutral conductor rod and a U shape conductor frame with a moving conductor rod are placed beside a uniform magnetic field. The conductor rod is moving upward.

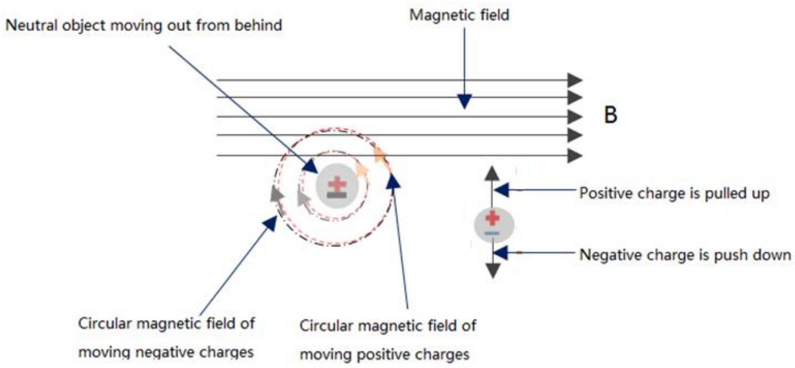

Fig. 8. A neutral object moves from behind beside an external magnetic field. There is interaction between the external magnetic field and the circular magnetic field around the moving object, which produces opposite force on the positive and negative charges of the object.

Conclusions

1. It is proved that a current wire experiences force from a nearby magnetic field, although the current does not flows through the magnetic field.
2. The same effect should exist for a moving charged particle, i.e., a moving charged particle will experience force from a nearby magnetic field, although the particles does not go through the magnetic field.
3. Considering the experimental results of this paper, if the relativistic transformation of field is universally valid, a motional electromotive force should be created in a neutral conductor moving through a space where there is no magnetic field, as long as there is a magnetic field nearby. Experimental designs are proposed to prove this motional electromotive force.

References:

[1] Feynman, R. et al., "Feynman lectures on physics volume 2, Mainly Electromagnetism and Matter, Chapter 13", Addison-Wesley，2011.

[2] Raymond A Serway and John W. Jewett, Jr., “Physics for Scientists and Engineers with Modern Physics”, Chapter 29, Ninth Edition, Technology Update, CENGAGE Learning, 2015.

[3] Raymond A Serway and John W. Jewett, Jr., “Physics for Scientists and Engineers with Modern Physics”, Chapter 30, Ninth Edition, Technology Update, CENGAGE Learning, 2015.

[4] Purcell, Edward M. and Morin, David J. “Electricity and Magnetism”, chapter 6, (Berkeley Physics Course, Vol. 2), Cambridge University Press; 3 edition (January 21, 2013)

[5] Owen, George E. “Electromagnetic Theory (Reprint of 1963 ed.)”, Courier-Dover Publications. P.213, 2003.