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

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Abstract. Considering the concentric circle distribution characteristics of the magnetic field produced by a straight 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. An experiment is performed and the result proves the existence of this force. Similarly, the same effect is predicted 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. From 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, but there is a magnetic field nearby. Experimental designs are proposed to prove this motional electromotive force.

1. 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 $I$ in a magnetic field $B$ is given by [1, 2],

$$ F = I \times B L $$

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, 3].

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, 4, 5]. The magnetic field is perpendicular to the wire. For a long wire carrying a current $I$, the expression for the magnetic field is,

$$ B = \frac{\mu_0 I}{2\pi r} $$

Where, $r$ is the distance to the wire and $\mu_0$ 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 also be thought as 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
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 figure 1 and figure 2.

To verify existence of this force, an experiment is performed. The result confirms that a current experiences a force from a nearby magnetic field which the current does not go through. That is, there is no magnetic flux going through the current, but the current still feels a force from the nearby magnetic field.

**Figure 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.

**Figure 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.

## 2. Experiment

The experimental design is to simulate the situation in figure 2. A hollow cylinder made of 18 layers of permalloy film is placed beside a long magnet. A straight thin wire is suspended from a beam above and passes through the hollow cylinder as shown in figure 3. In principle, if the magnet is long enough, the magnetic field lines distribution will looks like in figure 4. There will be no magnetic field in the area close to the center section of the magnet. Because the magnet used here is not infinite long, there is inevitably some magnet field here. To be on the safe, the hollow cylinder of magnetic shielding material is used. Because of the shielding effect of the permalloy films, the strength of the magnetic field inside the cylinder is very small. A magnetic needle is placed inside the cylinder and shows that the inner magnetic field is almost zero. During the experiment, a 5A electric current is flowed through the wire. Then we observe that the wire moves towards to or away from the long magnet. The moving direction is depended on the direction of the current, as if the wire were in the magnetic field. Figure 3 shows that when a left to right current is applied, the wire moves towards to the magnet.

The experimental conditions and components description are listed in table 1.
Figure 3. A magnetic shielding hollow cylinder is placed beside a long magnet. A current wire passes through the cylinder. When a current flowing through, the wire is pulled towards to or away from the magnet depending on the direction of the current.

Figure 4. The magnetic field lines distribution within and outside of the long magnet.

Table 1. Experimental conditions and components description.

| Component                                | Description                                                                 |
|------------------------------------------|-----------------------------------------------------------------------------|
| The magnet                               | NdFeB; Geometry: length 270mm, width 20mm, thickness 4mm.                   |
| The magnetic shielding cylinder          | Made of 18 layers of permalloy film. Geometry: length 35mm, inner diameter 42mm, outside diameter 52mm. |
| The wire that passes through the cylinder| Thing copper wire. Diameter: 1mm; Length: 50mm                              |
| Distance from the wire to the beam       | 1000mm                                                                     |
| DC power                                 | ZHAOXIN DC POWER SUPPLY KXN-30100; The current is adjustable in the range of 0–10A. |
| Compass (magnetic needle)                | Diameter: 35mm                                                             |

3. Results and discussion

From the above experimental result, 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.
Similarly, the 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 go through the field. The force direction is the same as if it were cutting across the magnetic field.

According to the experimental result, it seems 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 figure 5, when a neutral conductor bar moves beside a magnetic field and there is no magnetic field in the vicinity of the conductor, will an electromotive force (EMF) be created in the 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 should not be created in the conductor bar of figure 5.

However, 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 figure 5, 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 conductor bar is at rest in figure 5. Otherwise, it will conflict with relativistic transformation of fields and cause the following trouble: In the same inertia reference, there is an electric field being felt by a charged object but not by a neutral object. In order to avoid the paradox, there must have a transferred electric field in the reference where the conductor bar is at rest in figure 5. So, an EMF should be created in the conductor bar in figure 5.

Instead of a conductor bar, if it is a U shape conductor frame with a moving bar to form a loop as shown in figure 6, an induced current will be produced in the loop while there is not only no magnetic flux change, but also completely no magnetic flux through the loop. This is will be a very typical case violating Faraday's law of induction.

In the laboratory reference where the neutral conductor bar is moving in figure 5, we can think this way. For a moving neutral object, the magnetic fields, which produced by the positive and negative charges inside the body of the object, are always existed around the object. The reason that we do not feel them is due to the two magnetic fields cancel out each other. But when being placed close to an external magnetic field, they interact respectively with the external field, which cause the positive and negative charges inside the moving neutral object move to opposite direction. This produces an EMF in the moving neutral conductor bar of figure 5. The mechanism is explained by figure 7. Just like there are always electric fields of positive and negative charges in a neutral object, but they cancel each other out. When being placed in an external electric field, the different charges are forced to opposite direction.

By careful designed experiments as shown in figure 5 or figure 6, the EMF can be verified.

![Figure 5](image5.png)

**Figure 5.** Beside a uniform magnetic field, a neutral conductor rod is moving upward.
Figure 6. A U shape conductor frame with a moving conductor rod are placed beside a uniform magnetic field. The conductor rod is moving upward.

Figure 7. 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.

4. Conclusions
   - Based on theoretical analysis, a hypothesis is proposed that a current wire experiences force from a nearby magnetic field, although the current does not flow through the magnetic field.
   - The proposed hypothesis is qualitatively proved by the experimental result of this paper.
   - Based on the same analysis, the effect is predicted 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.
   - By further analysis, we predict that a motional electromotive force may 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 verify the existence of this motional electromotive force.

References
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