The magnetic field of an electric current

and its action on the current

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Abstract

By analyzing the magnetic field of a direct electric current within conductors and its action on the charge carrier in the current, a new effect is proposed for a conduct when current flowing through. Similar to the Hall Effect, this effect make the directionally moving charge carrier in the current deflected towards to the center of the current. If the charge carriers of the conductor with only one type charge (positive or negative), a radical electric field will form in the current cross section and a voltage will be produced between the center and the edge of the current. This effect also predicts that for a steady DC current the current density is not evenly distributed in the cross section of the current. The current density in the center area is larger than that in the edge area. It is not like what we always thought that the current density is evenly distributed in the current cross section.

Keywords: A new kind of Hall Effect; Magnetic field of current; Charge carriers distribution.

1. Introduction

Hall Effect was discovered in 1879 by Edwin Hall, an American physicist [1]. It is the production of a voltage difference (the Hall voltage) across an electrical conductor, transverse to an electric current in the conductor and a magnetic field perpendicular to the current. Since then, several different kinds of Hall Effect were discovered in different materials. Besides the normal Hall Effect in general conductors, Anomalous Hall Effect in magnetic materials, Spin Hall Effect in semiconductors were also discovered, and Quantum Hall effect was observed in 1980's [5]. These discoveries are significant for people to understand the solid electronic properties and greatly enriched the research area of Hall Effect [5-7]. Recently in 2013, a Quantum Anomalous Hall Effect was experimentally observed in a Magnetic Topological Insulator together by Chinese and US scientists [8].

In this article, through analyzing the magnetic field of a direct electric current through conductors and its action on the charge carrier in the current, a new effect is proposed for a conduct when current flowing through. Similar to the Hall Effect, this effect make the directionally moving charge carrier in the current deflected. The action deflects the charge carrier within the current not towards to the side of the conductor, but towards to the center of the conductor. This effect also predicts that for a steady DC current the current density is not evenly distributed in the cross section of the current. The current density in the center area is larger than that in the edge area. It is not like what we always thought that the current density is evenly distributed in the current cross section.

2. Analysis and Discussion

2.1 For a cylindrical conductor case

Consider a cylindrical conductor of radius R carrying a current I of uniform current density, as shown in Figure 1. Inside the conductor where r, the amount of current encircled by the Amperian loop (circle 2) is proportional to the area enclosed, i.e.,

$$I_{enc} = \left(\frac{\pi r^2}{\pi R^2} \right) I$$

Thus, we have

$$\oint \vec{B} \cdot d\vec{s} = B(2\pi r) = \mu I \left(\frac{\pi r^2}{\pi R^2} \right)$$

$$B = \frac{\mu I r}{2\pi R^2} \qquad （1）$$

The magnetic field distribution of the electric current is shown in Figure 2. The magnitude of the field is proportional to the distance to the center of the conductor.

Because of this magnetic field, the directionally moving charge carriers in the current will experience a Lorentz force. The Lorentz force drives the moving charge carriers towards to the center of the current cross section. No matter it is positively charged or negatively charged, all the charge carriers are deflected towards to the center of the current. As a result, when in steady state, the charge carrier density in the center area will be larger than that in the side area of the current cross section. If the charge carriers in the conductor consist of single type charged particles, either positive or negative, a radical electric field will be formed in the current cross section and a voltage will be produced between the center and the edge of the current.

For the normal metal conductors where the charge carriers are free electrons, the effect makes the free electrons move to the center of the current cross section. As a result, there will be more electrons in the center area than in the side area. The direction of the radical electric field is from the edge to the center and a voltage will be produced between the center and the edge of the current, as shown in figure 3.

If the charge carriers are only positive charged particles, such as p-type semiconductor, the holes are driven to the center and a radical electric field from the center to the edge will be formed in the current cross section.

If the charge carriers consist of both positively and negatively charged particles, both the positive and negative charge carriers appear more in the center area than in the edge area of the current cross section, so there will not be a radical electric field created in the current cross section.

Quantitatively, the magnitude of the radical electric field E is determined by following formulas,

$$qE = q\frac{v}{c}B \qquad (2)$$

$$J = nqv \qquad (3)$$

$$B = \frac{\mu Ir}{2\pi R^2} \qquad (4)$$

Where *q, v, n,* μ, *J* are respectively the electric quantity of the charge carrier, directional drift speed of the charge carrier, density of the charge carriers, magnetic permeability of the conductor and the average electric current density. Combine the three formulas above, we have

$$E = \left(\frac{\mu}{2nqc}\right)rJ^2 \qquad (5)$$

From the relationship (5) we see that the effect is positively proportional to the current density squared and magnetic permeability of the conductor, and inversely proportional to the charge carrier density of the conductor.

2.2 For a plate conductor case

When an electric current flowing through a plate conductor, the magnetic field distribution within the conductor in current cross section looks roughly like what shown in Figure 4. Similar to the situation of the cylindrical conductor, the charge carriers in the current are driven by the Lorentz force towards to the center of the current. A similar electric field will be formed between the center and the edge of the current if the charge carriers are single type charged and a voltage between the center and the edge of the current will be produced, as shown in Figure 5.

2.3 For an ion solution case

In Figure 6, a cylindrical container is filled with ion solution. When an electric current flows through the axis, the charge carriers enrich in the center area of the current cross section. With appropriate ion detection technologies，the difference of the ion concentration in the center area and side area might be detected if the effect is strong enough.
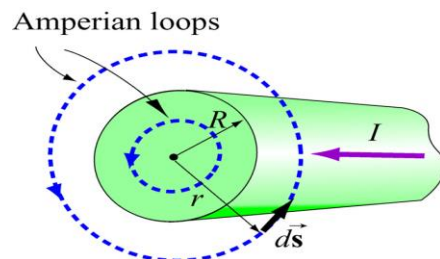

Fig.1. Amperian loops for calculating the magnetic field of a cylindrical conductor of electric current **I** and radius R.
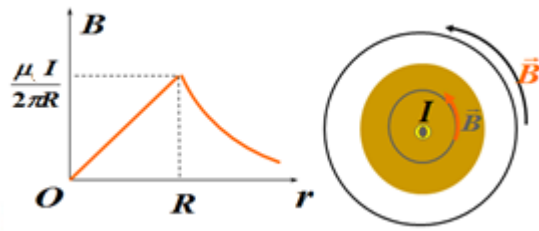
Fig.2. Magnetic field distribution in current cross section within a cylindrical conductor of radius R carrying a steady current **I**.
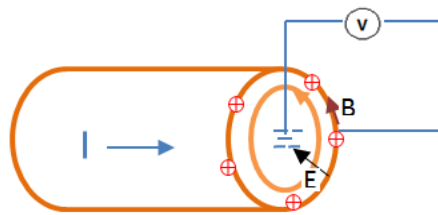

Fig.3. Charge distribution in current cross section for a cylindrical metal conductor carrying a steady current **I**.
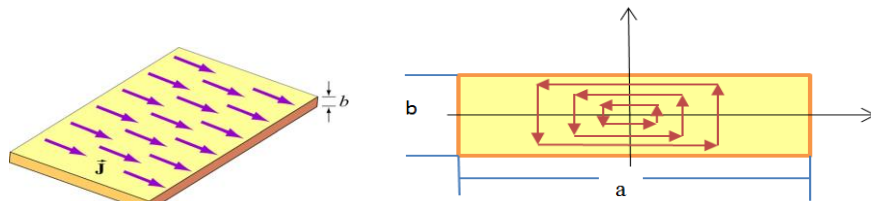

Fig.4. Magnetic field distribution in current cross section within a plate conductor of width a and thickness b carrying a steady current **I**.
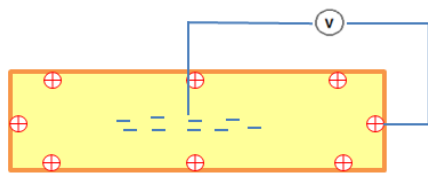

Fig.5. Charge distribution in current cross section for a plate metal conductor carrying a steady current **I**.
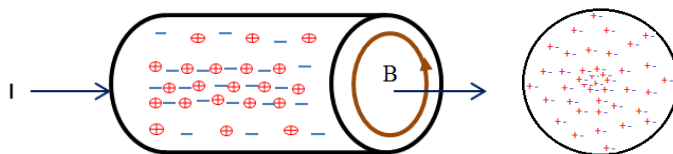

Fig.6. Charge carrier distribution in current cross section for a cylindrical ion solution conductor carrying a steady current **I**.

3. Conclusion

In a steady DC current, the magnetic field produced by the current within the conductor has action on the charge carriers in the current. The Lorentz force drives the charge carriers (both positive and negative charge carriers) moving towards to the center in the cross section of the current. As a result, the charge carrier density and current density are not evenly distributed in the cross section area of the current. The densities are higher in the center area and smaller in the side area. If the charge carriers in the conductor consist of single type charged particles, either positive or negative, there will be a radical electric field formed in the current cross section and a voltage will be produced between the center and the edge of the current.

References

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