MOVING CHARGES AND MAGNETISM

FORCES BETWEEN TWO PARALLEL CURRENTS, THE AMPERE

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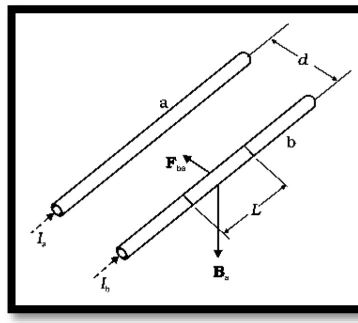
We have learnt that there exists a magnetic field due to a conductor carrying a current which obeys the Biot-Savart law. Further, we have learnt that an external magnetic field will exert a force on a current-carrying conductor. This follows from the Lorentz force formula. Thus, it is logical to expect that two current-carrying conductors placed near each other will exert (magnetic) forces on each other. In the period 1820-25, Ampere studied the nature of this magnetic force and its dependence on the magnitude of the current, on the shape and size of the conductors, as well as, the distances between the conductors. In this section, we shall take the simple example of two parallel currentcarrying conductors, which will perhaps help us to appreciate Ampere's painstaking work.



Two long straight parallel conductors carrying steady currents I a and I b and separated by a distance d. Ba is the magnetic field set up by conductor 'a' at conductor 'b'.

Shows two long parallel conductors a and b separated by a distance d and carrying (parallel) currents I a and I b, respectively. The conductor 'a' produces, the same magnetic field Ba at all points along the conductor 'b'. The right-hand rule tells us that the direction of this field is downwards (when the conductors are placed horizontally). Its magnitude is or from Ampere's circuital law,

$$B_a \frac{\mu_0 I_0}{2\pi d}$$

The conductor 'b' carrying a current I b will experience a sideways force due to the field Ba the direction of this force is towards the conductor 'a' (Verify this). We label this force as Fba, the force on a segment L of 'b' due to 'a'. The magnitude of this force is given

$$F_{ba} = I_b L B_a$$
$$= \frac{\mu_0 I_0 I_b}{2\pi d} L$$

It is of course possible to compute the force on 'a' due to 'b'. From considerations similar to above we can find the force Fab, on a segment of length L of 'a' due to the current in 'b'. It is equal in magnitude to Fba, and directed towards 'b'. Thus,

$$F_{ba} = -F_{ab}$$

Note that this is consistent with Newton's third Law. Thus, at least for parallel conductors and steady currents, we have shown that the Biot-Savart law and the Lorentz force yield results in accordance with Newton's third Law*.

We have seen from above that currents flowing in the same direction attract each other. One can show that oppositely directed currents repel each other. Thus,

Note that this is consistent with Newton's third Law. Thus, at least for parallel conductors and steady currents, we have shown that the Biot-Savart law and the Lorentz force yield results in accordance with Newton's third Law*. We have seen from above that currents flowing in the same direction attract each other. One can show that oppositely directed currents repel each other. Thus,

et f ba represent the magnitude of the force Fba per unit length,

$$f_{ab} = \frac{\mu_0 I_0 I_b}{2\pi d}$$

The above expression is used to define the ampere (A), which is one of the seven SI base units.

The ampere is the value of that steady current which, when maintained in each of the two very long, straight, parallel conductors of negligible cross-section, and placed one metre apart in vacuum, would produce on each of these conductors a force equal to 2×10^{-7} newton's per metre of length.

This definition of the ampere was adopted in 1946. It is a theoretical definition. In practice, one must eliminate the effect of the earth's magnetic field and substitute very long wires by multiturn coils of appropriate geometries. An instrument called the current balance is used to measure this mechanical force.

The SI unit of charge, namely, the coulomb, can now be defined in terms of the ampere.

When a steady current of 1A is set up in a conductor, the quantity of charge that flows through its cross-section in 1s is one coulomb (1C).

Example The horizontal component of the earth's magnetic field at a certain place is 3.0×10^{-5} T and the direction of the field is from the geographic south to the geographic north. A very long straight conductor is carrying a steady current of 1A. What is the force per unit length on it when it is placed on a horizontal table and the direction of the current is (a) east to west; (b) south to north?

Solution

$$F = Il \times B$$

$$F = IlB \sin\theta$$

The force per unit length is $f = F/l = I\,B \sin\theta$

(a) When the current is flowing from east to west,

$$\theta = 90°$$

Hence, $f = I\,B$

$$= 1 \times 3 \times 10^{-5} = 3 \times 10^{-5}\ \text{N m}^{-1}$$

This is larger than the value 2×10^{-7} Nm–1 quoted in the definition of the ampere. Hence it is important to eliminate the effect of the earth's magnetic field and other stray fields while standardizing the ampere. The direction of the force is downwards. This direction may be obtained by the directional property of cross product of vectors.

(b) When the current is flowing from south to north,

$$\theta = 0o$$

$$f = 0$$

Hence there is no force on the conductor.