

8.3: Magnetic Force between Two Parallel Currents

Learning Objectives

By the end of this section, you will be able to:

- Explain how parallel wires carrying currents can attract or repel each other
- Define the ampere and describe how it is related to current-carrying wires
- Calculate the force of attraction or repulsion between two current-carrying wires

You might expect that two current-carrying wires generate significant forces between them, since ordinary currents produce magnetic fields and these fields exert significant forces on ordinary currents. But you might not expect that the force between wires is used to define the ampere. It might also surprise you to learn that this force has something to do with why large circuit breakers burn up when they attempt to interrupt large currents.

The force between two long, straight, and parallel conductors separated by a distance r can be found by applying what we have developed in the preceding sections. Figure [Math Processing Error] shows the wires, their currents, the field created by one wire, and the consequent force the other wire experiences from the created field. Let us consider the field produced by wire 1 and the force it exerts on wire 2 (call the force [Math Processing Error]). The field due to [Math Processing Error] at a distance r is

[Math Processing Error]

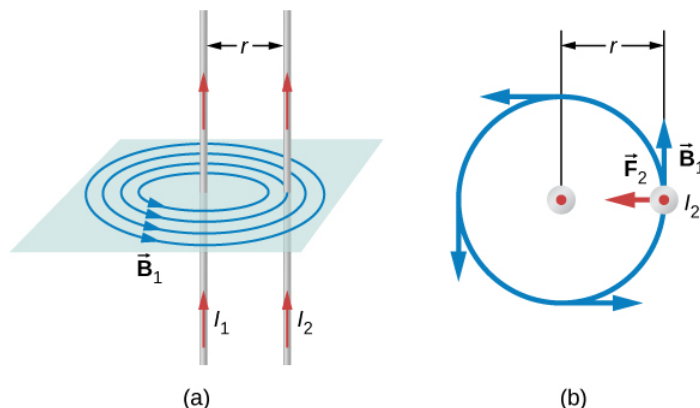


Figure [Math Processing Error]: (a) The magnetic field produced by a long straight conductor is perpendicular to a parallel conductor, as indicated by right-hand rule (RHR)-2. (b) A view from above of the two wires shown in (a), with one magnetic field line shown for wire 1. RHR-1 shows that the force between the parallel conductors is attractive when the currents are in the same direction. A similar analysis shows that the force is repulsive between currents in opposite directions.

This field is uniform from the wire 1 and perpendicular to it, so the force [Math Processing Error] it exerts on a length l of wire 2 is given by [Math Processing Error] with [Math Processing Error]:

[Math Processing Error]

The forces on the wires are equal in magnitude, so we just write F for the magnitude of [Math Processing Error] (Note that [Math Processing Error].) Since the wires are very long, it is convenient to think in terms of F/l , the force per unit length. Substituting the expression for [Math Processing Error] into Equation [Math Processing Error] and rearranging terms gives

✓ Note

[Math Processing Error]

The ratio F/l is the force per unit length between two parallel currents [Math Processing Error] and [Math Processing Error] separated by a distance r . The force is attractive if the currents are in the same direction and repulsive if they are in opposite directions.

This force is responsible for the **pinch effect** in electric arcs and other plasmas. The force exists whether the currents are in wires or not. It is only apparent if the overall charge density is zero; otherwise, the Coulomb repulsion overwhelms the magnetic attraction.

In an electric arc, where charges are moving parallel to one another, an attractive force squeezes currents into a smaller tube. In large circuit breakers, such as those used in neighborhood power distribution systems, the pinch effect can concentrate an arc between plates of a switch trying to break a large current, burn holes, and even ignite the equipment. Another example of the pinch effect is found in the solar plasma, where jets of ionized material, such as solar flares, are shaped by magnetic forces.

The definition of the **ampere** is based on the force between current-carrying wires. Note that for long, parallel wires separated by 1 meter with each carrying 1 ampere, the force per meter is

[Math Processing Error]

Since [Math Processing Error] is exactly [Math Processing Error] by definition, and because [Math Processing Error], the force per meter is exactly [Math Processing Error]. This is the basis of the definition of the ampere.

Infinite-length wires are impractical, so in practice, a current balance is constructed with coils of wire separated by a few centimeters. Force is measured to determine current. This also provides us with a method for measuring the coulomb. We measure the charge that flows for a current of one ampere in one second. That is, [Math Processing Error]. For both the ampere and the coulomb, the method of measuring force between conductors is the most accurate in practice.

✓ Example [Math Processing Error]: Calculating Forces on Wires

Two wires, both carrying current out of the page, have a current of magnitude 5.0 mA. The first wire is located at (0.0 cm, 3.0 cm) while the other wire is located at (4.0 cm, 0.0 cm) as shown in Figure [Math Processing Error]. What is the magnetic force per unit length of the first wire on the second and the second wire on the first?

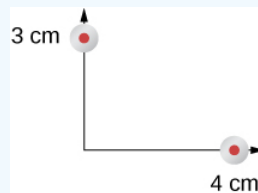


Figure [Math Processing Error]: Two current-carrying wires at given locations with currents out of the page.

Strategy

Each wire produces a magnetic field felt by the other wire. The distance along the hypotenuse of the triangle between the wires is the radial distance used in the calculation to determine the force per unit length. Since both wires have currents flowing in the same direction, the direction of the force is toward each other.

Solution

The distance between the wires results from finding the hypotenuse of a triangle:

[Math Processing Error]

The force per unit length can then be calculated using the known currents in the wires:

[Math Processing Error]

The force from the first wire pulls the second wire. The angle between the radius and the x -axis is

[Math Processing Error]

The unit vector for this is calculated by

[Math Processing Error]

Therefore, the force per unit length from wire one on wire 2 is

[Math Processing Error]

The force per unit length from wire 2 on wire 1 is the negative of the previous answer:

[Math Processing Error]

Significance

These wires produced magnetic fields of equal magnitude but opposite directions at each other's locations. Whether the fields are identical or not, the forces that the wires exert on each other are always equal in magnitude and opposite in direction (Newton's third law).

? Exercise *[Math Processing Error]*

Two wires, both carrying current out of the page, have a current of magnitude 2.0 mA and 3.0 mA, respectively. The first wire is located at (0.0 cm, 5.0 cm) while the other wire is located at (12.0 cm, 0.0 cm). What is the magnitude of the magnetic force per unit length of the first wire on the second and the second wire on the first?

Answer

Both have a force per unit length of *[Math Processing Error]*

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