Passage IV

A charged particle experiences a force when moving through a magnetic field. If a magnet is placed in the vicinity of a current-carrying wire of conducting material, the wire will experience a force due to the interaction between the magnetic field and the charged particles moving through the wire.

To study the interaction between a current-carrying wire and a magnetic field, a group of students conducted a series of experiments using a current balance (Figure 4), in which a current passing through a conducting loop of wire, or current loop, is acted on by the magnetic field produced by a permanent magnet. The current in the loop is produced using a variable power supply connected to the loop. The magnet, with a channel in its center, is placed on a digital electronic scale.

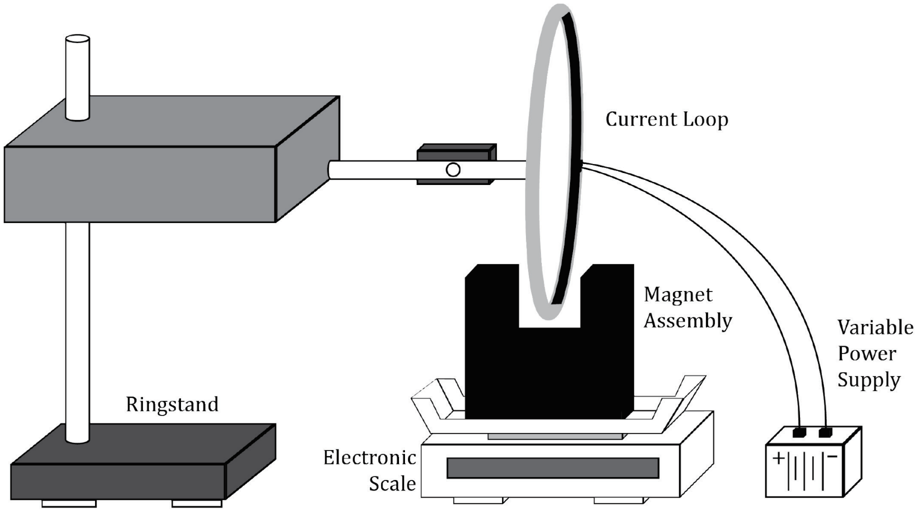

Figure 4

When lowered into the channel of the magnet, the current loop experiences a force due to the magnetic field produced by the magnet, as given by:

$$F = ILB \qquad \text{(Equation 1)}$$

where I is the current in the wire in amperes (A), L is the length of the current loop in meters (m), and B is the magnetic field strength in teslas (1 T = 1 kg/A/s^2). The standard unit of force is the newton (1 N = 1 kg • m/s^2).

Newton's third law of motion, or the law of action-reaction, states that the force on the current loop is equal to the force on the scale. According to Newton's second law of motion, the force on the scale is:

$$F = ma \qquad \text{(Equation 2)}$$

where m is the scale reading in kilograms (kg) and a is the acceleration due to gravity (9.8 m/s^2).

Experiment 1

To demonstrate how currents through the loop are affected by a magnetic force, the students applied different currents to a loop of length 2.4 cm. First, with the magnet in place and no current loop, the scale was zeroed so that scale readings with the current loop in the magnet channel correspond solely to the force acting on the current loop. Then the current loop was placed in the magnet channel without any part of the loop touching the magnet. The power supply was set to 0.5 A and the scale reading was recorded. This was repeated for increased current in steps of 0.5 A up to a maximum of 4.0 A. The students used Newton's second law of motion to calculate the force on the scale and thus the force on the current loop. The results are summarized in Table 3.

Table 3: Experiment 1 Data and Calculations			
Trial	Current, I (A)	Scale Reading, m (10^{-4} kg)	Force, F (10^{-2} N)
1	0.5	3.6	0.35
2	1.0	7.2	0.71
3	1.5	10.7	1.05
4	2.0	14.3	1.41
5	2.5	18.0	1.76
6	3.0	21.6	2.12
7	3.5	25.1	2.46
8	4.0	28.8	2.82

Experiment 2

To determine how the length of the current loop affects the magnetic force acting on it, Experiment 1 was repeated using four different current loop lengths: 1.2 cm, 2.4 cm, 3.6 cm, and 4.8 cm. The scale reading was recorded while 1.5 A of current was applied to each current loop length lowered into the magnet channel. The results are summarized in Table 4.

Table 4: Experiment 2 Data and Calculations			
Trial	Loop Length, L (10^{-2} m)	Scale Reading, m (10^{-4} kg)	Force, F (10^{-2} N)
1	1.2	5.4	0.53
2	2.4	10.7	1.05
3	3.6	15.9	1.56
4	4.8	21.6	2.12

Experiment 3

To determine how the strength of the magnetic field affects the magnetic force acting on the current loop, Experiment 1 was repeated using different numbers of parallel magnets. Each time a magnet was added, the scale was zeroed. For each magnet arrangement, the scale reading was recorded while 1.5 A of current was applied to a 2.4 cm loop lowered into the center magnet channel. The results are summarized in Table 5.

Table 5: Experiment 3 Data and Calculations			
Trial	Number of Magnets	Scale Reading, m (10^{-4} kg)	Force, F (10^{-2} N)
1	1	10.7	1.05
2	2	21.6	2.12
3	3	32.3	3.17
4	4	42.9	4.20

Passage V

The electrical resistance of a conductor represents its opposition to the flow of electrons and is defined by the relationship known as Ohm's law:

$$R = \frac{V}{I} \tag{Equation 3}$$

where R is the conductor's resistance in ohms (Ω), V is the potential difference across the conductor, or voltage, measured in volts (V), and I is the electrical current applied to the conductor in amps (A). The material from which a conductor is made, the length of the conductor, the diameter of the conductor, and the temperature of the conductor are all things that impact its resistance.

Using a simple circuit (Figure 5), a group of students investigated the dependence of a conductor's electrical resistance on its length, material, and diameter. The ammeter measures the current produced by a variable power supply. The voltmeter measures the potential voltage across the conductor.

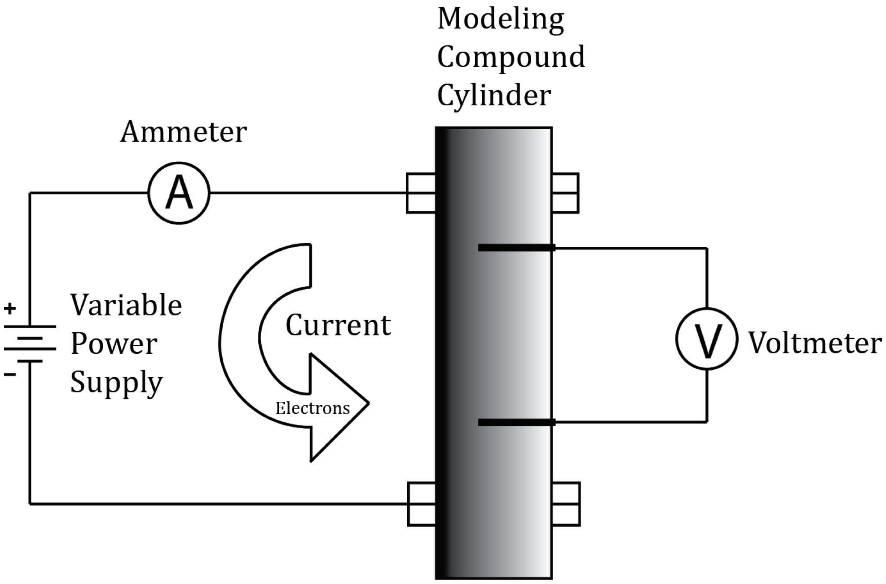

Figure 5

Experiment 1

To study the effect of a conductor's length on its resistance, the students used red modeling compound to make a cylinder 0.01 m in diameter and slightly longer than 0.1 m in length. The cylinder was connected to the circuit and a current of 0.04 A was applied. The voltmeter probes were inserted in the cylinder with a separation of 0.02 m and the voltage reading recorded. The separation distance between the probes is the conductor length. The separation was then increased by 0.02 m and the voltage recorded again. This was repeated until a total separation (conductor length) of 0.10 m was reached. The students calculated the resistance for each conductor length using Ohm's law. The results are summarized in Table 6.

Table 6: Experiment 1 Results			
Trial	Conductor Length (m)	Voltage, V (V)	Resistance, R (Ω)
1	0.02	1.58	39.5
2	0.04	3.15	78.8
3	0.06	4.79	119.8
4	0.08	6.34	158.5
5	0.10	8.10	202.5

Experiment 2

To study the effect of a conductor's material on resistance, the students repeated Experiment 1 for an identical cylinder made of blue modeling compound. The results are summarized in Table 7.

Table 7: Experiment 2 Results			
Trial	Conductor Length (m)	Voltage, V (V)	Resistance, R (Ω)
1	0.02	1.22	30.5
2	0.04	2.43	60.8
3	0.06	3.76	94.0
4	0.08	4.96	124.0
5	0.10	6.15	153.8

Experiment 3

To study the effect of a conductor's diameter on resistance, the students used red modeling compound to make three cylinders, each 0.12 m long and with diameters of 0.01 m, 0.02 m, and 0.03 m, respectively. Each cylinder was connected to the circuit with a voltmeter probe separation of 0.10 m and an applied current of 0.04 A. The resulting voltage reading was recorded for each cylinder diameter and the resistances calculated. The results are summarized in Table 8.

Table 8: Experiment 3 Results			
Trial	Conductor Diameter (m)	Voltage, V (V)	Resistance, R (Ω)
1	0.01	8.10	202.5
2	0.02	2.04	50.9
3	0.03	1.02	25.5