Section 8: Circuits and Magnetism

The following maps the videos in this section to the Texas Essential Knowledge and Skills for Physics TAC §112.39(c).

8.01 Current and Electric Circuits
- Physics (c)(5)(E)

8.02 Resistance and Ohm's Law
- Physics (c)(5)(F)

8.03 Resistors in Series and Parallel
- Physics (c)(5)(F)

8.04 Energy and Power in Electric Circuits
- Physics (c)(6)(C)

8.05 Magnetic Force and The Right-Hand Rule
Note: This section requires use of trigonometry.
- Physics (c)(5)(D)
- Physics (c)(5)(G)

Note: Unless stated otherwise, any sample data is fictitious and used solely for the purpose of instruction.

8.01

Current and Electric Circuits

Electric circuit – Any closed loop or conducting path allowing electric charges to flow

Current – The rate of flow of charge

- The symbol for current is I.
- Current is measured in ***amperes* (A)*.*** $1\ \mathrm{A} = 1\,\frac{\mathrm{C}}{\mathrm{s}}$.

Conventional current – The rate of flow of positive charge

Voltage – The amount of energy transferred by charges as they move through a circuit, per unit charge

- Voltage is like the engine that causes charge to flow from one end of the circuit to the other.
- As charge is moved through the circuit, the potential energies of the charges change.
- The symbol for voltage is V.
- Voltage is measured in ***volts* (V)*.*** $1\ \mathrm{V} = 1\,\frac{\mathrm{J}}{\mathrm{C}}$.

Conservation of charge – The idea that charge can be neither created nor destroyed

8.02

Resistance and Ohm's Law

Resistance – The property of a conductor that determines how much current will flow

- The symbol for resistance is R.
- Resistance is measured in ***ohms (Ω)***.

Resistor – A device in a circuit that possesses high resistance and dissipates energy

Resistors are typically made from ceramics coated with carbon films, metal films, and/or various lengths of wire.

The resistance of a given object depends primarily on three factors:

1) Geometry
    - As the *length* of a resistor _______________, the resistance ________________.
    - As the *cross-sectional area* of a resistor __________________, the resistance ________________.
2) Temperature   As temperature __________________, resistance _________________.
3) Type of material
    - Every material possesses a characteristic called ***resistivity***, which affects the resistance of resistors made from that material.
    - For example, silver has a very low resistivity, whereas rubber has a very high resistivity.

Ohm's law – The relationship between current, voltage, and resistance in a circuit

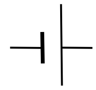
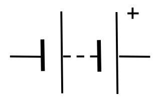
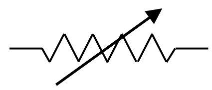
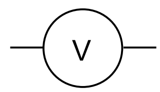
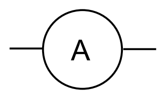
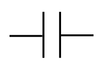
$$I = \frac{V}{R}$$

Ohm's law allows us to think about resistance as the ratio of voltage (V) to current (I).

$$R = \frac{V}{I}$$

A ***circuit diagram (schematic)*** is a drawing that represents the way the electrical components of a circuit are connected.

The following table lists some of the most common circuit components along with their schematic symbols.

Component Name	Schematic Symbol
Voltage source	
Battery	
Resistor	
Potentiometer (variable resistor)	
Voltmeter	
Ammeter	
Capacitor	
Switch	

1. Use a circuit diagram to show a voltage source connected to a switch and a resistor.

2. A desktop lamp with a resistance of $100\ \Omega$ is connected to a 9-V battery. Find the current in the circuit.

3. A computer monitor draws $1.5\ \text{A}$ of current when it is connected to a 5-V source. What is the resistance of the computer monitor?

8.03

Resistors in Series and in Parallel

When multiple resistors are connected, one can assign an ***equivalent resistance*** to the group of resistors.

The primary configurations of resistors are ***series*** and ***parallel***.

Resistors in Series

Resistors in series have the following properties:

- The resistors are connected one after the other in a line.
- There are no breaks in the wire connecting the resistors.
- The resistors share the same current.

To find the equivalent resistance of several resistors in series, add up the individual resistances according to the following formula:

$$R_{eq} = R_1 + R_2 + R_3 + \cdots$$

Resistors in Parallel

Resistors in parallel have the following properties:

- The resistors are connected on different sides of a split in a wire.
- The resistors share the same voltage.

To find the equivalent resistance of several resistors in parallel, add up the individual resistances according to the following formula:

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots$$

1. Find the equivalent resistance of four $15\text{-}\Omega$ resistors connected in series to a 180-V battery. What is the current in the circuit?

2. Suppose three $18\text{-}\Omega$ resistors are connected in parallel to a 12-V battery.

    i. Find the equivalent resistance.

    ii. Find the current through the entire circuit.

    iii. Find the current through each individual resistor.

8.04

Energy and Power in Electric Circuits

Energy and Power in Electric Circuits

- The energy change that a charge experiences as it moves across a potential difference is given by the following equation:

$$\Delta U = q\Delta V$$

- The rate at which energy is transferred in a circuit is often of concern, so we will be interested in power. Recall that power is given by this equation:

$$P = \frac{E}{t}$$

- Using Ohm's law ($V = IR$) and a little bit of substitution, we get the following equation for the ***power dissipated by a resistor***:

$$P = I^2R = \frac{V^2}{R}$$

- A resistor will typically get hotter when current passes through it.

- Rearranging the above equations, we can find the total ***thermal energy*** that a resistor dissipates in some amount of time, t.

$$E = Pt = I^2Rt = \left(\frac{V^2}{R}\right)t$$

- A common measurement for energy is the kilowatt hour (kWh). To convert between joules (J) and kilowatt hours, use the following relation:

$$1\ \text{kWh} = 3.6\times10^6\ \text{J}$$

1. A $30\text{-}\Omega$ stove coil operates on a 120-V outlet.

   i. Find the current through the heating coil.

   ii. Find the power dissipated by the heater.

   iii. Find the total energy that the heater uses in 20 seconds.

2. Daniela owns an electric space heater that draws $20\ \mathrm{A}$ of current from a 120-V source. She operates the heater 4 hours per day on average.

   i. How much power does the heater use?

   ii. How much energy (in kWh) does the heater consume in a month? Assume 30 days per month.

   iii. If the cost of power is $\$0.12$ per kWh, find the monthly operating cost for the space heater.

3. A 4,500-W electric clothing dryer is connected to a 240-V source. How much current does the clothing dryer draw?

4. The defroster in a car's rear window works by passing current through a resistor with low resistance and using the heat that develops to remove any moisture. Assume the resistance in a car's rear window is 1.5 Ω, and a 12-A current passes through the resistor.

   i. Find the voltage across the resistor.

   ii. Find the amount of power dissipated by the resistor.

   iii. If it takes 30 seconds to defrost the window, calculate the total thermal energy required to defrost the window.

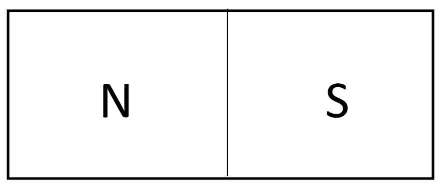
8.05

Magnetic Force and the Right-Hand Rule

A ***magnetic field*** is a vector quantity that accounts for the ***magnetic force*** that magnets have on one another and on moving electric charges.

Magnets have two poles: a north pole and a south pole.

Magnetic field lines exit from the _______________ pole and enter at the _________________ pole.



Electric currents create a magnetic field that circulates in a closed loop around the direction of current travel.

The ***first right-hand rule*** helps determine the direction of the magnetic field. To apply the first right-hand rule, do the following:

1) Point the thumb of your right hand in the direction in which current is travelling.
2) Curl your fingers.

The magnetic field circulates in the same direction that your fingers curl.

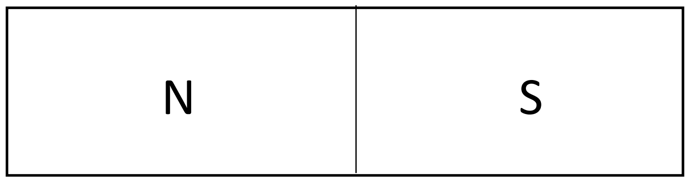
An ***electromagnet*** is a special type of magnet that is created when current flows through a coil of wire.

A ***solenoid*** is a long coil of wire composed of several loops.

The ***second right-hand rule*** is used to determine the direction of the magnetic field produced by an electromagnet. To apply the second right-hand rule, do the following:

1) Imagine that you are gripping a coil of wire with your right hand.
2) Curl your fingers in the direction of the current.

Your thumb will point in the direction of the magnetic field.



The force (F) on a current-carrying wire of length L, with current I, placed perpendicular to a magnetic field with strength B, is given by the following equation:

$$F = ILB$$

If the wire is not perpendicular to the magnetic field, then the equation is as follows:

$$F = ILB \sin\theta$$

The ***third right-hand rule*** is used to determine the direction of the force on a current-carrying wire in a magnetic field. To apply the third right-hand rule, do the following:

1) Point the fingers of your right hand in the direction of the magnetic field.
2) Point your thumb in the direction of the current in the wire.

Your palm will be facing the direction of the force on the wire.

1. A 1.5-m wire carries a current of 4 A and is perpendicular to a 0.8-T magnetic field. Find the magnitude of the force that acts on the wire.

2. A 0.4-m wire is carrying a current of 8 A and is perpendicular to a uniform magnetic field. The magnitude of the force acting on the wire is 0.2 N. What is the strength of the magnetic field?