Teacher Content Brief

Electric Circuits

Introduction

There are a variety of forces acting on the body of the Sea Perch. One important force is pushing electrons through the wires to allow navigation. The electrostatic force is the force between charged particles. If these particles are pushed uniformly through a conductor an electric current flows, which in turn allows the operation of a simple circuit.

This brief will introduce the quantities voltage, current, and resistance. The relationship of three quantities can be described using Ohm's Law. Ohm's Law is important for students to understand if they want to change the amount of current flowing through the Sea Perch, which controls the speed of the motor. Parallel circuits and series circuits will be introduced so that students will be able to use a multi-meter correctly to take measurements of current, resistance, and voltage. Circuit symbols will be introduced as a way to represent circuit diagrams without building them. Finally the brief will introduce the concepts behind wiring the motors so that they can run forwards and backwards at variable speeds.

Standards

Benchmarks 2061 Project (see References section to link to the online standards):

- At the end of 8th grade, students should know that
  - Energy can be transferred from one system to another (or from a system to its environment) in different ways: 1) thermally, when a warmer object is in contact with a cooler one; 2) mechanically, when two objects push or pull on each other over a distance; 3) electrically, when an electrical source such as a battery or generator is connected in a complete circuit to an electrical device; or 4) by electromagnetic waves.
  - Energy appears in different forms and can be transformed within a system. Motion energy is associated with the speed of an object. Thermal energy is associated with the temperature of an object. Gravitational energy is associated with the height of an object above a reference point. Elastic energy is associated with the stretching or compressing of an elastic object. Chemical energy is associated with the composition of a substance. Electrical energy is associated with an electric current in a circuit. Light energy is associated with the frequency of electromagnetic waves.
  - Electric currents and magnets can exert a force on each other.
  - Electrical circuits require a complete loop through which an electrical current can pass.
  - A charged object can be charged in one of two ways, which we call either positively charged or negatively charged. Two objects that are charged in the same manner exert a force of repulsion on each other, while oppositely charged objects exert a force of attraction on each other.

- At the end of 12th grade, students should know that
  - Thermal energy in a system is associated with the disordered motions of its atoms or molecules. Gravitational energy is associated with the separation of mutually attracting masses. Electrical potential energy is associated with the separation of mutually attracting or repelling charges.

- Many forms of energy can be considered to be either kinetic energy, which is the energy of motion, or potential energy, which depends on the separation between mutually attracting or repelling objects.
- The interplay of electric and magnetic forces is the basis for many modern technologies, including electric motors, generators, and devices that produce or receive electromagnetic waves
- The motion of electrons is far more affected by electrical forces than protons are because electrons are much less massive and are outside of the nucleus.

Background Information

Electric Potential

As a ball falls to the Earth it loses potential energy due to gravity and gains kinetic energy. This can be related to the Earth doing work on the ball. Remember work is defined as a force that causes displacement. As the force of gravity pulls on the ball it is being displaced, therefore work is done on the ball. This is similar to what happens to charged particles in an electric field. If you have two opposite charges that are attracted to each other, you would do work to pull them apart. This work would be stored as potential energy. The charge has the potential to move back towards the other charge. The electric potential difference is the amount of work on a charged particle.

$$\Delta V = (W_{on\ q})/q$$

This is measured in Joules per Coulomb, which is known as a Volt. In a circuit, as opposed to an electric field in general, the potential difference is often referred to as the voltage (V) of a circuit. The voltage drives electrons around the circuit, or the voltage does work moving the charges. How fast the charges move is known as the current.

The current (*i*) is the number of electrons to pass a set point in a certain amount of time.

$$i = \Delta q/\Delta t$$

The unit for current is the Ampere or Amp. One Amp is the equivalent of one Coulomb per second. Current can only flow if it has a path to a lower voltage. (Think of a stream of water, it tends to flow downstream not up a hill). When a closed path exists, this is called a closed circuit. When a path does not exist this is called an open circuit. This is important when designing and constructing circuits. If the circuit is open, no current will flow, so the motor will not spin. It is also possible to use this concept to your advantage by putting buttons or switches in a circuit to allow the operator to open and close the circuit. This allows them to start and stop the flow of electrons. To be able to push the electrons through the circuit there has to be a component able to do this work. Usually a battery is drawn in the circuit as the power supply.

How do batteries work?

Batteries are an important component in any electrical (or electro-mechanical) system. They supply a portable source of voltage. Batteries are containers with chemicals inside that produce electrons. These electrons are then drawn to an electrode inside the battery. When a circuit is connected between the plus (+) and minus (-) ends of the battery, electrons flow away from the – and towards the +. Note that the amount of electrons depends on Ohm's Law.

The resistance (R) is the measurement of how difficult it is for an electron to flow through a material. It measures how a material resists the movement of electrons. The unit for resistance is the Ohm (Ω).

Ohm's Law

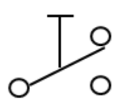
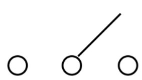
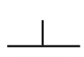
These three electrical quantities, voltage, current and resistance, are related using Ohm's Law. Ohm's Law is expressed with the following equation:

$$V = i \times R$$

For the Sea Perch the Voltage will be a constant supplied by the power supply. Your students will want to be able to control the current by changing the amount of resistance in a circuit. Also note that the current and resistance are inversely related. As the resistance increases the current decreases. As the resistance decreases the current increases. The current and voltage are directly related as long as the resistance remains constant.

Circuit Diagrams

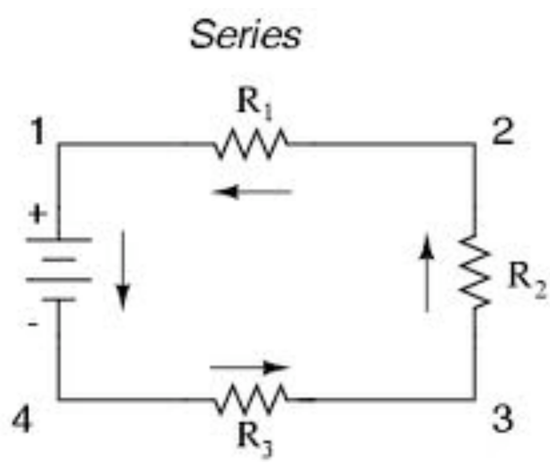
The goal of this section is to introduce the students to the basic concepts necessary in understanding, designing, and drawing circuits for the Sea Perch vehicle. Before the students can understand an entire circuit they need to be able to identify the different symbols for the individual components they might include in their circuit. For the purposes of this lesson the focus will be on the symbols that are used in the Sea Perch instructions. There are a few additional that will be helpful in exploring Ohm's Law.

Name	Symbol	Notes
Wire		Wires connect the other components and allow current to flow through them.
Button		Buttons are used to either a) open/close a circuit allowing current to flow or b) switch between two different circuits. Note that there is a normal position (either up or down) that the button will return to with no user input. (A button with two connections is shown).
Switch		Similar to a button, but there is no normal state -- the switch stays where the user puts it. (A two way switch is shown).
Fuse		This device is used to limit the current in a circuit. If the current gets to large, the fuse breaks causing an open circuit.
Motor		Motors are thoroughly discussed in the motor portion of the curriculum.
Battery		Supply a portable source of voltage and current.
Resistor		Resistors are elements that have a fixed resistance. They can be used to limit current using Ohm's law.
Ground		This is a point of zero voltage in a circuit. It is often used when analyzing circuits. This is where the current wants to go.

Circuit diagrams

Circuit Diagrams use the above symbols to represent different types of circuits. These diagrams allow the designer to visualize many different ideas without actually constructing the circuit. In addition to circuit diagrams being used to visualize ideas they also serve as records for circuits that have been designed, and tools for analysis. When drawing or reading a circuit diagram remember a circuit represents the path electrons will follow.

For the diagram below have your students follow the electrons' path, starting at the negative terminal of the battery. Have them describe what components the electrons flow through as they get to the positive terminal.



They should describe that the electrons are pushed by two batteries through a wire that passes through resistor 3 then a wire to resistor 2 then a wire through resistor 1 and finally back to the positive terminal of the battery. This is an example of a series circuit.

Parallel and Series

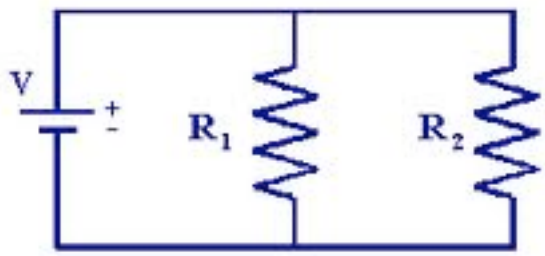
Think of the water flowing down the street after a heavy rain. The water will all flow to the low part of the street and then stay as a single stream of water. What happens if there is a pile of bricks in the way? The water may split into two or more streams until it can come back together as a single stream of water again. This can happen in electric circuits as well.

A series circuit is a circuit where the current only has one path to follow. This means the amount of current through each component is the same because it has nowhere else to go. Depending on the level of your students you could also explore that the voltage in resistors connected in series add up to the original voltage provided by the battery. The equation for finding the total resistance of resistors in series is

$$R_{total} = R_1 + R_2 + R_3 + \ldots\ldots.$$

This might be extra information depending on whether your students decide to add a variety of resistors in series to get a set resistance.

The other configuration used in circuits is a parallel circuit. A parallel circuit contains more than one path for the current to follow. Have your student follow the path in the following diagram? What does the current do when it has two paths to follow?



The current will follow the path of least resistance. This means if R_1 and R_2 are the same size the current will split evenly. If the R_1 is greater than R_2 then more of the current will flow through R_2. If the current in a parallel circuit is not equal for different size resistors it should still add up to the original amount of current flowing from the battery. According to Ohm's Law, even though the currents are different values the voltage across parallel resistors is the same.

If you are teaching more advanced students ask them to think about what happens to the total resistance of resistors in parallel, does it increase or decrease? Have them think of a hose with water flowing through it. If you buy a hose with a wider mouth (or a wider path) does the water flow more easily or is it harder to push the water through? Hopefully they can see that when the path is wider the resistance to the water is less. This is also true with resistors. The equation for finding the net resistance of parallel resistors is

$$\frac{1}{R_{TOT}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} \text{...etc.}$$

Note: Ask students if Christmas tree lights are connected in series what would happen if one bulb blew its fuse? They should answer that the path is then open and all of the lights would go out. What would happen in a parallel circuit if one bulb burned out? They should then answer that the circuit was still closed or complete and the current would flow through the remaining bulbs.

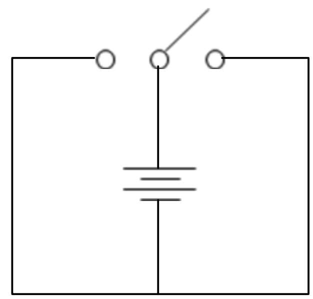
Multimeters

If you are working with advanced students you may have them use multi-meters to measure actual quantities of current and voltage in the circuits they build. A multi-meter is able to measure resistance, current and voltage.

There are a few things that will make the measurements more reliable. When measuring the resistance in a resistor, make sure there is no current flowing. When current flows through a resistor over time the temperature may increase and change the measurement of resistance. If measuring the current flowing into a component place the multi-meter in series. Remember objects in series have the same current. If you place the multi-meter in parallel then it will split the current and you will not measure what is actually flowing in the component but instead will measure the current in the multi-meter itself. If you measure voltage then place the multi-meter in parallel because objects in parallel have the same voltage. In the experiment portion of this module you can have the students practice these techniques.

Switches and Buttons

Sometimes when designing a circuit it is advantageous to be able to choose which path the electrons will follow. This requires a switch or a button. In the circuit below there is a parallel circuit where the two paths are connected by a switch. The switch changes the path of the electrons from one side of the circuit to the other depending on which side forms a closed circuit. If neither side is closed the current will not flow. This allows things like motors to be turned on or off (if you put a motor on one of the circuit paths.)



Buttons perform a very similar operation but when the button is not pressed the circuit goes back to its original path. For example, if the button were set to its normal position, the current would flow that way continually until the button was pushed to change the direction of the circuit. How would the circuit above change if there was a button instead of a switch? Have your students brainstorm the pros and cons of using a button instead of a switch.

Motor Circuits

This section will introduce students to the concepts required to wire the motor for forward, backward, and variable motion. The direction a motor spins is dependent on the direction of the current. Swapping the battery terminals connected to the motor can change the current direction in a motor. Remember the electrons flow from the negative terminal to the positive terminal. Given this information the students will want to think about designing circuits that can switch the way the battery is connected to the motor to change the direction of the current. Have your students draw a simple circuit diagram where a button or switch is used to change the direction the current flows through the motor.

The speed of the motor is also related to the current being applied to the motor. As the current increases so does the force induced in the motor. This leads to a faster spin for the propellers. There are a number of ways to vary the current flowing into a motor. One way is to vary the voltage by using a variable voltage source. According to Ohm's Law as the voltage changes so does the current. Another way is to change the resistance of the motor. Ohm's Law shows that as the resistance increases the current decreases. The students can change the resistance of the circuit by adding a fixed resistance in series with the motor.

Circuits and the Sea Perch

Your students will want to build circuits that will allow them to change the direction of the motors and the speed of the motors. In order to do this they will want to design and build some simple circuits where they use Ohm's Law to control the current, voltage, and resistance. Your students should be careful with their motors. Many electronic components have limits of how much current or voltage should be applied to see them work at maximum capacity. Have the students work on the experiments first to gain an understanding of how to set up circuits they have designed and possibly how to use multimeters to measure these values. Once they have shown proficiency with these experiments then they can work with their actual Sea Perch components.

Additional Resources

- **Please visit the following URLs, which links to simulations are from the University of Colorado at Boulder website.**
  - **Have students look inside a resistor to see how it works. Increase the battery voltage to make more electrons flow through the resistor. Increase the resistance to block the flow of electrons. Watch the current and resistor temperature change - http://phet.colorado.edu/en/simulation/battery-resistor-circuit**
  - **Look inside a battery to see how it works. Select the battery voltage and little stick figures move charges from one end of the battery to the other - http://phet.colorado.edu/en/simulation/battery-voltage**
  - **This simulation is an electronics kit in your computer. Build circuits with resistors, light bulbs, batteries, and switches. Take measurements with the realistic ammeter and voltmeter - http://phet.colorado.edu/en/simulation/circuit-construction-kit-dc**

Glossary

Electrostatic force: The force between two charged particles.

Current: The amount of charge to pass a set point in a certain amount of time.

Voltage: A measure of the difference in electric potential between two points in an electric circuit, expressed in volts.

Resistance: A property of a conductor by which the passage of current is opposed, causing electric energy to be transformed into heat; equal to the voltage across the conductor divided by the current flowing in the conductor, measured in Ohms.

Ohm's Law: Voltage = current x resistance

Parallel circuits: a closed electrical circuit in which the current is divided into two or more paths and then returns via a common path to complete the circuit

Series circuits: a closed electrical circuit in which the current has only one path to follow to complete the circuit.

multi-meter: a device consisting of one or more meters, as an ammeter and voltmeter, used to measure two or more electrical quantities in an electric circuit, as voltage, resistance, and current.

potential energy due to gravity: the stored energy of a body or a system with respect to the position of the body relative to the ground.

kinetic energy: the energy due to motion

work: The quantity found related to a force causing the displacement of an object.

electric potential difference: The work done per unit charge as a charge is moved between two points in an electric field.

Joules: The unit for energy and work

Coulomb: The unit to measure the size of a charge

Volt : The unit to measure voltage. 1 Volt = 1 Joule/Coulomb

Ampere: The unit to measure electric current. 1 Amp = 1 Coulomb/second

Ohms: The unit to measure resistance.

closed circuit: A circuit without interruption, providing a continuous path through which a current can flow.

open circuit: A discontinuous circuit through which no current can flow.

Button: Used to either a) open/close a circuit allowing current to flow or b) switch between two different circuits. Note that there is a normal position (either up or down) that the button will return to with no user input.

Switch: control consisting of a mechanical or electrical or electronic device for making or breaking or changing the connections in a circuit

Battery: a combination of two or more cells electrically connected to work together to produce electric energy.