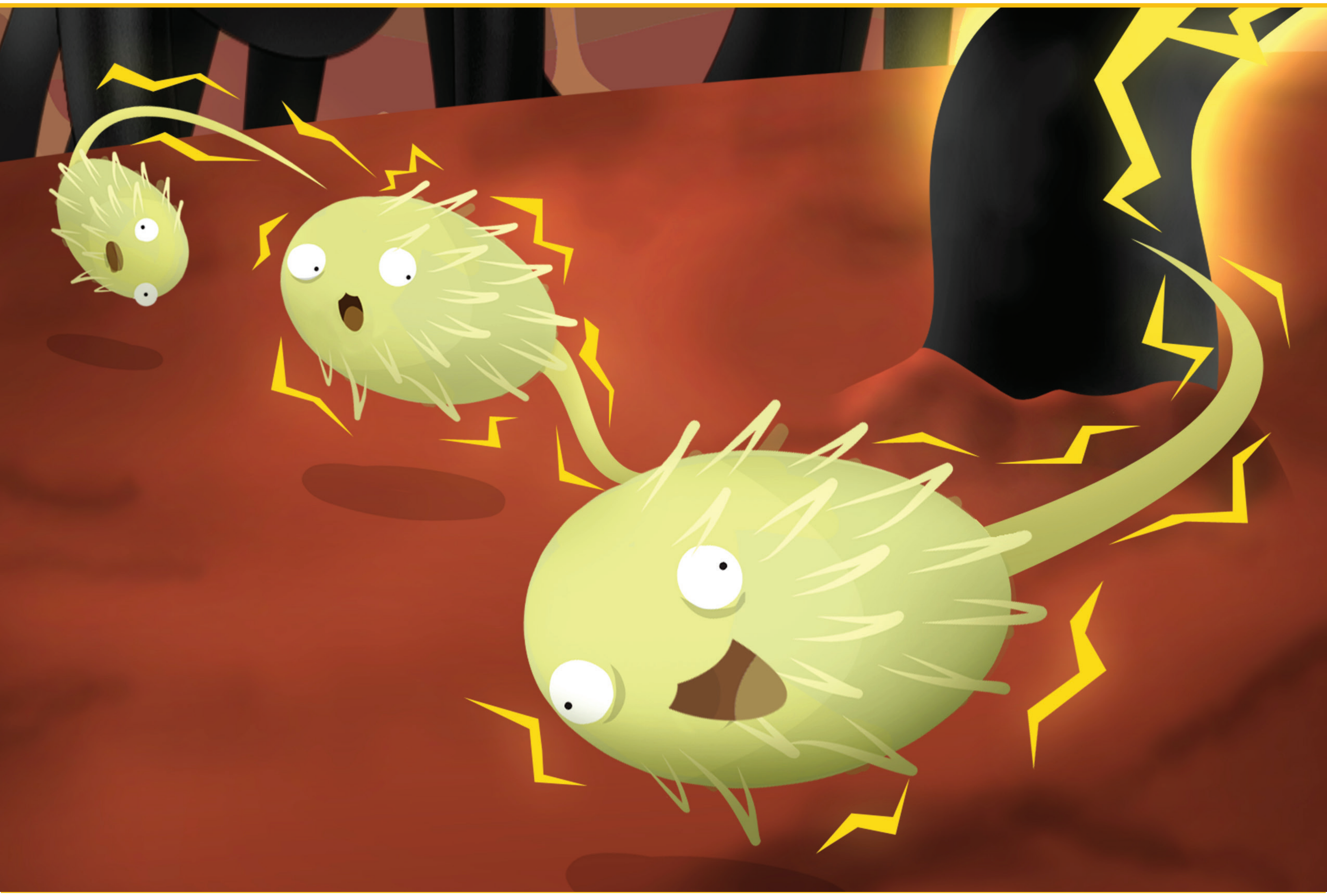
MODULE 2

MAGICAL MICROBES

NGSS TEACHER'S GUIDE

Electricity and Circuits



NGSS Alignment

CORE IDEAS

Core Idea PS1: Matter and Its Interactions

PS1.A: Structure and Properties of Matter

Core Idea PS3: Energy

PS3.A: Definitions of Energy

CROSS CUTTING CONCEPTS

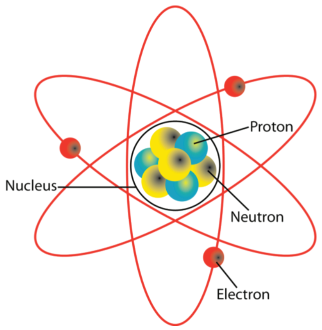
- ☐ Patterns
- ☐ Cause and effect: Mechanism and explanation
- ☐ Scale, proportion, and quantity
- ☐ Systems and system models
- ☑ **Energy and matter: Flows, cycles, and conservation**
- ☐ Structure and function
- ☐ Stability and change

PRACTICES

- ☑ **Asking questions (for science) and defining problems (for engineering)**
- ☐ Developing and using models
- ☑ **Planning and carrying out investigations**
- ☑ **Analyzing and interpreting data**
- ☑ **Using mathematics, information and computer technology, and computational thinking**
- ☑ **Constructing explanations (for science) and designing solutions (for engineering)**
- ☑ **Engaging in argument from evidence**
- ☑ **Obtaining, evaluating, and communicating information**

BACKGROUND

Part A: The Building Blocks of the Universe



http://www.ck12.org/book/CK-12-Earth-Science-Concepts-For-High-School/section/3.1/

Figure 1. An Atom

Atoms are the basic unit of a chemical element. They are the smallest unit of matter (that still retains its characteristics) and are made of smaller, subatomic particles called protons, neutrons and electrons. **Protons** are positively charged particles, **neutrons** are particles that have no electrical charge and **electrons** are negatively charged particles. If we could see an atom it would look approximately like the image in ***Figure 1***.

Protons and neutrons are concentrated in the center of the atom, in the nucleus, while the electrons are zipping around the nucleus. Even though the electrons are relatively far away from the nucleus and there seems to be a lot of empty space in an atom, the electrons are zipping around SO fast that, just like the blades of a fan when they are spinning, the atom behaves as if there were no empty space.

There are over 118 different types of atoms that have been identified and each one is made of identical subatomic particles: protons, neutrons and electrons.

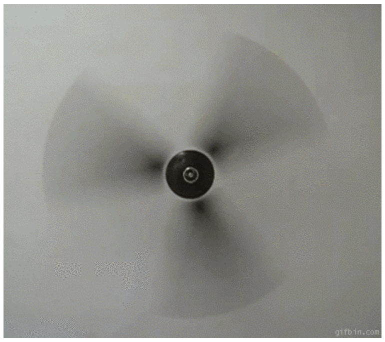


Figure 2. Fan blades spinning like electrons around an atom

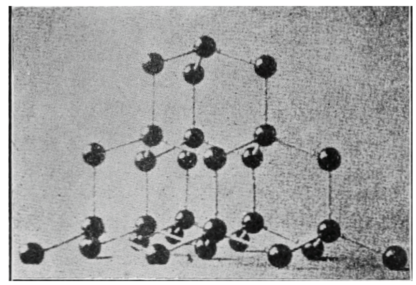
If all protons, neutrons, and electrons are identical, then what makes atoms different from each other?

The **number of protons** in the nucleus is what distinguishes one atom from another. Each atom has a unique number of protons in its nucleus, which makes that atom behave differently from any other atom.

The subatomic particles in atoms are held together by **attractive forces**. Particles having opposite charges attract strongly. The electrons closest to the nucleus experience a stronger attraction to the protons in the nucleus than electrons that are orbiting farther away from the nucleus. Electrons can be lost to another atom if the attractive force to the other atoms is stronger than the attractive force within the atom. How easily or not an atom's electrons are lost to other atoms determines how electrically conductive a material is, or how easily electricity can flow through that material.

Atoms sometimes gain or lose electrons to other atoms. When electrons move from atom to atom a **current** is produced. Electricity is the movement of electrons from one atom to another. Some atoms hold onto their electrons very tightly. Materials composed of such atoms tend not to let electricity move through them very easily and are called insulators. Other materials, particularly metals like copper and gold, don't hold onto electrons quite as strongly; thus, electrons can move more easily from one atom to the next. We call these types of materials that can carry electricity **conductors**.

For some atoms, such as Carbon atoms, the form in which the atoms are connected will change whether or not it is a conductor. For example, when Carbon molecules are connected together as sheets in a **hexagonal** pattern (creating graphite), it is a strong **conductor**, but when the Carbon molecules are connected in a **pyramid** pattern (creating diamond), it is a strong **insulator**.



https://commons.wikimedia.org/wiki/File:PSM_V87_D114_Arrangement_of_carbon_atoms_in_a_diamond.png#/media/File:PSM_V87_D114_Arrangement_of_carbon_atoms_in_a_diamond.png

Figure 3. Arrangement of carbon atoms in a diamond

Part B: Electric Potential and Current

How do electrons start to move?

Electrons need to get energized to be able to move just like you need energy to move. Where does that energy come from? For an object to move from rest, a **force** must be applied to that object. Newton cleverly has called this his **first law of motion** – an object at rest will stay at rest unless acted upon by an unbalanced force. No force, or equal forces all around, means a resting object will not move.

The force that moves electrons in a certain direction in a wire is called the **Electromotive Force** or **EMF**. Sometimes EMF is thought of as electrical "**pressure**." When there are more electrons in one place than another, the resulting imbalance in electrical charge moves the electrons to balance the charges between the two places.

The secret to electricity is creating a situation where one location has more electrons than another and connecting those two places by a wire so that electrons can move to try to balance the charges.

How does this EMF get created?

An EMF can be made in many ways. We can use the MudWatt as an example of a living battery in which an EMF is created.

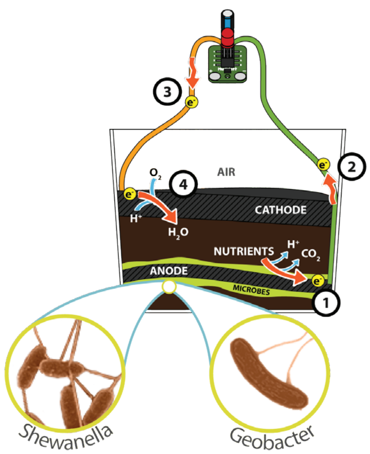


Figure 4. Diagram of a MudWatt

In a MudWatt, electrons are given off by the electrogenic bacteria surrounding the anode (the electrode that is buried in the mud). This creates a **higher concentration of electrons** at the anode than at the cathode so the electrons move through the wire towards the cathode.

In a chemical battery, such as the ones we use for our flashlights, a chemical reaction happens inside the battery. Electrons are given off during these reactions. Batteries consist of two electrodes (the anode and the cathode), just like the MudWatt. However, in chemical batteries, the anode is made of material that **concentrates electrons**, while the cathode is not. Thus, an imbalance of electrons is created between the two electrodes. When the two electrodes are connected by a wire, the electrons flow through the wire from the anode to the cathode.

EMF is measured as **voltage**, measured in units of volts. A volt is a measure of the electric potential, or EMF, that exists between two points.

Measuring Voltage

We learned earlier that voltage is a measure of the electric potential, or force that is set up to drive the flow of electrons. Another way to think of voltage is to think about water in a hose with a hand operated nozzle on the end. Even when the water is not flowing, there is still **pressure** in the hose. The amount of pressure in the hose is analogous to level of **voltage** in an electrical circuit. Like the water in the hose, the electrons will not flow until a **conductor** enables them to move from an area with higher negative charge to an area with lower negative charge.

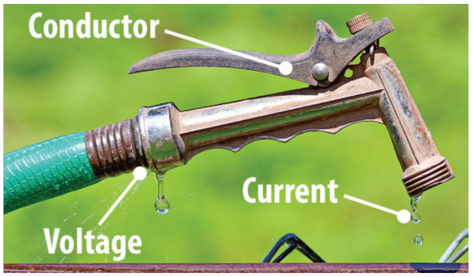


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Figure 4. Diagram of Voltage and Current in a Water Hose

Measuring Current

Another measurement we would like to know is how much electricity is flowing through the wires in a circuit. The amount of electricity that is flowing through the wires is called the **electrical current**. In the water hose analogy, current is like the rate of flow of the water in the hose. The amount of electrical current flowing in a wire is measured in Amps (short for Amperes).

Part C: Electric Potential and Current

Every electrical circuit has a certain amount of **resistance** to the flow of current through it. Many factors affect the resistance of a particular material. The resistance in a wire can change with the **thickness** of the wire and with the type of **material** the wire is made of. The amount of resistance in a circuit is measured in Ohms (Ω).

Resistance in a wire or other conductive material creates friction, which produces **heat**. If you send to much current through a wire that is not designed to handle that much current, then the friction causes so much heat that fires can start! In some cases where the EMF or voltage is too high for the wires used, components called **Resistors**, can be added to the circuit to protect against excessive heating. Resistors restrict the flow of electricity in a controlled way.

How are voltage, current and resistance related?

In 1827, George Ohm published an equation that relates voltage, current and resistance. This equation, known as Ohm's Law:

Equation 1: Ohm's Law

$$I = V/R$$

I = current (A), V = voltage (V), and R = resistance (Ω)

Understanding Ohm's law

As shown in **equation 1**, the electrical current in a circuit can be calculated by dividing the voltage by the resistance. If the resistance is held constant, and you increase your voltage (say by adding another battery to your circuit), then the current will also increase. In our hose analogy, this would be the equivalent of keeping your nozzle at the end of the hose slightly open, while opening up the faucet (leading to more pressure and therefore more water flow).

Ohm's Law can be rearranged if you are trying to solve for voltage or resistance. These equations are mathematically identical.

Equation 2: $$V = I \times R$$

In **equation 2**, voltage can be calculated if the current and the resistance in a circuit are known. From the equation, we can see that if either the current or the resistance in a circuit is increased (while the other is unchanged), the voltage will also increase.

Equation 3: $$R = V/I$$

In **equation 3**, resistance in a circuit can be calculated if the voltage and current are known. If the current is held constant, an increase in voltage will result in an increase in resistance. If the current is increased while the voltage is held constant, the resistance will decrease.

Note: For a wide variety of materials (such as metals) the resistance is fixed and does not depend on the amount of current or the amount of voltage.

Part D: Power, Glorious Power!

When talking about energy production, the term power is frequently used. **Power** is the amount of energy used per unit of time. The unit of power is the Watt, which is a rate of the amount of Joules (a discrete unit of energy) per second.

The amount of power can be calculated, if the voltage and current are known, using the following equation:
The **Power** (P) in Watts is equal to the **voltage** (V) in Volts multiplied by the **current** (I) in Amps, so increasing the voltage or current in a circuit will increase the amount of power produced.

Equation 4: $$P = V \times I$$

Power is also related to the resistance in a circuit by the following equation:
Here the **Power** (P) in **Watts** (W) is equal to the **voltage** in volts (V) squared divided by the **resistance** (R) in Ohms.

Equation 5: $$P = V^2/R$$