Transparent Alternator Kit
Introduction to Quantum Theory

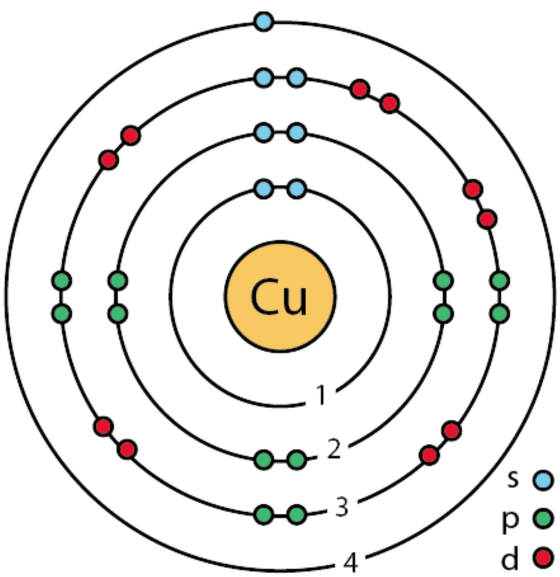
OHM-150

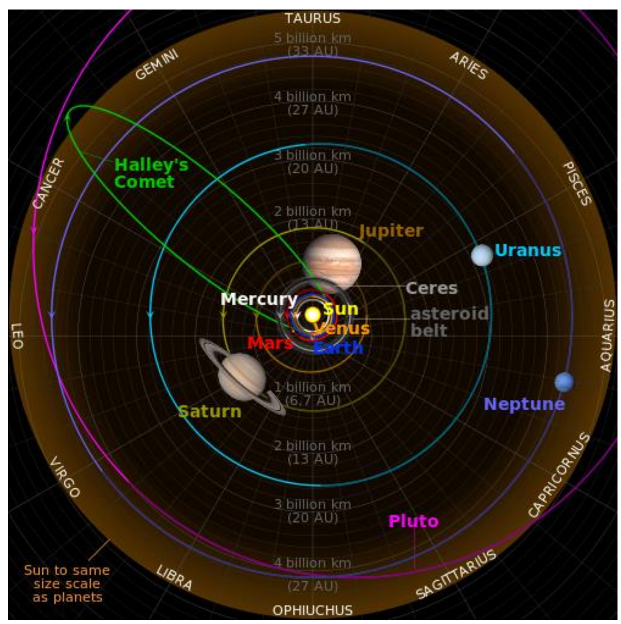
Basic Summary

The Transparent Alternator is composed of only four pieces: the magnet, the casing, the wire, and the LED. Together these pieces demonstrate some of the most important concepts of the last 100 years of physics.

You might know that everything we can see around us is made up of tiny smaller pieces called **atoms**. Atoms are made up of two pieces: a **nucleus** in the center and **electrons** which go around and around the nucleus. More than one nucleus are called **nuclei**.

We can draw a simple diagram of what this looks like:





This model of the atom and our understanding of the solar system look very similar. In fact, this is one of the ways that early scientists first started to make sense of atoms.

Electrons are very important particles. They're very small and they carry an **electrical charge**. They carry electricity to power our homes. Electrons are in everything we see around us, but they act differently depending on what material they're in.

In materials like wood or plastic, the electrons stick very closely to the nuclei.

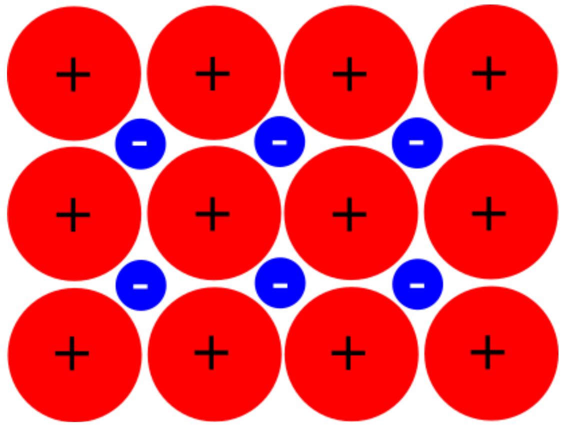


Image of an insulator. Red particles are nuclei, blue are electrons.

When electrons stick very closely to nuclei, electrical charge isn't carried very far. We call materials that behave this way **insulators**. The plastic casing of your Transparent Alternator is an insulator. If you connect the LED to the case instead of the wire, nothing will happen when the magnet spins.

In materials like metal, however, the electrons can move more freely because the electrons aren't held very tightly to the nuclei.

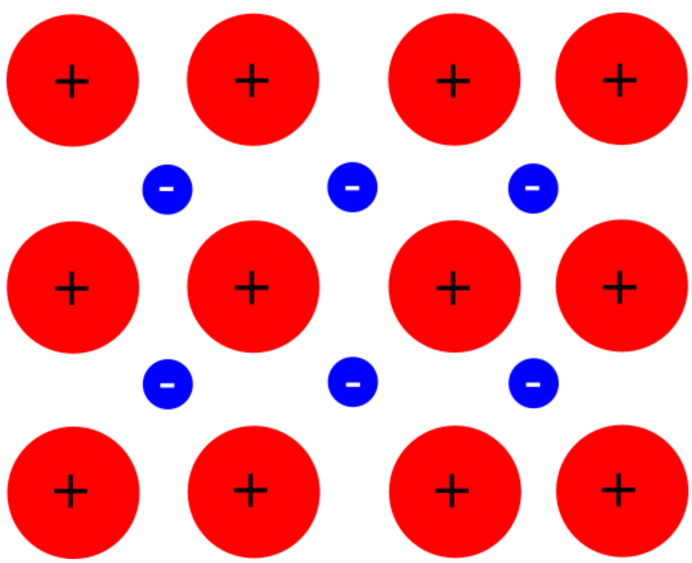


Image of a conductor. Red particles are nuclei, blue are electrons.

When electrons can move more freely, they can carry electric charge a further distance. We call materials where electrons can move freely **conductors**. Metals are usually very good conductors, which is why we make wires out of metal. The electrons in these wires move very easily, and can be used to provide electricity.

But we need more than just a conductor to generate electricity. If you try to connect just the wire to the LED, nothing happens! We need to add something to push the electrons and create an **electric current**—similar to how a bicycle won't move if someone doesn't pedal it. We can connect a battery to the LED using the wires, and the battery will push the electrons through the LED light bulb by creating a **voltage difference**.

Still, a battery will eventually run out of power. We can generate electricity in a different way, using magnets. If you connect the LED to the wire coiled around the magnet, the LED lights up when the magnet spins! This is because the magnetic field is moving the electrons, and directly creating an electric current.

But why does spinning the magnet cause the LED to light up?

Magnets are very special materials. They are attracted to metal because they are made of certain compounds. Normally in a material, the electrons would all push in different directions. The atoms that magnets are made up of have a very specific arrangement of electrons. In magnets, the electrons work *together as a team* to push or pull in one direction. When we spin a magnet around in the alternator, the electrons in the magnet push electrons around the wire, exactly as a battery does!

So when we spin the magnet in the Transparent Alternator, the magnet pushes on the electrons in the wire (creating an electric current), causing them to move through the LED to make it glow!

Lesson 1: Particles Are Everywhere

1. Ask students to identify the different materials used in the Transparent Alternator Kit.

2. Ask students: What is special about these materials? What are the properties of metals? What are the properties of plastic?

3. Ask students: What the smallest pieces are that a piece of metal can be broken down into? What about a piece of plastic? Are these pieces made of the same thing?

4. Ask students: Why do metals and plastics have such different properties?

5. Copy and distribute to students the *Molecules and Atoms* handout on page 6. To make things simpler—and to keep our focus on subatomic particles—we will only consider atoms in this lesson.

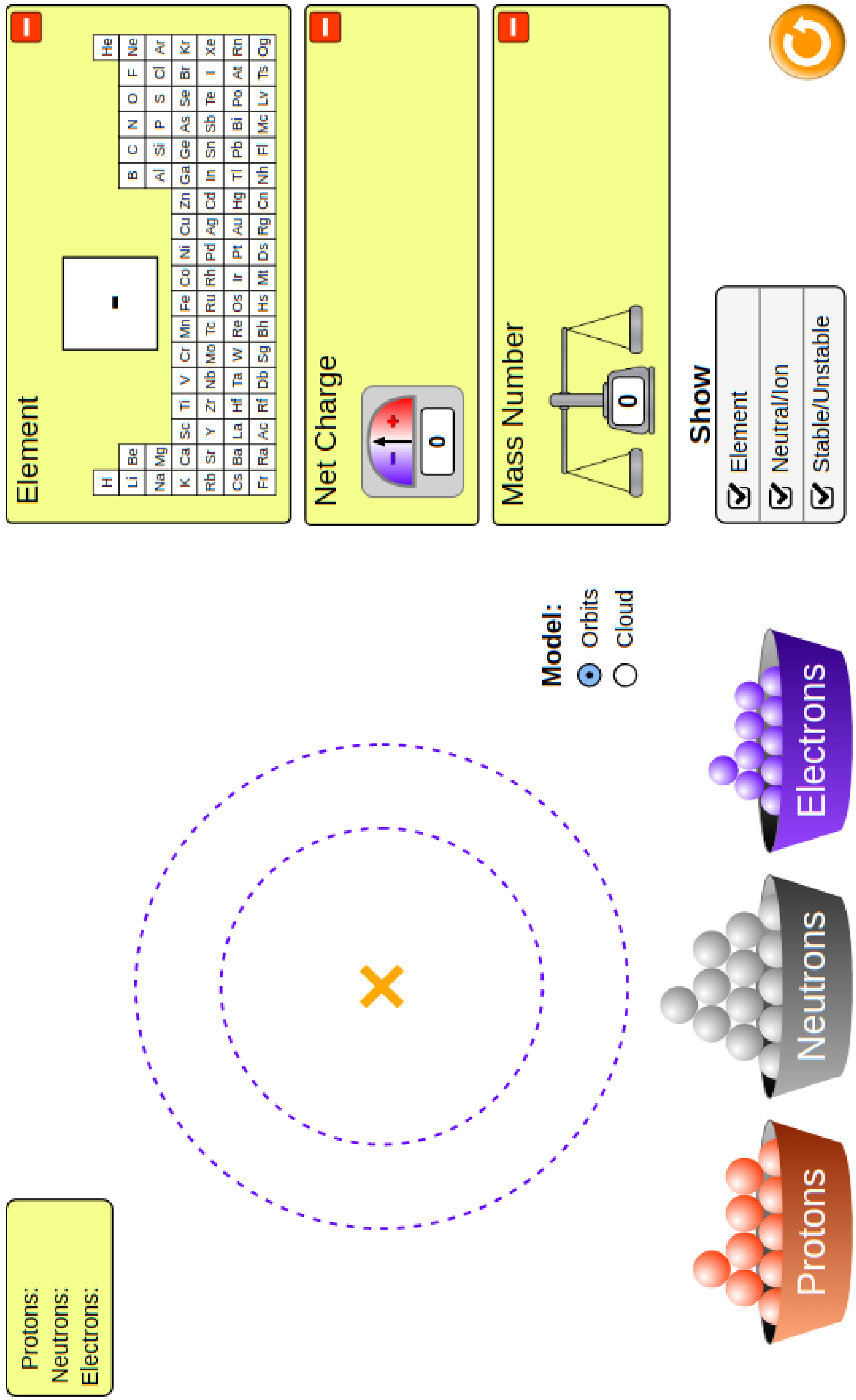
6. Introduce and describe the properties of three different elements to students. The three elements we suggest are carbon, oxygen, and copper. Copy and distribute the *Comparing the Electronic Structure of Elements* handout on page 7.

7. Ask students: Have they ever seen these elements in common life? Ask them to give some examples.

8. Ask students: What differences do they notice between these three elements? Discuss how different numbers of particles drastically change the phase, conductivity, color, malleability, etc. of these elements. Point out how the Periodic Table is organized—with conducting metals in the center and on the left side of the table.

9. **High School Option:** Have students open up the PhET interactive simulation on elements and atoms located here: **https://phet.colorado.edu/sims/html/build-an-atom/latest/build-an-atom_en.html**. Ask students to expand all of the displays on the right side of the PhET, and ensure all checkboxes are selected (Element, Neutral/Ion, and Stable/Unstable). They should also confirm that the simulation is set to orbits. See the image on the next page for a representation of what the starting configuration should look like.

10. Give students ample time to play with the PhET—adding neutrons, protons, and electrons in order to discover what the "rules" might be for stable elements. Instruct them to record their observations as to how the Periodic Table is organized, what makes an element stable, and so on.


Element
Net Charge
0
Mass Number
0
Show
Element
Neutral/Ion
Stable/Unstable
Model:
Orbits
Cloud
Protons
Neutrons
Electrons
Protons:
Neutrons:
Electrons:

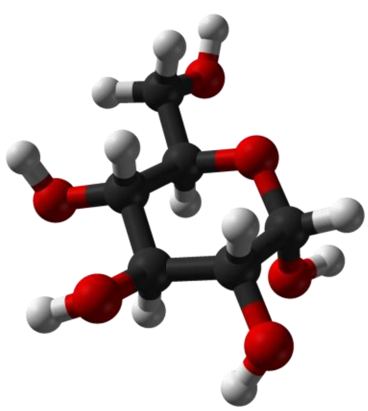
Molecules and Atoms

Everything we see around us is made up of small particles that can be sorted based on their size or mass. This is how we get the Periodic Table of Elements.

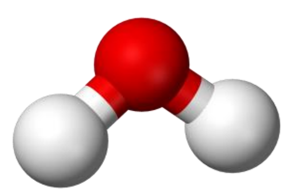
Group → / Period ↓	1	2	3		4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1	1 H																		2 He
2	3 Li	4 Be												5 B	6 C	7 N	8 O	9 F	10 Ne
3	11 Na	12 Mg												13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
4	19 K	20 Ca	21 Sc		22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
5	37 Rb	38 Sr	39 Y		40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
6	55 Cs	56 Ba	57 La	*	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
7	87 Fr	88 Ra	89 Ac	**	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
				*	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
				**	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Everything on this table represents a single particle called an **atom**. Atoms are made up of subatomic particles: protons, neutrons, and electrons. These particles work together to give atoms different properties. Lighter elements are more common, while some of the heaviest elements can only be produced in a laboratory. Every atom on the Periodic Table is slightly different, but many of them act in similar ways. Usually atoms in the same column have related properties. For example, all the elements in the first column (called **Groups**) under Lithium (symbol **Li**) react with water very violently.

The world has many more substances and materials than the 118 listed here. While everything we see and touch is made up of atoms, most of the time the materials we see are made up of a collection of atoms called **molecules.** Molecules are complex structures made by atoms interacting with one another. Some are more complex, like the glucose molecule (a component of table sugar) shown at left below, but many are very simple, like the water molecule shown at right below.



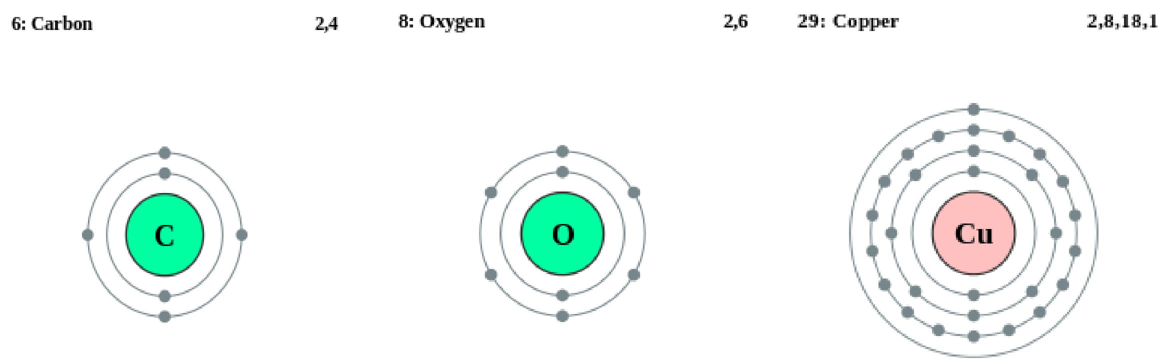
glucose molecule



water molecule

Comparing the Electronic Structure of Elements

The images below are called **Bohr Orbital Diagrams**. They're simple and effective ways of investigating the properties of elements and how they interact with one another. It's important to realize that these are just models—they're tools that help us investigate, and not necessarily what these elements actually look like. There are rules as to how to construct these diagrams, but we won't go through them here.



Bohr orbital diagrams for a variety of elements.
Image source: Greg Robson, Creative Commons Attribution-Share Alike 2.0 UK: England & Wales

A few points regarding each of these elements:

Carbon

- A building block of life: 18.5% of the human body
- Comes in two forms: graphite and diamond
- Graphite is a good conductor, diamond is a poor conductor
- Solid at room temperature
- Molecular form is solid
- Four electrons in furthest orbital

Oxygen

- Main component of the air we breathe
- Poor conductor in gas state
- Gaseous at room temperature
- 65% of the human body
- Six electrons in furthest orbital; only two electrons different from carbon, with drastically different properties

Copper

- Excellent conductor
- Metal; solid at room temperature
- Single electron in its furthest orbital is further away from the center nucleus, and can be removed easily

Properties of elements depend on how tightly the nucleus will hang onto the outer electrons. As elements get bigger, they have the ability to hold onto more electrons, but the electrons also get further away, making them harder to control.

Elements that tend to lose electrons more easily are usually considered metals; copper here is one example. Notice that it has a single electron in its furthest orbital, which is much further away than the electrons in the carbon or oxygen atoms.

Lesson 2: Conductors and Insulators

1. Remind students that everything we see is made up of protons, neutrons, and electrons.

2. Have the students examine the assembled Transparent Alternator and spend some time exploring it. Ask them to pay attention to how it works, and to form some guesses about why these particular materials were used.

3. Have the students carefully remove and reattach (or just hold) the leads from the wires to the plastic casing.

4. Ask them to play with this version of the Transparent Alternator, and take note of what's different.

5. Why does the alternator not work when the leads are attached to the plastic casing? What different properties might the metal have that the plastic does not have?

6. Copy and distribute to students the *Conductors and Insulators* handout on page 9. Introduce the subject of conductors and insulators.

7. Have the students name some conductors that they know. Identify these (or have the students identify them) on the Periodic Table. Where are they located?

8. Show the students the Bohr Orbital diagrams for a few common conducting metals (i.e., copper, nickel, gold, or silver). Discuss how electricity emerges from moving electrons and how the charges on these elements are loosely held by the atoms, allowing them to move freely in metals.

In materials like wood or plastic, the electrons stick very closely to the nuclei.

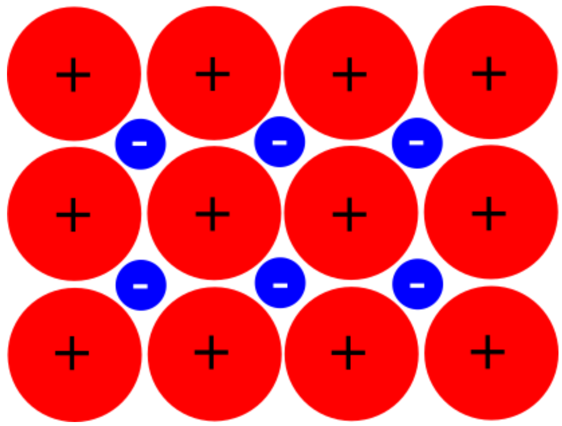


Image of an insulator. Red particles are nuclei, blue are electrons.

When electrons stick very closely to nuclei, electrical charge isn't carried very far. We call materials that behave this way **insulators**. The plastic casing of your Transparent Alternator is an insulator. If you connect the LED to the case instead of the wire, nothing will happen when the magnet spins.

In materials like metal, however, the electrons can move more freely because the electrons aren't held very tightly to the nuclei.

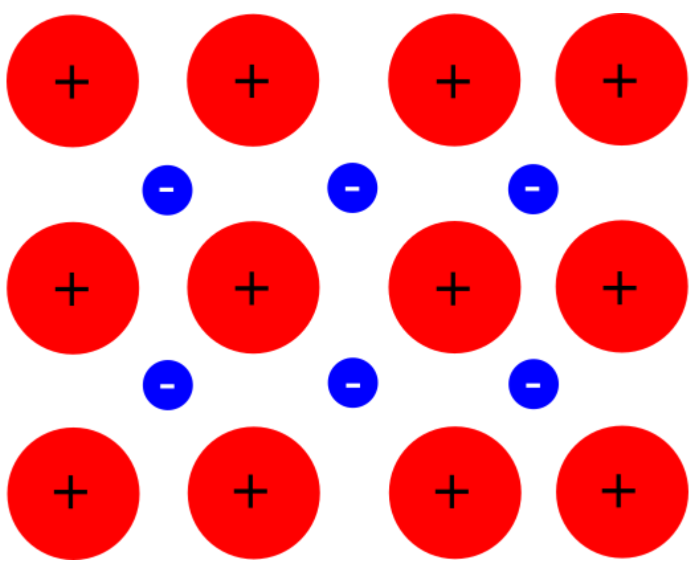


Image of a conductor. Red particles are nuclei, blue are electrons.

When electrons can move more freely, they can carry electric charge a further distance. We call materials where electrons can move freely **conductors**. Metals are usually very good conductors, which is why we make wires out of metal. The electrons in these wires move very easily and can be used to provide electricity.

Lesson 3: Magnetism

1. Remind students about conductors and insulators, and how electrons can easily move in conductors.

2. Remind students that electricity is caused by the coordinated movement of electrons.

3. Ask the students to play with the Transparent Alternator. Explain that today they will be investigating how the magnet is able to power the lightbulb.

4. Discuss with the students what they observe when they spin the magnet in the Transparent Alternator.

5. Ask the students what they think the magnet might be doing to the electrons in the wire.

6. **Optional:** Use the Faraday's Law PhET to show students a simulation of what is going on. **https://phet.colorado.edu/sims/html/faradays-law/latest/faradays-law_en.html**

7. Copy and distribute to students the *Interactions between Charged Particles and Magnets* handout on pages 11-12. Introduce the subject of how electrons and magnets interact with one another.

8. **High School Option:** Ask the students where they think magnetism comes from. Ask them to name different sources of magnetism.

9. Introduce the concept of permanent magnets and electromagnets. Explain that magnetism in both of these cases comes from the organized arrangement of electrons.

10. Introduce the concept of spin. Just as electrons have properties like mass, charge, and size, each electron also has a special property called *spin*. This causes each electron to behave like a tiny bar magnet.

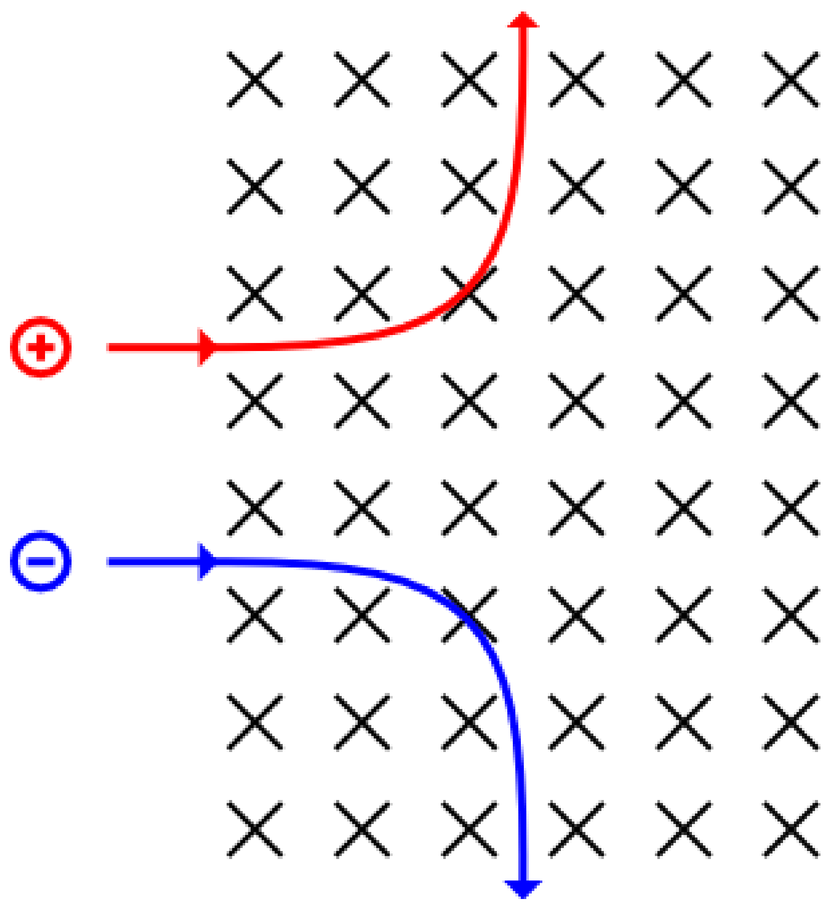
11. Normally in a material, the electron spins would all push and pull in completely different directions, and there would be no overall magnetism. The atoms that magnets are made up of have a very specific arrangement of electrons. In magnets, the electrons work together as a team to push or pull in one direction.

Interactions between Charged Particles and Magnets

Magnetism is fundamentally a result of quantum mechanics and quantum properties. Magnetism cannot be explained using only classical physics. This is what is known as the **Bohr-van Leeuwen theorem**.

Magnets are very special materials. They are attracted to metal because they are made of certain compounds. Normally in a material, the electrons would all push in different directions. The atoms that magnets are made up of have a very specific arrangement of electrons; in magnets, the electrons work together as a team to push or pull in one direction. When we spin a magnet around in the alternator, the electrons in the magnet push electrons around the wire, creating electricity.

Elementary particles which we've introduced that carry charge are protons (+1 charge) and electrons (-1 charge). Magnets are an important tool in physics for controlling particles with charge. Any time an object with charge enters a magnetic field, it experiences a force. In a uniform magnetic field, this force causes particles to move in a circular motion.



Magnetic forces on charged particles (red = positive, blue = negative) in a uniform magnetic field.

We can see this in nature using a device called a cloud chamber. We can see the paths of subatomic particles using this device. As an optional activity, you may want to make your own cloud chamber. Information here: **www.symmetrymagazine.org/article/january-2015/how-to-build-your-own-particle-detector**.

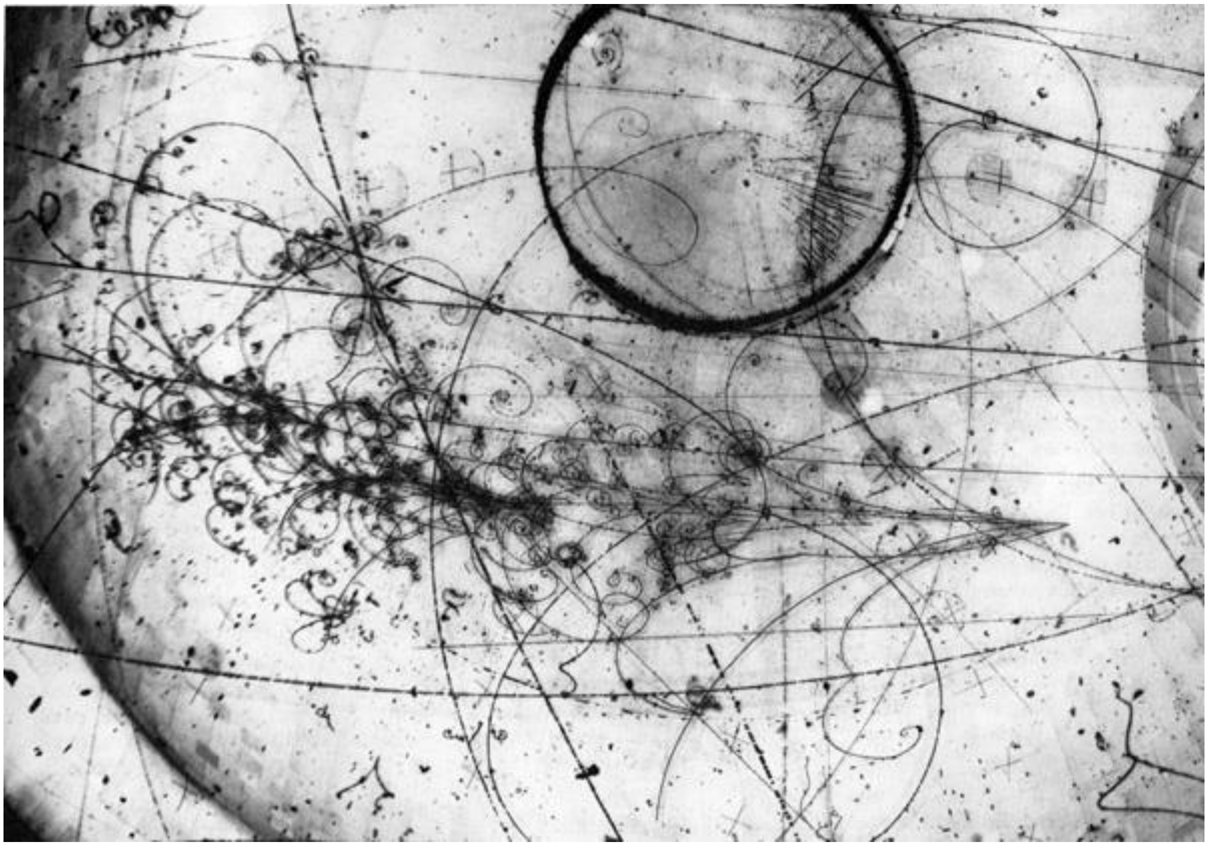


Photo of paths in a cloud chamber at Fermilab.
Image source: https://history.fnal.gov/visitors.html

The black curved lines represent charged particles moving through the cloud chamber. These are **free particles**—particles that are not bound to a nucleus or other particle.

Remember that we have atoms bonded together in the materials in our Transparent Alternator. We don't have free particles we can consider like the photo above, but we do have conductors. In conductors, electrons are very loosely bound to their nucleus, and have a lot of freedom to move.

Because of this, they can act very similarly to the free particles above, only confined to the metal they exist in. Magnets create a force on charged particles, and in the case of the electrons in our conducting wire, magnets push and pull the electrons around the loop to create electricity.

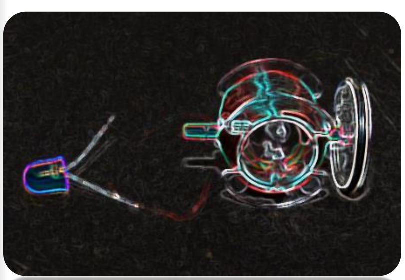
NGSS Correlations

Our Transparent Alternator Kit and these lesson ideas will support your students' understanding of these Next Generation Science Standards (NGSS):

Elementary

4-PS3-2
Students can make observations of the Transparent Alternator to provide evidence that energy can be transferred from place to place by sound, light, heat, and electric currents.

4-PS3-4
Students can use the Transparent Alternator in an investigation to apply scientific ideas to design, test, and refine a device that converts energy from one form to another.



Middle School

MS-PS2-3
Students can make observations of the Transparent Alternator and use the data collected in an investigation to ask questions about data to determine the factors that affect the strength of electric and magnetic forces.

MS-PS2-5
Students can make observations of the Transparent Alternator and conduct an investigation and evaluate the experimental design to provide evidence that fields exist between objects exerting forces on each other even though the objects are not in contact.

MS-PS3-5
Students can use the Transparent Alternator in an investigation to construct, use, and present arguments to support the claim that when the motion energy of any object changes, energy is transferred to or from the object.

High School

HS-PS2-5
Students can plan and conduct an investigation with the Transparent Alternator to provide evidence that an electric current can produce a magnetic field and that a changing magnetic field can produce an electric current.

HS-PS3-1
Students can plan and conduct an investigation with the Transparent Alternator to collect data for use in a computational model to calculate the change in the energy of one component in a system when the change in energy of the other component(s) and energy flows in and out of the system are known.

HS-PS3-3
Students can plan and conduct an investigation with the Transparent Alternator to design, build, and refine a device that works within given constraints to convert one form of energy into another form of energy.

HS-PS3-5
Students can plan and conduct an investigation with the Transparent Alternator to develop and use a model of two objects interacting through electric or magnetic fields to illustrate forces between objects and the changes in energy of the objects due to the interaction.

Also see "PS1 Disciplinary Core Ideas" here: **https://ngssqa.sdcoe.net/Disciplinary-Core-Ideas/DCI-Physical-Sciences/PS1A-Structures-and-Properties-of-Matter**

Take Your Lesson Further

As science teachers ourselves, we know how much effort goes into preparing lessons.
For us, "*Teachers Serving Teachers*" isn't just a slogan—it's our promise to you!

Please visit our website for more lesson ideas:

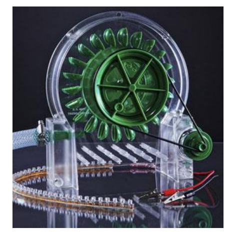
TeacherSource.com/lessons

Check our blog for classroom-tested teaching plans on dozens of topics:

http://blog.TeacherSource.com

To extend your lesson, consider these Educational Innovations products:

The PowerWheel (GRN-200)



The PowerWheel is a micro hydro generator—an amazing tool for teaching lessons about energy, hydro-power and other renewable sources of energy. Now you can charge cell phones or power laptops all from the power from your faucet. The PowerWheel can be used to enhance lessons for students from kindergarten through 12th grade.

Light Bulb Experiment Kit (OHM-300)

Demonstrate the difference between parallel and series circuits in a way that students can easily understand. This kit contains 4 Light Bulb Holders with Fahnestock Clips, 4 pairs of wires with alligator clips, 10 Miniature Light Bulbs, 8 D Cell Battery Holders, and 8 D batteries.

Build Your Own Light Bulb Kit (LIT-100)

Retrace the steps of Edison and other inventors as you build a working light bulb using the filament materials of your choice. Learn about electricity, light, properties of matter, energy, and the scientific method. Test the effects of vacuum on the life of your bulb. Perform exciting experiments. Experiments are suited to elementary, middle school, and high school level science and technology classes with extension activities for history and social studies.

HomoMotor Kit (KIT-700)

Introduce your students to one of the simplest devices, the homopolar or 'one pole' electric motor. Credited to Michael Faraday, it does not involve the polarity change of more complex motors. Includes instructions to make three styles of HomoMotors: pinwheel, spiral, and butterfly. Students build the motor, make it run, and can then break it down to make a different one. They can even design and build their own variations.

Hand-Powered Flashlight (SS-234)

Change kinetic energy from your hand into light energy. This hand-held 'dynamo' is easily visible. It clearly demonstrates how electrical energy can be produced by moving an electrical conductor through a magnetic field—a discovery made by Michael Faraday in 1831. This unit has a built in non-rechargeable, non-replaceable battery that can provide light for many hours showing the efficiency of modern LED lighting technology. However, no batteries are ever required—no bulbs to replace.