SCOPE, SEQUENCE, and COORDINATION

A National Curriculum Project for High School Science Education

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SCOPE, SEQUENCE, and COORDINATION

National Science Education Standard—Physical Science

Motions and Forces

The electric force is a universal force that exists between any two charged objects. Opposite charges attract while like charges repel. The strength of the force is proportional to the charges, and, as with gravitation, inversely proportional to the square of the distance between them.

Teacher Materials

Learning Sequence Item:

1033

Coulomb's Law and Induced Polarization

May 1996
Adapted by: Stephen Druger

Electric Force: Coulomb's and Gauss' Laws. At this level, students should examine the process of induced polarization, creating their own models to account for what they observe. This provides an opportunity to postulate the existence of a negative or positive charge that moves in or on a metal-coated object to produce that polarization. Various demonstrations or experiments involving charging conductors by induction should be carried out to give students opportunities to explain such phenomena with testable hypotheses. Students should explore the quantitative aspects of electric charge, including Coulomb's law as a proportion (not using the constant, k). (*Physics, A Framework for High School Science Education, p. 21.*)

Contents

This micro-unit was adapted by **Stephen Druger** (Northwestern University, Evanston, Ill.)

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Learning Sequence

Electric Force: Coulomb's and Gauss' Laws. At this level, students should examine the process of induced polarization, creating their own models to account for what they observe. This provides an opportunity to postulate the existence of a negative or positive charge that moves in or on a metal-coated object to produce that polarization. Various demonstrations or experiments involving charging conductors by induction should be carried out to give students opportunities to explain such phenomena with testable hypotheses. Students should explore the quantitative aspects of electric charge, including Coulomb's law as a proportion (not using the constant k). *(Physics, A Framework for High School Science Education, p. 21.)*

Science as Inquiry	Science and Technology	Science in Personal and Social Perspectives	History and Nature of Science
The Galvanometer **Activity 1** Paper Clip on a String **Activity 2** Electroscope Revisited **Activity 3** Charging by Induction **Activity 4** Light and Currents **Assessment 1** Charging Action **Assessment 2** Placing Charges **Assessment 3** Capacitate This! **Assessment 4**			

Suggested Sequence of Events

Event #1

Lab Activity

1. The Galvanometer (35 minutes)

Event #2

Lab Activity

2. Paper Clip on a String (45 minutes)

Alternative or Additional Activities

3. Electroscope Revisited (45 minutes)
   This event largely repeats ideas in Activity 2 by showing that polarization of the charge distribution within the electroscope is produced by bringing the charged rod near the electroscope column. It also reviews observed behavior of electroscope if not sufficiently familiar already to students.

Event #3

Lab Activity

4. Charging by Induction (1 hour)

Event #4

Readings from Science as Inquiry, Science and Technology, Science in Personal and Social Perspectives, and History and Nature of Science

Suggested readings:

Greenslade, Thomas B., Jr., "Discovery of the Leiden Jar," *The Physics Teacher*, Vol. 32, December 1994, pp. 536–537.

Schonland, B., "Electricity in the Clouds and Lightning Rods," *The Flight of Thunderbolts*, Oxford: Clarendon Press, 1964, pp. 18–20.

Schonland, B., "The Effectiveness of Lightning Rods," *The Flight of Thunderbolts,* Oxford: Clarendon Press, 1964, pp. 32–33, 117.

Tomany, J. P., "Application to Air Pollution Control," *Air Pollution: The Emissions, the Regulations and the Controls,* New York: Elsevier, pp. 131–132.

Assessment items are at the back of this volume.

Assessment Recommendations

This teacher materials packet contains a few items suggested for classroom assessment. Often, three types of items are included. Some have been tested and reviewed, but not all.

1. Multiple choice questions accompanied by short essays, called justification, that allow teachers to find out if students really understand their selections on the multiple choice.

2. Open-ended questions asking for essay responses.

3. Suggestions for performance tasks, usually including laboratory work, questions to be answered, data to be graphed and processed, and inferences to be made. Some tasks include proposals for student design of such tasks. These may sometimes closely resemble a good laboratory task, since the best types of laboratories are assessing student skills and performance at all times. Special assessment tasks will not be needed if measures such as questions, tabulations, graphs, calculations, etc., are incorporated into regular lab activities.

Teachers are encouraged to make changes in these items to suit their own classroom situations and to develop further items of their own, hopefully finding inspiration in the models we have provided. We hope you may consider adding your best items to our pool. We also will be very pleased to hear of proposed revisions to our items when you think they are needed.

Science as Inquiry

The Galvanometer

What can moving charges do?

Overview:

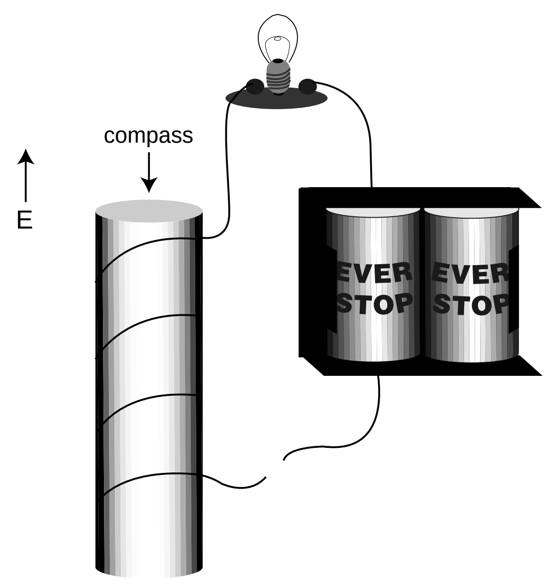
Students will observe that a current of moving charge has effects that can be detected by the deflection of a compass needle, thereby illustrating the principle of the galvanometer. The intention is only to illustrate the concept of being able to detect and measure current with such a device, not to explain how the device works in terms of magnetic fields.

Materials:

compass
clear plastic cylinder, about 3-in. dia., (or cardboard cut from mailing container for posters)
wire, insulated
batteries, 2, with terminals to connect wire or two AA, C, or D cells in corresponding holder with wire connectors
three 2.8-volt threaded base bulbs, each in E-10 socket
galvanometer and bar magnet (optional for demonstration)

Procedure:

Have students form a coil of wire by wrapping about 4 turns of wire around the cylinder. Then students connect one bulb terminal by a wire to the first battery terminal, and the other bulb terminal to the coil. When the current is allowed to flow by touching the other end of the coil to the second battery terminal, the bulb lights and the compass deflects. They place three bulbs in series so that there is not enough current flowing to light the bulbs as strongly, and a smaller deflection is still observed. The point is to have students conclude that a fairly sensitive device could be made on the basis of this principle to detect currents.



Background:

The current flow produces a magnetic field that causes the compass needle, itself a magnet, to align along the field lines, which inside the coil point approximately parallel to the cylinder axis. The magnetic field, and therefore its effectiveness in orienting the compass, increases in proportion to the number of turns of wire and to the current flowing. In an actual galvanometer, the compass needle would usually be replaced by a coil wound around a soft iron core forming itself an electromagnet that is free to rotate in the field of a fixed magnet, but the basic principle of the current-carrying coil and the magnet tending to align with respect to each other as a result of the current is the same.

Students should be told to orient the cardboard cylinder so its axis is aligned along the East-West direction. The N-S direction of the compass needle will then be perpendicular to the axis of the cylinder when no current flows, so that the compass deflects as far as possible when tending to line up parallel to the cylinder axis (E-W) with the current flowing in either direction through the loop. Reversal of the current flow by reversing the battery connections reverses the direction of the magnetic field inside the loop of wire and deflects the compass needle point toward the opposite E-W orientation. This shows students that a device using this principle could detect the direction of the current as well as merely its existence.

The small amount of charge on the charged rod used in the other activities produces too small a current for too brief a time to have any effect detectable by methods in this activity.

Variations:

Requires galvanometer and bar magnet. After completion of the activity, the instructor may wish to show an actual galvanometer connected to the coil. Do not try to drive it with the battery however since it could be burned out by excessive current. Instead, connect the end of the cardboard cylinder coil wires directly to its terminals, move a bar magnet in and out, and observe the needle deflecting, explaining that this is one way to make a small current move in a wire.

Adapted from:
Unknown.
Illustration: M. S. Young

Science as Inquiry

Paper Clip on a String

How does a charged object affect a neutral metallic object?

Overview:

Students are expected to observe that a neutral metallic object can also be attracted when a charged object is brought nearby. They should be encouraged to formulate hypotheses about the mechanism in terms of charges being attracted or repelled to move through the conducting clip so as to produce an induced net charge on each end, amounting to electric polarization of the paper clip.

Materials:

Per lab group (2 students per group):
sewing thread, (thin cotton)
pocket knife or scissors
paper clips
fur or wool, 1 piece
plastic rod
support stands (or other handy support to hang string and clip)
piece of copper wire
long nose pliers (optional)

Procedure:

Students hang the unfolded paper clip so that it is nearly horizontal and able to rotate with little restoring force in a horizontal plane. They then use a piece of thread to test for neutrality of the clip, and then observe that a charged rod attracts the suspended paper clip. In the second part, a partially unfolded clip is hung vertically, and students use a thin piece of thread or tissue paper to observe that bringing the charged rod beneath the clip without touching causes the top of the clip to acquire a net charge.

Background:

Induced polarization occurs in the clip when the rod is brought nearby and electrostatic forces move charges within the clip to produce a net charge of opposite sign on the near side of the clip, and therefore of like sign on the far side. The result is attraction between the rod and the near side of the clip. Students should not be told beforehand what to expect, because the attraction between the rod and a neutral metallic paper clip is likely to surprise them.

Part 2 of this activity, which uses a vertically suspended partially unfolded clip, is a more delicate experiment. The attraction of the neutral string to the upper end of the clip shows it to have a net charge only when the charged rod is below the clip. But if (as is likely) the string is attracted enough to make contact and pick up some charge, the string will thenceforth repel rather than attract the upper end of the clip, as well as giving easily misinterpreted results by being attracted to the neutral clip when the charged rod underneath is removed. Students should be advised to pay attention specifically to the initial response before the string touches, and to use a fresh piece of string each time they retest their observations. Also the area must be free of strong air currents for the attraction or lack of attraction of the small piece of string to be clearly observed. Remember that humidity in the air is the enemy of effective electrostatic experiments, tending to cause rapid dissipation of static charge by attachment of excess charge to water molecules. In warm humid climates, air conditioning improves the reliability of electrostatic experiments by decreasing the humidity in the room.

Variations:

None.

Adapted from:
None.

an alternative activity for Event 2

Teacher Sheet

Science as Inquiry

Electroscope Revisited

How do charged objects affect an electroscope?

Overview:

Students should observe that the charged rod brought near forces charges within the electroscope to move. They should observe the qualitative dependence on the distance between the rod and the top of the electroscope column, noting that the effect is stronger than simply inversely proportional. They observe that the effect appears to occur by displacing charges, without charge being created or destroyed.

Materials:

Per lab group (2 students per group):
electroscope*
plastic rod
fur or wool, 1 piece

Procedure:

Students rub the rod with fur or dry wool, and bring it near the top of the electroscope column without touching. They then observe that the leaves deflect in a way depending on distance. Next students observe qualitatively how the deflection varies with distance of the rod. Note the absence of deflection once the rod is removed and use a test string of freshly cut thread to observe that there is no particular electrostatic attraction to the top of the electroscope with the charged rod having been removed, showing that no net charge was produced. *See Technique Sheet, "How to Construct an Electroscope" to make a simple, but adequate electroscope.

Background:

The presence of the charged rod exerts forces on the electrical charge carriers (electrons) in the conducting metal rod of the electroscope because of the Coulombic repulsion of like charges and attraction of unlike charges, producing a net charge of the opposite sign closest to the rod. Since the charges merely move with no charge being created or destroyed, this produces a net charge of the same sign as the charged rod in the leaves of the electroscope. Removing the charged rod allows the leaves to collapse as the charge redistributes itself to have all parts of the electroscope neutral once again. The effect can be seen to depend strongly on distance. It is possible with a good electroscope to note that the displacement of the leaves is much more than twice as great when the charged rod is moved to about half the distance away once its proximity is having an effect. This is in accordance with Coulomb's law for the force between charges, which varies inversely as the square of the distance (i.e., as $1/r^2$), although the overall effect is more complicated.

Variations:

Electroscopes are also commercially available and can be used in this activity.

Adapted from:
Unknown.

Science as Inquiry

Charging by Induction

How can charges be induced?

Overview:

Students should observe that the forces between charges can induce a charge of the opposite sign nearby. They should also be led to see that connecting an object to "ground" (either a nearby pipe by a wire, or just to a large object such as the person doing the experiment) allows charge to leave or flow into an object in response to the force from a nearby charged body.

Materials:

Per lab group (2 students per group):
electroscope*
plastic rod
fur or wool, 1 piece
ground wire (i.e., connected at far end to pipe, or held at end by the student)

Procedure:

Bring the charged rod near the electroscope, and note the deflection. Allow the charge to leak off by touching the conducting electroscope shaft while still holding the charged rod near it, and note that the leaves of the electroscope collapse. *First*, remove the grounding contact, and *then* remove the nearby rod. The deflection of the leaves indicates that the electroscope has been left with a net charge.

*See Technique Sheet, "How to Construct an Electroscope" to make a simple, but adequate electroscope.

Background:

When the charged rod is brought near, it repels like charge and attracts unlike charge. Suppose for example the plastic rod is negatively charged. Since electrons are free to move through the metal, the negatively charged rod brought nearby will produce a positive net charge in the electroscope rod near it. If, as in Activity 3, the remainder of the electroscope is isolated, the displaced excess charge relocates on the leaves and on the lower part of the conducting shaft in the electroscope, farthest from the charged rod. This causes the leaves to separate because of the repulsion of like charges. But while forces between charge carriers tends to produce an unbalanced charge in the leaves of the electroscope, the forces between unlike charges also generally favor spreading the excess charge over as large a region as possible. So if a large object, such as the ground (or even just the student doing the Activity) makes electrical contact with the electroscope shaft, the net charge at the bottom of the electroscope shaft and in the leaves will tend to distribute itself over the larger region rather the relatively confined region available at the bottom of the electroscope shaft, and the electroscope leaves come together. That leaves a net total charge on the electroscope shaft (positive near the charged rod and almost neutral near the leaves of the electroscope). If the shaft is again isolated by removing contact with the ground, the net charge remains although concentrated in region closest to the rod. And if the rod is next removed, the presence of the net charge becomes apparent because it distributes itself over the entire electroscope shaft, including the leaves, so that they separate.

The net charge induced in this way is opposite in sign to that of the rod, and this is a method by which a negatively charged rod can be used to produce a positive net charge on another object through the effect of repulsion between like charges. Use of the string detector as described verifies the relative sign of the charge.

Variations:

The second alternative version of the experiment, using an aluminum can, corresponds to some of the experiments done by Faraday using a metal ice pail. This procedure is more effective in producing a strong deflection of the electroscope.

Use an aluminum can with the top cut off and a hole punched into the bottom for purposes of mounting the can onto the top of the elecgtroscope column. A net charge can be induced on the electroscope by bringing the charged rod carefully into the interior of the can without touching the sides—with other steps such as grounding the outside of the can to remove induced charge—then removing the ground connection, then removing the charged rod.

Adapted from:
Unknown.

Science as Inquiry

Light and Currents

Item:

Would a light bulb work as well as the compass in detecting a small current? Justify your answer.

Answer:

Not nearly as well, because the compass needle showed a very large change in direction even when the current was reduced to the point the bulb lit dimly or not at all, and because the direction of the compass needle also shows which way the current flows while the bulb shows only that it is flowing.

Science as Inquiry

Charging Action

Item:

A 3-in.-piece of wire rests on a dry electrically insulating wooden table. A negatively charged rod is brought near one end. Which of the following is true:

A. Significant charge from the wire will flow into the table so that the wire becomes positively charged by induction.

B. Significant charge from the table will flow into the wire, thereby charging it negatively by induction.

C. The wire will become electrically polarized with positive charge on the near side and negative charge on the far side of the rod.

D. The wire will become electrically polarized with positive charge on the far side and negative charge on the near side of the rod.

Justification:

The negative rod repels negative charge and attracts positive charge, so that the nearby part of the wire becomes positively charged. Since the table is an insulator, charge does not flow through it easily to be lost or gained by the wire.

Answer:

C.

Science as Inquiry

Placing Charges

Item:

A 3-in.-wire rests on top of an insulating table. You have a second, much longer copper wire and a negatively charged plastic rod. Explain how these might be used, by the methods applied in this Micro-Unit, to place a positive charge on the piece of wire resting on the table.

Answer:

Students should explain that bringing the charged rod near one end of the wire produces a net charge of opposite sign on the near end of the 3-inch wire. They should then describe allowing negative charge on the far end to leak off by grounding the needle with the negative rod still nearby, thus producing a positive total charge on the needle.

Science as Inquiry

Capacitate This!

Item:

Capacitors are devices used in many electronic devices. Like the Leyden jar, they consist essentially of two conductors separated by a small layer of insulator. Wires or other contacts connect each of the conductors to other parts of the electronic circuitry. After a television set has been used and unplugged from the wall, poking around inside without knowing what you're doing can lead to a nasty electrical shock. Why can the inside of the television still be hazardous in this way even though it is no longer plugged into the electrical wall outlet?

Answer:

The capacitors store charge, and even though the power has been turned off, the charge in the capacitors takes time to leak off. Placing your fingers across the two opposite contacts of the right capacitor can cause the capacitor to discharge through you even though no additional charge has been forced into the capacitor for some time.

Consumables

Item	Quantity (per lab group)	Activity
batteries, 2, with terminals, and w/holder	1	1
clear plastic cylinder, about 3-in. dia. (or cardboard cut from mailing container for posters)	1	1
fur or wool	1 piece	2, 3*, 4
light bulbs, threaded base, 2.8 volt, in E-10 socket	3	1
paper clips	—	2
thread, sewing (thin cotton)	—	2
wire, copper	1 piece	2
wire, ground	1 piece	4
wire, insulated	—	1
wire connectors	—	1

Nonconsumables

Item	Quantity (per lab group)	Activity
compass	1	1
electroscope	1	3*, 4
galvonatomer and bar magnet (optinal)	1 (for teacher demo)	1
plastic rod	1	2, 3*, 4
pliers, long-nose	1 pr	2
scissors (or pocket knife)	1 pr	2
support stand	1	2

*indicates alternative or additional activity

Key to activities:
1. The Galvanometer
2. Paper Clip on a String
3. Electroscope Revisited
4. Charging by Induction