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LESSON:

# Using a Spoon to Clean the Air

**Summary:** Students read the article "Coal: Poised for a Comeback?" and discuss the issues of using coal as a source of fuel to generate electricity. Then, students conduct a simple experiment with static electricity and analyze Coulomb's law to illustrate how electrostatic forces can be used to remove harmful particles from the air. This lesson extends discussion of a topic addressed within the article.

**EHP Article Title(s):** "Coal: Poised for a Comeback?"
*EHP Student Edition*, February 2005: A889–A891
http://ehp.niehs.nih.gov/members/2004/112-15/spheres.html

**Objectives:** By the end of this lesson, student should be able to:

1. Discuss the benefits and environmental costs of using coal as a fuel for generating electricity in a power plant.
2. Explain the operational principles of an electrostatic precipitator.
3. Apply Coulomb's law to improving the efficiency of an electrostatic precipitator.

**Estimated Class Time:** 2 hours

**Grade Level:** 11–12

**Subjects Addressed:** Environmental Science, Physical Science, Physics

## Prepping the Lesson: (15–20 minutes)

**INSTRUCTIONS:**

1. Obtain a class set of *EHP Student Edition*, February 2005, or download article at http://www.ehponline.org/science-ed and make copies.
2. Review the article "Coal: Poised for a Comeback?"
3. Make copies of the student instructions.
4. Assemble materials needed for the lesson activity.

**MATERIALS (per group):**

- 1 copy *EHP Student Edition*, February 2005
- 1 copy student instructions
- 1 pepper shaker (with pepper)
- 1 plastic spoon
- Wool (any source will do)
- 1 white sheet of paper
- Water
- Calculator
- Graph paper

**VOCABULARY:**

Coulomb (unit)
Coulomb's law
Electrical charge
Electrostatic precipitator
Force
Inverse square
Linear
Newton (unit)
Nonlinear

**BACKGROUND INFORMATION:**

Coal is an abundant fossil fuel found in the United States that could go a long way toward solving the world's dependency on oil, except for its significant environmental problems. Mining coal from the ground can harm the earth's ecosystems, and burning coal to generate electricity releases fine particles and other air pollutants that are harmful to the respiratory system and other parts of the body. The U.S. Environmental Protection Agency (EPA) has recently become concerned about the health effects of very fine particles with diameters less than 2.5 microns in size. As a result, new air standards have been adopted to help reduce exposure levels.

Increasingly, however, new technologies are being developed that help reduce the emission of harmful air pollutants such as particulate matter from burning coal. One of the methods for cleaning particles from the air is to use electronic air cleaners or electrostatic precipitators. Air contaminated with dust is passed near a high voltage source which causes the air to form ions called corona ions. These ions attach themselves to particles in the air causing the particles to become charged. The charged particles are then subjected to an electric field, which exerts a force on the charged particles causing them to collect on nearby plates or services. These collection plates or surfaces accumulate dust over time and must be cleaned periodically to ensure that the device continues to operate properly.

Using electrostatic charge to purify the air of particles is governed by both chemistry and physics. Chemical composition and molecular structure determine whether a particle is capable of becoming charged. Coulomb's law mathematically describes the vector force in newtons ($F_{electric}$) between two objects acting as point charges.

Coulomb's law is $F_{electric} = k \bullet q_1 \bullet q_2 / d^2$, where **$q_1$** represents the quantity of charge on object 1 (in coulombs), **$q_2$** represents the quantity of charge on object 2 (in coulombs), and **d** represents the distance of separation between the two objects (in meters). The symbol **k** is a proportionality constant known as the Coulomb's law constant. The value of this constant is dependent upon the medium around the charged objects. In the case of air, the value is approximately $9.0 \times 10^9$ $N \bullet m^2 / C^2$.

This lesson is an opportunity for the students to explore Coulomb's law, which is an inverse square law. Students are asked to evaluate the equation for Coulomb's law and graph some simplified examples. In the first example (Step #5 of the student instructions), the numerator ($k \bullet q_1 \bullet q_2$) is held constant, and d varies. This shows a nonlinear inverse square relationship between force and distance between charges. In the second example (Step #6), d and $q_1$ are held constant, and the charge on $q_2$ varies. In this case, the relationship between charge and force is linear.

The reality of electrostatic precipitators is more complex, and they only obey the principles of Coulomb's law. However, the exercise helps students understand mathematical relationships and conceptualize the relationship between charge, distance, and force.

**RESOURCES:**

*Environmental Health Perspectives*, Environews by Topic, http://ehp.niehs.nih.gov/topic. Choose Particulate Matter

Electric Charge and Coulomb's Law, http://physics.bu.edu/~duffy/PY106/Charge.html

Energy Information Administration, U.S. Department of Energy, http://www.eia.doe.gov/fuelcoal.html. Choose Coal Kid's Corner

Kentucky Foundation, Kentucky Coal Education Website, http://www.coaleducation.org

The Physics Classroom - Lesson 3: Electric Force, http://www.glenbrook.k12.il.us/gbssci/phys/Class/estatics/u8l3b.html

U.S. Environmental Protection Agency, http://www.epa.gov/ Select Air under Quick Finder

http://www.epa.gov/ttn/catc/dir1/fdespwpi.pdf Dry Electrostatic Precipitators (ESP): Wire-Pipe Type

http://www.epa.gov/ttn/catc/dir1/fdespwpl.pdf Dry Electrostatic Precipitators (ESP): Wire-Plate Type

http://www.epa.gov/ttn/catc/dir1/fwespwpi.pdf Wet Electrostatic Precipitators (ESP): Wire-Pipe Type

http://www.epa.gov/ttn/catc/dir1/fwespwpl.pdf Wet Electrostatic Precipitators (ESP): Wire-Plate Type

http://www.epa.gov/ttn/catc/dir1/cs6ch3.pdf EPA Air Pollution Cost Control Manual: Chapter 3: Electrostatic Precipitators

## Implementing the Lesson

**INSTRUCTIONS:**

1. Have students read "Coal: Poised for a Comeback?"
2. Lead a discussion about coal as a source of energy to generate electricity, summarizing its beneficial and harmful qualities.
3. Explain that one of the larger problems with burning coal for energy is the release of harmful particles and other toxic

contaminants (such as mercury) into the air, which can affect people's health. Explain that the small particles have been found to cause increased respiratory disease, and mercury can cause brain damage. Tell students that they will now look at one technology for removing particles from the air.

4. Hand out the Student Instructions and have students (in groups) complete the "Using a Spoon to Clean the Air" activity, steps 1 through 3.
5. Discuss with students their observations, explanations for what happened, and how this technology might be applied to remove particles from the air.
6. Explain that rubbing the wool on the spoon leaves electrons on the surface of the spoon. When the spoon is brought near the pepper, the negative electric field on the spoon causes the pepper particles to become polar and the positively charged end of the particle is attracted to the negative charge on the spoon. When the spoon is dipped into the water, the electrons on the spoon dissipate into the water, and the spoon loses its charge.
7. Tell students that Coulomb's law is a mathematical equation that explains the relationship between the force between two charged objects and the distance between those objects. Explain that the relationships in Coulomb's law can be used to help explain how electrostatic precipitators clean the air coming from a coal-fired power plant. In an electrostatic precipitator, electricity is used to charge particles in the air, and then the particles are subjected to an electric field that forces the particles to be collected on plates or other surfaces.
8. Write the equation for Coulomb's law on the board and explain the relationships between the different variables. Tell students that each variable has units, but for now, only the relationships are important.

$$F = k (q_1 \times q_2)/ d^2$$

F = the force of attraction between two point charges in newtons

k = is a constant that depends on the material separating the charges in $Nm^2/C^2$

$q_1$= the charge of one point charge in coulombs

$q_2$= the charge on the other point charge in coulombs

d = the distance between the point charges in meters

9. Ask students what would happen to the force of attraction between $q_1$ and $q_2$ if you doubled the charge on $q_1$ or $q_2$. (The force would be doubled). Ask students what would happen to the force of attraction between $q_1$ and $q_2$ if you doubled the distance between $q_1$ and $q_2$. The force would be 1/4 of what is was before.
10. Have the students finish steps 4 through 8 of the Student Instructions. Then lead a discussion about their results.
11. After the discussion, ask students what happens to the number of charged particles that are being collected on the collecting plates over time. (More and more particles would be collected on the surface, and the surface would have to be cleaned in order for the device to continue working properly.) Explain that this is one of the problems with this type of air cleaning device.

**NOTES & HELPFUL HINTS:**

- Ash or other small particles such as salt may be substituted for the pepper. Inflated balloons may be substituted for the plastic spoon.
- The inverse square law is seen in multiple applications in physics, including gravity. If your students have already studied gravity, have them compare the equations and identify the similarities and differences between the equations ($F_{gravity} = G \bullet M_1 \bullet M_2/d^2$ where $G = 6.67 \times 10^{-11}$ $N \bullet m^2 / kg^2$).

## Aligning with Standards

**SKILLS USED OR DEVELOPED:**

Communication (note taking, oral, written—including summarization); comprehension (listening and reading); computation; critical thinking and response; experimentation (conducting); graphing; graph reading; observation; tables (reading)

**SPECIFIC CONTENT ADDRESSED:**

Static electricity, Coulomb's law, and applied technology

**NATIONAL SCIENCE EDUCATION CONTENT STANDARDS MET:**

Unifying Concepts and Processes Standard

- systems, order, and organization
- evidence, models, and explanation

- change, constancy, and measurement

Science as Inquiry
- abilities necessary to do scientific inquiry
- understanding about scientific inquiry

Physical Science Standards
- structure of atoms
- structure and properties of matter
- motions and forces
- interactions of energy and matter

Science and Technology
- abilities of technical design
- understanding about science and technology

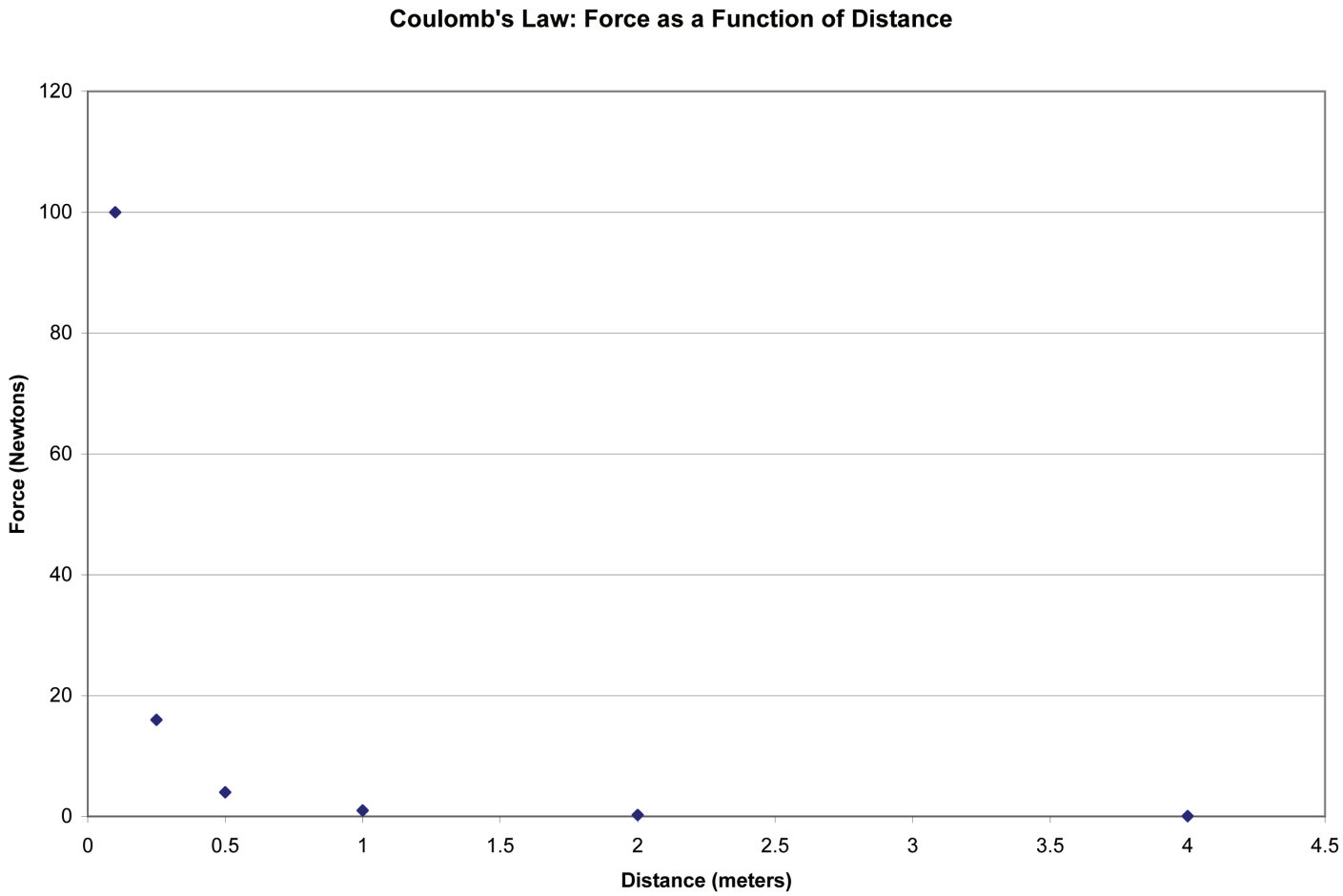
Science in Personal and Social Perspectives
- personal and community health
- natural resources
- environmental quality
- natural and human induced hazards
- science and technology in local, national and global challenges

## Assessing the Lesson

**KEY POINTS AND ANSWER EXAMPLES:**

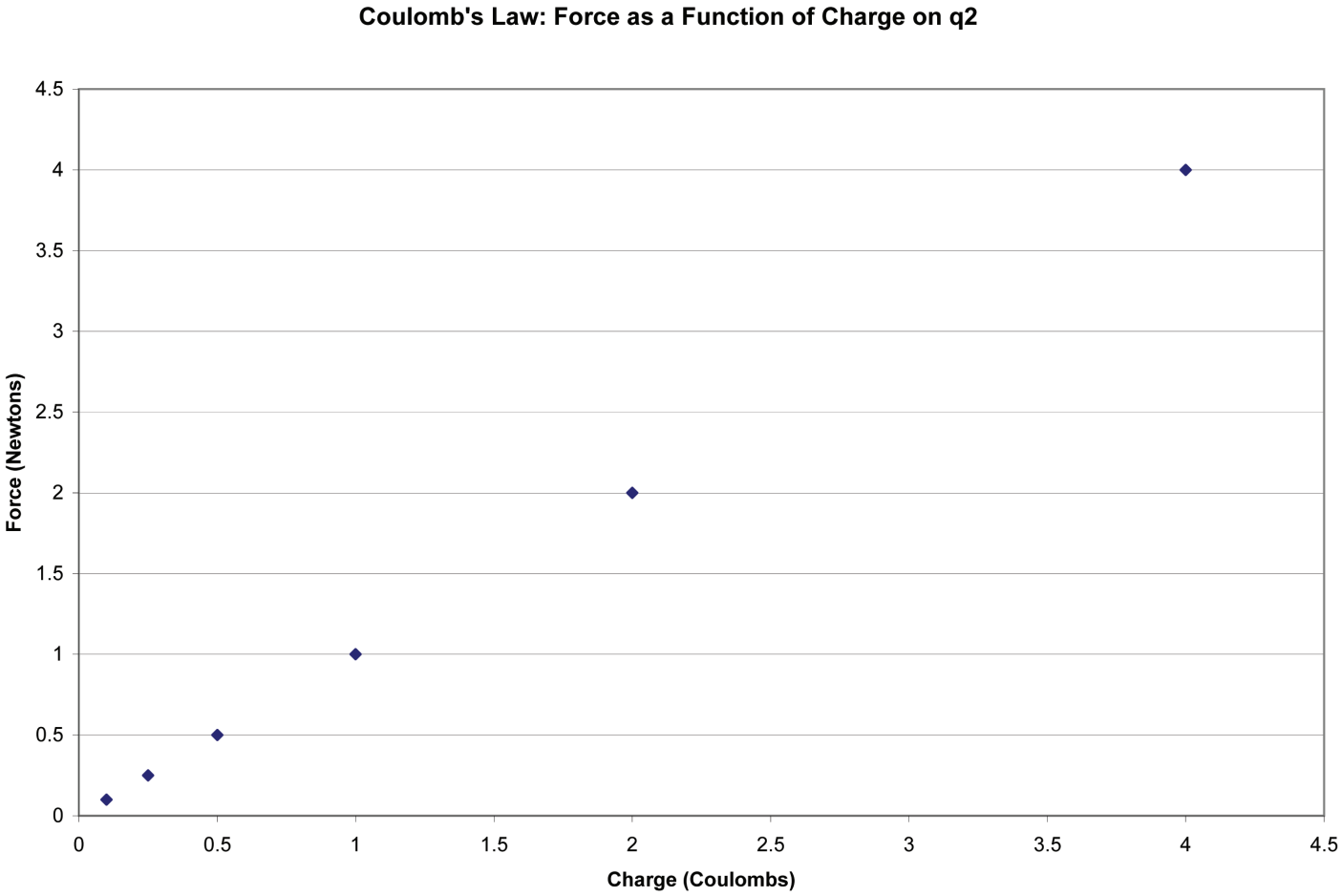
1. Assessment criteria: accuracy, detail of observations, use of vocabulary and quality of explanations.
2. Results for Step 5.

| $k(q_1 \times q_2)$ ($Nm^2$) | d (meters) | F (Newtons) |
|---|---|---|
| 1 | 0.1 | 100 |
| 1 | 0.25 | 16 |
| 1 | 0.5 | 4 |
| 1 | 1 | 1 |
| 1 | 2 | 0.25 |
| 1 | 4 | 0.0625 |




3. Results for Step 6.

| $k(q_1)$ ($Nm^2/C$) | $q_2$ (coulombs) | d (meters) | F (Newtons) |
|---|---|---|---|
| 1 | 0.1 | 1 | 0.1 |
| 1 | 0.25 | 1 | 0.25 |
| 1 | 0.5 | 1 | 0.5 |
| 1 | 1 | 1 | 1 |
| 1 | 2 | 1 | 2 |
| 1 | 4 | 1 | 4 |




4. Key responses for Step 8:

- The distance between the charged plates: The graph shows that as the distance between the plates decreases, the force exerted on the particles toward the plates increases. There are practical upper and lower limits, however, on the distance between the charged plates. If the plates are too close, the exhaust will not be able to move between the plates. If the plates are too far apart, the force between the plates and the particles would be too small to attract the particles to the plate.
- The charge on the particles and the plates: According to the graph, the force would continue to increase as the charge increases. Hypothetically, this could be limitless. However, there are a number of realities that would limit the charge including the amount of available electricity, the ability of the plate material to conduct electricity, and the voltage that would cause sparking.
- Humidity: Humidity would decrease the efficiency of the electrostatic precipitator by allowing the charged particle to be dissipated into the air.

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# STUDENT INSTRUCTIONS: Using a Spoon to Clean the Air

**Step 1:** Place some pepper on a white sheet of paper. Rub a plastic spoon with a piece of wool. Then slowly move the bottom of the spoon near the pepper. Describe what happens.

**Step 2:** Now, dip the spoon into some water, then slowly move the bottom of the spoon near the pepper. Describe what happens.

**Step 3:** Create a scientific explanation for what you observed.

**Step 4:** Define Coulomb's law and write the equation. Be sure to define each term in the equation and include the unit associated with each term.

**Step 5:** The following table holds the charges on $q_1$ and $q_2$ constant and varies the distance between the charged objects. For the sake of simplicity, the product of $k(q_1 \times q_2)$ is assumed to be 1. Complete the table showing how the force between the two objects changes with changing distance, and then graph the force as a function of distance. Be sure to properly label your graph and square the distance first to calculate the force.

| $k(q_1 \times q_2)$ ($Nm^2$) | d (meters) | F (newtons) |
|---|---|---|
| 1 | 0.1 | |
| 1 | 0.25 | |
| 1 | 0.5 | |
| 1 | 1 | |
| 1 | 2 | |
| 1 | 4 | |

NOTE: The data presented in these tables are not representative of actual events; they are intended for visual illustration of the effects of the variables in Coulomb's law.

**Step 6:** The following table holds constant the charge on $q_1$ and the distance between the objects while varying the charge on $q_2$. For the sake of simplicity, the product of $k(q_1)$ is assumed to be 1 and the distance between the two objects is assumed to be 1 meter. Complete the table showing how the force between the two objects changes with changing charge on $q_2$ and then graph **force as a function of the charge on $q_2$.** Be sure to properly label your graph.

| $k(q_1)$ ($Nm^2/C$) | $q_2$ (coulombs) | d (meters) | F (newtons) |
|---|---|---|---|
| 1 | 0.1 | 1 | |
| 1 | 0.25 | 1 | |
| 1 | 0.5 | 1 | |
| 1 | 1 | 1 | |
| 1 | 2 | 1 | |
| 1 | 4 | 1 | |



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**Step 7:** Describe what you see in each of the graphs and how they relate to Coulomb's law. Use the following terms in your description: force, charge, distance, linear, nonlinear, x-axis, y-axis, dependent variable, independent variable.

**Step 8:** Below is a diagram showing a very simplified electrostatic precipitator. Recalling your spoon and pepper observations and your graphs, describe how the following factors could affect the collection efficiency of an electrostatic precipitator used to clean particulates from coal-fired power plant exhaust:

- The distance between the charged plates
- The charge on the particles
- The charge on the plates
- Humidity

Assume that the electrostatic precipitator obeys Coulomb's law, $q_1$ are the charged particles created in the coal exhaust, and $q_2$ are the charged plates collecting the particles.