For a substance to conduct an electric current, the substance must possess free-moving charged particles. These charged particles may be delocalized electrons, such as those found in substances that form metallic bonds. The particles may also be mobile ions, such as those found in dissolved (or molten) salts, or they may be ions formed by certain molecular substances having polar covalent bonds that dissociate when dissolved in water.

Solid ionic substances that do not dissolve in water are usually considered to be **insulators**, substances that do not conduct electric current. Substances with nonpolar covalent bonds are also insulators, as are substances with polar covalent bonds that are not easily broken to form ions when they are dissolved in water.

The fact that a substance is a conductor in its pure form, or conducts only in solution, or is an insulator defines a physical property of the substance and provides clues about its inner structure and the type of bonding found in the substance. In this experiment, you will use qualitative measures of conductivity to determine the identities of eight unknown substances, identified as A, B, C, D, E, F, G, and H. Each letter corresponds to one of these substances: sodium sulfate, sugar, tap water, deionized (or distilled) water, tin, graphite, yellow chalk dust, and charcoal. These substances are not necessarily listed in the correct order. You will use your conductivity-test results and other information to identify each unknown as one of the substances listed.

**OBJECTIVES**

- **Observe and compare** conductivities of various substances.
- **Relate** conductivity to the type of bonds in a substance.
- **Infer** the identities of unknown substances.

**MATERIALS**

- dropper bottle of distilled water
- glass stirring rod, small, or toothpicks
- gloves
- hand-held conductivity tester
- lab apron
- labeled containers 8, each with a different unknown substance
- paper towels
- safety goggles
- spatula
- spot plate
- thin-stemmed pipet

**Always wear safety goggles, gloves, and a lab apron to protect your eyes and clothing.** If you get a chemical in your eyes, immediately flush the chemical out at the eyewash station while calling to your teacher. Know the location of the emergency lab shower and eyewash station and the procedures for using them.
Conductivity as an Indicator of Bond Type continued

Do not touch any chemicals. If you get a chemical on your skin or clothing, wash the chemical off at the sink while calling to your teacher. Make sure you carefully read the labels and follow the precautions on all containers of chemicals that you use. If there are no precautions stated on the label, ask your teacher what precautions to follow. Do not taste any chemicals or items used in the laboratory. Never return leftovers to their original container; take only small amounts to avoid wasting supplies.

Never put broken glass in a regular waste container. Broken glass should be disposed of separately according to your teacher's instructions.

Procedure

1. Put on safety goggles, gloves, and a lab apron.

2. Examine each of the eight unknowns and record in your lab notebook your observations about their state (solid or liquid), color, texture, and other qualities.

3. Test your conductivity apparatus to make sure that it lights up when the two wires or leads touch different parts of a conducting substance. Your teacher will tell you what conducting substance to use.

4. Using a clean spatula for each solid and a clean pipet for each liquid, deliver a small sample of each unknown into a separate well of a spot plate. Keep track of which unknown is in which well. The spatula should be wiped with a clean paper towel between each use to prevent contamination. Similarly, the pipet should be wiped with a clean paper towel and rinsed with distilled water between each use. Put any water used for rinsing into the sink.

5. Place the wire leads in good contact with the first unknown sample, as shown in Figure 1. Note whether or not it conducts, as indicated by the light on the conductivity tester. (It may help to move the tester around a bit while watching the light.) If the two leads on the tester touch each other, the light will automatically go on. Do not mistake this for a positive test. Some results may be faint and require careful observations. Most pure substances are nonconductors, so don’t expect a majority of your substances to conduct. Record all observations in your lab notebook.

Figure 1
6. Repeat step 5 for the other unknown samples. Be sure to thoroughly wipe the leads of the conductivity probe with a clean paper towel between each test. For those substances that do conduct, compare the conductivities. Rate them on a scale from 0 to 4, with 4 as the best conductor. Record your observations and ratings in your lab notebook.

7. Using the pipet, add 10 drops of distilled water to each of the eight unknowns. Hold the tip of the pipet 1 to 2 cm above the unknowns. Use a small glass stirring rod or toothpicks to stir each mixture. Be sure to wipe the stirring rod or toothpick thoroughly with a clean paper towel after each use.

8. Observe each of the wells, and record in your lab notebook any observations about the dissolving or mixing of the unknowns.

9. Test the conductivity of each mixture, again wiping the leads thoroughly between each test. Record your results.

10. Clean all apparatus and your lab station. Return equipment to its proper place. Dispose of chemicals and solutions in the containers designated by your teacher. Do not pour any chemicals down the drain or into the trash unless your teacher directs you to do so. Wash your hands thoroughly before you leave the lab and after all work is finished.

Analysis

1. Organizing Ideas Which types of bonding are likely to be involved in the unknowns that were conductors in their pure form? Explain what free-moving charged particles are available in these types of bonds.

2. Organizing Ideas Which types of bonding are likely be involved in the unknowns that were not conductors in their pure form but conducted a current when they were mixed with water? Explain what free-moving charged particles are available in these types of bonds.
3. **Organizing ideas** Which types of bonding are likely to be involved in the unknowns that were not conductors in their pure form or when they were mixed with water? Explain why there were no free-moving charged particles available in these types of bonds.

4. **Organizing Data and Relating Ideas** Fill in the table below by using the Useful Information that follows to determine which type of bonding is likely to be present in each of the substances listed and whether the substances are likely to conduct an electric current. Predict which will be the best conductor in pure form and dissolved in water, which will conduct only marginally, and which will not conduct at all.

**TABLE 1 CONDUCTIVITY OF VARIOUS SUBSTANCES**

<table>
<thead>
<tr>
<th>Substance</th>
<th>Type of bonding</th>
<th>Conductivity</th>
<th>Conductivity in H₂O</th>
<th>Matches unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalk</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Charcoal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Graphite</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sodium sulfate</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tin</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distilled water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tap water</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Useful Information

- Chalk is mostly CaCO₃ and dissolves only slightly in water.
- Sodium sulfate is white and dissolves in water.
- Tin is a metal.
- Charcoal is a form of carbon with the atoms bonded to each other in a randomly organized way.
- Graphite is a form of carbon. The atoms are bonded to each other in systematic sheets with some free electrons holding the sheets together.
- Sugar is a molecular substance that dissolves in water.
- Distilled or deionized water can be considered pure H₂O.
- Tap water contains many dissolved impurities that are molecular and ionic.

Conclusions

1. In the fifth column of your table, write the letter of the unknown that corresponds to the substance in each row. Explain your reasons for making each identification.
2. Designing Experiments and Predicting Outcomes  Predict the conductivities of each of the materials listed below, and give reasons for your predictions. How would the conductivity of each material be affected if water were added to it? If your teacher approves, test your predictions for all the materials except liquid bromine, which is too dangerous to work with.

a. an iron nail
b. liquid bromine, Br₂
c. wax (a random arrangement of molecules with long, nonpolar chains of carbon and hydrogen atoms)
d. a dilute hydrochloric acid solution, HCl(aq)
e. table salt, NaCl
CONDUCTIVITY AS AN INDICATOR OF BOND TYPE

Teacher Notes

TIME REQUIRED One 45-minute lab period

SKILLS ACQUIRED
Collecting data
Experimenting
Identifying patterns
Inferring
Interpreting
Organizing and analyzing data

RATING
Easy 1 2 3 4 Hard
Teacher Prep–3
Student Set-Up–2
Concept Level–3
Clean Up–2

THE SCIENTIFIC METHOD

Make Observations Students collect conductivity data.

Analyze the Results Analysis question 4.

Draw Conclusions Conclusions questions 1 and 2.

Communicate the Results Analysis questions 1, 2, and 3 and Conclusions question 1.

MATERIALS

Materials for this lab activity can be purchased from WARD’S. See the Master Materials List on the One-Stop Planner CD-ROM for ordering instructions.

LED conductivity testers may be purchased from Lab Aids or made according to the directions below. A conductivity tester that emits a tone rather than a light is also available from Lab Aids. Some students find it easier to distinguish small differences in conductivity by observing differences in tone rather than differences in intensity of light.

MATERIALS FOR BUILDING LED CONDUCTIVITY TESTER

- battery, 9 V
- battery clip
- electrician’s tape
- film-canister lid
- LED (light-emitting diode)
- nail or ice-pick
- resistor, 212 Ω (¼ W)
- straw or tubing, 3.5 cm
- wire, insulated copper, AWG #22, solid, 10 cm (2)
CONDUCTIVITY TESTER ASSEMBLY

See the diagram of this apparatus at the end of the Teacher Notes.

1. Strip 1.5 cm of insulation from the ends of the copper wires and from the battery clip leads. Cut the resistor leads down to half of their length.

2. Poke two holes in the film-canister lid that are about as far apart as the two LED leads are. Insert the leads through the holes, and spread them apart slightly.

3. Connect the circuit as shown in the illustration. Be sure the **red** battery-clip lead is connected to the **longer** LED lead. The black battery-clip lead should connect to the resistor, and the other end of the resistor should connect to one 10-cm length of wire. The shorter LED lead should be connected to the other 10-cm wire. Bend the leads up and tape them against the inside of the lid so that they are not touching each other and there are no exposed wires.

4. Wrap tape around the resistor and its exposed wires.

5. As shown in the illustration, connect the battery and resistor. Adjust the free ends of the insulated copper wires so that they extend down about 5 cm.

6. Wrap electrician’s tape around the straw, and place it over the LED to provide a “dark tunnel” through which the LED may be viewed for testing weak electrolytes.

MATERIALS FOR EIGHT UNKNOWNS

- charcoal (grind up chunks of charcoal, or use charcoal dust), 3–4 g
- graphite, 3–4 g
- Na₂SO₄, 3–4 g
- sugar, 3–4 g
- tap water, 3–4 mL
- tin, 3–4 g
- water, distilled, 3–4 mL
- yellow chalk dust (grind up sticks of chalk), 3–4 g

OPTIONAL MATERIALS FOR CONCLUSIONS QUESTION 2

- HCl solution, 1.0 M, 3–4 mL
- iron nail
- NaCl, 3–4 g
- wax, 5 g

While preparing 50 mL of optional 1.0 M HCl solution for Conclusions question 2, observe the required safety precautions. Add 4.3 mL of concentrated HCl, while stirring, to enough water to make 50 mL of solution.

SAFETY CAUTIONS

Safety goggles, gloves, and a lab apron must be worn at all times.

Read all safety precautions, and discuss them with your students.
In case of a spill, use a dampened cloth or paper towel (or more than one towel, if necessary) to mop up the spill. Then rinse the towel in running water at the sink, wring it out until it is only damp, and put it in the trash.

Remind students of the following safety precautions:

- Always wear safety goggles, gloves, and a lab apron to protect your eyes and clothing. If you get any chemical in your eyes, immediately flush the chemical out at the eyewash station while calling to your teacher. Know the location of the emergency lab shower and the eyewash stations and procedures for using them.

- Do not touch any chemicals. If you get a chemical on your skin or clothing, wash the chemical off at the sink while calling to your teacher. Make sure you carefully read the labels, and follow the precautions on all containers of chemicals that you use. If there are no precautions stated on the label, ask your teacher what precautions you should follow. Do not taste any chemicals or items used in the laboratory. Never return leftovers to their original containers; take only small amounts to avoid wasting supplies.

- Call your teacher in the event of a spill. Spills should be cleaned up promptly, according to your teacher’s directions.

- Never put broken glass in a regular waste container. Broken glass should be disposed of properly.

**DISPOSAL**

All solutions can be washed down the sink with plenty of water, provided your school drains are connected to a sanitary sewer system with a treatment plant. The solid precipitates should be dried and buried in a landfill that is approved for chemical disposal. You may want to consider drying and reusing the materials that are not soluble in water. The tin has value as scrap metal, so you may want to recycle it instead of discarding it. The microplates or spot plates can be wiped with a clean paper towel, rinsed with tap water, rinsed with distilled water, and allowed to dry.

**TECHNIQUES TO DEMONSTRATE**

Show students how to use the conductivity tester, and suggest materials in the lab that they can use to test the apparatus before beginning the experiment (for example, the laboratory faucets).

You may wish to emphasize the role of hypotheses in scientific work by having students try to narrow the unknowns before they begin the experiment. Have them use the information provided in Useful Information following Analysis question 4 to make predictions about conductivities before they perform the conductivity tests. This approach, however, will take more time.

Review proper safety precautions required when dealing with chemicals.

Show the students the proper method for filling and using a pipet.
**TIPS AND TRICKS**

Assign a letter from A through H to each of the eight materials, and place them in containers that can be reused from year to year. Keep track of which letter corresponds to which material so that you can check students’ work.

**Analysis**

Review the different types of bonding with students before they begin the lab.
For a substance to conduct an electric current, the substance must possess free-moving charged particles. These charged particles may be delocalized electrons, such as those found in substances that form metallic bonds. The particles may also be mobile ions, such as those found in dissolved (or molten) salts, or they may be ions formed by certain molecular substances having polar covalent bonds that dissociate when dissolved in water.

Solid ionic substances that do not dissolve in water are usually considered to be insulators, substances that do not conduct electric current. Substances with nonpolar covalent bonds are also insulators, as are substances with polar covalent bonds that are not easily broken to form ions when they are dissolved in water.

The fact that a substance is a conductor in its pure form, or conducts only in solution, or is an insulator defines a physical property of the substance and provides clues about its inner structure and the type of bonding found in the substance. In this experiment, you will use qualitative measures of conductivity to determine the identities of eight unknown substances, identified as A, B, C, D, E, F, G, and H. Each letter corresponds to one of these substances: sodium sulfate, sugar, tap water, deionized (or distilled) water, tin, graphite, yellow chalk dust, and charcoal. These substances are not necessarily listed in the correct order. You will use your conductivity-test results and other information to identify each unknown as one of the substances listed.

OBJECTIVES

Observe and compare conductivities of various substances.
Relate conductivity to the type of bonds in a substance.
Infer the identities of unknown substances.

MATERIALS

- dropper bottle of distilled water
- glass stirring rod, small, or toothpicks
- gloves
- hand-held conductivity tester
- lab apron
- labeled containers 8, each with a different unknown substance
- paper towels
- safety goggles
- spatula
- spot plate
- thin-stemmed pipet

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Conductivity as an Indicator of Bond Type continued

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Figure 1
Conductivity as an Indicator of Bond Type continued

6. Repeat step 5 for the other unknown samples. Be sure to thoroughly wipe the leads of the conductivity probe with a clean paper towel between each test. For those substances that do conduct, compare the conductivities. Rate them on a scale from 0 to 4, with 4 as the best conductor. Record your observations and ratings in your lab notebook.

7. Using the pipet, add 10 drops of distilled water to each of the eight unknowns. Hold the tip of the pipet 1 to 2 cm above the unknowns. Use a small glass stirring rod or toothpicks to stir each mixture. Be sure to wipe the stirring rod or toothpick thoroughly with a clean paper towel after each use.

8. Observe each of the wells, and record in your lab notebook any observations about the dissolving or mixing of the unknowns.

9. Test the conductivity of each mixture, again wiping the leads thoroughly between each test. Record your results.

10. Clean all apparatus and your lab station. Return equipment to its proper place. Dispose of chemicals and solutions in the containers designated by your teacher. Do not pour any chemicals down the drain or into the trash unless your teacher directs you to do so. Wash your hands thoroughly before you leave the lab and after all work is finished.

Analysis

1. Organizing Ideas Which types of bonding are likely to be involved in the unknowns that were conductors in their pure form? Explain what free-moving charged particles are available in these types of bonds.

   Metallic bonding and other bonds involving free electrons, such as the bonds between graphite sheets, are the types of bonding that should conduct in pure form. The free-moving electrons are the charged particles that carry the current.

2. Organizing Ideas Which types of bonding are likely be involved in the unknowns that were not conductors in their pure form but conducted a current when they were mixed with water? Explain what free-moving charged particles are available in these types of bonds.

   Ionic substances that dissolve in water and polar covalent substances that form ions when dissolved in water are likely to conduct an electric current when mixed with water. The ions themselves serve as free-moving charged particles to carry the current.
3. Organizing ideas  Which types of bonding are likely to be involved in the unknowns that were not conductors in their pure form or when they were mixed with water? Explain why there were no free-moving charged particles available in these types of bonds.

The nonpolar covalent substances and those ionic substances that do not dissolve in water are likely to be insulators in their pure form. The covalent bonds in nonpolar molecules hold the electrons too firmly for them to carry the current. In ionic substances that do not dissolve in water, the ions are firmly bound in a lattice and are not available to move freely and carry the current.

4. Organizing Data and Relating Ideas  Fill in the table below by using the Useful Information that follows to determine which type of bonding is likely to be present in each of the substances listed and whether the substances are likely to conduct an electric current. Predict which will be the best conductor in pure form and dissolved in water, which will conduct only marginally, and which will not conduct at all.

**TABLE 1 CONDUCTIVITY OF VARIOUS SUBSTANCES**

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<th>Substance</th>
<th>Type of bonding</th>
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<th>Conductivity in H₂O</th>
<th>Matches unknown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chalk</td>
<td>ionic</td>
<td>no</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Charcoal</td>
<td>nonpolar covalent</td>
<td>no</td>
<td>not soluble</td>
<td></td>
</tr>
<tr>
<td>Graphite</td>
<td>nonpolar covalent with some free electrons</td>
<td>slight</td>
<td>not soluble</td>
<td></td>
</tr>
<tr>
<td>Sodium sulfate</td>
<td>ionic</td>
<td>no</td>
<td>yes</td>
<td></td>
</tr>
<tr>
<td>Sugar</td>
<td>nonpolar covalent</td>
<td>no</td>
<td>no</td>
<td></td>
</tr>
<tr>
<td>Tin</td>
<td>metallic</td>
<td>yes</td>
<td>not soluble</td>
<td></td>
</tr>
<tr>
<td>Distilled water</td>
<td>polar covalent</td>
<td>no</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>Tap water</td>
<td>polar covalent</td>
<td>slight</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
Useful Information

- Chalk is mostly CaCO₃ and dissolves only slightly in water.
- Sodium sulfate is white and dissolves in water.
- Tin is a metal.
- Charcoal is a form of carbon with the atoms bonded to each other in a randomly organized way.
- Graphite is a form of carbon. The atoms are bonded to each other in systematic sheets with some free electrons holding the sheets together.
- Sugar is a molecular substance that dissolves in water.
- Distilled or deionized water can be considered pure H₂O.
- Tap water contains many dissolved impurities that are molecular and ionic.

Conclusions

1. In the fifth column of your table, write the letter of the unknown that corresponds to the substance in each row. Explain your reasons for making each identification.

Students' answers will vary, depending on the assignment of letter designations to the unknowns. The following are some possible rationales for their identifications:

- Chalk is an ionic compound that does not dissolve in water, so it will not conduct. Charcoal is a molecule with nonpolar covalent bonds that will not conduct. Graphite consists mostly of nonpolar covalent bonds, but it also has some free electrons between bonding layers, so it will conduct slightly. Sugar is a molecule with nonpolar covalent bonds that will not conduct an electric current even when dissolved in water. Sodium sulfate is an ionic compound that will conduct after it is dissolved in water. Tin has metallic bonds and will conduct an electric current. Distilled or deionized water has polar covalent bonds that do not dissociate appreciably, so it will not conduct.
2. Designing Experiments and Predicting Outcomes  Predict the conductivities of each of the materials listed below, and give reasons for your predictions. How would the conductivity of each material be affected if water were added to it? If your teacher approves, test your predictions for all the materials except liquid bromine, which is too dangerous to work with.

a. an iron nail
b. liquid bromine, Br₂
c. wax (a random arrangement of molecules with long, nonpolar chains of carbon and hydrogen atoms)
d. a dilute hydrochloric acid solution, HCl(aq)
e. table salt, NaCl

An iron nail should conduct, because it contains metallic bonds with free electrons. Liquid bromine is a molecule that contains nonpolar covalent bonds, so it should not conduct. Wax is a molecule that contains nonpolar covalent bonds, so it should not conduct. Hydrochloric acid is a molecule that contains polar covalent bonds that dissociates in water, so it will conduct. If water is added, the conductivity of HCl will decrease as the concentration decreases. Table salt will not conduct in the solid form, but because it is an ionic compound, it will conduct when dissolved in water.