Electrons and Light: Using Indirect Evidence
Teacher Activity

Procedure

Demonstration 1

Demonstrate a stream of electrons using a cathode-ray tube if you have one. These tubes can be purchased from most chemistry supply houses. You will also need a high-voltage power supply and a strong magnet.

1. Set up the cathode-ray tube on your demonstration table with the coated side of the metal plate facing the class.
2. Connect a high-voltage power source to the cathode and anode of the tube with wire and alligator clamps.
3. Turn on the current. Students will see a narrow horizontal green band appear across the coated screen. This band is the result of electrons moving through the partially evacuated tube from cathode to anode. Emphasize to students that they are not seeing electrons directly but that they are seeing the effect of these electrons on the coated screen inside the tube.
4. Place a strong magnet near the tube. The stream of electrons will be deflected either toward or away from the magnet. Reversing the magnet will cause the reverse effect on the stream of electrons. Students probably already understand that a magnet acts on matter. This part of the demonstration should help students understand that the green band of light on the screen is being caused by some form of matter, and this fact is often used as evidence for the existence of electrons. Thomson did, in fact, interpret these "cathode rays" as bodies "much smaller than atoms." He called these small bits of matter "electrons."

Demonstration 2

Demonstrate the spectrum tubes for several elements, if you have the tubes and power source available. Typically available elements include hydrogen, helium, argon, neon, mercury, krypton, and nitrogen. Spectrum tubes and the power source can be purchased from most chemistry supply companies. Spectrum tubes are clear gas tubes that contain a single element in gaseous form. When high-voltage current is applied to the tubes, the element inside gives off visible energy. The gas seems to glow. A neon light is an example. Viewed by the naked eye, different tubes have different colors, but some are similar.

1. Place one tube in the power source and briefly turn on the power. Instruct students to view the glowing tube. Hydrogen is the simplest element and a good element to start this demonstration. Do not leave the power on too long. The tubes become hot. Be careful handling the tubes. Do not touch the electrodes at the end of the tubes while the power is on.
2. Distribute a handheld diffraction grating to each student. Supply companies also sell cardboard tubes with diffraction gratings in one end and a narrow slit in the other end. These may also be used. Advise students to look through the grating at an angle in order to see the bright lines of the spectrum. Have students sketch the lines they see and identify the colors of the lines.
3. Have students view the first tube a second time while looking through the gratings.
4. Repeat step 2 using different tubes containing different elements.

Student Lab Activity

In advance:

- Prepare 0.5-M solutions of as many of these ions as you have available: sodium, potassium, strontium, barium, and copper. If possible, use different soluble compounds of each metal. For example, for testing potassium use two different soluble potassium salts. When students compare their results with other groups in the class, they will be able to see that it is the metal ions that are responsible for the observed colors. Prepare sufficient separate samples so that each pair of lab groups at one station will have five to six solutions to test. Label each container with the formula (or name) of the solute.

- Place a wood splint in each sample solution. Use about 20 to 25 mL of solution in each container. Soak the wood splints (or popsicle sticks or tongue depressors) overnight. You can help keep students organized during the lab by writing the formula for the compound in the container on the wood splint. Warn students to match the formula on the wood splint with the formula on the container before replacing the wood splint during the lab.

For this lab you will need (for each group of two students)

- Small quantities of each solution (approx. 20 to 25 mL), labeled (per 2 lab groups) Wood splints, one for each solution
- Burner
- Striker (or other means of igniting the burner)
- Eye protection

Teacher Notes on Student Procedure

1. You and your partner must wear eye protection throughout this procedure.

2. Determine the number of solutions at your lab station.
In order to save on materials you can prepare one set of solutions for every two lab groups, and they can share the solutions. Be sure to label the beakers or other containers you use for the solutions and also label the wood splints. Emphasize to students that they should replace the wood splint in a solution only after checking the label on the container and the label on the wood splint to be sure they match.

3. Prepare a two-column table, one column for the formula of each solution and the other column for the flame color you observe during the lab. In your table, record the formula for the compounds in the solutions at your station.

Formula for Solution	Flame Color

4. Ignite your lab burner. Adjust the air supply so that a blue inner cone is produced within the flame.
You have probably already instructed students about how to light and adjust a lab burner. Review safety with them and also remind them that in order to achieve the blue inner cone they will need to increase the air flow to the burner.

5. Remove a wood splint from one of the solutions. Briefly place it in the flame at the tip of the blue cone. Observe the color of the flame.
You may have to let students practice distinguishing the flame colors. The wood splints tend to produce a yellowish flame color. The characteristic flame color resulting from the presence of an ion may be partly masked by this. Record this color on your table next to the appropriate compound. Students will use their own language to describe the colors they see. Remind them that this kind of qualitative observation must be used tentatively. It may be helpful at some point in the lab or the lesson to refer to the use of diffraction gratings in the earlier demonstration as a way to quantify the results by breaking up the emitted light into its constituent color bands according to frequencies, which can be measured. If you are not certain about the color, dip the wood

splint back in the solution and place the wood splint in the flame again. Be sure to replace the wood splint in the correct solution.

6. Repeat step 5 until you have recorded the flame color for all the compounds at your lab station.

7. Compare your results with several other lab groups. Compare the names of the compounds and the flame colors produced.
   If you have included different salts of the cations being tested, this step is important so students can see that the flame colors are characteristic of the cations in the solutions and not the anions. If the solutions are identical at each lab station, students can skip this step. You will have to come back to this concept, however, in the post-lab discussion since it is an important one.

Student Skills Required

Prior to starting this lab activity, students should know how to safely ignite and adjust a lab burner. As part of the lab activity, students should learn to distinguish multiple colors in the flame produced by a wood splint that has been soaked in a solution of a chemical salt.

Student Misconceptions

1. Students may think that in the demonstrations they are "seeing" electrons. This is not true. Chemists often rely on indirect evidence to arrive at conclusions. Many chemists, including Thomson, have relied on the evidence provided by the interaction of electrons with other forms of matter to make conclusions about the electrons themselves. By observing the effects produced by electrons, we can learn more about them. Thomson's initial assumption that electrons existed began many investigations about electrons and their properties.
2. Students often mistakenly think that the bright lines in the emission spectra are the result of electrons absorbing energy or that the lines are the result of atoms losing electrons. It is difficult to get students to understand that the light emitted by atoms is the result of electrons first absorbing energy (in specific amounts, or quanta) and then releasing that energy as they return to ground state. You should also refer to ionization energy to remind students that atoms lose electrons only when their ionization energy is added to them.

Answers to Pre-Lab Questions

1. Record your observations of the cathode-ray-tube demonstration.
   Be sure the students have noted the colored beam that appears on the coated surface in the tube when the current is turned on. Also be sure that they have noted the displacement of the beam in the presence of a magnet. Use these observations to develop the concept that they are evidence for the existence of electrons.

2. What indirect evidence does this demonstration provide for the existence of electrons?
   Note that students are not seeing the electrons themselves, but the result of the presence of the electrons and their interactions with the coated surface and the magnet. This kind of evidence is called indirect evidence, and you should stress to students that chemists must often use indirect evidence to support ideas in chemistry because the particles that make up matter are too small to be seen directly.

3. Record your observations of the spectrum-tube demonstration.
   Students should simply diagram the lines they see. They can record lines with colored pencils, if they are available. If not, have students label the color of the major visible

lines.

4. What indirect evidence does this demonstration provide for the existence of electrons?
Since each spectral line is the result of an excited electron losing energy ("falling" to a lower energy level) and since each time we observe the emission spectrum of an element the lines have the same frequencies, this indicates that all atoms of the same element have the same arrangement of electrons.

5. When you observe the results of the demonstration for a second time, how do the bright lines compare with those you observed the first time?
The results will be the same. Turning off the power source for any given tube and then turning it back on so students can see the spectral lines a second time is an important step because students should note that the emission spectra for a given element is characteristic of the element. Since this activity is designed to show students how they can use indirect evidence to learn about electrons in atoms, linking the spectral lines and electron arrangement is important. The fact that the emission spectrum of an element is always the same means that the element has a specific electron arrangement.

Answers to Post-Lab Questions

1. By comparing your results with the results of other lab groups, identify the ions responsible for the flame colors.
Answers here will depend on the cations you make available to students. A typical list includes
    - **Lithium: red**
    - **Sodium: orange**
    - **Potassium: purple/violet/lilac**
    - **Rubidium: red**
    - **Calcium: orange-red**
    - **Strontium: deep red**
    - **Barium: pale green**
    - **Copper: blue/green**

   Students should name cations because they are the ions common to each of the colors. For example, if you used both potassium nitrate and potassium chloride solutions, students should recognize that the potassium ion is present each time the purple-violet color appears in the flame.

2. As a class, make a list of ions and the characteristic color each one produces in the flame tests. **See above.**

3. Other students in your class may have used different color words to describe the observed flames. Based on the demonstrations you observed, how could you observe the flame colors so that everyone would get the same results?
Because the human eye is unable to discriminate between subtle color differences and because students naturally use different words to describe observed colors, the results in this lab are very qualitative. If students observed the flame test using spectroscopes or diffraction gratings (as they did in the demonstration), they would observe unique spectral lines for each different cation. These results would be quantitative.

4. In one or two sentences explain why each element displays a unique flame color.
Each element (or cation) displays a characteristic flame color because all atoms of the same element have the same electron arrangement. So when energy is added to those electrons,

they emit energy in the same way each time.

5. What element is present in the unknown solution given you by your teacher after the lab? **Answers will vary depending on the solutions you choose.**

Assessment
After the lab is completed, give each lab group an unknown solution and assign them the task of identifying the cation present in the solution. You could give every group the same unknown or assign different unknowns throughout the class.

Answers to Extension Questions

How could the results of this activity be applied to the production of fireworks?
Students should be able to apply what they learn in this activity to the idea that flame colors can be produced using compounds containing specifications. Compounds similar to the ones in this lab activity are used in the manufacture of fireworks.