

The Case

A small storage shed behind a fireworks supplier caught fire overnight. Investigators collected a white, salt-like residue from the floor, labeled it **Unknown X**, and sent it to your crime lab. Fireworks get their colors from metal salts, so the metal in this residue could tell investigators which product was stored there. Your job is to identify the metal using a flame test, and then decide how confident you can be in that identification.

Purpose

To observe the characteristic flame colors of several metal ions, use those observations to identify the metal in an unknown sample, and explain both the colors and the limits of the test using the behavior of electrons.

Learning Goals

- I can perform a flame test safely and correctly using a Bunsen burner.
- I can explain flame colors using ground states, excited states, and electron transitions.
- I can calculate the frequency and energy of a photon from its wavelength.
- I can identify a limitation of the flame test and propose a better method.

Background

Electrons in an atom can only occupy certain energy levels. In the **ground state**, every electron is in the lowest energy level available to it. When a metal salt is held in a hot flame, the metal ions absorb energy and some electrons jump to higher energy levels. The atom is now in an **excited state**, which is unstable. Almost immediately, each excited electron falls back to a lower level and releases the difference in energy as a single packet of light called a **photon**.

Because the energy levels are fixed, the energy of each photon is fixed too. The photon's energy determines its frequency and wavelength, and therefore its color:

$c = \lambda \nu$	$E = h\nu$	$E = hc / \lambda$
$c = 2.998 \times 10^8 \text{ m/s}$	$h = 6.626 \times 10^{-34} \text{ J}\cdot\text{s}$	$1 \text{ nm} = 1 \times 10^{-9} \text{ m}$

A larger drop between energy levels produces a higher-energy photon with a shorter wavelength (toward violet). A smaller drop produces a lower-energy photon with a longer wavelength (toward red). Every element has a different number of protons and electrons, so every element has its own set of energy-level spacings. The color you see in a flame test is actually a **mixture** of several wavelengths emitted at the same time, and your eye blends them into a single color. During the lab, you will use Table 1 to assign a representative wavelength to each color you observe.

Table 1: Representative Wavelengths of Visible Colors

Color	Violet	Blue	Blue-green	Green	Yellow-green	Yellow	Orange	Red
Wavelength (nm)	410	470	490	520	565	580	600	650

Pre-Lab Questions

Complete before lab day using the background and your notes.

1. Define **ground state**.
2. Define **excited state**.
3. The flame heats the metal ions. What happens to their electrons as they absorb this energy?
4. Describe what the electrons are doing at the moment an atom releases light.
5. Which photon carries more energy, red light (650 nm) or violet light (410 nm)? Explain using $E = hc/\lambda$.
6. Is a flame test a **qualitative** or **quantitative** test for identifying a metal? Explain.
7. Identify the independent variable, the dependent variable, and one controlled variable in this lab.
8. Every salt in this lab is a chloride. Why is that an important design choice?
9. Why don't all metals produce the same flame color?

Materials

- Chemical splash goggles
- Bunsen burner, gas hose, and striker
- Wooden splints, soaked in water (one per test)
- Beaker of water for used splints
- Test tube rack with labeled solutions

Solutions (0.5 M unless noted):

lithium chloride, LiCl
sodium chloride, NaCl
potassium chloride, KCl
calcium chloride, CaCl_2
strontium chloride, SrCl_2
barium chloride, BaCl_2 (0.1 M)
copper(II) chloride, CuCl_2
Unknown X

Safety

- Wear chemical splash goggles from setup through cleanup. Tie back long hair and secure loose sleeves and hoodie strings before lighting the burner.
- Never leave a lit burner unattended. Keep papers, backpacks, and the splint beaker away from the flame.
- **Barium chloride** is toxic if swallowed. **Copper(II) chloride** is harmful if swallowed, irritates skin and eyes, and is toxic to aquatic life. **Strontium chloride** can cause serious eye damage. **Lithium chloride** is harmful if swallowed and irritates body tissues. Avoid contact with all solutions.
- If a splint catches fire, drop it into the water beaker. Never return a used splint to any solution.
- Do not pour any solution down the drain. Wash your hands thoroughly before leaving the lab.

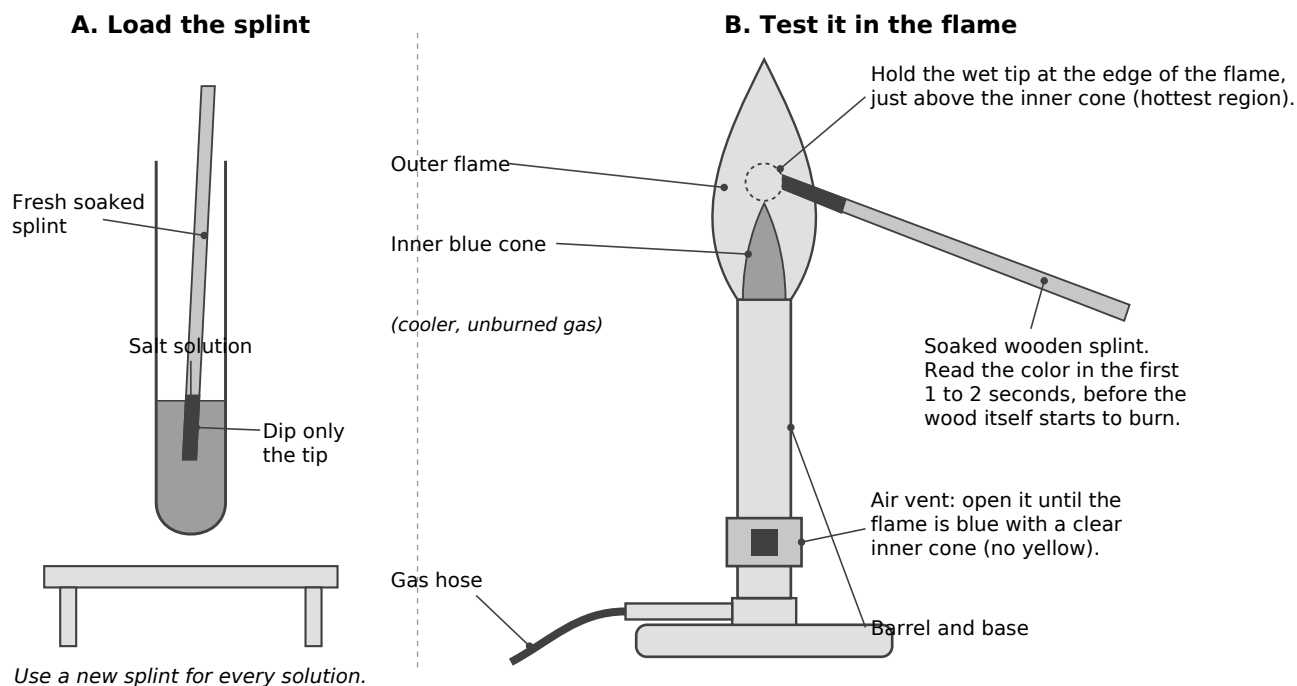


Figure 1: Loading a splint (A) and holding it in the correct region of a Bunsen burner flame (B).

Procedure

1. Put on your goggles. Connect the burner to the gas valve and light it with the striker.
2. Adjust the air vent until the flame is blue with a clear inner cone and no yellow tip (Figure 1B).
3. Take a **fresh** soaked splint and dip only its tip into the first known solution for 2 to 3 seconds (Figure 1A).
4. Hold the wet tip at the edge of the flame, just above the inner cone (Figure 1B). Watch the color in the first 1 to 2 seconds, before the wood begins to burn.
5. Record the flame color in Table 2. Then find the color in **Table 1: Representative Wavelengths of Visible Colors** (page 1) that best matches what you saw, and record that wavelength in Table 2. Drop the used splint into the water beaker.
6. Repeat Steps 3 to 5 for each known solution, using a new splint every time.
7. Test Unknown X the same way, using a new splint, and record its color and wavelength in Table 2.
8. Turn off the gas at the valve. Return all solutions to the station, wipe your area, and wash your hands.

Results

For each sample, record the flame color, then use Table 1 (page 1) to record the representative wavelength that best matches that color.

Table 2: Flame Test Colors and Estimated Wavelengths of Metal Chlorides

Metal salt	Metal ion	Flame color	Wavelength from Table 1 (nm)
Lithium chloride, LiCl	Li ⁺		
Sodium chloride, NaCl	Na ⁺		
Potassium chloride, KCl	K ⁺		
Calcium chloride, CaCl ₂	Ca ²⁺		
Strontium chloride, SrCl ₂	Sr ²⁺		
Barium chloride, BaCl ₂	Ba ²⁺		
Copper(II) chloride, CuCl ₂	Cu ²⁺		
Unknown X	?		

Post-Lab Questions

1. **Identify Unknown X** using a claim, evidence, and reasoning.

Claim: What metal ion(s) could Unknown X contain? **Evidence:** Cite specific colors and wavelengths from Table 2. **Reasoning:** Explain how your evidence supports your claim, and state how certain your identification is.

2. Describe a **limitation** of the flame test that this lab revealed, and explain why it happens.

3. Propose one additional test that could identify Unknown X with more certainty. Explain why it would work.

4. The red flame from Unknown X has a representative wavelength of 650 nm. Calculate the **frequency** and the **energy** of one photon of this light. Show your work with units.

5. Calculate the energy of one photon at the wavelength you recorded for copper(II) chloride. Compare it to your answer to Question 4: in which ion did the electron fall across a **larger** energy gap? Explain.
6. Draw a simplified **Bohr model**: a nucleus surrounded by three energy levels labeled $n = 1$, $n = 2$, and $n = 3$.
- a. Draw an arrow showing an electron absorbing energy from the flame and moving from $n = 1$ to $n = 3$. Label it.
 - b. Draw two arrows showing two different ways the electron could fall back: $n = 3$ to $n = 2$, and $n = 3$ to $n = 1$. Label each as a photon being emitted.
 - c. Which falling arrow releases the higher-energy photon? Use your model to explain why one element's flame contains more than one wavelength.
7. A student tested potassium chloride and saw a yellow-orange flame instead of lilac. Give the most likely cause and one way to fix it.
8. A fireworks designer wants one deep red burst and one green burst. Which metal compounds from this lab should she use, and why do they produce those colors?