

Teacher Notes

This is a one-day formative lab for Unit 2 (Quantum). Students observe the flame colors of seven metal chlorides, then try to identify Unknown X. Two of the knowns, lithium chloride and strontium chloride, give the same crimson red flame, and Unknown X is one of them. Students run into the problem on their own, which sets up the post-lab questions on the limitations of the flame test and leads directly into the gas discharge tube spectroscopy lab.

NGSS Alignment

This formative lab builds toward the performance expectations below rather than fully assessing them.

Dimension	NGSS element	Where it appears
Performance expectation	HS-PS4-1: Use mathematical representations to support a claim regarding relationships among the frequency, wavelength, and speed of waves traveling in various media.	Post-lab 4 and 5 ($c = \lambda\nu$)
Performance expectation	HS-PS4-3: Evaluate the claims, evidence, and reasoning behind the idea that electromagnetic radiation can be described either by a wave model or a particle model.	Background; pre-lab 5; post-lab 4 to 6 (wavelength and frequency alongside photon energy, $E = h\nu$)
DCI: PS4.B Electromagnetic Radiation	Atoms of each element emit and absorb characteristic frequencies of light, which allows identification of an element (secondary to HS-ESS1-2).	The core idea of the lab; post-lab 1 to 3
DCI: PS4.B Electromagnetic Radiation	Electromagnetic radiation can be modeled as a wave or as particles called photons.	Background; pre-lab 4 and 5
SEP	Planning and Carrying Out Investigations	Procedure; pre-lab 7 and 8 (variables and controls)
SEP	Developing and Using Models	Post-lab 6 (Bohr model)
SEP	Using Mathematics and Computational Thinking	Post-lab 4 and 5
SEP	Engaging in Argument from Evidence	Post-lab 1 (CER) and 2
CCC	Patterns	Each metal gives a characteristic color; two metals breaking the pattern reveals the limitation
CCC	Energy and Matter	Energy absorbed from the flame is released as photons; pre-lab 3 and 4, post-lab 6

Timing (45-minute period)

- **Night before:** background reading and pre-lab questions (about 15 minutes). Check pre-labs at the door; no pre-lab, no burner.
- **Class:** 5 minutes safety and Figure 1 walkthrough, about 25 to 30 minutes of testing, 10 minutes cleanup and debrief.
- **After:** post-lab questions as homework or the next day. They work well as preparation for a lab quiz.

Recommended Chemicals and Preparation

Make 100 mL of each solution in deionized water. That is enough for several sections, and the solutions store well in labeled, capped bottles. CsCl from the original version is left out: it is expensive and its faint blue-violet is almost always hidden by sodium yellow in a student flame, and KCl already covers the violet end.

Solution	Conc.	Mass per 100 mL	Expected flame	Table 1 value (nm)
Lithium chloride, LiCl	0.5 M	2.12 g LiCl	Crimson red	650
Strontium chloride, SrCl ₂	0.5 M	13.33 g SrCl ₂ ·6H ₂ O	Crimson red	650
Calcium chloride, CaCl ₂	0.5 M	7.35 g CaCl ₂ ·2H ₂ O (5.55 g anhydrous)	Orange-red (brick red)	600 or 650
Sodium chloride, NaCl	0.5 M	2.92 g NaCl	Bright yellow-orange	580 or 600
Potassium chloride, KCl	0.5 M	3.73 g KCl	Pale lilac (violet)	410
Barium chloride, BaCl ₂	0.1 M	2.44 g BaCl ₂ ·2H ₂ O	Pale yellow-green	520 or 565
Copper(II) chloride, CuCl ₂	0.5 M	8.52 g CuCl ₂ ·2H ₂ O	Blue-green	490
Unknown X (strontium chloride)	0.5 M	13.33 g SrCl ₂ ·6H ₂ O	Crimson red	650

Barium chloride is made at 0.1 M because it is the most toxic salt in the set and still gives a clear green at that concentration. Masses assume the hydrates listed; check the bottle label and adjust if your stock differs. Check every concentration against your current SDS and district chemical hygiene plan.

The Unknown and the Predicament

- **Recommended unknown: strontium chloride**, labeled only "Unknown X." Its crimson flame matches lithium chloride closely enough that students cannot tell them apart by eye in a Bunsen flame, so the data honestly support two possible answers.
- **Why Li and Sr:** they are the most reliably confused pair. Calcium is a useful "near miss" (more orange), so careful observers can rule it out and still be left with two candidates. That is the exact limitation you want them to name.
- **Optional rotation:** use lithium chloride as Unknown X in some sections. The predicament is identical and answers cannot be passed between periods.
- **Do not tell students in advance** that two knowns match. Let them find it. Expect some groups to commit to one answer with confidence; the post-lab CER asks them to defend that against their own data.

Station Setup (groups of 2 or 3)

- Bunsen burner, gas hose, striker, and chemical splash goggles for every student.
- Test tube rack with 8 labeled test tubes, about 3 mL of each solution (7 knowns plus Unknown X). A shared reagent station also works if tubes stay labeled.
- About 12 wooden splints per group, soaked in deionized water overnight (30 minutes minimum). Soaked splints resist burning and give a clean color.
- 250 mL beaker half full of tap water for spent splints.
- Optional: a handheld spectroscope or diffraction grating glasses for a quick teacher demo during the debrief.

Why splints instead of inoculation loops?

A fresh splint for every solution removes cross-contamination, which matters when students are comparing two similar reds. Loops must be cleaned in acid and heated between samples, and leftover sodium is the most common reason students see yellow. If you prefer loops, dip in dilute HCl and heat until the loop gives no color before each new sample, and change Step 3 to match.

Debrief (about 10 minutes)

- Poll the room: "Who said lithium? Strontium? Calcium?" The split vote is the evidence for the limitation.
- Ask: "Everyone followed the same procedure. Why can't we agree?" Steer toward the idea that a flame color is a blend of wavelengths and the eye reports only one blended color.
- Ask: "What tool could see the individual wavelengths?" Introduce the spectroscope. If you have one, show LiCl, SrCl₂, and Unknown X through it as a demo. Lithium shows one dominant red line (about 671 nm); strontium shows several red and orange lines plus a blue line near 461 nm.
- Preview the gas discharge tube lab: same physics, sharper lines. Reveal Unknown X only after spectroscope evidence, or hold it until that lab.

Troubleshooting

- **Everything looks yellow-orange:** sodium contamination or a burning splint. Use a fresh, well-soaked splint, rinse tubes with DI water, and read the color in the first 1 to 2 seconds.
- **Potassium shows yellow:** this is normal; sodium is a common impurity and its yellow is far brighter than potassium's lilac. Use fresh splints and clean tubes to keep sodium out.
- **Weak color:** the tip is in the inner cone or the flame is yellow. Open the air vent and hold the tip at the edge, just above the cone.
- **Splint catches fire:** drop it in the water beaker. Remind students that a lit splint gives the orange color of burning wood, not the metal.

Disposal

Spent splints: soak in the water beaker, then trash. Leftover solutions: store labeled for reuse. Do not pour barium, copper, or strontium solutions down the drain; collect any waste in a labeled container for your district's chemical waste pickup, following the SDS and your chemical hygiene plan.

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**.

The lowest-energy arrangement of an atom's electrons, with every electron in the lowest energy level available to it.

2. Define **excited state**.

A higher-energy, unstable arrangement in which one or more electrons have absorbed energy and moved to a higher energy level than in the ground state.

3. The flame heats the metal ions. What happens to their electrons as they absorb this energy?

Electrons absorb energy and jump from lower energy levels to higher energy levels, putting the atom in an excited state.

4. Describe what the electrons are doing at the moment an atom releases light.

Excited electrons fall back from a higher energy level to a lower one. The energy difference between the levels is released as a photon of light ($\Delta E = h\nu$).

5. Which photon carries more energy, red light (650 nm) or violet light (410 nm)? Explain using $E = hc/\lambda$.

Violet. Energy is inversely proportional to wavelength, so the shorter 410 nm wavelength has the higher energy (4.85×10^{-19} J vs. 3.06×10^{-19} J for red).

6. Is a flame test a **qualitative** or **quantitative** test for identifying a metal? Explain.

Qualitative. It identifies the metal by observing a color, not by measuring an amount or number.

7. Identify the independent variable, the dependent variable, and one controlled variable in this lab.

Independent: the identity of the metal ion (which salt is tested). Dependent: the flame color (and estimated wavelength). Controlled (any one): every salt is a chloride, same concentration, same flame setting and position, a fresh splint each time.

8. Every salt in this lab is a chloride. Why is that an important design choice?

Keeping the anion the same means any difference in flame color can be attributed to the metal cation, not to the chloride.

9. Why don't all metals produce the same flame color?

Each element has a different number of protons and electrons, so its energy levels are spaced differently. Different energy drops produce photons of different energies and wavelengths, and therefore different colors.

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.

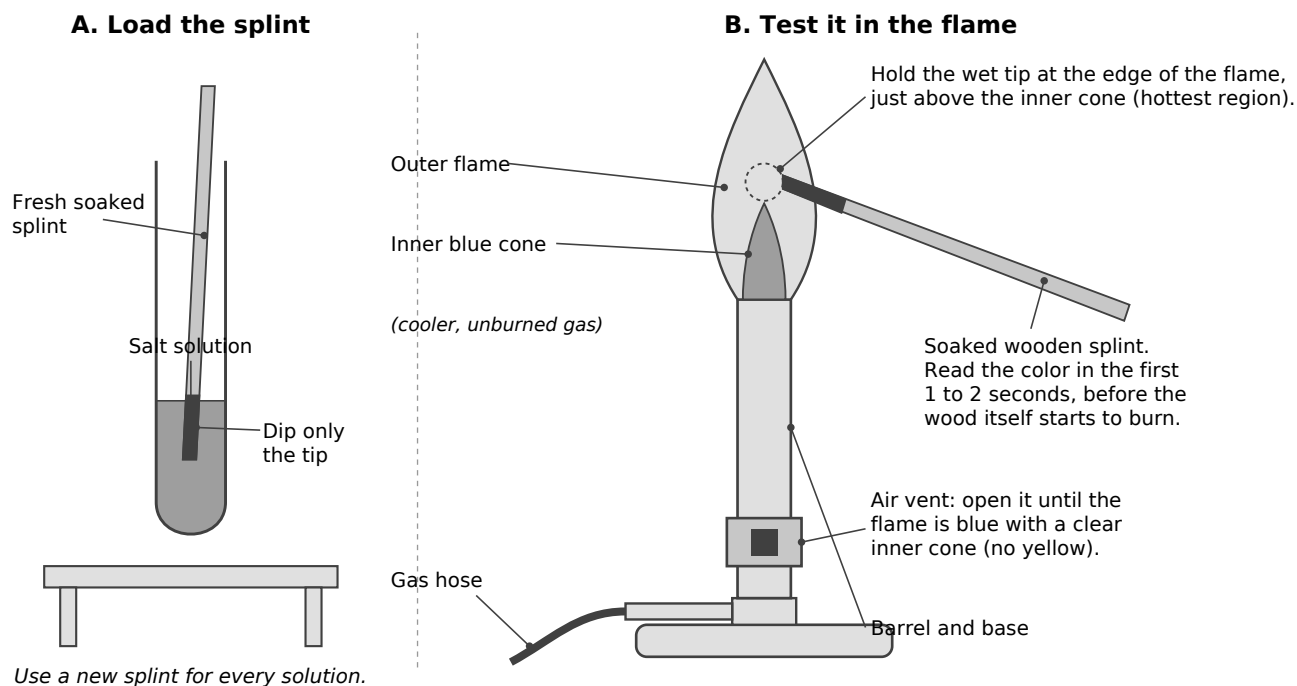


Figure 1: Loading a splint (A) and holding it in the correct region of a Bunsen burner flame (B).

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 ⁺	Crimson red	650
Sodium chloride, NaCl	Na ⁺	Bright yellow-orange	580
Potassium chloride, KCl	K ⁺	Pale lilac (often masked by yellow)	410
Calcium chloride, CaCl ₂	Ca ²⁺	Orange-red	600
Strontium chloride, SrCl ₂	Sr ²⁺	Crimson red	650
Barium chloride, BaCl ₂	Ba ²⁺	Pale yellow-green	565
Copper(II) chloride, CuCl ₂	Cu ²⁺	Blue-green	490
Unknown X	?	Crimson red	650

Colors are descriptive; accept reasonable student language and the neighboring Table 1 value when a color falls between two entries (for example, 520 or 565 for barium, 600 or 650 for calcium). The key result is that Unknown X matches both LiCl and SrCl₂, and is more red than CaCl₂.

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.

Claim: Unknown X contains either lithium or strontium ions; the flame test alone cannot decide between them. **Evidence:** Unknown X gave a crimson red flame (about 650 nm), the same color as LiCl and SrCl_2 , and redder than the orange-red of CaCl_2 . **Reasoning:** Matching colors mean the unknown emits light similar to Li and Sr, but because two knowns gave the same observed color, the data support two identities, so the identification is uncertain. A confident single answer with no mention of the second match is not supported by the data.

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

Two different metals (Li and Sr) produced flame colors that look identical, so the test cannot always distinguish them. Each flame color is a mixture of several wavelengths, and the eye blends the mixture into one perceived color, so different combinations of wavelengths can look the same. The test is also subjective and easily affected by sodium contamination.

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

View the flames through a spectroscope (diffraction grating). It separates the light into individual lines; lithium shows one strong red line (about 671 nm) while strontium shows several red-orange lines plus a blue line near 461 nm, so the line patterns differ even though the colors look the same. Also accept a chemical test, such as adding sodium sulfate: strontium sulfate forms a white precipitate, while lithium sulfate stays dissolved.

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.

$$\nu = c/\lambda = (2.998 \times 10^8 \text{ m/s}) / (650 \times 10^{-9} \text{ m}) = 4.61 \times 10^{14} \text{ s}^{-1}. E = h\nu = (6.626 \times 10^{-34} \text{ J}\cdot\text{s})(4.61 \times 10^{14} \text{ s}^{-1}) = 3.06 \times 10^{-19} \text{ J}.$$

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.

Using 490 nm: $E = hc/\lambda = (6.626 \times 10^{-34})(2.998 \times 10^8) / (490 \times 10^{-9}) = 4.05 \times 10^{-19} \text{ J}$. Copper's photon has more energy than the red photon ($3.06 \times 10^{-19} \text{ J}$), so the electron in copper fell across the larger energy gap. Shorter wavelength means higher energy, which means a larger drop between levels. (Accept answers using the student's own recorded wavelength.)

6. Draw a simplified **Bohr model**: a nucleus surrounded by three energy levels labeled $n = 1$, $n = 2$, and $n = 3$.
- Draw an arrow showing an electron absorbing energy from the flame and moving from $n = 1$ to $n = 3$. Label it.
 - 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.
 - Which falling arrow releases the higher-energy photon? Use your model to explain why one element's flame contains more than one wavelength.

a. Arrow from the $n = 1$ ring outward to the $n = 3$ ring, labeled "absorbs energy" (from the flame). b. Two arrows pointing inward from $n = 3$, one ending at $n = 2$ and one at $n = 1$, each labeled "emits photon (light)." c. The $n = 3$ to $n = 1$ drop releases the higher-energy photon (shorter wavelength) because it crosses the larger energy gap. Excited electrons can fall back by different paths, and each path emits a different wavelength, so the flame is a mixture of wavelengths that the eye sees as one color. Electron counts are not required; this is a model of transitions, not of a specific element.

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.

Sodium contamination (from fingers, a reused or dirty splint, or an impure sample). Sodium's bright yellow overpowers potassium's faint lilac. Fix: use a fresh splint and a clean test tube, and avoid touching the wet tip of the splint.

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?

Red: strontium compound (lithium also gives red). Green: barium compound (copper gives blue-green). When heated, electrons in these ions are excited and then fall to lower levels, emitting photons whose energies correspond to red (smaller energy gaps) or green (larger energy gaps) wavelengths.