

Flame Tests

Atomic Emission and Electron Energy Levels

Introduction

Just as a fingerprint is unique to each person, the color of light emitted by an element heated in a flame is also unique to each element. In this experiment, the characteristic color of light emitted by calcium, copper, lithium, potassium, sodium, and strontium ions will be observed.

Concepts

- Atomic emission
- Wavelength and energy of light
- Excited vs. ground states
- Flame tests

Background

When a substance is heated in a flame, the atoms absorb energy from the flame. This absorbed energy allows the electrons to be promoted to excited energy levels. From these excited energy levels, there is a natural tendency for the electrons to make a transition or drop back down to the ground state. When an electron makes a transition from a higher energy level to a lower energy level, a particle of light called a photon is emitted (see Figure 1). Both the absorption and emission of energy are quantized—only certain energy levels are allowed.

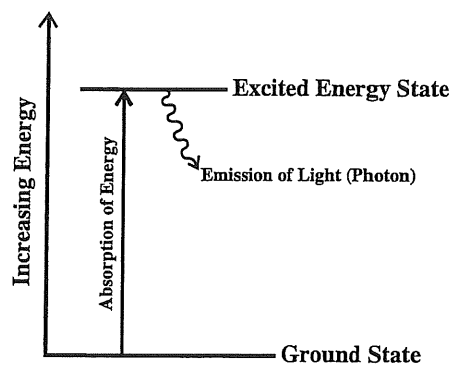


Figure 1. Absorption and emission of energy.

An electron may drop all the way back down to the ground state in a single step, emitting a photon in the process. Alternatively, an electron may drop back down to the ground state in a series of smaller steps, emitting a photon with each step. In either case, the energy of each emitted photon is equal to the difference in energy between the excited state and the state to which the electron relaxes. The energy of the emitted photon determines the color of light observed in the flame. The flame color may be described in terms of its wavelength, and Equation 1 may be used to calculate the energy of the emitted photon.

$$\Delta E = \frac{hc}{\lambda} \quad \text{Equation 1}$$

ΔE is the difference in energy between the two energy levels in joules (J),

h is Planck's constant ($h = 6.626 \times 10^{-34}$ J·sec),

c is the speed of light ($c = 2.998 \times 10^8$ m/sec), and

λ (lambda) is the wavelength of light in meters. The wavelengths of visible light are given in units of nanometers ($1 \text{ m} = 1 \times 10^9 \text{ nm}$). See Table 1 on the following page.

The color of light observed when a substance is heated in a flame varies from one substance to another. Because each element has a different spacing of electron energy levels, the possible electron transitions for a given substance are unique. Therefore, the difference in energy between energy levels, the exact energy of the emitted photon, and the corresponding wavelength and color are unique to each substance. As a result, the colors observed when a substance is heated in a flame may be used as a means of identification.

The Visible Portion of the Electromagnetic Spectrum

Visible light is a form of electromagnetic radiation. Other familiar forms of electromagnetic radiation include γ -rays, X-rays, ultraviolet (UV) radiation, infrared (IR) radiation, microwave radiation, and radio waves. Together, all forms of electromagnetic radiation make up the electromagnetic spectrum. The visible portion of the electromagnetic spectrum is the only portion that can be detected by the human eye—all other forms of electromagnetic radiation are invisible.

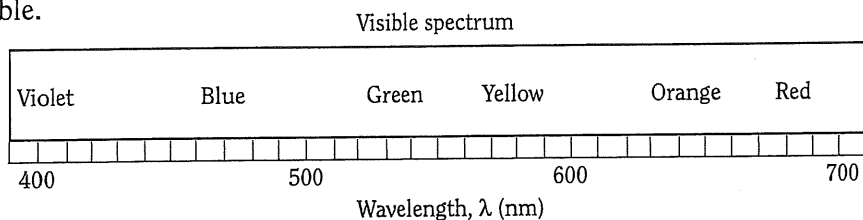


Figure 2. The visible spectrum.

The visible spectrum spans the wavelength region from about 400 to 700 nm (Figure 2). Light of 400 nm is seen as violet and light of 700 nm is seen as red. According to Equation 1, wavelength is inversely proportional to energy. Therefore, violet light is higher energy light than red light. As the color of light changes, so does the amount of energy it possesses.

Table 1 lists the wavelengths associated with each of the colors in the visible spectrum. The representative wavelengths may be used as a benchmark for each color. For example, instead of referring to green as light in the wavelength range 500–560 nm, we may approximate the wavelength of a green light as 520 nm. An infinite number of shades of each color may be observed.

Table 1.

Representative Wavelength, nm	Wavelength Region, nm	Color
410	400–425	Violet
470	425–480	Blue
490	480–500	Blue-green
520	500–560	Green
565	560–580	Yellow-green
580	580–585	Yellow
600	585–650	Orange
650	650–700	Red

Experiment Overview

The purpose of this experiment is to observe the characteristic flame test colors of different metal compounds and to use this information to identify an unknown metal ion.

Pre-Lab Questions

1. Fill in the blanks: When an atom absorbs energy, the electrons move from their _____ state to an _____ state. When an atom emits energy, the electrons move from a(n) _____ state to their _____ state and give off _____.
2. Is a flame test a qualitative or quantitative test for the identity of an unknown? Explain.

Materials

Calcium chloride, $\text{CaCl}_2 \cdot 2\text{H}_2\text{O}$, 0.5 g	Beakers, 250-mL, 2
Copper(II) chloride, $\text{CuCl}_2 \cdot 2\text{H}_2\text{O}$, 0.5 g	Laboratory burner
Lithium chloride, LiCl , 0.5 g	Scoop or spatula
Potassium chloride, KCl , 0.5 g	Weighing dishes, 7
Sodium chloride, NaCl , 0.5 g	Wooden splints soaked in water, 7
Strontium chloride, $\text{SrCl}_2 \cdot 6\text{H}_2\text{O}$, 0.5 g	Water, distilled or deionized
Unknown metal chloride, 0.5 g	

Safety Precautions

Copper(II) chloride is highly toxic by ingestion; avoid contact with eyes, skin, and mucous membranes. Lithium chloride is moderately toxic by ingestion and is a body tissue irritant. Fully extinguish the wooden splints by immersing them in a beaker of water before discarding them in the trash to avoid trash can fires. Wear chemical splash goggles, chemical-resistant gloves, and a chemical-resistant apron. Wash hands thoroughly with soap and water before leaving the laboratory.

Procedure

1. Fill a 250-mL beaker about half-full with distilled or deionized water. Obtain seven wooden splints that have been soaked in distilled or deionized water. Place them in this beaker of water to continue soaking at your lab station.
2. Fill a second 250-mL beaker about half-full with tap water. Label this beaker "rinse water".
3. Label seven weighing dishes Ca, Cu, Li, Na, K, Sr, and unknown. Place one scoopful (about 0.5 g) of each solid metal chloride into the corresponding weighing dish.
4. Light the laboratory burner.
5. Dip the soaked end of one of the wooden splints in one of the metal chlorides, then place it in the flame. Observe the color of the flame. Allow the splint to burn until the color fades. Try not to allow any of the solid to fall into the barrel of the laboratory burner. If necessary, repeat the test with the same splint and additional salt.

6. Immerse the wooden splint in the “rinse water” to extinguish it, then discard it in the trash.
7. Record your observations for the flame color produced by the metal chloride in the Data Table.
8. Repeat Steps 5–7 for the other five metal chlorides. Record your observations for the flame color produced by each metal ion in the Data Table.
9. Perform a flame test on an unknown metal chloride and record its characteristic color(s) and the probable identity of the unknown in the Data Table.

Name: _____

Class/Lab Period: _____

Flame Tests

Data Table

Metal Ion	Color of Flame
Calcium	
Copper	
Lithium	
Sodium	
Potassium	
Strontium	
Unknown	

Results Table

Metal/Flame Color	λ (nm)	λ (m)	ΔE (J)

Post-Lab Questions

1. Use Table 1 in the *Background* section to record the approximate wavelength of light emitted for each known metal ion in the Results Table.
2. Convert each wavelength in the Results Table from nanometers to meters. Show one sample calculation in the space below and record all values in the Results Table.
3. The characteristic color of the sodium flame is due to two closely-spaced energy transitions. Use Equation 1 from the *Background* section to calculate the average energy (ΔE) corresponding to the observed flame color for each metal. Show one sample calculation in the space below and record all values in joules in the Results Table.
4. What evidence is there from your results that the characteristic color observed for each compound is due to the metal ion in each case? Describe an additional test that could be done to confirm that the color is due to the metal ion.
5. A glass rod was heated in a burner flame and gave off a bright yellow flame. What metal ion predominates in the glass rod?
6. The alkali metals cesium (Cs) and rubidium (Rb) were discovered based on their characteristic flame colors. Cesium is named after the sky and rubidium after the gem color. What colors of light do you think these metals give off when heated in a flame?