



FLAME TESTS

Lab Report 1

Abstract

In this paper we investigate valence electron excitation and subsequent photon emission from various metal cations in solution.

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Introduction

Light, visible to humans, falls approximately between wavelengths 400-750nm on the electromagnetic spectrum^[1]. Meaning that the eye can be used as a crude biological spectrophotometer enabling identification of unknown ionic compounds by comparing experimental colours to a data sheet of known ones. Photoemission from metal ions being the phenomenon studied during this experiment. It is caused by excited valence electrons relaxing to the ground state energy level, and releasing photons of discrete energies that correspond to the energy of excitation from the ground state, which in turn is perceived as coloured flame by the observer. Plank, Einstein and de Broglie paved the way for our understanding of quantum mechanics and the wave-particle duality that underpins interactions at this level, applying not only to photons and electrons but, protons, quarks, neutrinos and many more^[2].

$$E = hf = \hbar\omega \text{ {1}}, \text{The Plank – Einstein Relation.}$$

$$p = \frac{h}{\lambda} = \hbar k \text{ {2}}, \text{The de Broglie Relation.}$$

$$c = \lambda f \text{ {3}}, \text{Speed of light in freespace.}$$

Equations {1} and {2}, state that the energy of a photon (E) is proportional to its frequency ($\omega = 2\pi f$), and that its momentum is inversely proportional to its wavelength ($k = 2\pi/\lambda$). Given that the speed of light in free space is known one can determine the energy and momentum of a photon given either its wavelength or frequency allowing the energy of excitation of an electron for each metal ion to become apparent.

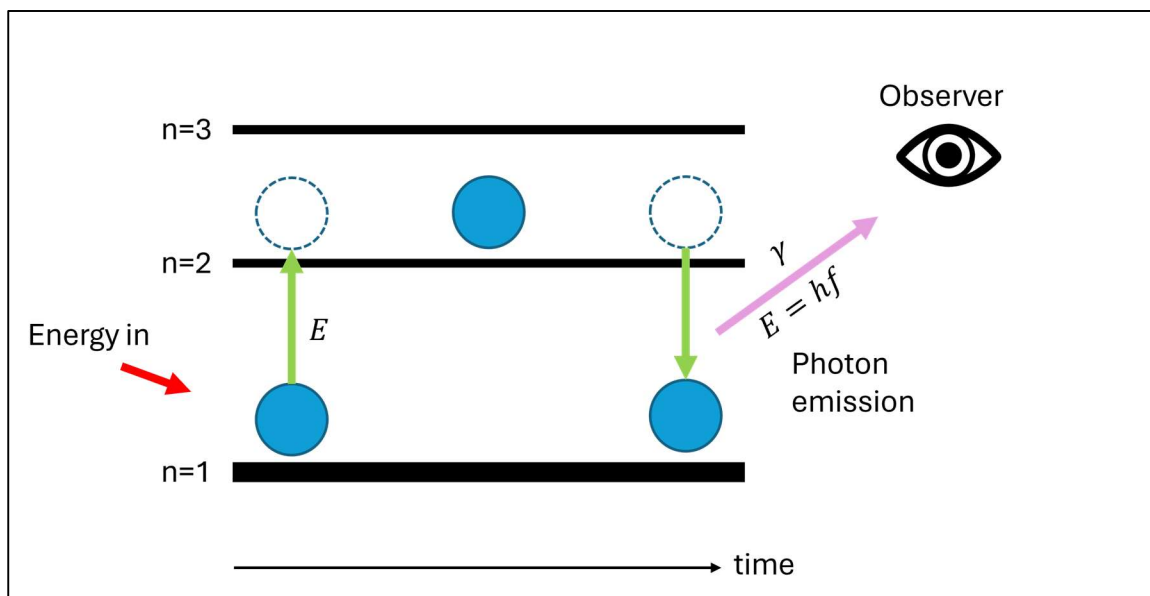


Figure 1: Visual representation of an electron being excited and relaxed from and to the ground state, resulting in photon emission.

Materials and Methods

The experimental procedure to identify unknown metal ions in solution was as follows and required the following equipment.

There were eight unknown metal salts dissolved in solution(A-H). Set up and the experimental process undertaken to identify them were as follows.

- Bunsen burner.
- Heat-resistant mat.
- Matches/lighter.
- Metal/wire rod.
- 1M solutions of unknown metal salts, labelled A-H.
- 1M solution of HCl.
- Deionised water.
- Blue cobalt glass.

Prior to setting up equipment a safety data sheet of chemical hazards was consulted. Initial setup required putting down a heat proof mat to ensure a safe working environment when using the Bunsen burner. The Bunsen burner was lit in the safety flame position, with the vent only fully opened when in operation. The metal/wire rod was thoroughly cleaned in the hydrochloric acid and any residual contaminants burnt off repeating this as necessary until the wire was clean. Before dipping the wire in salt solution, it was rinsed in deionised water to remove the hydrochloric acid and this step was repeated before changing the sample of unknown metal salts. The rod with the unknown salt solution was then heated by the Bunsen burner giving a coloured flame.

The above procedures were repeated as appropriate and each of the eight experimental flame colours were recorded.

Results & Discussion

During the test, the different salts produced varying qualities of flames. For example, sample A, had vivid and clear colour that was easily observable, whereas group D, was difficult to readily assign a definitive colour. Contamination both light and chemical, was naturally present. Chemical contamination was negligible. The light contamination from the large commercial lights in the lab was an obstacle, as typical of commercial lighting there was a blue-purple tint that washed out some of the duller flames.

The experiment was able to identify the unknown cations by comparing the observed colours to emission spectra of known cations and their colours. Observation by eye, provided a fast, and intuitive way to qualitatively identify possible cations present. The experimental results were straightforward with few surprises, by consulting the data sheet the following table was produced matching observed colours to cations.

Sample	Observed Colour 1	Metal Ion
A	green	Ba 2+
B	red	Sr 2+
C	orange	K+, Na+
D	Lavender	K+
E	yellow	Na +
F	pink/red	Li +
G	blue/green	Cu 2+
H	orange/yellow-	Ca 2+

Table 1: Observed colour of flame.

Sodium has distinct and well-known emission spectra, dominated by what is called the sodium D-lines. Producing a yellow photon of either 589 nm or 589.6 nm^[3] and this is an example of a doublet split state energy level, where the 3p energy levels split into sub-subshells of 3p_{1/2} and 3p_{3/2}. This splitting occurs because of magnetic interactions between the electrons orbiting the nucleus creating a magnetic field which reacts with the individual magnetic fields created by each electron due to electron spin. Cu²⁺ emits a photon in the blue-green region, this means that it has a shorter wavelength and therefore at higher energy than sodium photons. This is because where is the greater energy level relaxation to the ground state higher energy photons tend towards the purple end of the spectrum.

OME context

Outside of the obvious colours that fireworks make, emissions of spectra have a wide array of applications from identification of materials, spectroscopy, and pyrotechnic countermeasures.

Conclusion

From analysis of the colours resulting from photoemission, unknown salts were able to be identified. The flame colours were typical of the following, Ba²⁺, Sr²⁺, K⁺, Na⁺, Li⁺, Cu²⁺, Ca²⁺, cations.

Bibliography

- [1] C. Starr, *Biology concepts and applications*. 6th ed. Belmont, CA : Thomson, Brooks/Cole, 2006, p. 94.
- [2] M. Goray, "The 'pliable character' might be the reason for wave-particle duality of light," *Optik*, vol. 274, p. 170537, Mar. 2023, doi: <https://doi.org/10.1016/j.ijleo.2023.170537>.
- [3] Rodolphe Momier, A. V. Papoyan, and C. Leroy, "Sub-Doppler spectra of sodium D lines in a wide range of magnetic field: Theoretical study," *Journal of Quantitative Spectroscopy & Radiative Transfer*, vol. 272, pp. 107780–107780, Sep. 2021, doi: <https://doi.org/10.1016/j.jqsrt.2021.107780>.