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Apprenticeship

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Chemistry Lab Report 1: Flame Test

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Academic integrity declaration

I declare that:

- the report submitted has been written by me alone.
- the report submitted has not been previously submitted to this university or any other.
- that all content, including primary and/or secondary data, is true to the best of my knowledge.
- that all quotations and references have been duly acknowledged according to the requirements of academic research.

I understand that to knowingly submit work in violation of the above statement will be considered by examiners as academic misconduct.

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List of Abbreviations

HCl	Hydrochloric Acid
DI	Deionised
CBRN	Chemical Biological Radiological and Nuclear
OME	Ordnance Munitions and Explosives

1 Introduction

A flame test conceptually relies on the characteristic of an atom's electrons to move from lower energy orbitals to higher energy orbitals upon exposure to external energy (in this case a high temperature flame) and their subsequent emission of electromagnetic radiation, i.e. a photon with energy equal to the difference between the two orbitals. Since each element's orbitals have a unique energy gap, the exact energy of the photon can be used to identify the element.

In this experiment the student intends to use the above concept to identify a set of unknown metal salts by comparing their flame test emission colour. This colour will then be converted into its approximate wavelength and via the combination [see eq. (3)] of the basic sinusoidal wavelength-frequency relation [1] (where λ is the wavelength, ν is the speed of the wave and f is the frequency) [see eq. (1)] and the Planck relation [2] (where E is energy and h is the Planck constant) [see eq. (2)], the energy of the photon emission for each element will be calculated.

$$(1) \quad \lambda = \frac{\nu}{f} \quad \text{where } \nu = c \quad \text{the speed of light in a vacuum}$$

$$(2) \quad E = hf$$

$$(3) \quad E = \frac{hc}{\lambda}$$

Additionally, the wavelength/emission energy will be compared to known emissions for metals to identify each salt's metallic element.

2 Results

The set of unknown metal salts labelled A through to H were tested and their colours were recorded. These colours were compared to a table of corresponding wavelengths to approximate respective wavelength of each salt's flame test emission. They were then collated into a table [see Table 1] wherein the photon energies were also calculated. Furthermore, the colours were compared to a

known set of elemental emissions [3] to match each solution to a corresponding metal salt.

Table 1: a collation of all solution colours, wavelengths and photon energies

Solution	Flame colour	Suspected ion	Suspected solution	Wavelength (nm)	Photon energy (J)
A	Orange	Ca ²⁺	Calcium chloride	620	3.20394E-19
B	Lavender	K ⁺	Potassium chloride	400	4.96611E-19
C	Yellow	Na ⁺	Sodium chloride	590	3.36686E-19
D	Red	Sr ²⁺	Strontium chloride	650	3.05607E-19
E	Blue/Green	Cu ²⁺	Copper (II) chloride	490	4.05397E-19
F	Red/pink	Li ⁺	Lithium chloride	650	3.05607E-19
G	Green	Ba ²⁺	Barium chloride	520	3.82009E-19
H	Yellow/lavender	Na ⁺ /K ⁺	Sodium/potassium mixture	590	3.36686E-19
			and	400	4.96611E-19

Overall, each solution was matched with a unique metal salt however it is worth noting that sodium contamination was present in some of the samples.

3 Discussion

It can be seen from the results that each solution could be identified from its flame test photon emission by comparing it to a known spectral emission of an element [4,5]. For example, solution E gave off a unique green/blue hue which can be specifically attributed to the element copper. From this wavelength of approximately 490 nm it can be calculated via a combination of the wavelength frequency relation and the Planck relation [see eq. (3)] that the photon emitted had an approximate energy of 4.1×10^{-19} J, or 2.4 eV. This suggests that when exposed to an open flame, electrons in a low energy orbital of a copper atom are promoted to an orbital higher in energy and then demoted to an orbital 2.4 eV lower in energy. In the case of solution F, a reddish pink flame appeared, indicating lithium [6]. Pink does not necessarily have a corresponding wavelength but rather is the result of a mixture of white and red light. As such, it is not reasonable to expect an accurate wavelength assignment, however the student has approximated the wavelength to be around 650 nm, suggesting a photon energy of around 3.1×10^{-19} J or 1.9 eV.

It should be noted that there were various issues with the flame test which may cast doubt on the efficacy of the test results. For example, as mentioned with the suspected lithium solution, a pink hue cannot realistically be corresponded to a given wavelength without sophisticated equipment. Additionally, sodium contamination was rampant among samples, meaning many colours had to be observed through cobalt glass, which blocks the main sodium emission wavelength. Observing these colours through the blue cobalt glass may have affected the interpretation of the colour of the flame.

There are, however, more reliable use-cases for the concepts that underlie the flame test. For example, flame photometry is commonly used as an inexpensive method to detect trace amounts of various elements and has uses in Chemical, Biological, Radiological and Nuclear (CBRN) contaminated environments [7] which could be of significant utility in an Ordnance, Munitions and Explosives (OME) post-incident investigatory setting. Similarly, more sophisticated methods of emission spectroscopy exist, such as Inductively Coupled Plasma Atomic Emission Spectroscopy (ICP-AES) which uses high temperature plasma to induce spectral emissions in a sample, which can then be compared to known elemental spectra to precisely identify trace elements in said sample [8]. This method sees wide applications for metal identification in various fields such as the food industry [9], but it is easy to see how this method could be transferrable to an OME setting, for example detecting trace metals in a post explosion environment.

4 Conclusion & Evaluation

To summarise, the student was able to identify the elemental constituents of several unknown samples using the flame test and then used that information to further calculate potential information about the electron orbitals present in the atoms. The student was also able to identify practical applications of the concepts at play in the flame test but remained critical of the inherent flaws that should be accounted for when drawing conclusions about the results. In future, there would likely be value in investigating what range of elements are possible to identify via

this test, as well as how to limit contamination of sodium specifically. Additionally, here it may be of interest to investigate how changing the flame temperature might affect the colour given by the same element.

References

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Appendix

4.1 Materials and methods

The student made use of the following materials:

- A Bunsen burner
- A small piece of cobalt glass
- A metal tipped rod
- Glass vials of 1M metal salt solutions
- A lighter
- Glass beakers
- 2M Hydrochloric acid (HCl)
- Deionised water (DI water)
- Heatproof matt

The student followed the below procedure:

1. Set up and ignite the Bunsen burner
2. Collect a metal salt solution, as well as a beaker each of HCl and DI water
3. Wash the metal tip of the rod with HCl, then dry with the flame, repeat until no colour is shown
4. Wash the metal tip of the rod with DI water
5. Dip the tip of the rod into the salt solution and then insert it into the hottest region of the Bunsen burner's blue flame
6. Record the colour of the flame, making sure to view with cobalt glass if sodium appears to be present
7. Repeat steps 3, 4, 5 and 6 for each metal salt solution

Cobalt glass was also used to block the stronger sodium wavelengths from being observed, as they would likely overpower any other colours.

4.2 Copy of the original data sheet

DATA SHEET to RECORD OBSERVATIONS, CALCULATIONS and RESULTS

STUDENT'S NAME: Conor

PARTNERS' NAMES: Callum

REPORT IS DUE MARCH 14th (21st with DD), 2025

submitted via Moodle

Observations and Identification:

Complete the table below. Based on the observed colour of the flame and Table 1, identify the metal ion in each unknown salt. Using the electromagnetic spectrum in Fig 2, estimate and report with the appropriate unit the wavelength for each observed colour. Identify the solution containing mixture of sodium and potassium:

Unknown metal salt	Colour of the flame	Identity of metal	Wavelength
DI water	No colour	---	---
1 M HCl	No colour	---	---
A	Orange red?	Ca	620
B	Orange	K	400
C	Red/orange ^(light with Co glass)	Na?	589
D	Red	Sr	650
E	Blue/green	~~Cu~~ Cu ²⁺	490
F	Red/pink	Li	650
G	Green	Ba	520
H	orange → Lav	Mixture	590 → 400