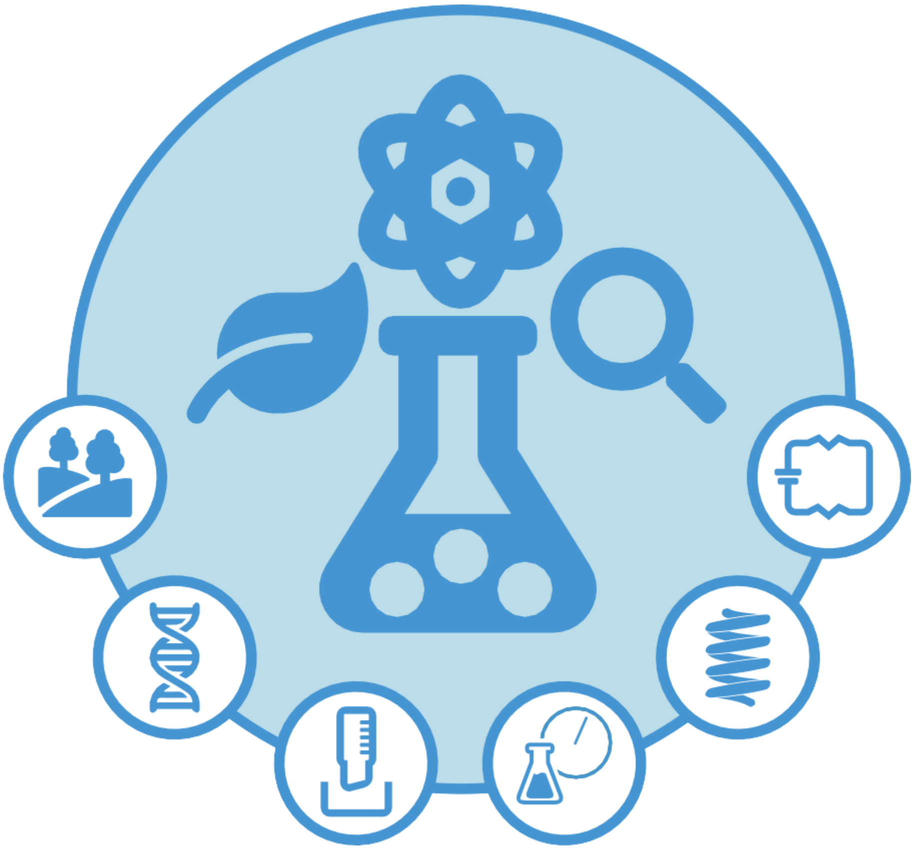
EXEMPLAR LESSON

OpenSTEM Africa

EXPLORING THE PROPERTIES OF METAL IONS USING A HOT FLAME



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Ministry of Education

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For information on OpenSTEM Africa see: www.open.ac.uk/ido

OPITO for their generous support, which has made OpenSTEM Africa and the development of the Virtual Laboratory and these materials possible.

Contents

Exemplar lessons for the OpenSTEM Africa Virtual Laboratory applications

All the exemplar lessons are examples of lessons which could be used both individually and by whole classes of Senior High School (SHS) students in the elective sciences of Biology, Chemistry and Physics. Each of the lessons is linked specifically to one of the applications in the OpenSTEM Africa Virtual Laboratory. The exemplar lesson is created to give, both to SHS students and to SHS teachers, a clear example of the ways in which the applications can be used in the learning and teaching of practical science. There is a focus throughout the lesson on the student's development of the practical and experimental skills which, along with knowledge and understanding, are integral to the profile of learning, teaching and assessment in SHS sciences.

The 'you' in this lesson is 'you', the Senior High School student. Remember that you can repeat the experiments and activities in this lesson as often as you have time for in class. This freedom to repeat experiments and activities is also important if you are accessing the lesson outside the classroom, for example for homework. Every application in the OpenSTEM Africa Virtual Laboratory contains real data – the experiments are real experiments. This means you might make mistakes the first or second or third time you try an experiment or an activity – and that is exactly what often happens in the real world in the sciences. So, it is helpful for you as a student to share in some of the real-world trial and error of science as you develop your skills as a scientist.

The exemplar lesson also contains a set of teaching notes at the end of this document for 'you' the SHS science teacher, to suggest how you might want to set up this particular lesson with one of your classes. Hopefully it will also generate ideas for other lessons on the same topic, or other lessons which use the same OpenSTEM Africa Virtual Laboratory application.

Exploring the properties of metal ions using a hot flame

Lesson objectives

By the end of the lesson, you will be able to:

- Describe flame colours and line spectra for different metal ions.
- Explain how line spectra are formed.
- Compare continuous and line spectra.
- Apply your knowledge of line spectra to new situations.

The following practical and experimental Skills will be developed:

- Observations
- Drawing
- Interpretation
- Reporting
- Conduct in Laboratory.

Background

Have you ever wondered why fireworks (Figure 1) have different colours? Fireworks contain gun powder (a source of heat) and metal ions, and by the time you have finished this practical lesson you will be able to explain the science behind the colour of fireworks.

Figure 1. Fireworks of different colours

In this lesson you will observe the colours produced by different metal ions in a hot flame and describe the emission line spectrum (plural, spectra) produced. You will explain your observations in terms of atomic structure.

If you are unfamiliar with some of the terms used, please refer to the Glossary section at the end of this lesson for a fuller explanation.

Atoms and energy levels

The behaviour of electrons in an atom determines many of its characteristic properties. The electrons in atoms have specific energies. This is quantisation of energy. Each element has its own characteristic energy levels.

The simplest atom, in terms of its atomic structure, is the hydrogen atom. It consists of a single proton at its centre and one electron as shown in Figure 2.

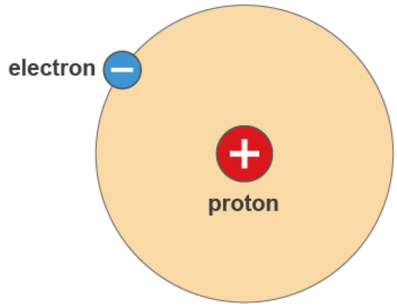


Figure 2. The atomic structure of a hydrogen atom consisting of one proton and one electron.

The hydrogen atom can exist in one of 7 energy states and this can be represented by an energy level diagram, (Figure 3(a)). The lowest energy level is E_1 and the highest level is E_7. Another way to think about this is to imagine the rungs of a ladder with the proton fixed at the bottom but the electron free to climb the ladder; the higher it gets, the higher its energy level (Figure 3(b)).

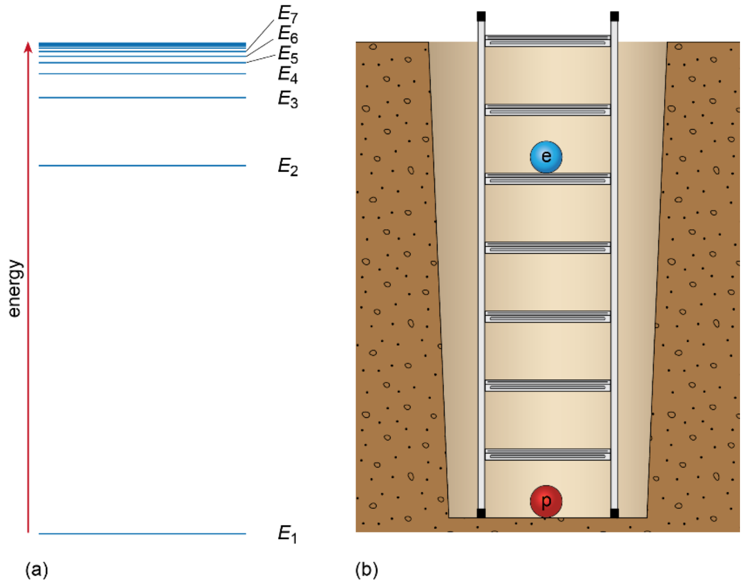


Figure 3. (a) The energy level diagram of hydrogen. Energy increases moving up this diagram. (b) The energy level diagram is like the rungs of a ladder sunk into a deep pit. The higher the energy level, the greater the separation between the proton and the electron.

When an atom is heated, its electrons move from their ground state (E_1) to a higher energy level and are said to be in an excited state (e.g., E_2 or higher). When the electrons return to a lower energy state or the ground state, energy is emitted in the form of light. The 'packets' of light produced by individual atoms are called photons. The change of an electron from one energy level to another is called a transition.

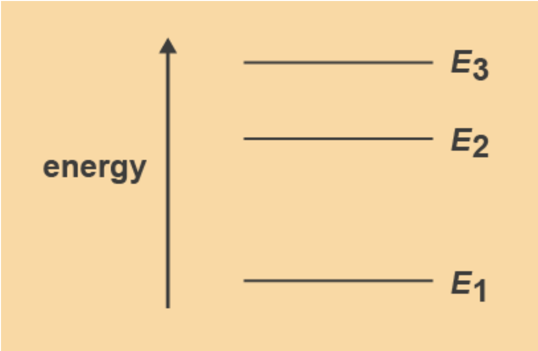


Figure 4. Energy level diagram with three levels

A hypothetical atom, shown in Figure 4, has three energy levels (E_1, E_2 and E_3). How many different transitions are possible that would result in the emission of photons?
Go to Appendix 3 for the answer.

The relative separation between two energy levels determines the energy of the photons emitted. In Figure 4 the energies of emitted photons are: E_3 to E_1, E_3 to E_2 and E_2 to E_1, respectively. Each transition produces light of a particular wavelength.

Every element produces light of several specific wavelengths and when a metal ion is heated in a hot flame this gives the flame of each element a characteristic colour. The more energy the photons have, the shorter their wavelength.

Yellow light has photons of lower energy than green light. Which colour has the longer wavelength?
Go to Appendix 3 for the answer.

When sodium ions are placed in a hot flame, the flame burns with a distinctive yellow colour, as shown in Figure 5.

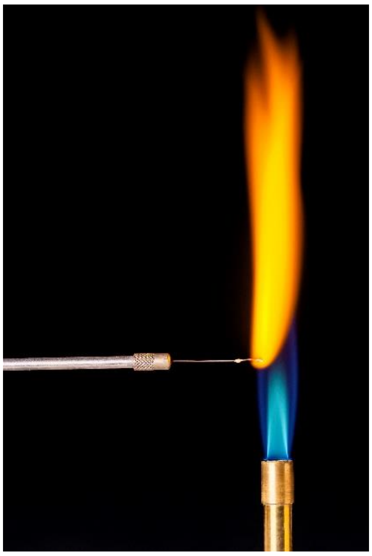


Figure 5. Flame test for sodium ions.

To answer the following questions, you may need to refer to a Periodic Table.

What is the chemical symbol for sodium?
Go to Appendix 3 for the answer.

What Group of the Periodic Table is sodium in, and what other elements are in the same group?
Go to Appendix 3 for the answer.

In this practical activity you will examine behaviour of some Alkali metal ions and other metals.

Spectral lines: an atom's signature

When a beam of white light from the Sun is passed through a prism it is broken up or dispersed, into a range of colours that form a pattern similar to a rainbow. Such a band of colours is called a spectrum (plural, spectra). The spectrum of white light or sunlight forms an uninterrupted band of colours known as a continuous spectrum, as shown in Figure 6.

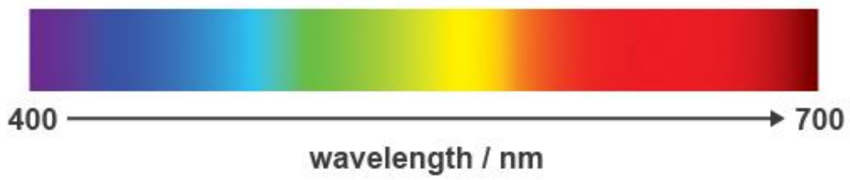


Figure 6. A continuous spectrum from a beam of white light or sunlight.

The spectrum in Figure 6 goes from violet to red. Which of the following two colours has the longer wavelength – blue or yellow?
Go to Appendix 3 for the answer.

A similar technique can be used to study the light emitted by atoms and ions when they are heated in a flame. The spectrum produced is different from the continuous spectrum for sunlight as it consists of very narrow lines of specific colours. Figure 7 shows the emission line spectrum for sodium ions.

Figure 7. Emission line spectrum for sodium ions in the visible region.

Some lamps, such as some road lamps, contain sodium vapour in an excited state and produce yellow light. Why does the light appear yellow when there are lines of other colours in the spectrum?
Go to Appendix 3 for the answer.

Spectroscopy: studying spectral signatures of metals

The technique for identifying which metal atoms are present in a sample of material by analysing the emission line spectrum is called **spectroscopy**. Scientists often want to discover which elements may be present in a sample of material. They may also want to make compounds that produce light of specific colours, for instance in fireworks.

In this practical activity you will observe the flame colours for lithium, potassium and other metallic elements and examine them using a **spectroscope** (see Figure 8). This is an instrument that contains **prisms** and produces a **spectrum** of light in the form of a set of coloured lines.

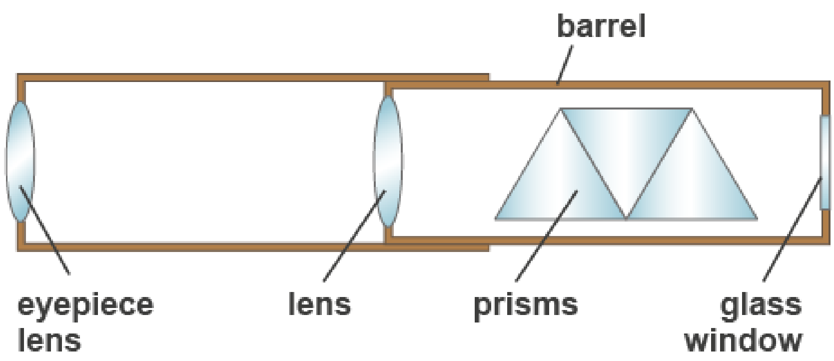


Figure 8: Main components of a hand spectroscope

What type of spectrum will you observe using the spectroscope to examine the colour of the flames?
Go to Appendix 3 for the answer.

Practical activity

You will now use the hot flame in the Flame test application to explore the properties of metal ions. Read the following sections before accessing the application.

In this practical you will collect solid samples of different metal compounds on a nichrome wire and place each one in the hot flame of a Bunsen burner.

You will observe the colour of the flame and use a spectroscope to observe the emission line spectrum of each element examined.

If you were carrying out this experiment in a laboratory, what personal protective equipment would you need?
Go to Appendix 3 for the answer.

When you access the Flame test application homepage, first watch the introductory video which explains how to carry out the activity.

Once you have watched the video, make the following notes in your laboratory notebook:

1. Write the step-by-step method you will use to carry out the experiment.
2. Draw a labelled diagram of the apparatus.
3. Copy the tables below into your laboratory notebook. You will use this to record your observations for the named metal ions salt solutions and the two mystery samples.

Element	Chemical symbol	Colour of flame	Description of the spectrum
Sodium	*Na*	*Yellow*	*Two bright yellow lines, one weaker blue line, one weaker green line and one weaker red line*
Lithium			
Potassium			
Copper			
Strontium			

Sample	Colour of flame	Description of the spectrum	Elements present
1			
2			

You are now ready to access the experiment and start your investigation in the OpenSTEM Africa Virtual Laboratory.

Flame test
Go to the OpenSTEM Africa Virtual Laboratory.  Click on the icon to access the Flame test application homepage in the OpenSTEM Africa Virtual Laboratory Watch the introductory video before entering the experiment.

Once you have completed your investigation, write your answers to the following questions in your laboratory notebook.

1. Explain how the flame colours and emission line spectra enabled you to identify mystery samples 1 and 2.
2. Explain in your own words how the colours are produced in fireworks. If possible, discuss your ideas with your classmates and teacher.

Summary

You have seen that each element has its own ‘signature’ emission line spectrum and this can be used to identify elements. The lines arise because light is emitted when electrons move from an excited energy state to a lower energy state or the ground state.

Quiz

Answer the questions, then search for the correct answers in Appendix 4.

Question 1

What metals could be mixed with gunpowder to make a display of red and yellow fireworks?

Select **one**:

a) Strontium and sodium
b) Copper and sodium
c) Strontium and Lithium

Question 2

What spectrum would you see if a mixture of sodium and copper compounds was placed in a flame and examined using a spectroscope?

Select **one**:

a) Four yellow lines, one red line and many green and blue lines.
b) Two bright yellow lines and weak red, green and blue lines.
c) Yellow and blue lines only.

Question 3

Read the paragraph below and fill in the blanks by selecting the correct word from the choices below.

When a metal atom is heated, the electrons are _________ and move to _________ energy levels. When they return to the _________ state, energy is _________ in the form of light.

[excited, emitted, higher, ground]

Question 4

Read the paragraph below and fill in the blanks by selecting the correct word from the choices below.

Each element has a characteristic arrangement of energy levels. When _________ move between energy levels, the _________ (and frequencies) of _________ emitted are unique for that element. This is why different elements have different emission line _________.

[electrons, light, spectra, wavelengths]

Question 5

Is the following statement true or false? Circle or highlight your answer.

Instead of heating a metal in a flame, another way in which energy could be supplied to raise the energy levels of electrons is by passing an electric current through a vapour contained in a sealed glass tube.

True/False

Question 6

Is the following statement true or false? Circle or highlight your answer.

Stars only emit radiation in the visible spectrum.

True/False

Question 7

Is the following statement true or false? Circle or highlight your answer.

The chemical composition of a star can be determined by examining the spectra of radiation it emits.

True/False

Glossary

Alkali metals – The elements in Group 1 of the Periodic Table.

Compound – A substance made up from two or more different types of atom.

Continuous spectrum – A spectrum consisting of light (or other electromagnetic radiation) of all colours.

Electron – One of the component particles from which an atom is made. Electrons have a negative electric charge.

Electronic structure – The arrangement of electrons in an atom.

Element – A substance made up from one type of atom.

Emission line spectrum – A display of the distribution of emitted light of different wavelengths (or frequencies).

Emitted – To be released.

Energy level – A fixed distance from the nucleus of an atom where electrons are found.

Excited state – Any energy arrangement of an atom that is not the ground state.

Ground state – The lowest energy arrangement of electrons in an atom.

Ion – An atom or molecule that has gained or lost one or more electrons. As a result, it carries a negative or positive charge.

Nichrome – A nickel-base alloy with stability at high temperatures.

Periodic table – An arrangement of elements which organises them in order of increasing atomic number across several rows known as periods. The vertical groups contain elements with related properties.

Photon – A particle of light or other electromagnetic radiation. Photons have no mass or electric charge.

Proton – The nucleus of a hydrogen atom or a constituent of all other atomic nuclei. Protons are positively charged.

Prism – A glass or other transparent object in a shape which separates white light into a spectrum.

Quantisation –The system of discrete energy levels.

Spectroscope – An instrument that contains a prism and produces a spectrum of light in the form of a set of coloured lines.

Spectroscopy – Investigation of spectra produced when matter interacts with or emits electromagnetic radiation.

Spectrum – A display of the distribution of light or another electromagnetic radiation.

Transition –The change of an electron from one energy level to another in the atom.

Wavelength – The distance between a point on a wave and the next identical point.

Appendix 1: Teacher notes – organisation of the lesson

Teaching notes for the flame tests and the lesson: Physics SHS1 Section 6, Unit 1 Atomic and Nuclear Physics.

This lesson, using the flame tests links directly to SHS and the teaching and learning activities associated with it.

Ideas for organising this exemplar lesson link directly to activities and teaching examples in the OpenSTEM Africa CPD units on *Using ICT to support learning*, and *Approaches to active notetaking*.

A full list of the OpenSTEM Africa CPD units can be found at: https://www.open.edu/openlearncreate/CPD_units

Overview

If possible, this lesson should take place in the ICT Lab in your school if this can be arranged through your Head of Science and the Head of ICT. If the lesson takes place in the ICT Lab, it may be possible for each student to work individually at a computer; otherwise divide the class so that students are in small groups at a computer.

If it is not possible to use the ICT Lab for this lesson, then try to set up this lesson in your classroom. You may be lucky enough in your school to have a set of 'empty' tablets or mobile phones which students can use. Or you may be able to bring into the classroom a laptop connected to the internet or to your school intranet – and perhaps connected to a projector to make it possible for the whole class to view at once. If access to ICT is a real challenge in your school but you want your students to view an experiment, you might be able demonstrate it to small groups of your students at a time, using your own mobile phone

Whatever way(s) you set up the class, it would still be helpful to the students to be able to work in pairs or small groups for at least some of the lesson. Do remember as well that students need desk space to be able to write in their notebooks and to draw diagrams.

Steps in organising the lesson

Step 1: This takes place in the lesson before the one where you and your class access the OpenSTEM Africa Virtual Laboratory flame tests. Have students work in pairs to pre-read the Background section of the exemplar lesson and ask each other the questions in the Background section. While they are doing so, you may want to walk round the class and check their laboratory notebooks, as accurate note-taking and filling in the tables is important for this exemplar lesson.

Step 2: At the beginning of this exemplar lesson, check understanding by asking them the questions in the Background section. Organise the class, if possible, to work in the same pairs as in the previous lesson. Have each person in the pair create a frame for their drawing of the apparatus and each of them creates the tables in their own laboratory notebook in preparation for their data collection.

Step 3: Once the students have seen the video one time, give the class a set time to draw the apparatus in their laboratory notebook and label it. Within each pair, have them check each other's work.

Step 4 Make sure that each pair has access to/can see the computer screen to begin the actual experiments. Ensure that each pair knows how to carry out the experiments– or if you are using a laptop/projector, that you draw on the expertise of the class as you go through each step of the flame test with each of the metal ions – i.e., ask them what the next step is

Step 5: Have the class follow the instructions for both the known metal ion samples and the mystery samples. Make sure, if working in a pair on a PC, that each student in the pair gets to follow all the steps in testing several of the samples; if working in a group on a PC,have the group leader ensure that everyone in the group is involved.

Step 5: What they write in their tables will be agreed between the pair or within the group but allow enough time for everyone in the class to fill in their own set of tables for the five named samples and the two mystery samples. Have them check each other's writing.

Step 6: Ten minutes before the end of the lesson, tell the students to complete the quiz.

Other examples of lessons which could be relevant to the flame tests include:

- Physics SHS 2 Section 6
- Chemistry SHS 1 Section 2 Unit 3 Periodicity, Properties of Alkali metals

Appendix 2: Teacher notes – outputs of the lesson

Syllabus sections addressed by this lesson

Teaching Syllabus for Chemistry (SHS 1–3)

SHS1 Section 2 Unit 3 Periodicity

- 2.3.1 Relate the position of an element in the periodic table to its atomic number and electron configuration.
- 2.3.4 Distinguish between the terms ‘group’ and ‘period’ (example Alkali metals)

The following Practical and Experimental Skills in Chemistry will be developed:

- Observations
- Drawing
- Interpretation
- Reporting
- Conduct in Laboratory

Teaching Syllabus for Physics (SHS 1–3)

SHS1 Section 6 Unit 1 Models of the Atom and Atomic Structure

- 6.1.2 Explain the existence of quantized energy levels in an atom
- 6.1.3 Describe the types of spectra and their uses

The following Practical and Experimental Skills in Physics will be developed:

- Make observations
- Design and conduct investigations
- Analyse and interpret results of scientific investigations
- Communicate and apply the results of scientific investigations

Setting up equipment

To carry out this lesson, students can work on a computer individually or in pairs. Students who are not able to distinguish between different colours should work with another person.

Students need their laboratory notebooks, pen, pencil (for diagrams) and ruler.

Organising the lesson

The estimated lesson time is 60 minutes, but it could be completed in less time by reducing the amount of writing required in laboratory notebooks, or omitting Activity 2 to identify the mystery samples. It could be split between two shorter lessons by covering the background theory and Method in Lesson 1 and carrying out the experiment and recording the results, discussion and conclusions in Lesson 2. Computers would be needed for both lessons.

The lesson could be extended in the following ways:

- Produce a presentation about the activity for students who have not studied this topic (using presentation software or on paper).
- Produce a one-page summary of the difference between continuous and line spectra, with examples and illustrations.

Laboratory notebook record for practical on using flame tests to identify metal ions

Title: Using flame tests to identify metal ions

Aim: To identify elements using flame colours and emission line spectra.

Introduction

When metal ions are heated in a flame they produce a characteristic flame colour and emission line spectrum. A spectroscope can be used to observe the emission line spectrum, from which we can identify the elements present. The light is produced when electrons move from an excited state to a lower energy level.

Method

1. Step by step method

- Turn on gas tap and light Bunsen burner.
- Open air hole of Bunsen burner to obtain a blue flame.
- Pick up nichrome wire and clean it.
- Dip the nichrome wire into one of the metal compound samples.
- Place the sample in the centre of the blue flame and observe the colour of the flame.
- Use the spectroscope to observe the line emission spectrum.
- Record your results in a table.
- Wash the nichrome wire in the wash beaker and repeat for the next sample.

2. Labelled diagram of the apparatus

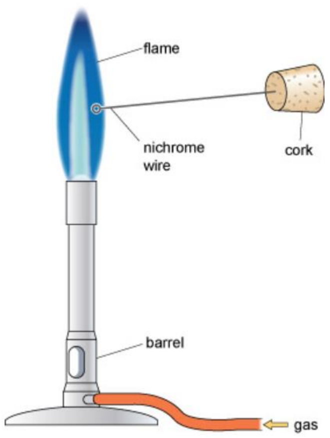
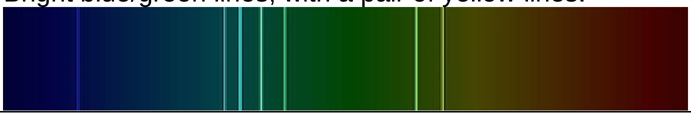
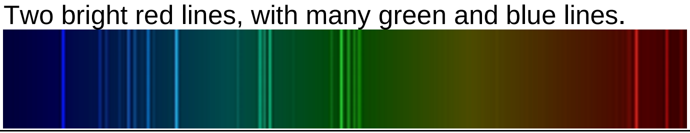


Figure: Components of a Bunsen burner and position of the nichrome wire for flame tests.

Results

Known metal ion salts

Element	Chemical symbol	Colour of flame	Description of the spectrum
Sodium	Na	Yellow	Two bright yellow lines, one weaker blue line, one weaker green line and one weaker red line 
Lithium	Li	Magenta red	Bright orange/red line and weaker red and blue lines. 
Potassium	K	Purple/ pink/ lilac	Yellow, green, blue and purple lines. 
Copper	Cu	Green/ blue	Bright blue/green lines, with a pair of yellow lines. 
Strontium	Sr	Crimson red	Two bright red lines, with many green and blue lines. 

Mystery metal ion salt samples

Sample	Colour of flame	Description of the spectrum	Elements present
1	Green/blue	Bright blue/green lines, with a pair of yellow lines. 	Copper
2	Purple/pink/lilac	Yellow, green, blue and purple lines 	Potassium

Note: mystery sample 1 does not show the blue colour of the copper metal ion salt in solution – this was done so that the student has to interpret the flame colour and spectrum in order to identify the metal ion. In fireworks, gunpowder is mixed with compounds of different metals to produce different colours. Red fireworks contain strontium and lithium compounds. Blue fireworks contain copper compounds. Yellow fireworks contain sodium compounds. Purple fireworks contain copper and strontium compounds.

Appendix 3: In-text question answers

A hypothetical atom, shown in Figure 4, has three energy levels (E_1, E_2 and E_3). How many different transitions are possible that would result in the emission of photons?

Answer: There are three possible transitions of this atom that will result in the emission of light: $E_3 \rightarrow E_1$, $E_3 \rightarrow E_2$ and $E_2 \rightarrow E_1$.

ITQ Yellow light has photons of lower energy than green light. Which colour has the longer wavelength?

Answer: Yellow light has a longer wavelength.

What is the chemical symbol for sodium?

Answer: The chemical symbol for sodium is Na (from Latin 'natrium').

What Group of the Periodic Table is sodium in, and what other elements are in the same group?

Answer: Sodium is in Group 1 of the **Periodic Table**, the **Alkali Metals**, and the other elements in this group are lithium (Li), potassium (K), rubidium (Rb), caesium (Cs) and francium (Fr).

The spectrum in Figure 6 goes from violet to red. Which of the following two colours has the longer wavelength – blue or yellow?

Answer: Yellow has a longer wavelength than blue.

Some lamps, such as some road lamps, contain sodium vapour in an excited state and produce yellow light. Why does the light appear yellow when there are lines of other colours in the spectrum?

Answer: The two yellow lines are much brighter than the other lines. A spectrum consists of some bright lines and some weaker lines.

What type of spectrum will you observe using the spectroscope to examine the colour of the flames?
Answer: This is an **emission line spectrum**. The colours will be characteristic of the **ions** in the flame.

If you were carrying out this experiment in a laboratory, what personal protective equipment would you need?
Answer: You would need to wear chemical goggles and an apron or laboratory coat.

Appendix 4: Quiz answers

Correct answers are highlighted in green.

Question 1

What metals could be mixed with gunpowder to make a display of red and yellow fireworks?

Select **one**:

d) Strontium and sodium
e) Copper and sodium
f) Strontium and Lithium

Feedback

Strontium can be used to make red fireworks and sodium can be used to make yellow fireworks.

Question 2

What spectrum would you see if a mixture of sodium and copper compounds was placed in a flame and examined using a spectroscope?

Select **one**:

d) Four yellow lines, one red line and many green and blue lines.
e) Two bright yellow lines and weak red, green and blue lines.
f) Yellow and blue lines only.

Feedback

The line spectrum from sodium contains two bright yellow lines and weaker blue, green and red lines. The line spectrum from copper contains two yellow lines and multiple blue/green lines. The combined spectrum contains all these lines.

Question 3

Read the paragraph below and fill in the blanks by selecting the correct word from the choices below.

When a metal atom is heated, the electrons are excited and move to higher energy levels. When they return to the ground state, energy is emitted in the form of light.

[excited, emitted, higher, ground]

Feedback

This explains why atoms release coloured light when they are heated in a flame.

Question 4

Read the paragraph below and fill in the blanks by selecting the correct word from the choices below.

Each element has a characteristic arrangement of energy levels. When electrons move between energy levels, the wavelengths (and frequencies) of light emitted are unique for that element. This is why different elements have different emission line spectra.

[electrons, light, spectra, wavelengths]

Feedback

This explains why different elements have different emission line spectra.

Question 5

Is the following statement true or false? Circle or highlight your answer.

Instead of heating a metal in a flame, another way in which energy could be supplied to raise the energy levels of electrons is by passing an electric current through a vapour contained in a sealed glass tube.

True/False

Feedback

This is the principle of gas discharge tubes which are used to produce coloured lights such as neon advertising signs.

Question 6

Is the following statement true or false? Circle or highlight your answer.

Stars only emit radiation in the visible spectrum.

True/False

Feedback

As well as visible radiation, stars emit other types of electromagnetic radiation, including infrared and ultraviolet radiation.

Question 7

Is the following statement true or false? Circle or highlight your answer.

The chemical composition of a star can be determined by examining the spectra of radiation it emits.

True/False

Feedback

The spectra of radiation from a star can tell us which elements are present in the star.

ACKNOWLEDGEMENTS

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