Twig

Non-Metals

CHEMISTRY • PERIODIC TABLE • NON-METALS

Section 1: Introduction

• What are the non-metal elements and why are they important?

Oxygen is an essential element for life on Earth

• Suggested Film

- Introduction to the Periodic Table

Non-metal elements are simply the elements that are NOT metals, and include hydrogen, carbon, nitrogen and oxygen. They are found on the right-hand side of the periodic table, and can be solids, liquids or gases at room temperature, as they vary widely in melting point and boiling point, from very high (carbon) to very low (helium). At room temperature some are solids (carbon, silicon, phosphorus, sulphur, iodine), one is a liquid (bromine), but most are gases. They are nearly all poor conductors of heat and electricity. The solid non-metal elements are brittle.

Compounds containing oxygen and non-metals (the oxides of non-metals) are either acidic in aqueous solution (carbon dioxide, sulphur dioxide, nitrogen dioxide, phosphorus pentoxide) or neutral (carbon monoxide, water, nitrogen monoxide).

The atoms of the non-metal elements are the fundamental building blocks of all biological molecules. Proteins, nucleic acids, starches, sugars, fats and vitamins are composed of non-metal elements. They are the chemical basis of all life on Earth, whether plants, animals, fungi, protists or bacteria. The enormous diversity of these compounds stems from the amazing ability of carbon atoms to form large, complex, stable molecules.

Extension Question

Q1. Why is oxygen a gas and sulphur a solid, even though they are both in Group 6 of the periodic table?

Sulphur and oxygen are both non-metal elements in Group 6. Sulphur forms S_8 molecules and oxygen forms O_2 molecules. The intermolecular forces in sulphur are much stronger than in oxygen, because S_8 molecules have 8 x 16 = 128 electrons per molecule, whereas oxygen molecules have only 2 x 8 = 16 electrons per molecule. It takes much more energy to pull sulphur molecules apart, hence the melting point and boiling point of sulphur are far higher than those of oxygen, meaning it is a solid at room temperature.

• What types of bonds do the atoms of non-metal elements form?

Non-metal atoms usually have 4, 5, 6, 7 or 8 outer electrons, and it is relatively hard to pull these electrons away. The non-metal elements, therefore, do not form positive ions by losing electrons: they either share their outer electrons with another atom to make covalent bonds, or they may completely capture electrons from other atoms to form negative ions.

Chlorine atoms, for example, have 17 electrons and an electron configuration 2,8,7. In chlorine gas, two chlorine atoms pair up, forming chlorine molecules Cl_2. These molecules contain a covalent Cl-Cl bond, with each chlorine atom sharing a pair of electrons so both chlorine atoms now have 8 electrons in their outer shell.

• Suggested Films

- Introduction to Chemical Bonding
- Covalent Bonding
- Ionic Bonding
- Alkali Metals
- Hard and Soft Water

• Worksheet Questions

- Questions 1, 2 and 3

Chlorine atoms can also combine with other non-metal atoms to form molecules, for instance, with hydrogen atoms to form HCl molecules. HCl molecules contain an H-Cl covalent bond holding the atoms together. The hydrogen atom and the chlorine atom share a pair of electrons, so the hydrogen atom ends up with 2 electrons in its outer shell (a full shell) and the chlorine atom ends up with 8 outer electrons (also a full shell).

When reacting with metal atoms, non-metal atoms tend to capture one or more outer electrons from the metal atom to form a negative ion. For example, when chlorine combines with sodium to make sodium chloride, chlorine atoms gain an electron from a sodium atom, making a chloride ion Cl^- with configuration $[2,8]^-$, and a sodium ion Na^+ $[2,8]^+$.

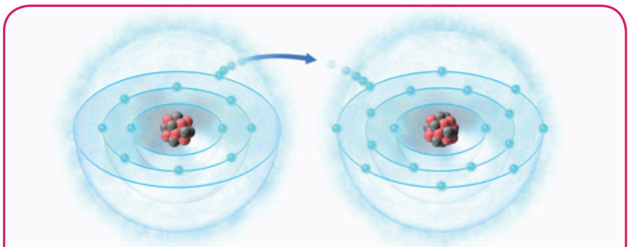
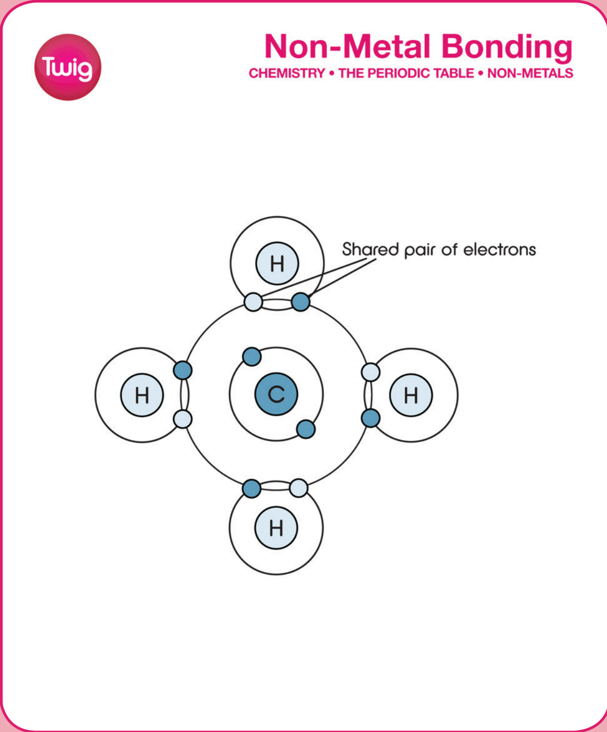


Illustration of electron transfer from sodium atom to chlorine atom

DIAGRAM 01:



Extension Question

Q2. What happens when chlorine is passed into a solution of sodium iodide?

Sodium iodide solution is colourless. Chlorine is more reactive than iodine, so when it is bubbled into sodium iodide solution, chlorine displaces iodine, making a brown solution.

chlorine + iodide ions → iodine + chloride ions

$$Cl_2(g) + 2I^-(aq) \rightarrow I_2(g) + 2Cl^-(aq)$$

Chlorine behaves as an oxidising agent, as they absorb electrons. Iodide ions behave as reducing agents, as they release electrons.

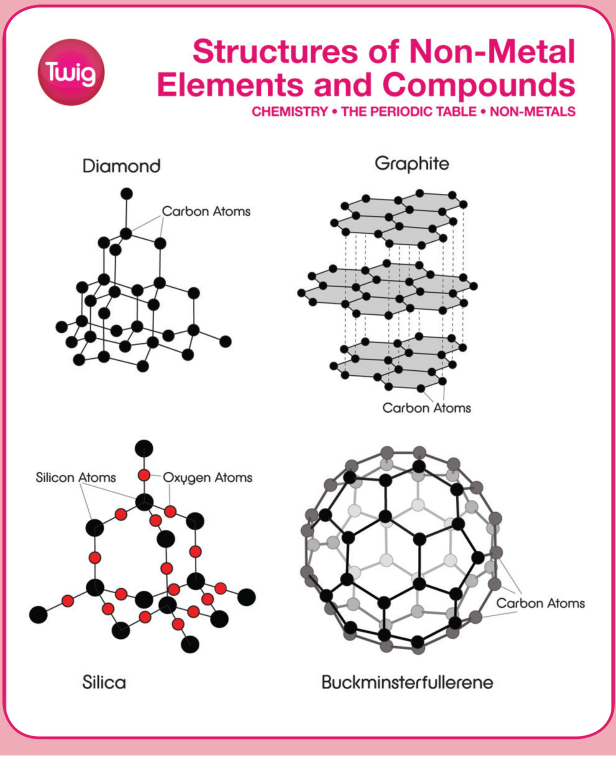
• How can we explain the properties of non-metal elements?

Solid non-metal elements (with one exception, the graphite allotrope of carbon) are poor conductors of electricity. This is because the electrons are either strongly attached to the non-metal atoms or fixed in covalent bonds between the atoms. In either case the electrons cannot move freely and so cannot carry an electric current.

Non-metal elements vary widely in their melting points, from very high (carbon and silicon) to very low (hydrogen and helium). The reason for this variation lies in the structures of the elements. Carbon has several allotropes – different structural forms – and three of them are giant structures of atoms, in which each carbon atom is covalently bonded to several other carbon atoms. Two of these allotropes – diamond and graphite – can only be melted by breaking all these strong C-C covalent bonds, requiring very large amounts of energy, hence the very high melting points (over 3000°C) of these carbon allotropes.

Buckminsterfullerene, a third allotrope of carbon, is made of C_{60} molecules and, as in this case, melting does not involve breaking C-C bonds, it only requires the separation of C_{60} molecules from one another. With the intermolecular forces being much weaker than the covalent bonds, buckminsterfullerene has a much lower melting point of around 527°C. Recently graphene, a fourth carbon allotrope, has been discovered, consisting of a single flat sheet of carbon atoms just one atom thick. Silicon has a similar structure to that of diamond, but with a giant structure of silicon atoms rather than carbon atoms.

DIAGRAM 02:



Most non-metal elements do not have giant structures of atoms, but exist as simple molecules (H_2, F_2, O_2, P_4, S_8) or even, in the case of the noble gases, as single atoms (He, Ne, etc.) The bonds within the molecules are strong covalent bonds, but the forces between the molecules are weak intermolecular forces. For example, the bonds in a chlorine molecule are strong Cl-Cl covalent bonds (as explained above), but the forces between chlorine molecules are weak intermolecular forces. Relatively small amounts of energy are needed to overcome these forces, hence the low melting point of chlorine, which is a gas at room temperature.

• Suggested Films

- Introduction to Chemical Bonding
- Covalent Bonding
- Intermolecular Forces
- Carbon: Introduction
- Carbon: Synthetic Diamonds
- Carbon: Buckminsterfullerene
- The Elements: Silicon
- The Elements: Hydrogen
- The Elements: Oxygen
- The Noble Gases

Section 2: The Halogens

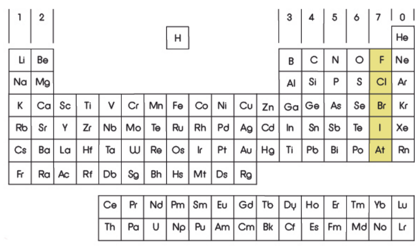
• Why are the halogens regarded as a group of elements?

All the halogen atoms have seven outer electrons. For example, fluorine has electron configuration 2,7, chlorine 2,8,7 and bromine 2,8,18, 7. These atoms can all gain 1 electron to form ions with single negative charges. For example, the chloride ion Cl^- has configuration $[2,8,8]^-$.

The halogens are all non-metal elements, forming diatomic molecules (for example, chorine Cl_2) and they all have coloured vapours. Fluorine = yellow; chlorine = green; bromine = brown; iodine = purple. They all react with sodium, making white, ionic compounds called salts, which is how they originally got their name (halogen = salt-maker). For example,

chlorine + sodium → sodium chloride

$$Cl_2(g) + 2Na(s) \rightarrow 2NaCl(s)$$



The elements in Group 17 of the periodic table are called the halogens.

• Suggested Films

- The Halogens
- Ionic Bonding
- Intermolecular Forces

• Suggested Activity

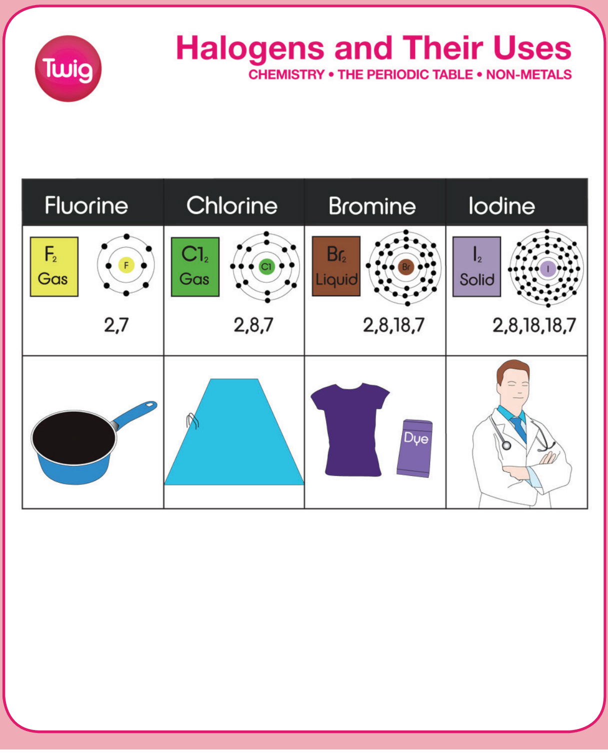
- Ask students to find out the main uses of the elements fluorine, chlorine, bromine and iodine

• Worksheet Question

- Question 4

• How and why do the states of the halogen elements vary from fluorine to iodine?

DIAGRAM 03:



The states of these elements at room temperature reflects the strength of the intermolecular forces between their molecules, which is related to the number of electrons in their molecules.

Iodine molecules I_2 have 106 electrons, whereas fluorine molecules F_2 only have 18 electrons. The forces of attraction between the molecules are therefore much stronger in iodine than in fluorine, meaning much more energy is needed to pull iodine molecules apart. Iodine also melts at a much higher temperature than fluorine. The states of the elements at room temperature is explained in the same way: F_2(g) = yellow gas; Cl_2(g) = green gas; Br_2(g) = brown liquid; I_2(g) = grey solid, purple vapour.

• Suggested Films

- **The Halogens**
- **Intermolecular Forces**

• How and why does the reactivity of the halogen elements vary from fluorine to iodine?

The halogens become less reactive from fluorine to iodine. The reactivity of the halogen elements stems from the ability of these atoms to pull electrons towards themselves. They become less able to do this as you go down from fluorine to iodine, as each element has one more shell of electrons than the one above it. These full shells of electrons 'shield' the nucleus, making it less able to attract electrons and hence the halogen atoms become less reactive as we go down the group.

This can be seen in the displacement reactions of the halogens. If chlorine gas is bubbled into a colourless solution of sodium bromide, a yellow or brown colour is seen, as a solution of bromine is produced.

chlorine + sodium bromide → bromine + sodium chloride

$$Cl_2(g) + 2NaBr(aq) \rightarrow Br_2(g) + 2NaCl(aq)$$

Chlorine has 'displaced' bromine by pulling away an electron from the bromine ion, because chlorine is more reactive than bromine. If we write the same reaction as an ionic equation this is written as:

chlorine + bromide ions → bromine + chloride ions

$$Cl_2(g) + 2Br^-(aq) \rightarrow Br_2(g) + 2Cl^-(aq)$$

We can see that electrons have been removed from the bromide ions and given to the chlorine molecules. This can also be written as two half-equations:

chlorine molecule + 2 electrons → chloride ions

$$Cl_2(g) + 2e^- \rightarrow 2Cl^- (aq)$$

Chlorine molecules are reduced: they gain electrons as they turn into chloride ions.

bromide ions → bromine molecule + 2 electrons

$$2Br^- (aq) \rightarrow Br_2(g) + 2e^- (aq)$$

• Suggested Films

- The Halogens
- Intermolecular Forces

Section 3: The Noble Gases

• Why are the noble gases regarded as a group of elements?

The noble gases – helium, neon, argon, krypton, xenon and radon – were the last group of elements to be discovered. Their properties were not investigated until the very late 19th and early 20th century, long after Mendeleev first proposed his periodic table.

They are monatomic gases (made of single atoms) and so unreactive that at first they were called the inert gases, meaning that they would not react with any other elements. They have very low boiling points and melting points, and are only present in trace amounts on Earth, except for argon which occupies 1% of the atmosphere. They all emit visible light when electricity is passed through them.

The element helium was named after the Sun

Their lack of reactivity is due to their electron configurations: their atoms all have full shells of electrons. Very large amounts of energy would be needed to disrupt these full shells to make the atoms react. However, in 1962 it was discovered that xenon could form compounds, and so we now call them noble gases rather than inert gases. A number of noble gas compounds have been made containing radon, xenon and krypton, mainly combined with fluorine or oxygen.

• Suggested Films

- The Noble Gases
- Flame Colours and Fireworks
- Flame Colours and Spectroscopy
- FactPack: Atmospheric Gases

• Worksheet Question

- Question 5

• Suggested Activities

- Ask students to find out how careful measurements by Rayleigh and Ramsay of the density of nitrogen led to the discovery of argon
- Ask students to look up the boiling points of the gases helium to xenon. Explain this pattern in terms of intermolecular forces
- Ask students to research the uses of the gases helium, neon, argon, krypton and xenon. How do the properties of these gases relate to their uses?

Extension Question

Q3. How was helium first discovered?

Helium was first discovered by observations of the gases around the Sun during a solar eclipse in 1868. A yellow line in the emission spectrum did not correspond to the spectrum of any known element, so it was accepted that a new element had been discovered. It was named ‘helium’ from the Greek word for ‘sun’. However, nothing was known of its properties until helium was isolated in 1895 from the mineral cleveite. There are only traces in the Earth’s atmosphere, but large quantities of helium have been found in natural gas.

• What is radon, and why is it regarded as a health hazard?

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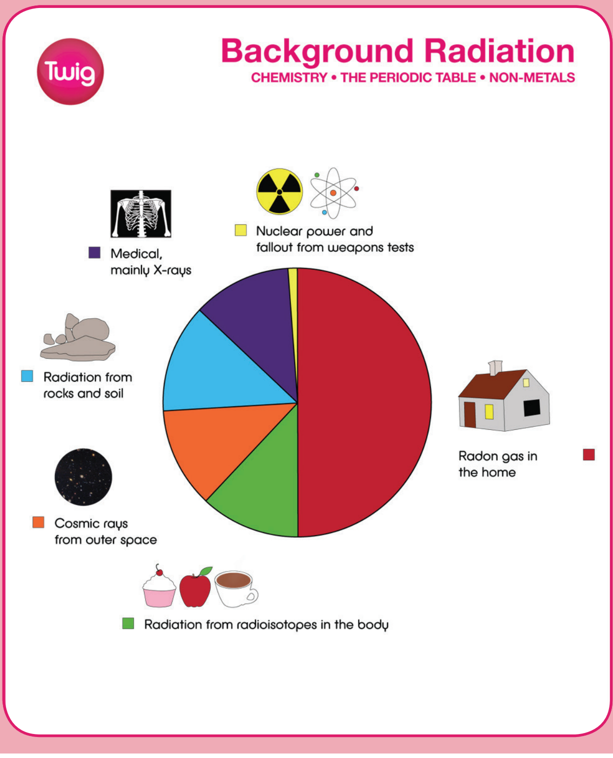

Radon, atomic number 86, is the heaviest noble gas. It has an unstable nucleus, which spontaneously disintegrates releasing alpha particles, a form of ionising radiation. Radon is formed by the radioactive decay of certain elements – uranium, thorium and radium – which are found in rocks, such as granite, and it can slowly seep to the surface. Since radon, like all noble gases, is made of single atoms it can easily pass through materials, such as wood, plastic, paint, concrete blocks and plaster. It is therefore very difficult to prevent radon from entering houses and becoming trapped. As radon can be inhaled and enter the lungs, it poses a significant risk to the occupants of the house, as alpha particles can damage cell DNA, inducing mutations which may lead to cancer.

• Suggested Films

- The Noble Gases
- The Elements: Uranium
- The Elements: Radium
- The Elements: Plutonium

• Worksheet Question

- Question 6

• Suggested Activity

- Ask students to research which areas in your country have high concentrations of radon in houses, and how these relate to the geology of those areas. What can be done to reduce the concentration of radon inside a house?

Extension Question

Q4. Which noble gas is most likely to react with other elements and why?

Radon has the largest atom of the noble gases and its full shells of electrons make it most effective in shielding the nucleus. This makes it relatively easy for the outer electrons in radon to take part in bonding with other atoms. Radon forms compounds, such as radon fluoride RnF_2, but the extremely radioactive nature of this element makes it very hard to study its chemistry.

• How do the acid-base properties of the compounds of the elements relate to the periodic table?

The oxides of the elements in Groups 1 (alkali metals) and Group 2 (alkaline–earth metals) are usually bases, meaning that they react with acids to make a salt + water, for example:

sodium oxide + hydrochloric acid → sodium chloride + water

$$Na_2O(s) + 2HCl(aq) \rightarrow 2NaCl(aq) + H_2O(l)$$

magnesium oxide + sulphuric acid → magnesium sulphate + water

$$MgO(s) + H_2SO_4\ (aq) \rightarrow MgSO_4(aq) + H_2O(l)$$

Group 1 oxides react with water, making metal hydroxides:

sodium oxide + water → sodium hydroxide

$$Na_2O(s) + H_2O(l) \rightarrow 2NaOH(aq)$$

Group 1 hydroxides are all very strong alkalis, typically with solutions of pH 14.

Group 2 oxides also react with water, making metal hydroxides:

magnesium oxide + water → magnesium hydroxide

$$MgO(s) + H_2O(l) \rightarrow Mg(OH)_2\ (aq)$$

Group 2 hydroxides are also alkaline, but much less alkaline than Group 1 hydroxides, typically making solutions of pH 10.

The oxides of the elements in Groups 4 to 7 are usually (but not always) acidic when dissolved in water:

Group 4

carbon dioxide + water → carbonic acid

$$CO_2(g) + H_2O(l) \rightarrow H_2CO_3\ (aq)$$

Group 5

dinitrogen pentoxide(s) + water → nitric acid

$$2N_2O_5(s) + 2H_2O(l) \rightarrow 4HNO_3(aq)$$

phosphorus pentoxide + water → phosphoric acid

$$P_4O_{10}(s) + 6H_2O(l) \rightarrow 4H_3PO_4\ (aq)$$

Group 6

sulphur trioxide + water → sulphuric acid

$$SO_3(l) + H_2O(l) \rightarrow H_2SO_4\ (aq)$$

In Group 7, the hydrogen halides are all strongly acidic when dissolved in water: hydrochloric acid HCl(aq), hydrobromic acid HBr(aq), hydroiodic acid HI(aq)

- **Suggested Films**
  - **- The Elements: Oxygen**
  - **- The Elements: Phosphorus**
- **Suggested Activity**
  - **- Make two sets of cards, one with the names of a selection of metal elements and non-metal elements, the other with properties of the element on them. Ask students to match the properties to the element**

Extension Question

Q5. Fluorine forms an oxide F_2O. Would you expect it to be acidic or alkaline in solution? Why?

The trend across the periodic table is for the oxides of the elements to become increasingly acidic as you go from left to right. You would therefore expect all the oxides of Group 7 elements to be acidic in solution. Fluorine is in Group 7, so fluorine oxide is acidic in solution. It reacts with water, making hydrofluoric acid and oxygen:

$$F_2O(l) + H_2O(l) \rightarrow 2HF(aq) + O_2(g)$$

• Worksheet Questions

Q1. An element X is a silvery solid, which is an excellent conductor of electricity and is also attracted to a magnet. When heated in oxygen X makes a black solid which is neutral and insoluble in water. The black solid dissolves in warm hydrochloric acid to make a deep green solution. Suggest where X may be found in the periodic table, and identify it.

Q2. An element Y is a red solid, which does not conduct electricity. Y burns in oxygen to make a white solid with formula Y_2O_5, which dissolves in water to make a strongly acidic solution. Suggest where Y may be found in the periodic table, and identify it.

Q3. An element Z is a silvery solid, usually stored under oil. Z is an excellent conductor of electricity, and is both malleable and ductile. It burns in oxygen with a lilac flame to make a white oxide of formula Z_2O, which dissolves in water to make a strongly alkaline solution with pH14. Suggest where Z may be found in the periodic table, and identify it.

• Worksheet Questions

Q4.

(a) Predict the state and colour of astatine at room temperature.
(b) Predict the charge on an astatide ion.
(c) How will astatine react with sodium?
(d) Discuss how the reactivity of astatine will compare with that of iodine.
(e) How will chlorine gas react with a solution of potassium astatide? What might you observe?

(a)

(b)

(c)

(d)

(e)

Q5. An oxide of xenon is found to contain 73.19 % xenon.

(a) Calculate its empirical formula. (Xe = 131; O = 16)
(b) Is this compound more likely to be made of ions or molecules? Explain your answer.

(a)

(b)

• Worksheet Questions

Q6. Predict how

(a) the density and **(b)** the boiling point of radon would compare with xenon. Explain your answers.

(a)

(b)

• Worksheet Answers

Q1. An element X is a silvery solid, which is an excellent conductor of electricity and is also attracted to a magnet. When heated in oxygen X makes a black solid which is neutral and insoluble in water. The black solid dissolves in warm hydrochloric acid to make a deep green solution. Suggest where X may be found in the periodic table, and identify it.

X is a metal and is also magnetic. **X** makes a neutral, insoluble black oxide, which dissolves in hydrochloric acid to make a green solution of **X** chloride. This coloured compound strongly suggests that **X** is a transition metal. Only three metal elements in the whole periodic table are magnetic: iron, cobalt and nickel. Of these, only nickel forms a deep green chloride, so the element is nickel.

Q2. An element Y is a red solid, which does not conduct electricity. Y burns in oxygen to make a white solid with formula Y_2O_5, which dissolves in water to make a strongly acidic solution. Suggest where Y may be found in the periodic table, and identify it.

Y is clearly a non-metal element, as it is not an electrical conductor and its oxide is acidic. The fact that the element **Y** is a solid suggests that it is either made of relatively large molecules or has a giant structure of atoms. The formula of its oxide suggests that **Y** is in Group 5. Y is actually the red allotrope of phosphorus, made of a giant structure of atoms.

Q3. An element Z is a silvery solid, usually stored under oil. Z is an excellent conductor of electricity, and is both malleable and ductile. It burns in oxygen with a lilac flame to make a white oxide of formula Z_2O, which dissolves in water to make a strongly alkaline solution with pH14. Suggest where Z may be found in the periodic table, and identify it.

Z is clearly a metal. The strongly alkaline nature and the formula of its oxide both suggest **Z** is in Group 1. The lilac flame identifies **Z** as potassium.

• Worksheet Answers

Q4.

(a) Predict the state and colour of astatine at room temperature.
(b) Predict the charge on an astatide ion.
(c) How will astatine react with sodium?
(d) Discuss how the reactivity of astatine will compare with that of iodine.
(e) How will chlorine gas react with a solution of potassium astatide? What might you observe?

(a) Astatine will be a solid, probably black, at room temperature.

(b) Astatide ion At^- has a single negative charge.

(c) Astatine reacts with sodium, making sodium astatide NaAt, a white ionic solid:

$$2Na(s) + At_2(s) \rightarrow 2NaAt(s)$$

(d) Astatine will be much less reactive than iodine. The extra full shell of electrons in an astatine atom will shield the nucleus even more effectively than in an iodine atom, making it even harder for the astatine atom to attract electrons and so react with the atoms of other elements.

(e) Chlorine will displace astatine from potassium astatide, as chorine is much more reactive than astatine:

chlorine + potassium astatide → astatine + potassium chloride

$$Cl_2(g) + 2KAt\ (aq) \rightarrow At_2(s) + 2KCl\ (aq)$$

A dark coloured – possibly black – precipitate of solid astatine would form in the colourless solution of potassium astatide.

Q5. An oxide of xenon is found to contain 73.19 % xenon.

(a) Calculate its empirical formula. (Xe = 131; O = 16)
(b) Is this compound more likely to be made of ions or molecules? Explain your answer.

(a) 73.19/131 = 0.5587 Xe. 26.81/16 = 1.676 O. Hence the ratio Xe:O = 1:3; the empirical formula is XeO_3.

(b) It is made of molecules. Xenon and oxygen are both non-metals, so they are likely to be covalently bonded in this compound.

• Worksheet Answers

Q6. Predict how
(a) the density and **(b)** the boiling point of radon would compare with xenon. Explain your answers.

(a) Radon atoms have relative atomic mass 222 compared to 131 for xenon, so radon is denser than xenon as its atoms are much heavier. At 0°C, the density of xenon is 5.89 grams per litre, and the density of radon is 9.73 grams per litre. Radon is the densest of all known gases.

(b) Radon has a much higher boiling point than xenon. Radon boils at -62°C and xenon at -108°C, and the main reason for this is the strength of the intermolecular forces between radon atoms. Radon atoms have 86 electrons and xenon atoms have 54 electrons, so in the liquefied gases much more energy is needed to pull radon atoms apart than to separate xenon atoms, hence the higher boiling point of radon.

• Quizzes

The Halogens

Basic

• Which these elements is NOT a halogen?

A – chlorine
B – bromine
C – fluorine
D – oxygen

• The colour of solid iodine is

A – purple
B – green
C – black
D – brown

• CFCs are harmful to

A – humans
B – insects
C – the ozone layer
D – pets

• The number of outer electrons in halogen atoms is

A – 5
B – 6
C – 7
D – 10

Advanced

• The most reactive halogen element is

A – fluorine
B – chlorine
C – bromine
D – iodine

• The halogen with the highest boiling point is

A – chlorine
B – bromine
C – iodine
D – astatine

• The halogen element that is a liquid at room temperature is

A – fluorine
B – chlorine
C – bromine
D – iodine

• Which of these statements is NOT true of the halogens?

A – they form coloured vapours
B – they exist as diatomic molecules
C – they react with metals to form salts
D – their reactivity increases from fluorine to iodine

The Noble Gases

Basic

• Which of these is NOT a noble gas?

A – xenon
B – nitrogen
C – argon
D – helium

• Argon was discovered by

A – Ramsay
B – Moseley
C – Mendeleev
D – Lavoisier

• The noble gas with the highest atomic number is

A – krypton
B – xenon
C – argon
D – radon

• One use of argon is in

A – making plastics
B – rocket fuel
C – fertilisers
D – light bulbs

Advanced

• Neon is used in

A – light bulbs
B – advertising signs
C – balloons
D – fizzy drinks

• Mendeleev did not include the noble gases in his 1869 Periodic Table because

A – they were so unreactive
B – he was not sure where to put them
C – they had not yet been discovered
D – they are made of single atoms

• The second most abundant element in the Universe is

A – helium
B – neon
C – argon
D – xenon

• Which of the following statements is NOT true of all the noble gases?

A – they have full outer shells of electrons
B – they react with metals to form salts
C – they consist of single atoms
D – they have low boiling points

• Answers

The Halogens

Basic

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