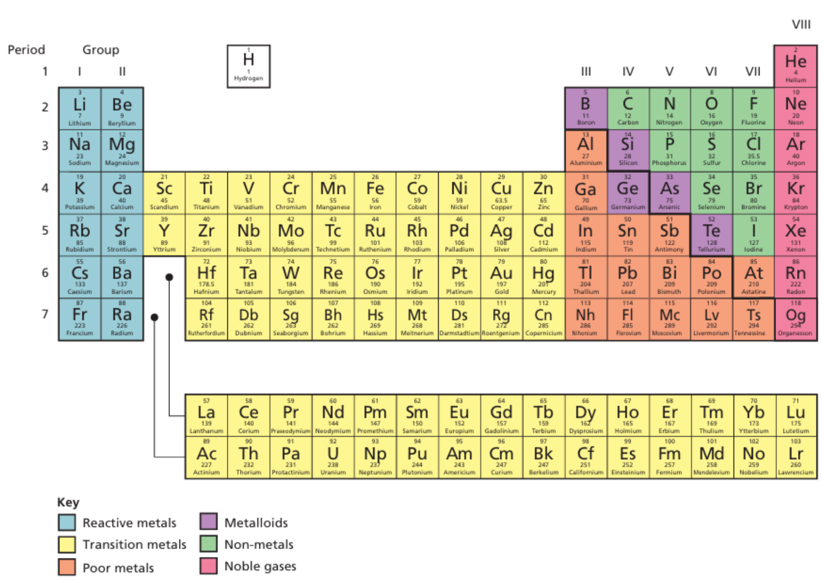
Cambridge OL

Chemistry

CODE: (5070)

Chapter 09

The periodic table



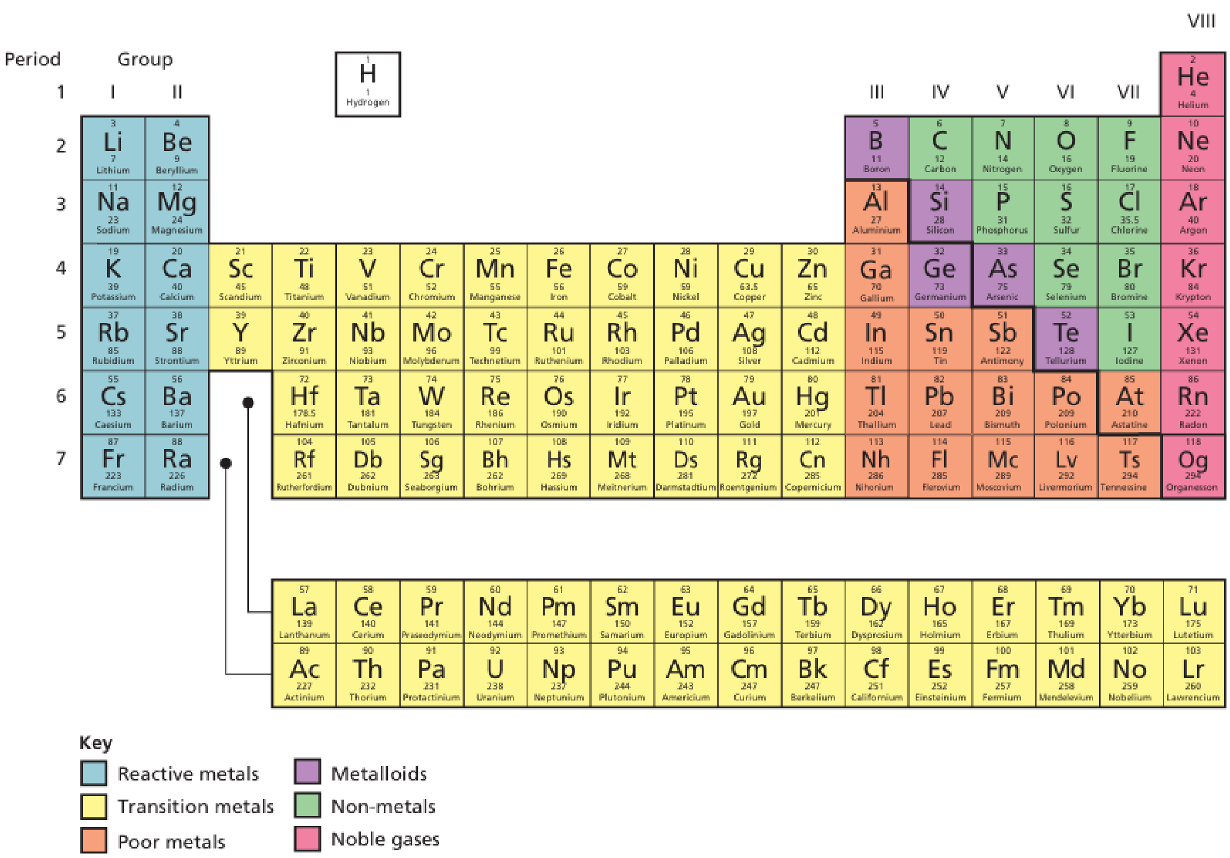
9.1 Development of the Periodic Table

The Periodic Table, created in 1869 by Russian Dmitri Mendeleev, is a crucial tool for chemists to predict chemical reactions. Initially developed around 150 years ago, it categorizes elements based on their chemical and physical properties. Mendeleev's classification was the most successful among other early 19th-century attempts.

▲ **Figure 9.1** Dmitri Mendeleev (1834–1907)

Period	Group							
	1	2	3	4	5	6	7	8
1	H							
2	Li	Be	B	C	N	O	F	
3	Na	Mg	Al	Si	P	S	Cl	
4	K	Ca	*	Ti	V	Cr	Mn	Fe Co Ni
	Cu	Zn	*	†	As	Se	Br	

▲ **Figure 9.2** Mendeleev's periodic table. He left gaps for undiscovered elements

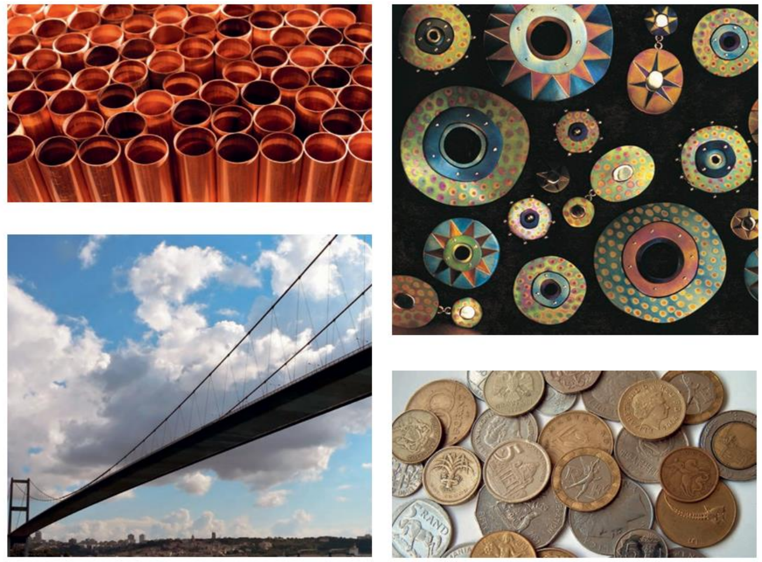


▲ **Figure 9.3** The modern Periodic Table

The horizontal rows are called **periods**, and these are numbered 1–7 going down the Periodic Table. Between Groups II and III is the block of elements known as the **transition elements** (Figure 9.4).

Those elements with similar chemical properties are found in the same columns or **groups**.

The elements which lie on this dividing line are known as **metalloids** (Figure 9.5).



▲ **Figure 9.4** Transition elements have a wide range of uses, both as elements and as alloys

9.2 Electronic configuration and the Periodic Table

Chapter 2 discusses the number of electrons in an element's outer shell, which corresponds to the group in the Periodic Table. Group I elements have one electron, while Group 0 elements have two or eight. The number of occupied shells is equal to the period number in which the element is found. For example, sodium is in Group I with one electron.

▼ **Table 9.1** Electronic configuration of the first three elements of Group I

Element	Symbol	Proton number	Electronic configuration
Lithium	Li	3	2,1
Sodium	Na	11	2,8,1
Potassium	K	19	2,8,8,1

▼ **Table 9.2** Electronic configuration of the first three elements of Group II

Element	Symbol	Proton number	Electronic configuration
Beryllium	Be	4	2,2
Magnesium	Mg	12	2,8,2
Calcium	Ca	20	2,8,8,2

▼ **Table 9.3** Electronic configuration of the first three elements in Group VII

Element	Symbol	Proton number	Electronic configuration
Fluorine	F	9	2,7
Chlorine	Cl	17	2,8,7
Bromine	Br	35	2,8,18,7

9.3 Group 1 – the alkali metals

Group I metal lithium, sodium, potassium, rubidium, caesium, and francium are reactive and commonly used in schools, stored under oil to prevent contact with water or air.

These three metals have the following properties.

» They are good conductors of electricity and heat.

» They are soft metals. Lithium is the hardest and potassium the softest.

» They are metals with low densities.

» They have shiny surfaces when freshly cut with a knife (Figure 9.6).

» They have low melting points.

» They burn in oxygen or air, with characteristic flame colours, to form white solid oxides.

These Group I oxides all react with water to form alkaline solutions of the metal hydroxide.

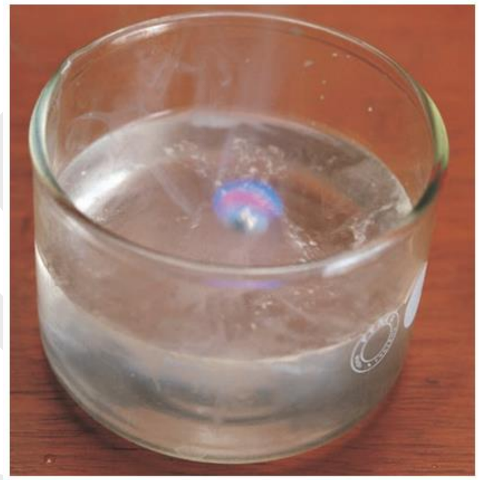
» They react vigorously with water to give an alkaline solution of the metal hydroxide as well as producing hydrogen gas.

» Potassium, sodium, and lithium are the first three metals in Group I, with **trends** indicating their reactivity towards water, aiding chemists in making predictions.

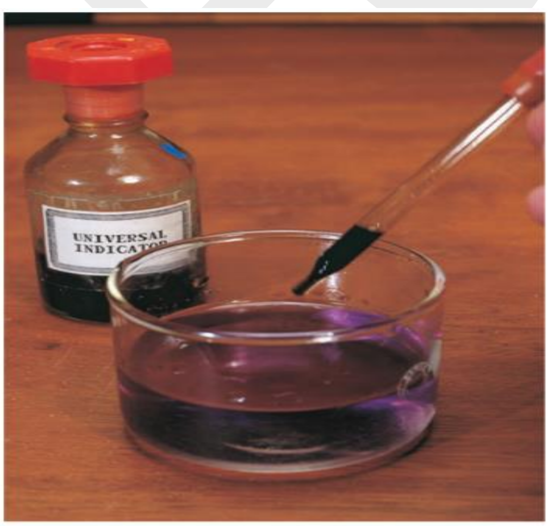
» They react vigorously with halogens, such as chlorine, to form metal halides.

The more reactive a metal is, the further down the group, with Francium being the most reactive Group I metal. The first three elements of Group I have an outer shell with one electron, losing it to become more stable.

▲ **Figure 9.6** Cutting sodium metal

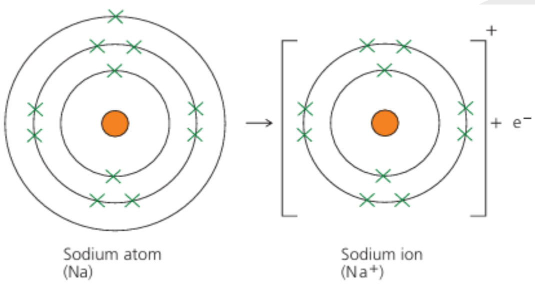


a Potassium reacts very vigorously with cold water



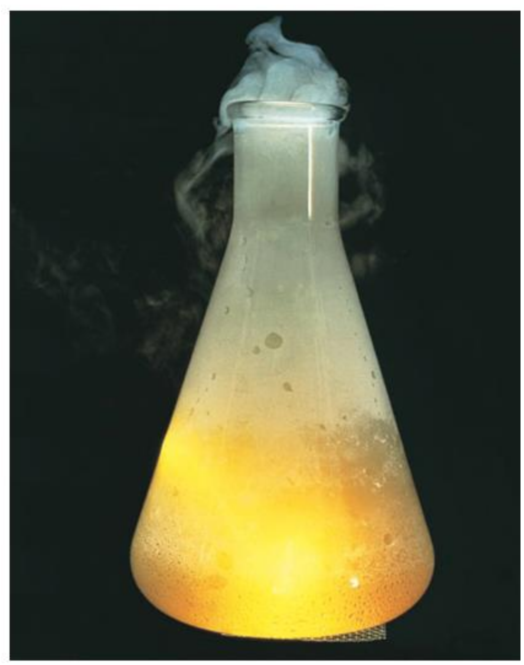
b An alkaline solution is produced when potassium reacts with water

▲ **Figure 9.7**



$Na \longrightarrow Na^{+} + e^{-}$

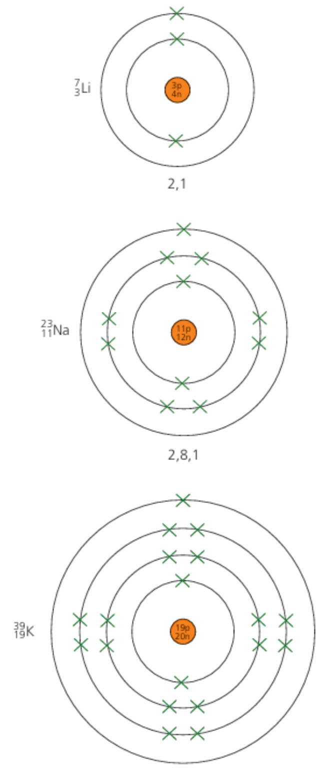
▲ **Figure 9.9** This sodium atom loses an electron to become a sodium ion



▲ **Figure 9.8** A very vigorous reaction takes place when sodium burns in chlorine gas. Sodium chloride is produced

Look at Figure 9.10. Why do you think potassium is more reactive than lithium or sodium?

Potassium is more reactive because less energy is required to remove the outer electron from its atom than for lithium or sodium. This is because as you go down the group, the size of the atoms increases, and the outer electron gets further away from the nucleus and becomes easier to remove.



▲ **Figure 9.10** Electronic configuration of lithium, sodium and potassium

9.4 Group VII – the halogens

Group VII consists of the four elements fluorine, chlorine, bromine and iodine, and the radioactive element astatine. Of these five elements, chlorine, bromine and iodine are generally available for use in school.

» These elements are coloured and become darker going down the group (Table 9.4).

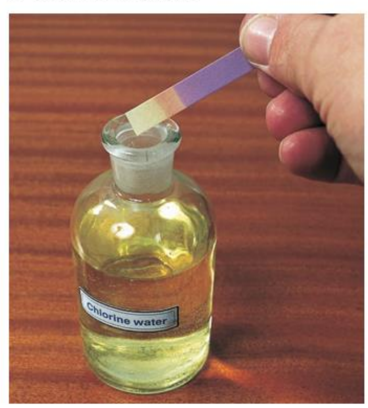
▼ **Table 9.4** Colours of some halogens

Halogen	Colour
Chlorine	Pale yellow-green gas
Bromine	Red-brown liquid
Iodine	Grey-black solid

» They exist as diatomic molecules,

» At room temperature and pressure they show a gradual change from a gas (Cl_2), through a liquid (Br_2), to a solid (I_2) (Figure 9.12) as the density increases.

a Chlorine, bromine and iodine



b Chlorine gas bleaches moist indicator paper

▲ **Figure 9.12**

» They form molecular compounds with other non-metallic elements,

» They react with hydrogen to produce the hydrogen halides, which dissolve in water to form acidic solutions.

hydrogen + chlorine → hydrogen chloride

$$H_2(g) + Cl_2(g) \rightarrow 2HCl(g)$$

hydrogen chloride + water → hydrochloric acid

$$HCl(g) + H_2O \rightarrow HCl(aq) \rightarrow H^+(aq) + Cl^-(aq)$$

» They react with metals to produce ionic metal halides, for example chlorine and iron produce iron (III) chloride.

iron + chlorine → iron(III) chloride

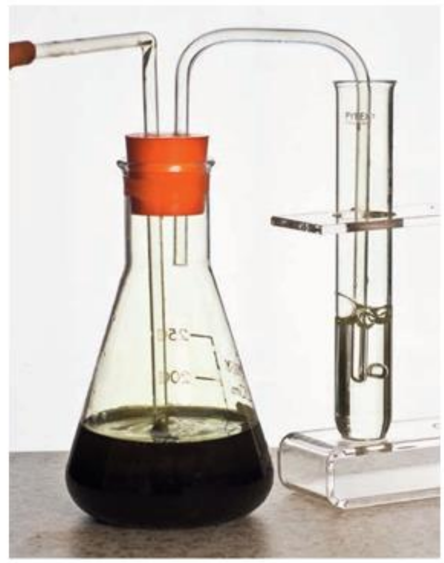
$$2Fe(s) + 3Cl_2(g) \rightarrow 2FeCl_3(s)$$

Displacement reactions

If chlorine is bubbled into a solution of potassium iodide, the less reactive halogen, iodine, is displaced by the more reactive halogen, chlorine, as you can see from Figure 9.13:

potassium iodide + chlorine → potassium chloride + iodine

$$2KI(aq) + Cl_2(g) \rightarrow 2KCl(aq) + I_2(aq)$$



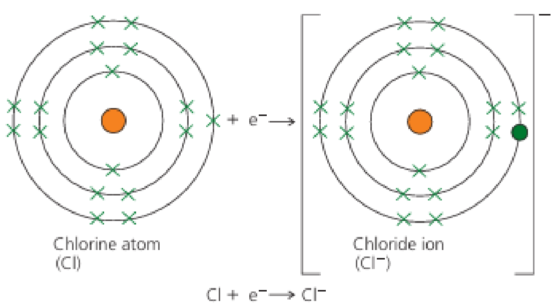
▲ **Figure 9.13** Iodine being displaced from potassium iodide solution as chlorine is bubbled through

The observed order of reactivity of the halogens, confirmed by similar **displacement reactions**, is:

Decreasing reactivity →

chlorine bromine iodine

The order of reactivity decreases as the group order decreases. Chlorine and bromine have an electronic configuration with seven electrons, gaining one electron per atom to form a stable noble gas, such as chlorine.



▲ **Figure 9.14** A chlorine atom gains an electron to form a chloride ion

▼ **Table 9.5** Electronic configuration of chlorine and bromine

Element	Symbol	Proton number	Electronic configuration
Chlorine	Cl	17	2,8,7
Bromine	Br	35	2,8,18,7

9.5 Group VIII – the noble gases

The noble gases, including helium, neon, argon, krypton, xenon, and radon, were discovered between 1894 and 1900 by British scientists Sir William Ramsay and Lord John Strutt Rayleigh.

» They are colourless gases.
» They are monatomic gases – they exist as individual atoms,
» They are very unreactive.

No helium, neon, or argon compounds have been found, but xenon and krypton with fluorine and oxygen have been produced, creating chemically unreactive gases with stable electronic configurations. Other elements attempt to attain these configurations during chemical reactions.

▼ **Table 9.6** Electronic configuration of helium, neon and argon

Element	Symbol	Proton number	Electronic configuration
Helium	He	2	2
Neon	Ne	10	2,8
Argon	Ar	18	2,8,8

9.6 Transition elements

This block of metals includes many you will be familiar with, for example copper, iron, nickel, zinc and chromium (Figure 9.17).

» They are less reactive metals.
» They form a range of brightly coloured compounds (Figure 9.18).
» They are harder and stronger than the metals in Groups I and II.
» They have much higher densities than the metals in Groups I and II.
» They have high melting points (except for mercury, which is a liquid at room temperature).
» They are good conductors of heat and electricity.
» They show catalytic activity (Chapter 7) as elements and compounds.
» They do not react (corrode) so quickly with oxygen and/or water
» They form simple ions with variable oxidation numbers.
» They form more complicated ions with high oxidation numbers.

a Copper is used in many situations which involve good heat and electrical conduction. It is also used in medallions and bracelets

b These gates are made of iron. Iron can easily be moulded into different shapes

c Monel is an alloy of nickel and copper. It is extremely resistant to corrosion, even that caused by sea water

d This bucket has been coated with zinc to prevent the steel of the bucket corroding

e The alloy stainless steel contains a high proportion of chromium, which makes it corrosion resistant

▲ **Figure 9.17** Everyday uses of transition elements and their compounds. They are often known as the 'everyday metals'

a Some solutions of coloured transition element compounds

b The coloured compounds of transition elements can be seen in these pottery glazes

▲ **Figure 9.18**

9.7 The position of hydrogen

Hydrogen is often placed by itself in the Periodic Table. This is because the properties of hydrogen are unique. However, useful comparisons can be made with the other elements. It is often shown at the top of either Group I or Group VII, but it cannot fit easily into the trends shown by either group; see Table 9.7.

▼ **Table 9.7** Comparison of hydrogen with lithium and fluorine

Lithium	Hydrogen	Fluorine
Solid	Gas	Gas
Forms a positive ion	Forms positive or negative ions	Forms a negative ion
1 electron in outer shell	1 electron in outer shell	1 electron short of a full outer shell
Loses 1 electron to form a noble gas configuration	Needs 1 electron to form a noble gas configuration	Needs 1 electron to form a noble gas configuration

Revision questions

9. Nov/2021/Paper_21/No.10

This question is about elements in Group IV of the Periodic Table.

(a) The table shows some properties of the Group IV elements.

element	density at room temperature in g/cm^3	melting point in °C	boiling point in °C
carbon (diamond)		3550	4827
silicon	2.34	1410	2355
germanium	5.35	937	2830
tin		232	2260
lead	11.34	328	1740

(i) Predict the density of tin.

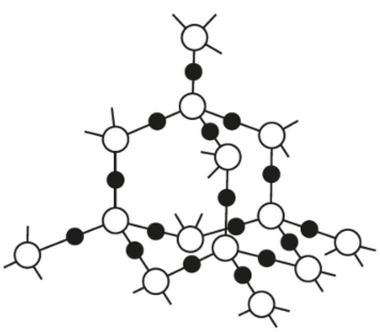
.... [1]

(ii) Describe the general trend in the boiling points of the Group IV elements.

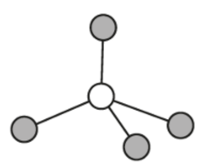
.... [1]

(iii) Predict the state of silicon at 1600 °C.
Give a reason for your answer.

(b) The structure of two compounds of silicon, **P** and **Q**, are shown.



P



Q

(i) Explain in terms of structure and bonding why compound **P** has a high melting point and compound **Q** has a low melting point.

(ii) Draw a dot-and-cross diagram for a molecule of compound **Q**.

Show only the outer shell electrons.

(c) A compound of carbon, hydrogen and silicon has the formula $Si(CH_3)_4$.

Calculate the percentage by mass of **carbon** in this compound.

10. Nov/2021/Paper_22/No.7

Sodium is a metal in Group I of the Periodic Table. Diamond (carbon) is a non-metal which is a good conductor of heat.

(a) State two **differences** in the physical properties of sodium and diamond.

1 ....

2 ....
[2]

(b) An ion of sodium has the symbol

$$^{23}_{11}Na^{+}$$

Deduce the number of protons, neutrons and electrons in this ion.

number of protons ....

number of neutrons ....

number of electrons ....
[3]

(c) Sodium reacts with nitrogen to form sodium nitride.
Complete the equation for this reaction.

$$\text{......}\ Na\ +\ \text{...........}\ \rightarrow\ \text{......}\ Na_3N$$ [1]

(d) When carbon is heated with steam in a closed container an equilibrium mixture is formed.

$$C(s)\ +\ H_2O(g) \rightleftharpoons CO(g)\ +\ H_2(g)$$

The forward reaction is endothermic.

(i) Describe and explain the effect, if any, on the position of equilibrium when the temperature is increased.

(ii) Describe and explain the effect, if any, on the position of equilibrium when the pressure is decreased.

11. Nov/2021/Paper_22/No.10

This question is about elements in Group V of the Periodic Table.

(a) The table shows some properties of the Group V elements.

element	density at room temperature in g/cm^3	melting point in °C
nitrogen	1.17×10^{-3}	–210
phosphorus	2.34	44
arsenic	5.73	
antimony		631
bismuth	9.80	272

Use the information in the table to:

(i) predict the density of antimony

.... [1]

(ii) suggest why it is difficult to predict the melting point of arsenic.

.... [1]

(ii) Explain why compound **R** conducts electricity when molten.

.... [1]

(iii) Draw a dot-and-cross diagram for a molecule of compound **S**.

Show only the outer shell electrons.

19. Jun/2021/Paper_21/No.2

Helium, neon, argon, krypton, xenon and radon are noble gases in Group VIII.

(a) Name the noble gas which has the greatest volume composition in air.

.... [1]

(b) State one use for helium.

.... [1]

(c) Radon is very unreactive.

Use the electronic structure of radon to explain why.

....

.... [1]

(d) Two isotopes of radon are shown.

$^{220}_{86}Rn$ $^{222}_{86}Rn$

(i) Give one similarity in the atomic structure of these two isotopes.

.... [1]

(ii) Give one difference in the atomic structure of these two isotopes.

.... [1]

(e) Xenon forms a compound that contains only xenon, oxygen and fluorine.

The compound contains 22.1% oxygen by mass and 17.5% fluorine by mass.

Calculate the empirical formula of this compound.

(f) A sample of neon has a volume of 21 dm^3 at room temperature and pressure.

(i) The temperature of the sample is increased.

The pressure remains constant.

Describe and explain, using kinetic particle theory, what happens to the volume of the sample.

....

.... [1]

(ii) The pressure of the sample is increased.

The temperature remains constant.

Describe and explain, using kinetic particle theory, what happens to the volume of the sample.

....

.... [1]

(iii) Calculate the mass of neon in the 21 dm^3 sample.

Give your answer to **two** significant figures.

20. Jun/2021/Paper_21/No.8
Silver is a transition element with proton number 47.

(a) Use the Periodic Table to state the number of occupied electron shells in an atom of silver.

.... [1]

(b) Describe, with the aid of a diagram, the metallic bonding in silver.

....

....

....

.... [3]

(c) Give two physical properties of silver that are **only** characteristic of transition elements but **not** of all metals.

1. ....

2. ....
[1]

(d) Silver nitrate is a white crystalline soluble salt.

Name a suitable combination of an acid and an insoluble base which is used to prepare silver nitrate.

(e) Aqueous silver nitrate, $AgNO_3(aq)$, is electrolysed using inert electrodes.

The products of the electrolysis are silver and oxygen.

(i) Silver ions are reduced at the cathode to make silver atoms.

Construct the ionic equation for this reduction.

.... [1]

(ii) Hydroxide ions are oxidised at the anode to make both oxygen molecules and water molecules.

Construct the ionic equation for this oxidation.

.... [1]

(iii) Explain why solid silver nitrate cannot be electrolysed.

....

.... [1]

(f) Acidified aqueous silver nitrate reacts with aqueous sodium iodide.

State the observations for this reaction.

22. Jun/2021/Paper_22/No.8

Lead is a metal with proton number 82.

(a) **(i)** Use the Periodic Table to state the number of occupied electron shells in an atom of lead.

.... [1]

(ii) Use the Periodic Table to state the number of electrons in the outer shell of an atom of lead.

.... [1]

(b) Describe, with the aid of a labelled diagram, the metallic bonding in lead.

(c) Give two physical properties of lead that are characteristic of all metals.

1. ....

2. ....
[1]

(d) Lead(II) ethanoate is a white crystalline soluble salt.

Name a suitable combination of an acid and an insoluble base which is used to prepare lead(II) ethanoate.

acid ....

base ....
[1]

(e) Aqueous lead(II) ethanoate reacts with aqueous sodium iodide.

A yellow precipitate of lead(II) iodide, PbI_2, is formed.

Construct the ionic equation, with state symbols, for this reaction.

.... [2]

(f) Explain why solid lead(II) iodide cannot be electrolysed.