WJEC Chemistry A-level

3.3: Chemistry of the *p*-block

Practice Questions

Wales Specification

1. Name an element that has a half-filled set of *p*-orbitals.

[1]

(Total 1)

2. Sketch the shape of **one** *p*-orbital.

[1]

(Total 1)

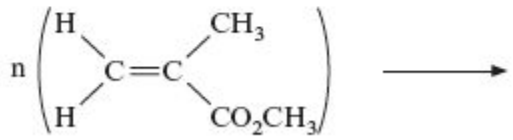
3. Boron, B, has the atomic number 5 and it forms a fluoride, BF_3.

(a) BF_3 is used to initiate certain types of addition polymerisation of unsaturated compounds.

(i) Ethene is an example of an unsaturated compound. Describe the bonding between the carbon atoms in ethene. You may wish to draw a labelled diagram. [2]

(ii) State what is meant by *polymerisation*. [1]

(iii) A colourless plastic used to cover lights is made from methyl methacrylate by a process similar to the polymerisation of ethene. Complete the equation by giving the formula of the repeating unit. [1]



(iv) Addition polymerisation is used to make synthetic rubber. The molecular formula of the monomer used is C_4H_5Cl. What is the **empirical** formula of the synthetic rubber polymer? [1]

.....

(b) (i) Use the VSEPR theory to deduce the shapes of BF_3 and NH_3. [2]

Shape of BF_3 .....

Shape of NH_3 .....

(ii) Explain the difference in the shapes of BF_3 and NH_3. [2]
QWC [1]

.....

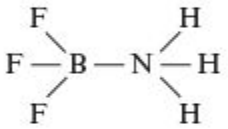
.....

.....

.....

(c) Boron fluoride reacts with ammonia, NH_3, to make the compound shown in the following equation.

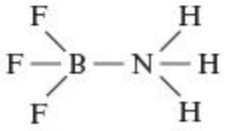
$$BF_3 + NH_3 \longrightarrow$$



(i) Name the type of bond formed between N and B. [1]

.....

(ii) Suggest a value for the F–B–F bond angle in this molecule.



Bond angle ..... [1]

(iii) Explain your answer to part (ii). [1]

.....

.....

Total [13]

4.

Read the passage below and then answer the questions in the spaces provided.

The Chemistry of Boron

Boron is an element at the top of Group 3. It forms a range of compounds whose behaviour is very different from the other elements in the same group. Boron shows the properties of a non-metal, however the remaining elements, including aluminium, gallium, indium and thallium all show metallic properties. This change is similar to that seen in other groups in the p-block with Group 4 having the non-metal carbon at the top and the metal lead at the bottom. In its compounds, boron exhibits the +3 oxidation state exclusively, forming materials such as BCl_3, BF_3 and B_2O_3. No compounds with a +1 oxidation state are known. Aluminium also exists only as the +3 oxidation state, however the +1 oxidation state becomes more common as the group is descended.

Boranes

There are very many compounds formed between boron and hydrogen and these are called boranes. These boranes are grouped into series and two examples of these are:

- *Nido*-boranes with a general formula of B_nH_{n+4}. This series includes pentaborane(9), B_5H_9, and decaborane(14), $B_{10}H_{14}$.
- *Arachno*-boranes with a general formula of B_nH_{n+6}. The first member of this series is tetraborane(10), B_4H_{10}.

All of these boranes are electron deficient, which leads them to be very reactive. The majority react explosively on contact with air, which led to their proposed use as a rocket fuel. To destroy the stockpile of B_5H_9 when it was no longer needed, the US government treated it with steam to form a solution of boric acid (H_3BO_3) and hydrogen gas.

Boron nitride

Boron nitride has a giant covalent structure that has the same number of electrons as graphite and diamond. They are said to be isoelectronic. Boron nitride exists in two forms:

- Hexagonal boron nitride has a structure similar to graphite, and is sometimes called 'white graphite' because of its excellent lubricating properties. Unlike graphite, hexagonal boron nitride is an insulator and has applications which depend upon this property.
- Cubic boron nitride has a diamond structure, and is the second hardest natural material known. It has high thermal conductivity and is chemically inert.

Uses of boron compounds

Nearly all boron ore extracted from the Earth is destined for refinement into boric acid and sodium tetraborate. Most boric acid is used in the production of shock-resistant glass, whilst sodium tetraborate is used as an additive to detergents. Boron is also used in nuclear reactors, where boron shielding is used as a control, taking advantage of its high cross-section for neutron capture.

- End of passage -

(a) Explain why boron forms compounds with the +3 oxidation state alone, but thallium compounds are more stable with the +1 oxidation state *(lines 6-9).*

[2]

(b) Boranes are compounds made up of boron and hydrogen only *(lines 11-16)*. A sample of a gaseous borane was found to contain 78.14 % boron and 21.86 % hydrogen by mass. A sample of this borane of mass 1.232 g occupied a volume of 1 dm3 at 273 K and 1 atm pressure.

[The molar volume of a gas at 273 K and 1 atm pressure is 22.4 dm^3.]

(i) What is the empirical formula of this borane?

[2]

Empirical formula .....

(ii) What is the molecular formula of this borane?

[3]

Molecular formula .....

(c) Explain the term *electron deficient (line 17)*.

[1]

(d) Balance the equation for the reaction of pentaborane(9), B_5H_9, with steam *(lines 18-20)*. [1]

..... B_5H_9 + ... H_2O ⟶ ..... H_3BO_3 + ... H_2

(e) The standard enthalpy change of formation of pentaborane(9) is +42.8 kJ mol^{-1}. State what information this value gives about the stability of this compound. [1]

(f) Hexagonal boron nitride and graphite have similar structures *(lines 24-26)*. Describe the differences between these two isoelectronic materials in terms of their bonding and structure.

[3] QWC [1]

(g) Boron-10 absorbs a neutron *(line 33)* to form an intermediate, which then decays by emission of an alpha particle.

Give the mass number and atomic number of the final product.

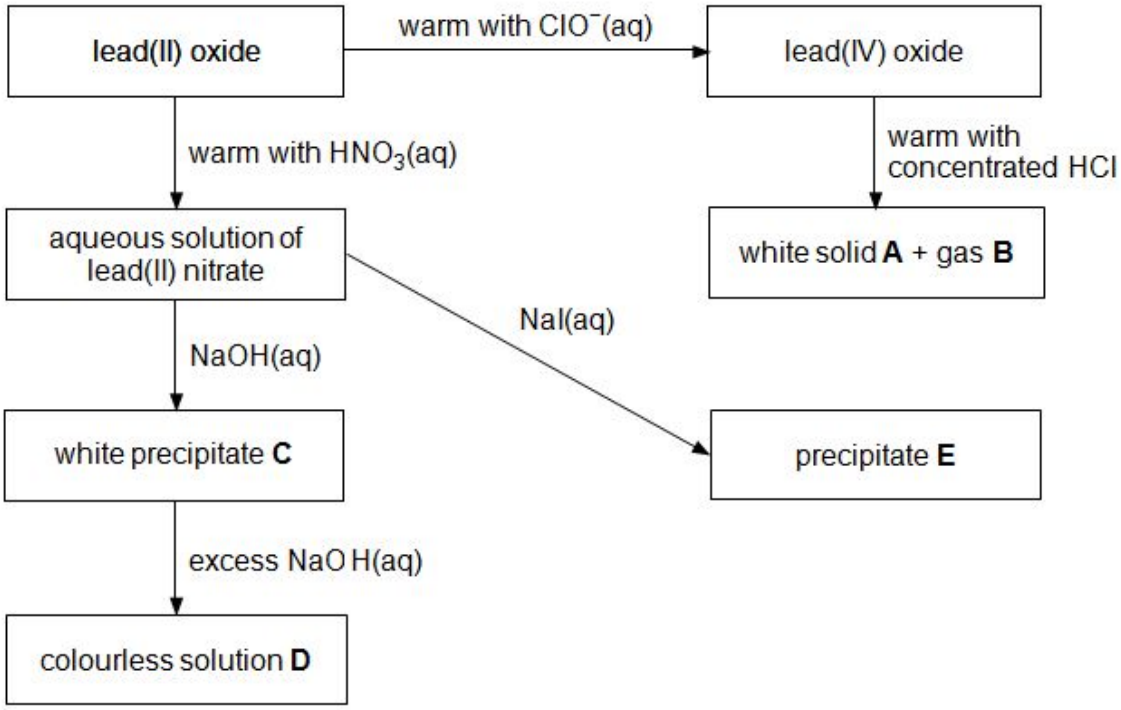
[1]

Mass number.....

Atomic number.....

(Total 15)

5. *(a)* The diagram shows some of the reactions of lead compounds.



(i) State the role of lead(IV) oxide in the reaction with concentrated hydrochloric acid.

[1]

(ii) Name white solid **A** and gas **B**.

[2]

(iii) Give the formula of the lead-containing species present in colourless solution **D**.

[1]

(iv) Give the colour of precipitate **E**.

[1]

(v) Write the equation for the formation of lead(II) nitrate from lead(II) oxide.

[1]

(b) Carbon is the first element in Group 4. Two of its allotropes are diamond and graphite. A compound that forms structures corresponding to diamond and graphite is boron nitride.

(i) Describe the structure of graphite and explain why **hexagonal** boron nitride can adopt the same structure yet have different electrical conductivity properties.

[4] QWC [1]

(ii) State **one** use for the **cubic** boron nitride structure.

[1]

(c) Another element in Group 4 is tin. At low temperatures tin exists as its grey form. At higher temperatures the white form is stable. The change can be represented by the equation:

$$Sn_{(grey)} \longrightarrow Sn_{(white)} \qquad \Delta H^{\ominus} = 1.92\,kJ\,mol^{-1}$$

The standard entropy values are $44.8\,J\,K^{-1}\,mol^{-1}$ for grey tin and $51.5\,J\,K^{-1}\,mol^{-1}$ for white tin.

(i) Calculate the minimum temperature needed to cause grey tin to change to white tin.

[3]

(ii) During Napoleon's disastrous campaign in Russia from June to December in 1812 the tin buttons on his infantry's uniforms disintegrated. Suggest a reason why this might have happened.

[1]

(d)An important technological development in recent years has been the hydrogen fuel cell. This uses electrochemical methods to get energy from hydrogen.

(i) Write the half-equations for the processes occurring at the electrodes and an equation for the overall reaction.

[3]

(ii) Give **one** disadvantage of using hydrogen fuel cells to power vehicles.

[1]

(Total 20)

6. This question is about atomic structure.

(a) Give the full electronic configuration of a nitrogen atom and use this to describe the way in which electrons are arranged in atoms.

[4] QWC [1]

(b) Describe the main features of the atomic emission spectrum of hydrogen in the visible region. Explain how these features arise and how their interpretation provides evidence for energy levels in the atom.

[6]

(c)(i) Hydrogen has a first ionisation energy of 1312 kJ mol^{-1}.Explain why helium has a higher first ionisation energy than hydrogen

[2]

(ii) Beryllium and magnesium are both in Group 2 of the Periodic Table.Explain why beryllium has a higher first ionisation energy than magnesium

[2]

(iii) The table below gives the first three ionisation energies for boron and potassium.

Element	Ionisation energy/kJ mol^{-1}		
	1st	2nd	3rd
B	800	2420	3660
K	419	3051	4412

(I) Suggest why compounds containing B^{3+} ions are unlikely to exist.

[1]

(II) Write an equation to represent the **second** ionisation energy of potassium

[1]

(III) State how the first three ionisation energies of calcium would differ from those of potassium.

[2]

(Total 19)

7. Aluminium, boron and nitrogen all form chlorides containing three chlorine atoms, XCl_3.

(a) Molecules of boron chloride, BCl_3, and molecules of nitrogen chloride, NCl_3, have different shapes.

Use VSEPR (valence shell electron pair repulsion) theory to state and explain the shapes of these molecules. [6]

QWC [2]

(b) The boron atom in boron chloride, BCl_3, is described as being electron deficient. Draw a dot and cross diagram for BCl_3 and use it to show what is meant by the term *electron deficient*. [2]

(c) Nitrogen chloride, NCl_3, is insoluble in cold water whilst the similar compound ammonia, NH_3, is very soluble. Explain this difference in behaviour. [2]

(d) Aluminium chloride, $AlCl_3$, forms a dimer that contains both covalent bonds and coordinate bonds. Describe what is meant by the terms *covalent bond* and *coordinate bond*. [2]

(Total 14)