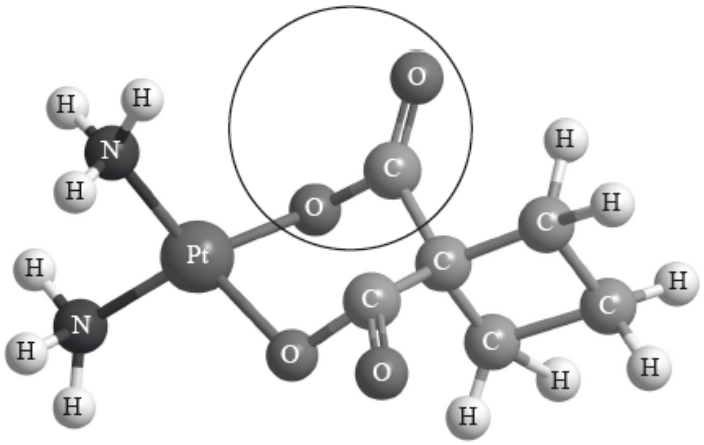
HL Paper 2

Carboplatin used in the treatment of lung cancer has the following three-dimensional structure.

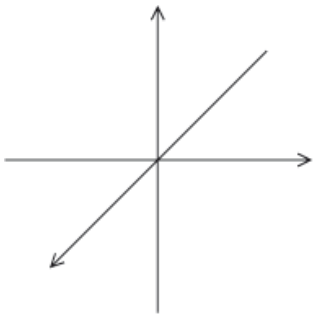


Elemental platinum has electrons occupying s, p, d and f atomic orbitals.

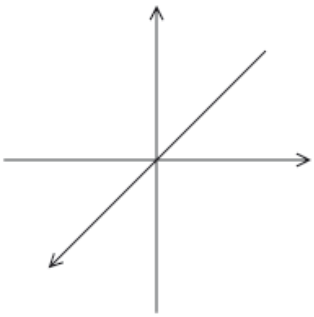
a. Identify the name of the functional group circled in the structure of carboplatin. [1]

b. State the type of bonding between platinum and nitrogen in carboplatin. [1]

c.i. Draw the shape of an s orbital and a p_x orbital. Label the *x*, *y* and *z* axes on each diagram. [2]



s orbital



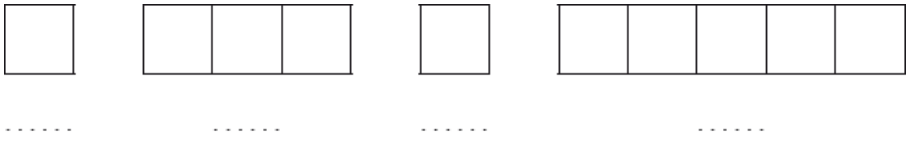
p_x orbital

c.ii. State the maximum number of orbitals in the $n = 4$ energy level. [1]

d. A number of ruthenium-based anti-cancer drugs have also been developed. State the **full** electron configuration of the ruthenium(II) ion, Ru^{2+}. [1]

e. Iron is in the same group in the periodic table as ruthenium. [1]

Construct the orbital diagram (using the arrow-in-box notation) for iron, showing the electrons in the $n = 3$ and $n = 4$ energy levels only **and** label each sub-level on the diagram.



The emission spectrum of an element can be used to identify it.

a.iii Hydrogen spectral data give the frequency of 3.28×10^{15} s^{-1} for its convergence limit. [1]

Calculate the ionization energy, in J, for a single atom of hydrogen using sections 1 and 2 of the data booklet.

a.iv Calculate the wavelength, in m, for the electron transition corresponding to the frequency in (a)(iii) using section 1 of the data booklet. [1]

c.iv Deduce any change in the colour of the electrolyte during electrolysis. [1]

c.v. Deduce the gas formed at the anode (positive electrode) when graphite is used in place of copper. [1]

d. Explain why transition metals exhibit variable oxidation states in contrast to alkali metals. [2]

Transition metals:

. . . . . .

. . . . . .

Alkali metals:

. . . . . .

. . . . . .

The element antimony, Sb, is usually found in nature as its sulfide ore, stibnite, Sb_2S_3. This ore was used two thousand years ago by ancient Egyptian women as a cosmetic to darken their eyes and eyelashes.

Antimony contains two stable isotopes, ^{121}Sb and ^{123}Sb. The relative atomic mass of antimony is given in Table 5 of the Data Booklet.

a.i. Calculate the percentage by mass of antimony in a sample of pure stibnite. State your answer to **four** significant figures. [2]

c.i. Calculate the percentage of each isotope in pure antimony. State your answers to **three** significant figures. [2]

c.iii State the number of neutrons present in an atom of ^{121}Sb. [1]

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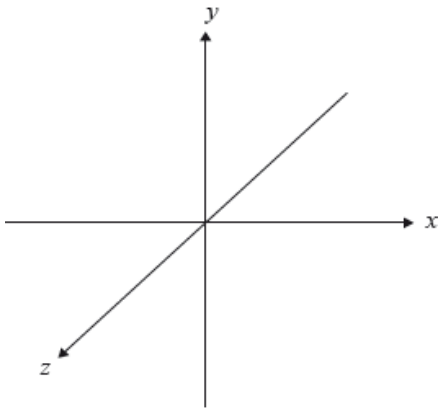
a.i. Draw the shape of the p_z orbital using the coordinates shown. [1]



a.ii. State the electron configuration of Fe^{3+}. [1]

a.iii. Define the term *ligand.* [1]

a.iv. Explain why the complex $[\mathrm{Fe}(\mathrm{H_2O})_6]^{3+}$ is coloured. [3]

a.v. The element selenium $(Z = 34)$ has electrons in the 4s, 3d and 4p orbitals. Draw an orbital box diagram (arrow-in-box notation) to represent these electrons. [1]

Two groups of students (Group A and Group B) carried out a project* on the chemistry of some group 7 elements (the halogens) and their compounds.

* Adapted from J Derek Woollins, (2009), Inorganic Experiments and Open University, (2008), Exploring the Molecular World.

In this project the students explored several aspects of the chemistry of the halogens. In the original preparation of ICl(l), they observed the yellow-green colour of chlorine gas, $Cl_2(g)$, reacting with solid iodine, $I_2(s)$.

e. When iodine reacts with excess chlorine, $\mathrm{ICl_3}$ can form. Deduce the Lewis (electron dot) structure of $\mathrm{ICl_3}$ and $\mathrm{ICl_2^-}$ and state the name of the shape of each species. [4]

	$\mathrm{ICl_3}$	$\mathrm{ICl_2^-}$
Lewis structure		
Name of shape		

f.i. State the **full** electron configuration of iodine $(Z = 53)$. [1]

f.iii. One important use of chlorine is in the synthesis of poly(chloroethene), PVC. Identify the monomer used to make PVC and state **one** of the uses of PVC. [2]

Monomer:

Use:

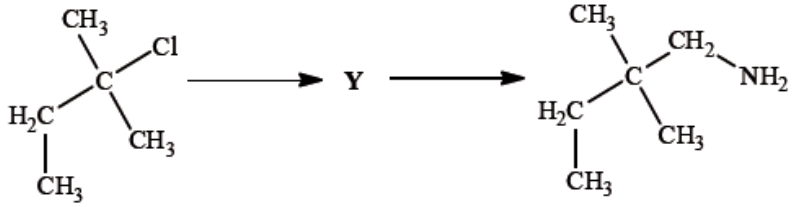
2-methylbutan-2-ol, $(CH_3)_2C(OH)CH_2CH_3$, is a liquid with a smell of camphor that was formerly used as a sedative. One way of producing it starts with 2-methylbut-2-ene.

As well as 2-methylbutan-2-ol, the reaction also produces a small quantity of an optically active isomer, **X**.

2-methylbutan-2-ol can also be produced by the hydrolysis of 2-chloro-2-methylbutane, $(CH_3)_2CClC_2H_5$, with aqueous sodium hydroxide.

2-chloro-2-methylbutane contains some molecules with a molar mass of approximately $106\ \text{g mol}^{-1}$ and some with a molar mass of approximately $108\ \text{g mol}^{-1}$.

2-chloro-2-methylbutane can also be converted into compound **Z** by a two-stage reaction via compound **Y**:



2-chloro-2-methylbutane Z

a. State the other substances required to convert 2-methylbut-2-ene to 2-methylbutan-2-ol. [2]

b. Explain whether you would expect 2-methylbutan-2-ol to react with acidified potassium dichromate(VI). [2]

c.i. State what is meant by *optical activity*. [1]

c.ii. State what optical activity indicates about the structure of the molecule. [1]

c.iii Optical activity can be detected using a polarimeter. Explain how this works. [3]

c.iv Deduce the structural formula of **X**. [1]

d. Explain why 2-methylbut-2-ene is less soluble in water than 2-methylbutan-2-ol. [2]

e.i. Explain the mechanism of this reaction using curly arrows to represent the movement of electron pairs. [4]

e.ii. State the rate expression for this reaction and the units of the rate constant. [2]

e.iii. Suggest why, for some other halogenoalkanes, this hydrolysis is much more effective in alkaline rather than in neutral conditions. [1]

f.i. Outline why there are molecules with different molar masses. [1]

g.i. Draw the structure of **Y**. [1]

g.ii. State the reagent and any catalyst required for both the formation of **Y** and the conversion of **Y** into **Z**. [3]

Formation of **Y**:

Conversion of **Y** into **Z**:

Bromine is a member of group 7, the halogens.

Iron is a transition metal.

Freshly prepared iron(II) bromide can be electrolysed both in the liquid state and in aqueous solution.

a.i. Explain the trend in reactivity of the halogens. [3]

a.ii. Deduce, using equations where appropriate, if bromine reacts with sodium chloride solution and with sodium iodide solution. [2]

b.i. Describe the bonding in metals and explain their malleability. [3]

b.ii. List **three** characteristic properties of transition elements. [2]

b.iii. Identify the type of bonding between iron and cyanide in $[\mathrm{Fe(CN)_6}]^{3-}$. [1]

b.iv. Deduce the oxidation number of iron in $[\mathrm{Fe(CN)_6}]^{3-}$. [1]

b.v. Draw the abbreviated orbital diagram for an **iron atom** using the arrow-in-box notation to represent electrons. [1]

b.vi. Draw the abbreviated orbital diagram for the **iron ion in $[Fe(CN)_6]^{3-}$** using the arrow-in-box notation to represent electrons. [1]

c.i. Describe, using a diagram, the essential components of an electrolytic cell. [3]

c.ii. Describe the **two** ways in which current is conducted in an electrolytic cell. [2]

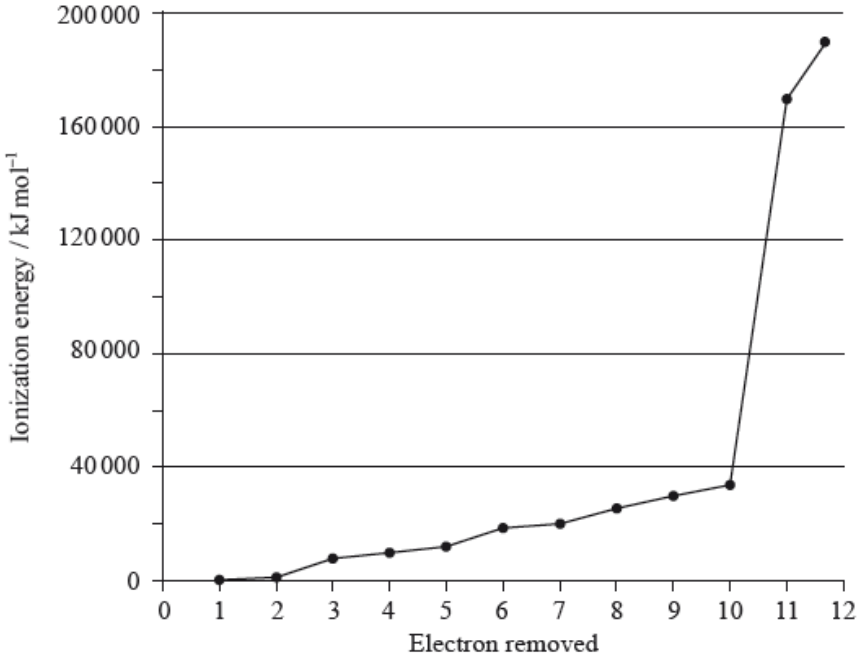
c.iii. Predict and explain the products of electrolysis of a **dilute** iron(II) bromide solution. [4]

c.iv. Identify another product that is formed if the solution of iron(II) bromide is **concentrated**. [1]

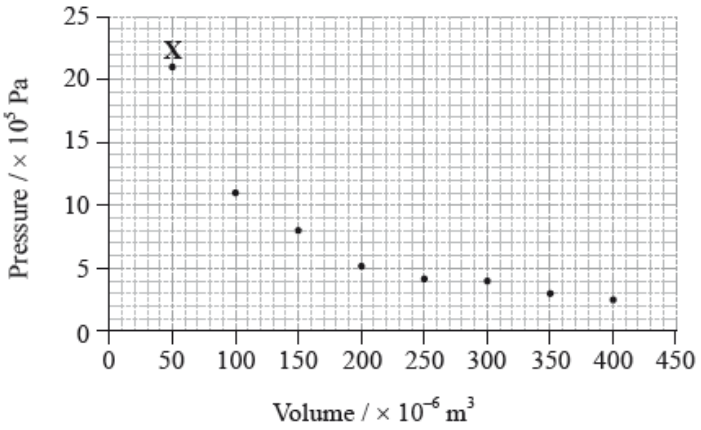
c.v. Explain why this other product is formed. [1]

A sample of magnesium contains three isotopes: magnesium-24, magnesium-25 and magnesium-26, with abundances of 77.44%, 10.00% and 12.56% respectively.

A graph of the successive ionization energies of magnesium is shown below.



The graph below shows pressure and volume data collected for a sample of carbon dioxide gas at 330 K.



a. (i) Calculate the relative atomic mass of this sample of magnesium correct to **two** decimal places. [4]

(ii) Predict the relative atomic radii of the three magnesium isotopes, giving your reasons.

b. (i) Explain the increase in ionization energy values from the 3rd to the 8th electrons. [3]

(ii) Explain the sharp increase in ionization energy values between the 10th and 11th electrons.

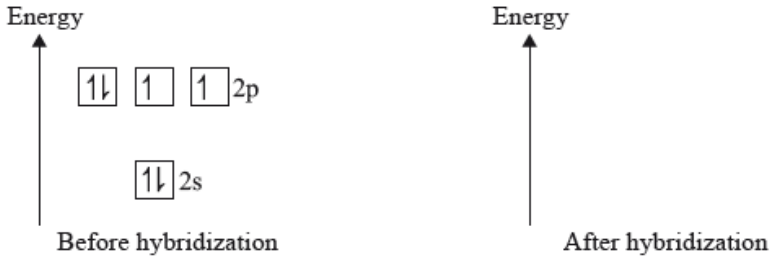
c. (i) Magnesium reacts with oxygen to form an ionic compound, magnesium oxide. Describe how the ions are formed, and the structure and bonding in magnesium oxide. [4]

(ii) Carbon reacts with oxygen to form a covalent compound, carbon dioxide. Describe what is meant by a covalent bond.

(iii) State why magnesium and oxygen form an ionic compound while carbon and oxygen form a covalent compound.

d. (i) Predict the type of hybridization of the carbon and oxygen atoms in CO_2. [7]

(ii) Sketch the orbitals of an oxygen atom in CO_2 on the energy level diagram provided, including the electrons that occupy each orbital.



(iii) Define the term electronegativity.

(iv) Explain why oxygen has a larger electronegativity than carbon.

e. (i) Draw a best-fit curve for the data on the graph. [4]

(ii) Use the data point labelled **X** to determine the amount, in mol, of carbon dioxide gas in the sample.

f. (i) Most indicators are weak acids. Describe qualitatively how indicators work. [3]

(ii) Identify a suitable indicator for a titration between a weak acid and a strong base, using Table 16 of the Data Booklet.

Brass is a copper containing alloy with many uses. An analysis is carried out to determine the percentage of copper present in three identical samples of brass. The reactions involved in this analysis are shown below.

$$\text{Step 1: } \mathrm{Cu(s) + 2HNO_3(aq) + 2H^+(aq) \rightarrow Cu^{2+}(aq) + 2NO_2(g) + 2H_2O(l)}$$
$$\text{Step 2: } \mathrm{4I^-(aq) + 2Cu^{2+}(aq) \rightarrow 2CuI(s) + I_2(aq)}$$
$$\text{Step 3: } \mathrm{I_2(aq) + 2S_2O_3^{2-}(aq) \rightarrow 2I^-(aq) + S_4O_6^{2-}(aq)}$$

In step 1 the copper reacts to form a blue solution.

c.i. State the full electronic configuration of $\mathrm{Cu^{2+}}$. [1]

c.ii. Explain why the copper solution is coloured. [2]

The electron configuration of chromium can be expressed as $\mathrm{[Ar]4s^x3d^y}$.

Hydrogen and nitrogen(II) oxide react according to the following equation.

$$\mathrm{2H_2(g) + 2NO(g) \rightleftharpoons N_2(g) + 2H_2O(g)}$$

At time = t seconds, the rate of the reaction is

$$\mathrm{rate} = k[\mathrm{H_2(g)}][\mathrm{NO(g)}]^2$$

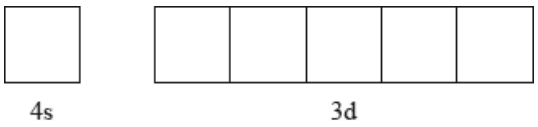
When concentrated hydrochloric acid is added to a solution containing hydrated copper(II) ions, the colour of the solution changes from light blue to green. The equation for the reaction is:

$$\mathrm{[Cu(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightarrow [CuCl_4]^{2-}(aq) + 6H_2O(l)}$$

a.i. Explain what the square brackets around argon, [Ar], represent. [1]

a.ii. State the values of x and y. [1]

a.iii. Annotate the diagram below showing the 4s and 3d orbitals for a chromium atom using an arrow, ↑ and ↓, to represent a spinning electron. [1]



b.i. Explain precisely what the square brackets around nitrogen(II) oxide, [NO(g)], represent in this context. [1]

b.ii. Deduce the units for the rate constant k. [1]

c.i. Explain what the square brackets around the copper containing species represent. [1]

c.ii. Explain why the $\mathrm{[Cu(H_2O)_6]^{2+}}$ ion is coloured and why the $\mathrm{[CuCl_4]^{2-}}$ ion has a different colour. [2]

d. Some words used in chemistry can have a specific meaning which is different to their meaning in everyday English. [1]

State what the term *spontaneous* means when used in a chemistry context.

Nitrogen and silicon belong to different groups in the periodic table.

Draw the Lewis structures, state the shapes and predict the bond angles for the following species.

Consider the molecule $\mathrm{HCONH_2}$.

a.i. Distinguish in terms of electronic structure, between the terms *group* and *period*. [2]

a.ii. State the maximum number of orbitals in the $n = 2$ energy level. [1]

b.i. $\mathrm{SiF_6^{2-}}$ [3]

b.ii $\mathrm{NO_2^+}$ [3]

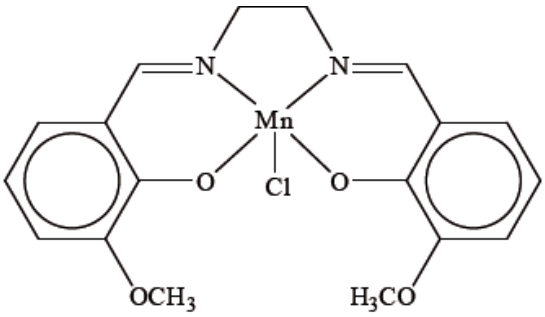
d. Explain, using diagrams, why $\mathrm{NO_2}$ is a polar molecule but $\mathrm{CO_2}$ is a non-polar molecule. [3]

f.ii. Explain the term *hybridization*. [1]

f.iii. Describe how σ and π bonds form. [2]

f.iv. State the type of hybridization of the carbon and nitrogen atoms in $\mathrm{HCONH_2}$. [2]

EUK-134, the structure of which is shown below, is a complex ion of manganese(III) that is used in expensive sun-protection products because of its powerful antioxidant properties.



a. State the electron configuration of the manganese ion in EUK-134. [1]

b. State the name given to species that bond to a central metal ion, and identify the type of bond present. [2]

Name given:

Type of bond:

c. Transition metals have certain characteristic properties. State **two** properties that are involved in EUK-134 rapidly decreasing the concentration of oxidizing agents. [2]

d. Substances like EUK-134 are often coloured. Explain why compounds of transition metals absorb visible radiation. [3]

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a. Explain why the relative atomic mass of cobalt is greater than the relative atomic mass of nickel, even though the atomic number of nickel is greater than the atomic number of cobalt. [1]

b. Deduce the numbers of protons and electrons in the ion Co^{2+}. [1]

c. Deduce the electron configuration for the ion Co^{2+}. [1]

Chromium is a typical transition metal with many uses.

A voltaic cell is constructed as follows. One half-cell contains a platinum electrode in a solution containing $\mathrm{K_2Cr_2O_7}$ and $\mathrm{H_2SO_4}$. The other half-cell contains an iron electrode in a solution containing Fe^{2+} ions. The two electrodes are connected to a voltmeter and the two solutions by a salt bridge.

a. Distinguish between the terms *oxidation* and *reduction* in terms of oxidation numbers. [1]

b. State the names of $\mathrm{Cr_2O_3}$ and $\mathrm{CrO_3}$. [2]

$\mathrm{Cr_2O_3}$:

$\mathrm{CrO_3}$:

c.i. Define the term *oxidizing agent*. [1]

c.ii. $\mathrm{Cr_2O_7^{2-}(aq)}$ and $\mathrm{I^-(aq)}$ ions react together in the **presence of acid** to form $\mathrm{Cr^{3+}(aq)}$ and $\mathrm{IO_3^-(aq)}$ ions. Deduce the balanced chemical equation for this redox reaction and identify the species that acts as the oxidizing agent. [3]

d.i. Draw a diagram of the voltaic cell, labelling the positive and negative electrodes (cathode and anode) and showing the direction of movement of the electrons and ions. Deduce an equation for the reaction occurring in each of the half-cells, and the equation for the overall cell reaction. [5]

d.ii. Define the term *standard electrode potential*. [1]

d.iii. Calculate the cell potential, in V, under standard conditions, using information from Table 14 of the Data Booklet. [1]

e.i. State **two** characteristic properties of transition elements. [2]

e.ii. State the type of bond formed by a ligand and identify the feature that enables it to form this bond. [2]

e.iii. Explain why the complex $\mathrm{[Cr(H_2O)_6]^{3+}}$ is coloured. [3]

e.iv. Draw an orbital box diagram (arrow-in-box notation) showing the electrons in the 4s and 3d sub-levels in chromium metal. [1]

f. Chromium is often used in electroplating. State what is used as the positive electrode (anode), the negative electrode (cathode) and the electrolyte in the chromium electroplating process. [3]

Isotopes are atoms of the same element with different mass numbers. Two isotopes of cobalt are Co-59 and Co-60.

State why the Co-60 radioisotope is used in radiotherapy.

There are only two isotopes, $^{63}_{29}\mathrm{Cu}$ and $^{65}_{29}\mathrm{Cu}$, in naturally occurring copper.

A chemist considered preparing a copper(I) salt by reacting copper metal with the corresponding copper(II) salt according to the equation below.

$$\mathrm{Cu}^{2+}(\mathrm{aq}) + \mathrm{Cu}\ (\mathrm{s}) \rightarrow 2\mathrm{Cu}^{+}(\mathrm{aq})$$

a. The relative atomic mass of copper is 63.55. Calculate the percentage of $^{63}_{29}\mathrm{Cu}$ in the naturally occurring element. [2]

b. State the **full** electronic configuration of a copper atom. [1]

c. Explain why most copper(II) compounds are coloured, whereas most copper(I) compounds are not. [2]

d. (i) Using data from Table 14 of the Data Booklet, calculate the cell potential for this reaction. [3]

(ii) Use this result to predict, with a reason, whether this reaction will be spontaneous.

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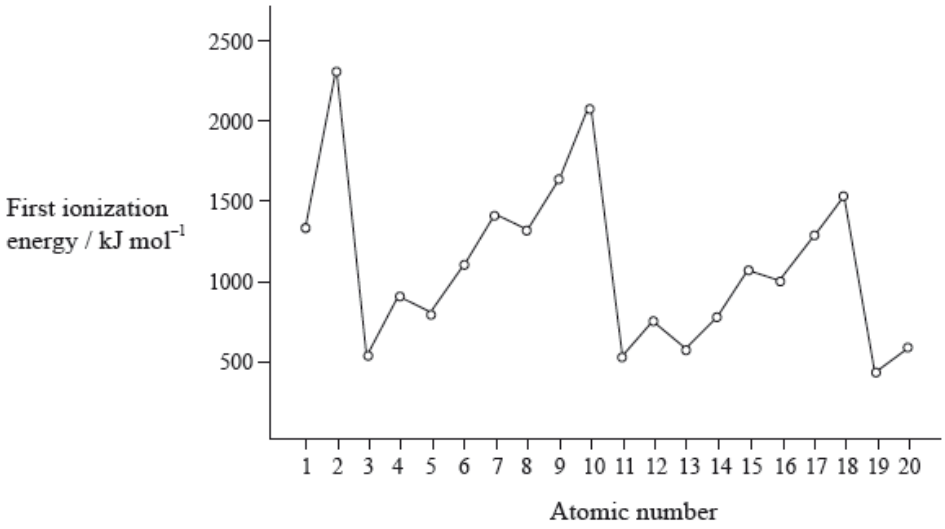
a. Describe the emission spectrum of hydrogen. Outline how this spectrum is related to the energy levels in the hydrogen atom. [3]

b. Transition elements form complexes such as $[\mathrm{Fe(CN)_6}]^{4-}$ and $[\mathrm{FeCl_4}]^{-}$. Deduce the oxidation number of iron in each of these complex ions. [2]

$[\mathrm{Fe(CN)_6}]^{4-}$

$[\mathrm{FeCl_4}]^{-}$

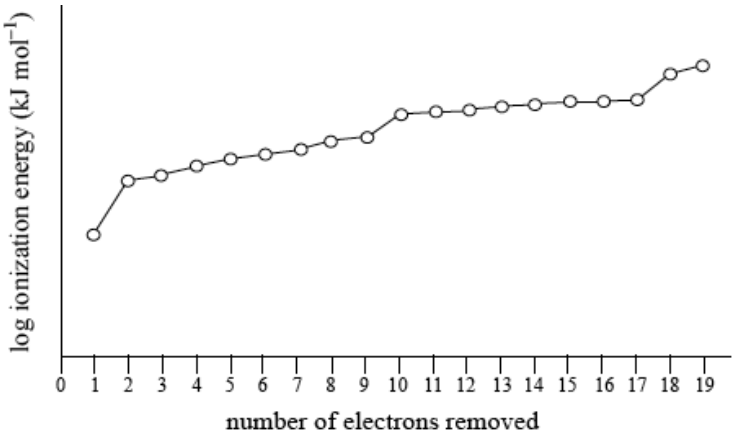
The graph of the first ionization energy plotted against atomic number for the first twenty elements shows periodicity.



b.ii. Explain how information from this graph provides evidence for the existence of main energy levels and sub-levels within atoms. [4]

b.iii. State what is meant by the term *second ionization energy*. [1]

b.iv. Sketch and explain the shape of the graph obtained for the successive ionization energies of potassium using a logarithmic scale for ionization energy on the *y*-axis against number of electrons removed on the *x*-axis. [4]



c.i. State the **full** electronic configurations of copper, Cu, and the copper(I) ion, Cu^+. [2]

c.ii. Explain why copper(II) compounds in aqueous solution are coloured whereas scandium(III) compounds in aqueous solution are colourless. [2]

Calcium carbide, CaC_2, is an ionic solid.

a. Describe the nature of ionic bonding. [1]

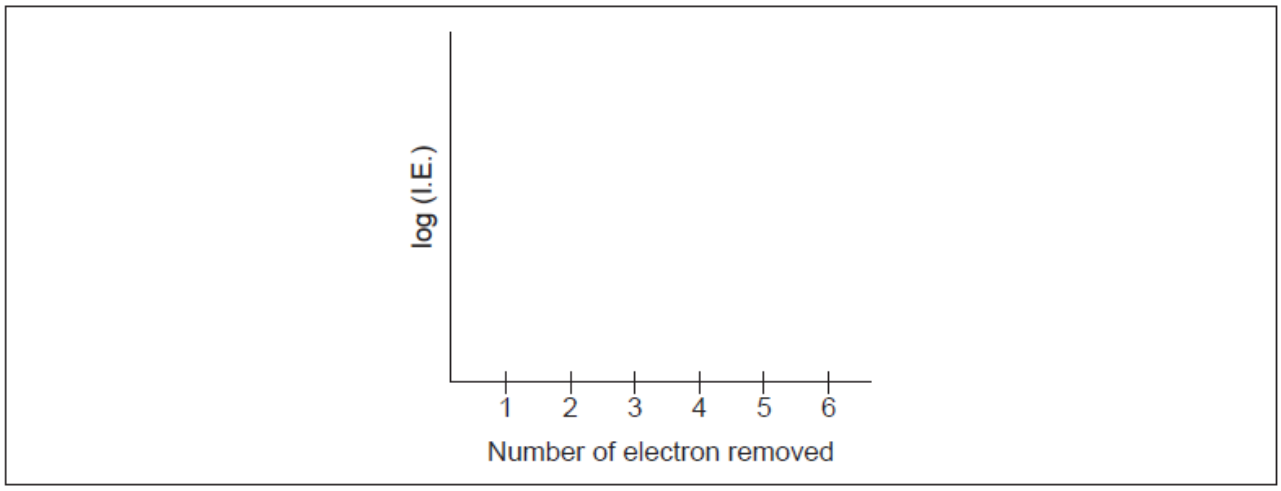
b. Describe how the relative atomic mass of a sample of calcium could be determined from its mass spectrum. [2]

c. When calcium compounds are introduced into a gas flame a red colour is seen; sodium compounds give a yellow flame. Outline the source of the colours and why they are different. [2]

d.i. Suggest **two** reasons why solid calcium has a greater density than solid potassium. [2]

d.ii. Outline why solid calcium is a good conductor of electricity. [1]

e. Sketch a graph of the first six ionization energies of calcium. [2]



f. Calcium carbide reacts with water to form ethyne and calcium hydroxide. [1]

$$CaC_2(s) + H_2O(l) \rightarrow C_2H_2(g) + Ca(OH)_2(aq)$$

Estimate the pH of the resultant solution.

g.i. Describe how sigma (σ) and pi (π) bonds are formed. [2]

sigma (σ):

. . . . . .

. . . . . .

pi (π):

. . . . . .

. . . . . .

g.ii. Deduce the number of σ and π bonds in a molecule of ethyne. [1]

sigma (σ):

. . . . . .

pi (π):

. . . . . .

Iron rusts in the presence of oxygen and water. Rusting is a redox process involving several steps that produces hydrated iron(III) oxide, $Fe_2O_3 \bullet nH_2O$, as the final product.

The half-equations involved for the first step of rusting are given below.

Half-equation 1: $Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-$

Half-equation 2: $O_2(aq) + 4e^- + 2H_2O(l) \rightarrow 4OH^-(aq)$

a. (i) Identify whether half-equation 1 represents oxidation or reduction, giving a reason for your answer. [5]

(ii) Identify the oxidation number of each atom in the three species in half-equation 2.

$$O_2(aq) + 4e^- + 2H_2O(l) \rightarrow 4OH^-(aq)$$

(iii) Deduce the overall redox equation for the first step of rusting by combining half-equations 1 and 2.

(iv) Identify the reducing agent in the redox equation in part (iii).

b. The oxygen in half-equation 2 is atmospheric oxygen that is found dissolved in water in very small concentrations. Explain, in terms of intermolecular forces, why oxygen is not very soluble in water. [2]

c. State the relationship between the electron arrangement of an element and its group and period in the periodic table. [2]

d. Transition metals and their compounds often catalyse reactions. The catalyzed decomposition of hydrogen peroxide by CuO is an example. [2]

State **two other** examples of catalyzed reactions giving the transition metal or its compound acting as catalyst.

e. (i) State a chemical equation for the partial dissociation of water into ions, including state symbols. [6]

(ii) The dissociation of water into ions is reversible. State the expression for the ionic product constant of water.

(iii) The ionic product constant of water was measured at three different temperatures.

Temperature / K	K_w
298	1.00×10^{-14}
313	2.92×10^{-14}
373	5.13×10^{-13}

Deduce whether the ionization of water is exothermic or endothermic, giving your reason.

(iv) Use the data in part (iii) to determine the pH of water at 373 K, correct to **two** decimal places.

f. (i) An aqueous solution of sodium chloride is electrolysed using inert electrodes. Explain which product is obtained at the positive electrode (anode) if the concentration of sodium chloride is high. [5]

(ii) State the half-equations occurring at the electrodes during the electrolysis of the **concentrated** aqueous solution of sodium chloride.

Negative electrode (cathode):

Positive electrode (anode):

g. Describe how electrolysis can be used to electroplate a bracelet with a layer of silver metal. Include the choice of electrodes and electrolyte needed in your description. [3]

The element boron has two naturally occurring isotopes, $^{10}\mathrm{B}$ and $^{11}\mathrm{B}$.

Phosphorus forms two chlorides, $\mathrm{PCl_3}$ and $\mathrm{PCl_5}$.

c.i. Apply the Aufbau principle to state the **full** electron configuration for an atom of phosphorus. [1]

c.ii. Deduce the Lewis structures for $\mathrm{PCl_3}$ and $\mathrm{PCl_5}$. [2]

$\mathrm{PCl_3}$ $\mathrm{PCl_5}$

c.iii. Predict the shapes and the bond angles in the two molecules. [4]

	$\mathrm{PCl_3}$	$\mathrm{PCl_5}$
Shape	....	....
Bond angles	....	....

c.iv. Identify the type of hybridization present in $\mathrm{PCl_3}$. [1]

c.v. Compare the melting points of $\mathrm{PCl_3}$ and $\mathrm{PCl_5}$ and explain the difference. [3]

d.i. Define an *acid* according to the Lewis theory. [1]

d.ii. State and explain the acid–base character of PCl_3 according to the Lewis theory. [2]

e. Explain the delocalization of π electrons using the O_3 molecule as an example, including **two** facts that support the delocalization. [4]

Magnesium is a group 2 metal which exists as a number of isotopes and forms many compounds.

c. Magnesium ions produce no emission or absorption lines in the visible region of the electromagnetic spectrum. Suggest why most magnesium compounds tested in a school laboratory show traces of yellow in the flame. [1]

d. (i) Explain the convergence of lines in a hydrogen emission spectrum. [2]

(ii) State what can be determined from the frequency of the convergence limit.

i. Magnesium chloride can be electrolysed. [5]

(i) Deduce the half-equations for the reactions at each electrode when **molten** magnesium chloride is electrolysed, showing the state symbols of the products. The melting points of magnesium and magnesium chloride are 922K and 987K respectively.

Anode (positive electrode):

. . . . . .

Cathode (negative electrode):

. . . . . .

(ii) Identify the type of reaction occurring at the cathode (negative electrode).

(iii) State the products when a very **dilute** aqueous solution of magnesium chloride is electrolysed.

Anode (positive electrode):

. . . . . .

Cathode (negative electrode):

. . . . . .

j. Standard electrode potentials are measured relative to the standard hydrogen electrode. Describe a standard hydrogen electrode. [2]

k. A magnesium half-cell, $Mg(s)/Mg^{2+}(aq)$, can be connected to a copper half-cell, $Cu(s)/Cu^{2+}(aq)$. [4]

(i) Formulate an equation for the spontaneous reaction that occurs when the circuit is completed.

(ii) Determine the standard cell potential, in V, for the cell. Refer to section 24 of the data booklet.

(iii) Predict, giving a reason, the change in cell potential when the concentration of copper ions increases.

Copper is a metal that has been used by humans for thousands of years.

a. State the full electron configuration of $^{65}\mathrm{Cu}$. [1]

b. State one difference in the physical properties of the isotopes $^{63}\mathrm{Cu}$ and $^{65}\mathrm{Cu}$ and explain why their chemical properties are the same. [2]

Physical:

Chemical:

c. Describe the bonding in solid copper. [2]

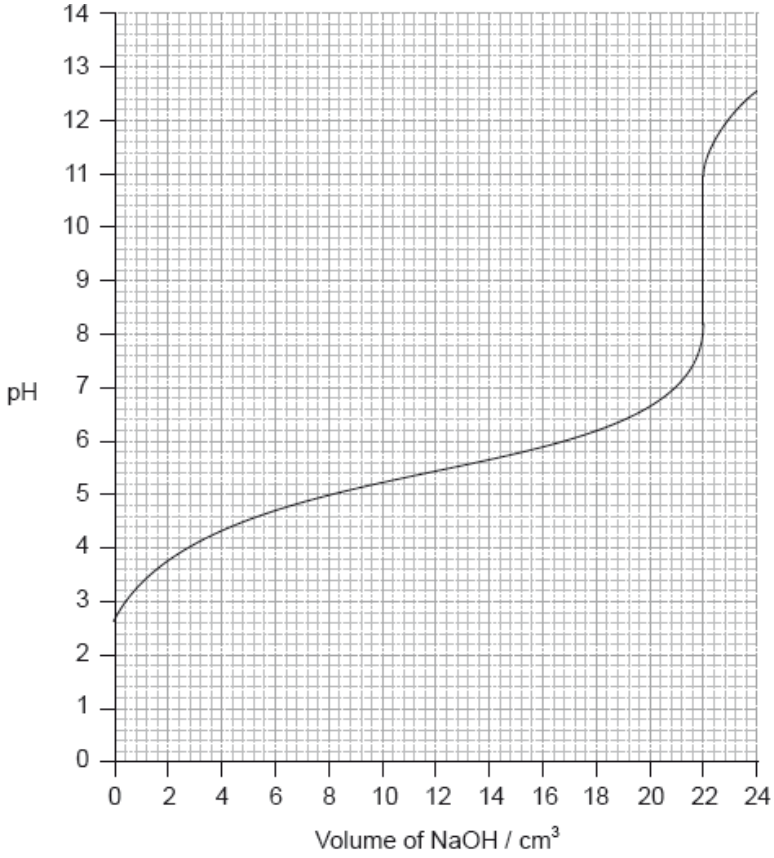
Acids can be described as strong or weak.

a. (i) Outline the difference in dissociation between strong and weak acids of the same concentration. [4]

(ii) Describe **three** tests that can be carried out in the laboratory, and the expected results, to distinguish between $0.10\ \mathrm{mol\,dm^{-3}}\ \mathrm{HCl(aq)}$ and $0.10\ \mathrm{mol\,dm^{-3}}\ \mathrm{CH_3COOH(aq)}$.

b. Calculate the pH, using table 15 of the data booklet, of a solution of ethanoic acid made by dissolving 1.40 g of the acid in distilled water to make a $500\ \mathrm{cm^3}$ solution. [4]

c.i. Determine the pH at the equivalence point of the titration and the $\mathrm{p}K_\mathrm{a}$ of an unknown acid using the acid-base titration curve below. [3]



c.ii. Identify, using table 16 of the data booklet, a suitable indicator to show the end-point of this titration. [1]

c.iii. Describe how an indicator, that is a weak acid, works. Use Le Chatelier's principle in your answer. [2]

d.i. State the formula of the conjugate base of chloroethanoic acid, $CH_2ClCOOH$. [1]

d.ii. Identify, with a reason, whether chloroethanoic acid is weaker or stronger than ethanoic acid using table 15 of the data booklet. [1]

d.iii. Determine the pH of the solution resulting when $100\ cm^3$ of $0.50\ mol\,dm^{-3}$ $CH_2ClCOOH$ is mixed with $200\ cm^3$ of $0.10\ mol\,dm^{-3}$ NaOH. [4]

e. Describe how chlorine's position in the periodic table is related to its electron arrangement. [2]

f. SCl_2 and $SClF_5$ are two sulfur chloride type compounds with sulfur having different oxidation states. Predict the name of the shape, the bond angle and polarity of these molecules. [[N/A

Analytical chemistry uses instruments to separate, identify, and quantify matter.

Menthol is an organic compound containing carbon, hydrogen and oxygen.

Nitric oxide reacts with chlorine.

$$2NO\ (g) + Cl_2\ (g) \rightarrow 2NOCl\ (g)$$

The following experimental data were obtained at 101.3 kPa and 263 K.

Experiment	Initial [NO] / mol dm^{-3}	Initial [Cl_2] / mol dm^{-3}	Initial rate / mol dm^{-3} min^{-1}
1	1.30×10^{-1}	1.30×10^{-1}	3.95×10^{-1}
2	1.30×10^{-1}	2.60×10^{-1}	7.90×10^{-1}
3	2.60×10^{-1}	2.60×10^{-1}	3.16

b. Outline how this spectrum is related to the energy levels in the hydrogen atom. [1]

c. A sample of magnesium has the following isotopic composition. [2]

Isotope	^{24}Mg	^{25}Mg	^{26}Mg
Relative abundance / %	78.6	10.1	11.3

Calculate the relative atomic mass of magnesium based on this data, giving your answer to **two** decimal places.

d.i. Complete combustion of 0.1595 g of menthol produces 0.4490 g of carbon dioxide and 0.1840 g of water. Determine the empirical formula of the compound showing your working. [3]

d.ii. 0.150 g sample of menthol, when vaporized, had a volume of 0.0337 dm^3 at 150 °C and 100.2 kPa. Calculate its molar mass showing your working. [2]

d.iii. Determine the molecular formula of menthol using your answers from parts (d)(i) and (ii). [1]

e.i. Deduce the order of reaction with respect to Cl_2 and NO. [2]

Cl_2:

. . . . . .

NO:

. . . . . .

e.ii. State the rate expression for the reaction. [1]

e.iii Calculate the value of the rate constant at 263 K. [1]

Tin(II) chloride is a white solid that is commonly used as a reducing agent.

a. (i) State why you would expect tin(II) chloride to have a similar lattice enthalpy to strontium chloride, using section 9 of the data booklet. [4]

(ii) Calculate the molar enthalpy change when strontium chloride is dissolved in water, using sections 18 and 20 of the data booklet.

(iii) Tin(II) chloride reacts with water to precipitate the insoluble basic chloride, Sn(OH)Cl.

$$SnCl_2(aq) + H_2O(l) \rightleftharpoons Sn(OH)Cl(s) + H^+(aq) + Cl^-(aq)$$

Suggest why tin(II) chloride is usually dissolved in dilute hydrochloric acid.

b. Tin can also exist in the +4 oxidation state. [3]

$$Sn^{4+}(aq) + 2e^- \rightleftharpoons Sn^{2+}(aq) \qquad E^\ominus = +0.15\,V$$

Vanadium can be reduced from an oxidation state of +4 to +3 according to the equation:

$$VO^{2+}(aq) + 2H^+(aq) + e^- \rightleftharpoons V^{3+}(aq) + H_2O(l) \qquad E^\ominus = +0.34\,V$$

(i) Calculate the cell potential, $E^\ominus$, and the standard free energy, $\Delta G^\ominus$, change for the reaction between the VO^{2+} and Sn^{2+} ions, using sections 1 and 2 of the data booklet.

$E^\ominus$:

$\Delta G^\ominus$:

(ii) Deduce, giving your reason, whether a reaction between $Sn^{2+}(aq)$ and $VO^{2+}(aq)$ would be spontaneous.

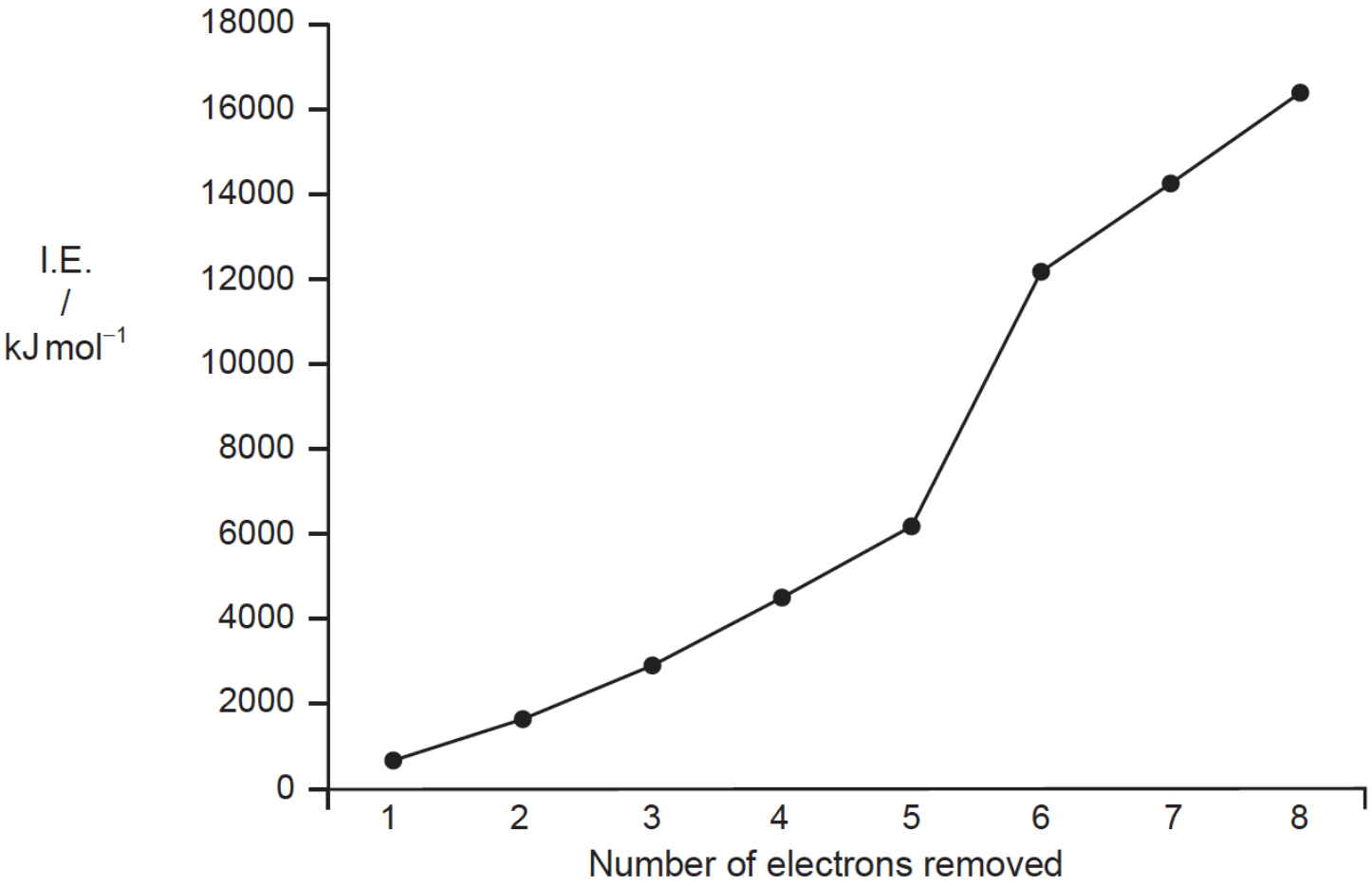
c. Outline, giving the **full** electron configuration of the vanadium atom, what is meant by the term transition metal. [2]

d. In an aqueous solution of vanadium(III) chloride, the vanadium exists as $[V(H_2O)_6]^{3+}$, $[VCl(H_2O)_5]^{2+}$ or $[VCl_2(H_2O)_4]^+$ depending on the concentration of chloride ions in the solution. [3]

(i) Describe how Cl^- and H_2O bond to the vanadium ion.

(ii) Outline what would happen to the wavelength at which the vanadium complex ions would absorb light as the water molecules are gradually replaced by chloride ions, using section 15 of the data booklet.

e. Eight successive ionisation energies of vanadium are shown in the graph below: [6]



(i) State the sub-levels from which each of the first four electrons are lost.

First: Second: Third: Fourth:

(ii) Outline why there is an increase in ionization energy from electron 3 to electron 5.

(iii) Explain why there is a large increase in the ionization energy between electrons 5 and 6.

(iv) Vanadium is comprised almost entirely of ^{51}V. State the number of neutrons an atom of ^{51}V has in its nucleus.