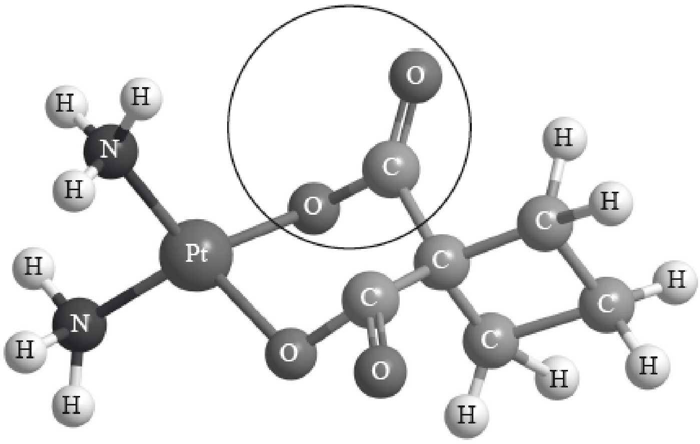
HL Paper 2

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

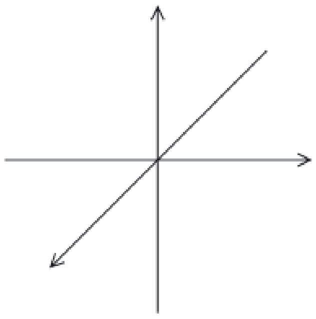


Elemental platinum has electrons occupying s, p, d and f atomic orbitals.

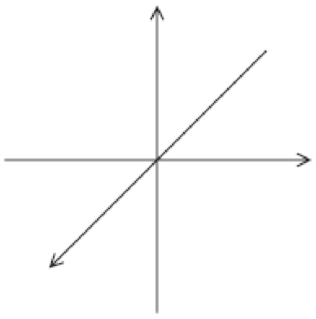
a. Identify the name of the functional group circled in the structure of carboplatin. [1]

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



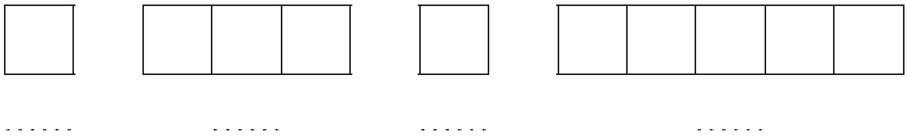
p_x orbital

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.



Markscheme

a. ester;

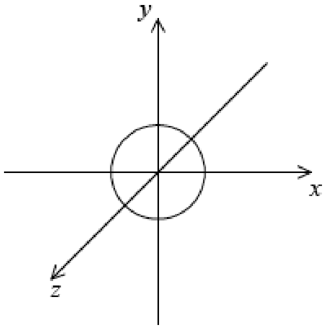
Do not accept just carbonyl.

Allow carboxylato (ligand)/carboxylate (ligand) but not carboxyl/carboxy.

b. dative (covalent) / coordinate;

Do not allow just covalent or co-dative.

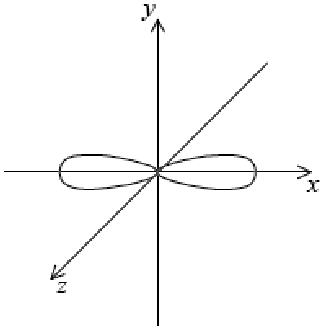
c.i.



symmetrical s orbital representation;

Do not penalize if axes are not labelled for s orbital.

x, y, z can be located in any direction.



dumbbell-shaped p_x orbital representation with electron density located along *x*-axis;

x-axis must be labelled for p_x orbital.

Do not accept if p_y and p_z are also drawn as question asks for orbital not sub-level.

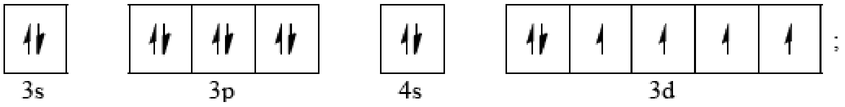
c.ii. 16;

d. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 4d^6$;

Order of 4s and 3d levels can be interchanged.

Do not accept other notation such as subscripts.

e.



Allow full arrows instead of half-arrows in orbital diagram.

Sub-levels must be labelled for mark.

Examiners report

a. Many candidates identified the functional group but not the type of bond between Pt and N in carboplatin. A surprising number of candidates were unable to draw a p_x orbital or drew all *p* orbitals, or did not label the axis

b. [N/A]
c.i. [N/A]
c.ii. Very few gave 16 as the answer.

d. [N/A]
e. [N/A]

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

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

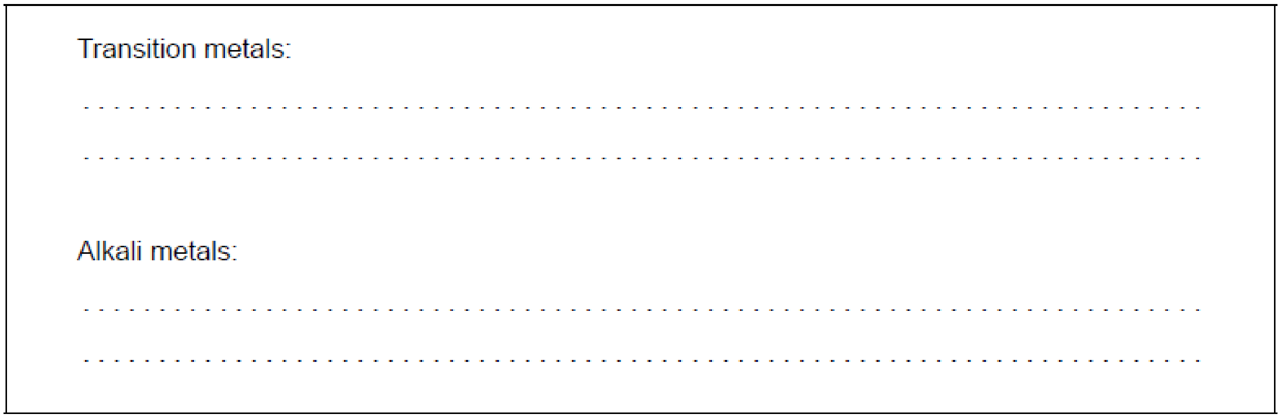
Calculate the ionization energy, in J, for a single atom of hydrogen using sections 1 and 2 of the data booklet.

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:

. . . .

. . . .

Markscheme

a.iii. IE «$= \Delta E = h\nu = 6.63 \times 10^{-34}\ J\ s \times 3.28 \times 10^{15}\ s^{-1}$» $= 2.17 \times 10^{-18}$ «J»

[1 mark]

a.iv. «$\lambda = \frac{c}{v} = \frac{3.00\times10^{8}\ ms^{-1}}{3.28\times10^{15}\ s^{-1}} =$» 9.15×10^{-8} «m»

[1 mark]

c.iv. no change «in colour»

*Do **not** accept “solution around cathode will become paler and solution around the anode will become darker”.*

[1 mark]

c.v. oxygen/O_2

Accept "carbon dioxide/CO2".

[1 mark]

d. *Transition metals:*

«contain» d and s orbitals «which are close in energy»

OR

«successive» ionization energies increase gradually

Alkali metals:

second electron removed from «much» lower energy level

OR

removal of second electron requires large increase in ionization energy

[2 marks]

Examiners report

a.iii. [N/A]
a.iv. [N/A]
c.iv. [N/A]
c.v. [N/A]
d. [N/A]

The element antimony, Sb, is usually found in nature as its sulfide ore, stibnite, $\mathrm{Sb_2S_3}$. 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, $^{121}\mathrm{Sb}$ and $^{123}\mathrm{Sb}$. 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 $^{121}\mathrm{Sb}$. [1]

Markscheme

a.i. $\mathrm{M_r\ for\ Sb_2S_3} = (2 \times 121.75) + (3 \times 32.06) = 339.68$;

% of Sb in $\mathrm{Sb_2S_3} = \frac{(2\times121.75)}{339.68} \times 100 = 71.69\%$;

Accept 71.68%.

Award ***[2]*** *for correct final answer.*

c.i. the (vaporized) ions are deflected by the (external) magnetic field;

the $^{121}\mathrm{Sb}$ /lighter ions are deflected more than the $^{123}\mathrm{Sb}$ /heavier ions / *OWTTE*;

Allow deflection depends on mass to charge ratio or momentum of ions.

the ions are detected by conversion into an electrical current / *OWTTE*;

the ratio of the intensity of the peaks in the spectrum is equal to the ratio of the ions in the sample / the ratio of the height of the peaks due to $^{121}\mathrm{Sb}$ and $^{123}\mathrm{Sb}$ will be 62.5:37.5 / *OWTTE*;

If atoms/elements used instead of ions, penalize only once.

Allow the use of sample or isotopes instead of ions.

c.iii70;

Examiners report

a.i. In (a) (i) most candidates calculated the molecular mass but many lost a mark as they forget to multiply by 2 when calculating the mass of antimony. A small number of candidates also lost the second mark as they failed to report the answer to four significant figures as directed by the question. Most candidates were able to deduce the oxidation state of antimony but many lost a mark as they used an incorrect format such as 3, or $3+$. It was expected that candidates would be able to deduce the other oxidation states from the position of the element in the periodic table but most candidates incorrectly gave $+2$ as an answer.

c.i. Most candidates were aware of some environmental concerns due to the production of pollutant gases but some incorrectly identified both carbon dioxide and sulfur dioxide as greenhouse gases. Most candidates were able to calculate the relative abundance of the two isotopes and the use of a magnetic field to deflect ions in a mass spectrometer was generally understood, although a significant number of responses were penalised as they referred to *atoms* rather than *ions*. Few students were able, however, to describe the deflection stage in sufficient detail.

c.iiiMost candidates were able to deduce the number of neutrons in $^{121}\mathrm{Sb}$.

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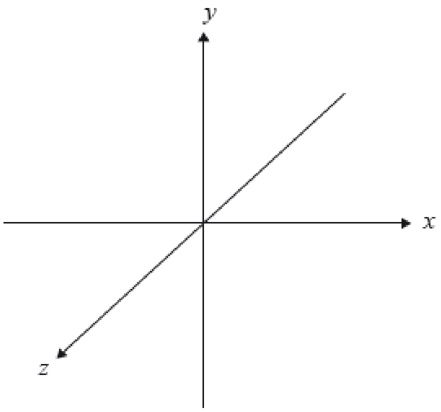
a.i. Draw the shape of the $\mathrm{p_z}$ orbital using the coordinates shown. [1]



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

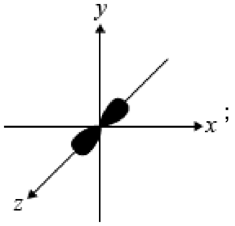
a.iiiDefine the term *ligand.* [1]

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

Markscheme

a.i. dumbbell-shaped representation along the z-axis:



;

Sign of wave function not required.

a.ii. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^5 / 1s^2 2s^2 2p^6 3s^2 3p^6 4s^0 3d^5 / [Ar] 4s^0 3d^5 / [Ar] 3d^5$;

Do not allow 2, 8, 13.

a.iii. Lewis base / (species/ion/molecule) with lone pair **and** dative covalent/coordinate bond (to metal) / bonds with metal (ion)/complex ion;

a.iv. has partially filled d subshell/sublevel/orbitals;

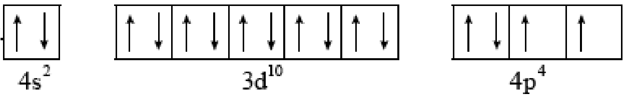
d orbitals are split (into two sets of different energies);

colour due to electron transition between (split) d orbitals;

frequencies of visible light absorbed by electrons moving from lower to higher d levels, colour due to remaining frequencies;

Allow wavelength as well as frequency.

a.v.



;

Accept half-arrows or full arrows.

Do not penalize if additional sublevels are shown, if sublevels are not labelled or if no boxes are drawn (providing system of arrows correct).

Do not award mark if sublevels are incorrectly labelled.

Orbital diagram may also be represented with sublevels shown at different relative energy positions.

Examiners report

a.i. Most candidates were able to draw the dumbbell shaped p_z orbital, although some candidates drew all three p-orbitals, hence failing to read the question carefully.

a.ii. For (ii) the electron configuration of Fe^{3+} was well answered compared to recent sessions. The very weak candidates wrote incorrect answers such $[Ar] 4s^2 3d^2$ and some very weak candidates just gave the electron arrangement 2, 8, 13, which would be a typical SL type answer.

a.iii. The definition of a ligand was poorly answered (iii) by even the strongest candidates. In general candidates showed some understanding but good definitions were rare. Very often candidates did not mention dative covalent bonding and some said that ligands are simply just lone pairs of electrons.

a.iv. In part (iv) most candidates referred to the splitting of d orbitals and related colour to d to d transitions. A very high number of candidates scored at least two points. Often candidates did not mention partially filled d subshells or did not score the point: frequencies of visible light absorbed by electrons moving from lower to higher d levels, colour due to remaining frequencies.

a.v. The orbital diagram of selenium (v) was very well answered by most candidates. The only minor mistake for the weaker candidates involved lack of understanding of Hund’s Rule for $4p^4$.

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, ICl_3 can form. Deduce the Lewis (electron dot) structure of ICl_3 and ICl_2^- and state the name of the shape of each species. [4]

	ICl_3	**ICl_2^-**
Lewis structure		
Name of shape		

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

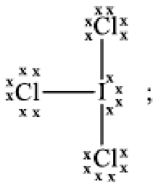
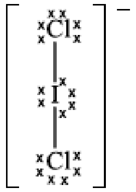
f.iii. One important use of chlorine is in the synthesis of poly(chloroethene), PVC. Identify the monomer used to make PVC and state **one** of the uses of PVC. [2]

Monomer:

Use:

Markscheme

e.

	ICl_3	ICl_2^-
Lewis (electron dot) structure	 ;	 ;
	Do not penalize for an incorrect shape for Lewis structures. *Accept lines, dots or crosses for electron pairs for both Lewis structures.* *Penalize missing lone pairs on Cl once only.* *Square brackets and negative charge must be shown for Lewis structure of $[ICl_2]^-$.*	
Name of shape	T-shaped;	linear;

No ECF for shape if Lewis structure is incorrect.

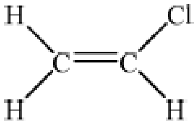
f.i. $1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^{10} 4p^6 5s^2 4d^{10} 5p^5 / 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^2 4p^6 4d^{10} 5s^2 5p^5$;

No mark for 2,8,18,18,7 or [Kr] $5s^2 4d^{10} 5p^5$.

Allow electron configurations with order of sublevels interchanged.

Electrons must be represented as superscript to award mark.

f.iii *Monomer*:

 / chloroethene /CH_2CHCl;

Accept vinyl chloride or chloroethylene.

Allow C_2H_3Cl.

Use:

raincoats / packaging / window frames / pipes / carpets / gutters / electrical cable sheathing / covers for electrical wires / rope / bottles;

Accept suitable alternatives.

Do not allow glue.

Do not allow just plastic(s) or just windows.

Allow plastic bag.

Examiners report

e. Part (e) was by far one of the most disappointing questions on the entire paper with only the top-end candidates scoring all four marks. Many mistakes were seen, such as the usual mistakes of omitting lone pairs on terminal atoms and not including square brackets and the negative charge for the Lewis structure of the anion. The biggest problem however for candidates was failing to realise that for Lewis structures based on five negative charge centres or five electron domains, the lone pairs are inserted in the equatorial position and not the axial position, resulting in a

T-shaped molecular geometry for ICl_3 and a linear shape for ICl_2^-. Candidates may benefit in class from a careful discussion of the various angles resulting from LP-LP, LP-BP and BP-BP repulsions for such structures emanating from five electron domains. As a result of poor comprehension of this aspect of VSEPR Theory, a common incorrect molecular geometry of trigonal planar was often cited for the molecular geometry forICl_3.

f.i. In part (f), the better candidates gave the correct full electron configuration for iodine. Surprisingly some of the weaker candidates gave electron arrangements which scored no marks and a few candidates gave rather sloppy configurations, either putting subscripts instead of superscripts or not putting the number of electrons as superscripts, which was rather disconcerting to see at HL.

f.iii.In part (iii), a large number of candidates stated chloroethane instead of chloroethene for the monomer. Plastic was often given as a use of PVC. This however was not allowed for M2 and a more precise answer was required.

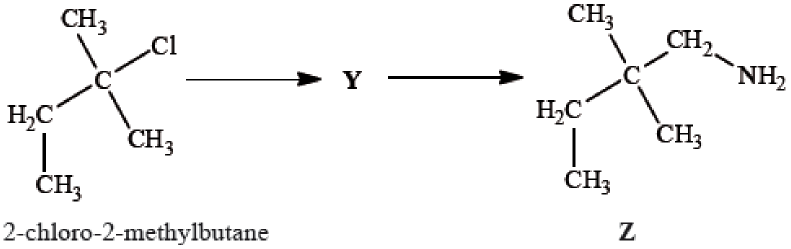
2-methylbutan-2-ol, $(CH_3)_2C(OH)CH_2CH_3$, is a liquid with a smell of camphor that was formerly used as a sedative. One way of producing it starts with 2-methylbut-2-ene.

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 $106\ g\,mol^{-1}$ and some with a molar mass of approximately $108\ g\,mol^{-1}$.

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



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.iiiOptical activity can be detected using a polarimeter. Explain how this works. [3]

c.ivDeduce 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**:

Markscheme

a. water/H_2O;

Accept steam.

(concentrated) sulfuric acid/H_2SO_4 (catalyst);

Accept phosphoric acid/H_3PO_4.

*Award **[2]** for HBr and NaOH (two-stage process via the halogenoalkane).*

b. not react;

tertiary alcohol (not easily oxidized);

c.i. rotates the plane (of polarization) of plane polarized light;

*Accept answers in which **one** of the "plane"s is missing.*

c.ii. two isomers that are enantiomers/chiral/non-superimposable mirror images;

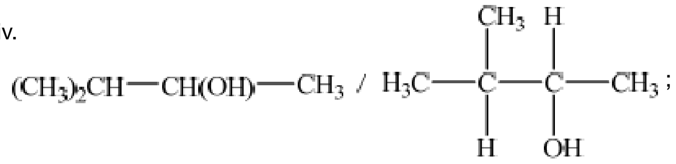
Accept "contains an asymmetric/chiral carbon" or "contains a carbon bonded to four <u>different</u> groups".

c.iii. polarizes light / polarized light source;

light passed through sample;

analyser / second polarizer detects whether plane of polarization rotated;

c.iv.



$(CH_3)_2CH—CH(OH)—CH_3$ / $H_3C—C(CH_3)(H)—C(H)(OH)—CH_3$;

Accept C_3H_7–CH(OH)–CH_3, but not CH_3–CH_2–CH_2–CH(OH)–CH_3.

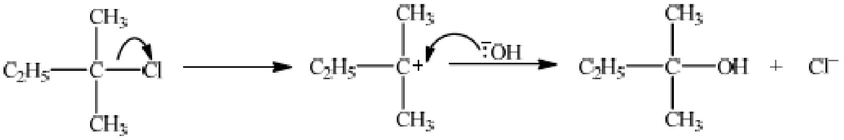
d. 2-methylbutan-2-ol has hydroxyl/OH group;

Do not accept "hydroxide group".

Allow 2-methylbutan-2-ol is an alcohol.

2-methylbutan-2-ol can form <u>H-bonds</u> (to water) / 2-methylbut-2-ene cannot form <u>H-bonds</u> (to water);

e.i.



curly arrow showing Cl^- leaving;

representation of tertiary carbocation;

curly arrow going from lone pair/negative charge on O in HO^- to C^+;

Do not allow arrow originating on H in HO⁻.

formation of organic product $CH_3CH_2C(CH_3)_2OH$ **and** Cl^-/NaCl

(somewhere in mechanism);

*Award **[3 max]** if a candidate gives a fully correct S_N2 mechanism.*

e.ii. $\text{rate} = k\times$ [2-chloro-2-methylbutane]/$[CH_3CH_2C(CH_3)_2Cl]$/[halogenoalkane]

/[R–Cl];

s^{-1};

e.iii. hydroxide ion/OH^- is a better nucleophile than water / hydroxide ion/OH^- has negative charge;

undergo S_N2 hydrolysis / RDS depends on attack of OH^-/hydroxide ion (nucleophile);

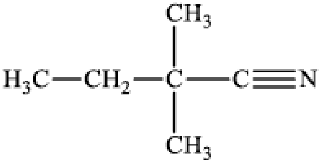
Accept other suggestions that are chemically valid.

f.i. chlorine can be ^{35}Cl/Cl–35 or ^{37}Cl/Cl–37;

Accept "chlorine can exist as two isotopes".

Answer must refer to chlorine rather than isotopes in general.

g.i.



;

Do not accept condensed formulas such as $CH_3CH_2C(CH_3)_2CN$.

Accept the cyanide group as –CN without showing the triple bond.

g.ii. *Formation of Y:*

cyanide ion/CN^- / potassium cyanide/KCN;

Accept hydrogen cyanide/HCN.

Conversion of Y into Z:

hydrogen/H_2;

nickel/Ni / platinum/Pt / palladium/Pd (catalyst);

Examiners report

a. Many students could recall the reagents for the hydration of an alkene and recognize the alcohol as a tertiary alcohol that would not undergo oxidation. Statements regarding optical activity often lacked precision and betrayed confusion with chirality. Very few could correctly describe how a polarimeter worked, especially the second rotating sheet of polaroid, and students frequently drew the structure of 2-methylbutan-2-ol rather than its chiral isomer. Most students stated that the alcohol was more polar than the alkene, but fewer mentioned that it could form hydrogen bonds to water and even less linked this to the presence of the hydroxyl group. Almost all students recognized that the hydrolysis was S_N1, with an encouraging number being able to write reasonable mechanisms, though many still lost marks through a lack of precision in where their curly arrows started and ended. Many candidates also stated an appropriate rate equation along with the units of the rate constant. Very few students linked the difference of two molar mass units to the presence in the molecule of chlorine, with its naturally occurring isotopes, and the discussion of any effect on the hydrolysis rate often revealed a lack of clear thinking. In contrast many students correctly identified the nitrile as the intermediate in the chain extension reaction and reagents for its formation and hydrogenation were generally well known.

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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 $[\mathrm{Fe(CN)_6}]^{3-}$** 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]

Markscheme

a.i. reactivity decreases down group;

as atomic radius increases / more electron shells;

attraction of nucleus on electrons decreases / electron affinity decreases;

Accept opposite argument for "up the group".

a.ii. no reaction with NaCl;

$\mathrm{Br_2(aq) + 2NaI(aq) \rightarrow 2NaBr(aq) + I_2(aq)}$;

Accept ionic equation.

Ignore state symbols.

b.i. (electrostatic attraction between a) lattice of positive ions/cations **and** delocalized/sea of electrons;

Accept suitable diagram.

atoms/ions/layers (of positive ions) can slide over each other / *OWTTE*;

without change in the bonding forces / *OWTTE*;

b.ii. variable oxidation numbers/valency

form complex (ions)

form coloured compounds/ions

catalytic (behaviour)

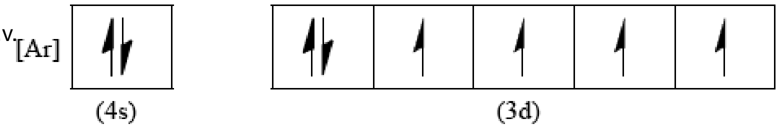
*Award **[2]** for any three, **[1]** for any two.*

b.iii. dative (covalent)/coordinate;

b.iv. III / $+3$;

Penalize incorrect format such as 3+ only if not penalized in 4 (b).

b.v.



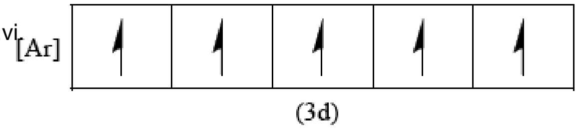
Penalise missing [Ar] only once in (v) and (vi).

Do not accept full orbital diagram; penalise only once in (v) and (vi).

Accept full or half-arrows in (v) and (vi).

Ignore absence of labels 4s and 3d.

b.vi.

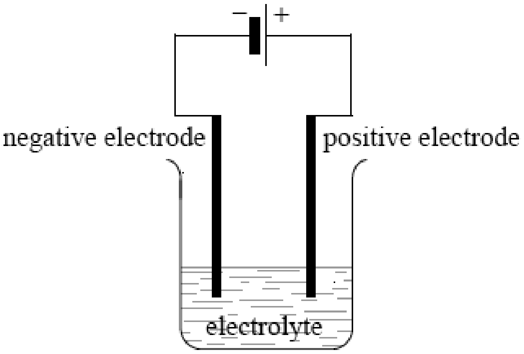


;

Accept empty 4s box in (vi).

No ECF from (iv).

c.i.



clear diagram containing all elements (power supply, connecting wires,

electrodes, container and electrolyte);

Accept power supply if shown as conventional long/short lines (as in diagram above) or clearly labelled DC power supply.

labelled positive electrode/anode **and** negative electrode/cathode;

Accept positive and negative by correct symbols near power supply.

labelled electrolyte/$FeBr_2(l)$/$FeBr_2(aq)$;

State must be included for $FeBr_2$.

c.ii. *Electrolyte:* positive ions/cations move to negative electrode/cathode **and** negative ions/anions to positive electrode/anode;

Conductors: electrons flow from negative pole of battery to positive pole of battery / *OWTTE*;

Look at diagram in (i) for possible clarification of electron flow.

*Award **[1 max]** for “electrons in wire/external circuit **and** ions in solution”.*

c.iii. *Negative electrode/cathode*:

H_2;

$E^\ominus(H_2)$ is less negative than $E^\ominus(Fe)$ / Fe is more reactive than H_2 / H_2 is lower in reactivity series / H^+ more easily reduced than Fe2+ / *OWTTE*;

Positive electrode/anode:

O_2;

$E^\ominus(O_2)$ is less positive than $E^\ominus(Br_2)$ / in a dilute Br^- solution OH^-/H_2O is

preferably discharged / *OWTTE*;

*Award **[3 max]** if electrodes reversed or omitted.*

c.iv. $\mathrm{Br_2}$;

Accept Fe.

c.v. $\mathrm{2Br^- \rightleftharpoons Br_2 + 2e^-}$ shifts to the right;

Accept similar reason for Fe.

Examiners report

a.i. This was the least popular of the Section B questions. In (a) (i) the trend was generally correctly identified but the reasons were not clear, many confusing *electronegativity* with *electron affinity*. Most knew about the reactions (or lack thereof) of bromine but the equations were sometimes unbalanced or included halogen atoms rather than molecules.

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b.i. There was a tendency to describe the bonding of metals in terms of nuclei rather than cations and malleability was not well understood.

b.ii. The properties in (b) (ii) were surprisingly poor. Many suggested that the metals themselves are coloured rather than the compounds, for instance.

b.iii. The bonding in (iii) was not well known but the oxidation number was generally answered correctly.

b.iv. [N/A]

b.v. In (v), some candidates gave the *full* orbital diagram, some omitted [Ar] – and some just got it wrong!

b.vi. [N/A]

c.i. The diagrams in (c) were poorly presented and often inaccurate (much confusion with a voltaic cell) and there was little understanding of how current was transmitted.

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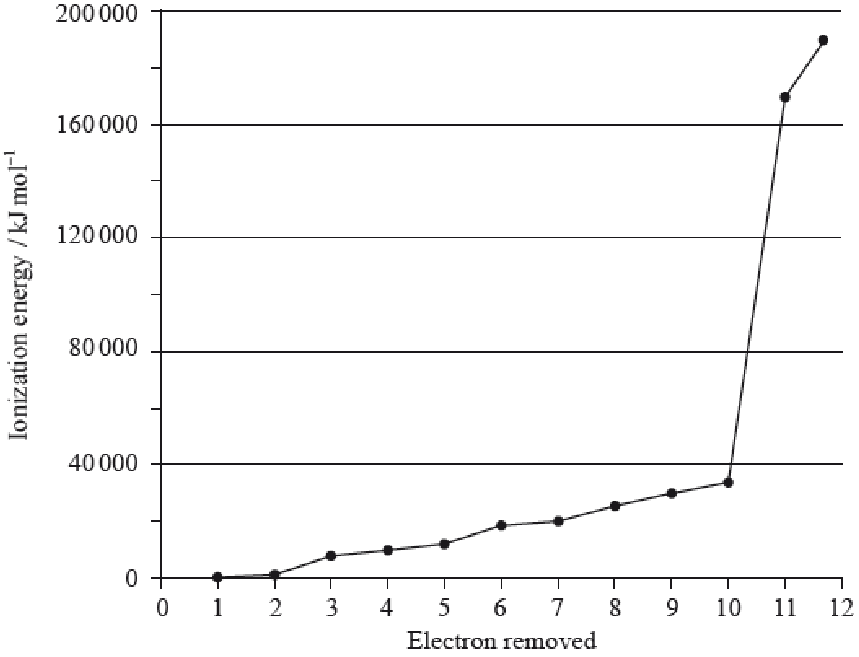
c.iii. In (iii), few candidates correctly predicted the products of electrolysis of dilute iron bromide, with many seeming to ignore the presence of hydrogen ions/hydroxide ions/water; correct explanations in terms of electrode potentials or preferential discharge were rare.

c.iv. In (iii), few candidates correctly predicted the products of electrolysis of dilute iron bromide, with many seeming to ignore the presence of hydrogen ions/hydroxide ions/water; correct explanations in terms of electrode potentials or preferential discharge were rare. Despite this, bromine was often correctly identified in (iv).

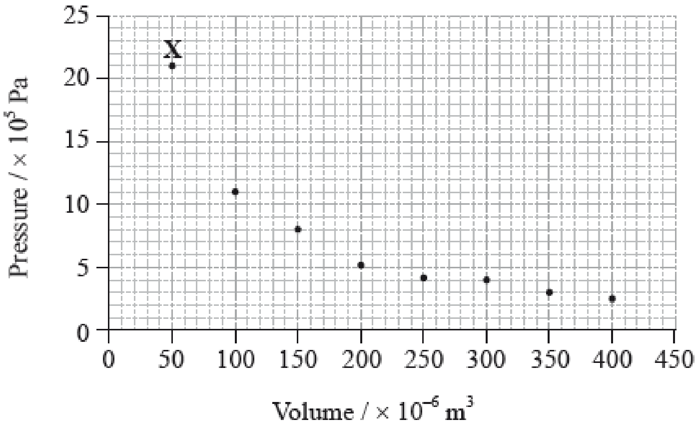
c.v. In (v), few understood the impact of concentrating the electrolyte.

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.

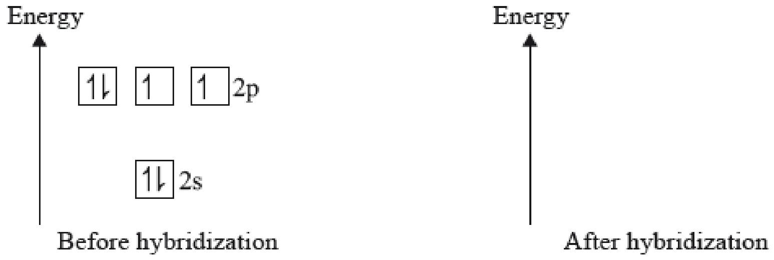
c. (i) Magnesium reacts with oxygen to form an ionic compound, magnesium oxide. Describe how the ions are formed, and the structure and bonding in magnesium oxide. [4]

(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.

Markscheme

a. (i) $\left(\frac{(77.44\times24)+(10.00\times25)+(12.56\times26)}{100}\right)$;

24.35;

*Award **[2]** for correct final answer.*

Two decimal places are required for M2.

Do not award any marks for 24.31 without showing method (as the value can be copied from the Data Booklet).

(ii) same atomic radii / 160 pm;

isotopes only differ by number of neutrons/size of nucleus / radius determined by electron shells and number of protons / *OWTTE*;

Accept neutrons do not affect distance of electrons / OWTTE.

b. (i) decreasing repulsion between electrons / radius decreases as electrons are removed;

Accept increasing positive charge on ion attracts electrons more strongly.

(ii) 10th electron is in second energy level/shell while 11th electron is in first energy level/shell / 10th is removing electron from electronic arrangement 2,1 while 11th ionization energy is removing electron from electronic arrangement 2;

11th electron removed is much closer to the nucleus / 11th electron removed from a (much) lower energy level/shell;

Accept opposite statement for 10th electron.

c. (i) magnesium (atom) gives two electrons to oxygen (atom) / oxygen (atom) takes two electrons from magnesium (atom) / magnesium (atom)

loses two electrons **and** oxygen (atom) gains two electrons;

3-dimensional/3-D arrangement of ions / lattice of ions;

(electrostatic) attraction between oppositely charged ions/Mg^{2+} and O^{2-};

(ii) electrostatic attraction between a pair of electrons and (positively charged) nuclei;

Accept a/two pairs of shared electrons.

(iii) difference in electronegativity is larger between Mg and O/smaller between C and O;

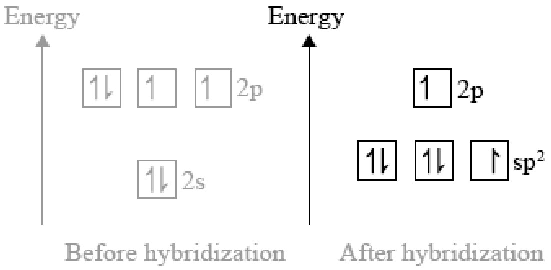
Accept reference to a numerical value of difference in electronegativity such as above and below 1.80.

d. (i) C: sp hybridization;

O: sp^2 hybridization;

*Award **[1]** if the answer is sp without specifying C or O atoms.*

(ii)



three sp^2 orbitals **and** one p-orbital at higher energy;

sp^2 orbitals contain: two, two and one electron **and** p-orbital contains one electron;

Do not allow ECF from (d)(i).

(iii) ability of atom/nucleus to attract bonding/shared pair of electrons / attraction of nucleus for bonding/shared pair of electrons / *OWTTE*;

(iv) (same number of shells but) increase in nuclear charge/atomic number/number of protons increases electronegativity / O has more protons than C;

Accept oxygen has a higher effective nuclear charge.

decrease in radius along the period increases electronegativity / O has smaller radius than C;

e. (i) smooth curve through the data;

*Do not accept a curve that passes through **all** of the points or an answer that joins the points using lines.*

(ii) $p = 21 \times 10^5 / 2.1 \times 10^6\ (\mathrm{Pa}) / 2.1 \times 10^3\ (\mathrm{kPa})$ **and**

$V = 50 \times 10^{-6} / 5.0 \times 10^{-5}\ (\mathrm{m}^3) / 5.0 \times 10^{-2}\ (\mathrm{dm}^3)$;

$\left(n = \frac{pV}{RT}\right) \frac{2.1\times10^{6}\times5.0\times10^{-5}}{8.31\times330}$;

$n = 0.038$ (mol);

*Award **[3]** for correct final answer.*

For M3 apply ECF for correct computation of the equation the student has written, unless more than one mistake is made prior this point.

f. (i) equilibrium between HIn and In^-/$HIn \rightleftharpoons In^- + H^+$;

the colours of HIn and In^- are different;

if added to acid, the equilibrium shifts to the left and the colour of HIn is seen / *OWTTE*;

if added to base/alkali, the equilibrium shifts to the right and the colour of In^- is seen / *OWTTE*;

(ii) phenolphthalein;

Accept phenol red.

Examiners report

a. (i) Most candidates were able to calculate the relative atomic mass to the correct number of decimal places.

(ii) Only strong candidates were able to predict the same radius for the isotopes and gave correct reasoning. However, the majority of candidates predicted that a larger number of neutrons resulted is a smaller radius, reflecting a poor understanding of atomic structure.

b. (i) Very few candidates were able to explain the increase in successive ionization energies for electrons removed from the same sub-shell. Many candidates gave incorrect reasoning.

(ii) The increase between the 10th and 11th ionization energies of magnesium was explained correctly by about half of the candidates. Few candidates scored the first mark by identifying the correct shells or sub-shells the electrons are removed from.

c. (i) Well answered by many candidates. A few candidates were confusing ionic with covalent bonding, and some referred to a linear MgO molecule in an ionic lattice.

(ii) Few candidates were able to describe the covalent bond precisely. Those who didn’t score usually didn’t make any reference to pairs of electrons.

(iii) Many candidates obtained this mark with satisfactory arguments. It was disappointing to see the abundance of answers based on “is a metal with a non-metal” or “both are non-metals”.

d. (i) A few candidates identified sp hybridization based on a linear structure. Only the strongest candidates were able to give the correct hybridization for oxygen as well.

(ii) This was the most challenging question on the paper. It was rare to see a correct answer. It seems candidates did not have a good understanding of hybridization.

(iii) Less than half the candidates were able to define electronegativity precisely. Many candidates did not relate it to the pair of electrons in a covalent bond, and simply talked about attracting electrons, which was not sufficient for the mark.

(iv) Many candidates gained the first mark by stating that oxygen has more protons than carbon. But very few candidates identified the second factor, which is the smaller radius of oxygen.

e. (i) More than half of the candidates drew a smooth curve that was central to the data points. Errors included straight lines, curves joining all data points, or a curve that was not central to the points.

(ii) A very well answered question. Some candidates converted the units of *p* and *V* incorrectly and others did not read the scales of the graph correctly.

f. (i) Many candidates could explain the behaviour of indicators, but there were also some poor answers that did not acknowledge the importance of equilibrium in the action of an indicator.

(ii) Most candidates suggested a suitable indicator.

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.

$$\begin{aligned}&\text{Step 1: Cu(s)} + \text{2HNO}_3\text{(aq)} + \text{2H}^+\text{(aq)} \rightarrow \text{Cu}^{2+}\text{(aq)} + \text{2NO}_2\text{(g)} + \text{2H}_2\text{O(l)}\\&\text{Step 2: 4I}^-\text{(aq)} + \text{2Cu}^{2+}\text{(aq)} \rightarrow \text{2CuI(s)} + \text{I}_2\text{(aq)}\\&\text{Step 3: I}_2\text{(aq)} + \text{2S}_2\text{O}_3^{2-}\text{(aq)} \rightarrow \text{2I}^-\text{(aq)} + \text{S}_4\text{O}_6^{2-}\text{(aq)}\end{aligned}$$

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

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

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

Markscheme

c.i. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^9$;

Do not allow [Ar]3d⁹.

c.ii. d orbitals are split;

(3d) electrons move between orbitals **and** absorb light/energy / complementary colour is transmitted when energy absorbed by d electrons moving / unpaired d electrons move between the different orbitals;

Accept levels instead of orbitals.

Examiners report

c.i. Several errors were seen in the electron configuration, the commonest of which was to give that of elemental copper.

c.ii. Few attempts at the explanation of colour referred to the splitting of the d orbitals and electron transitions, and in several instances candidates referred to emission instead of absorption. This proved to be the most difficult part of question 1.

The electron configuration of chromium can be expressed as $[\text{Ar}]4\text{s}^\text{x}3\text{d}^\text{y}$.

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

$$2\text{H}_2\text{(g)} + 2\text{NO(g)} \rightleftharpoons \text{N}_2\text{(g)} + 2\text{H}_2\text{O(g)}$$

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

$$\text{rate} = k[\text{H}_2\text{(g)}][\text{NO(g)}]^2$$

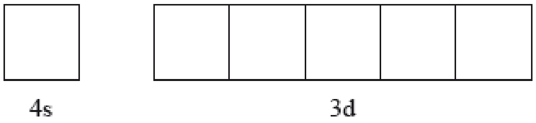
When concentrated hydrochloric acid is added to a solution containing hydrated copper(II) ions, the colour of the solution changes from light blue to green. The equation for the reaction is:

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

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 $[Cu(H_2O)_6]^{2+}$ ion is coloured and why the $[CuCl_4]^{2-}$ 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]

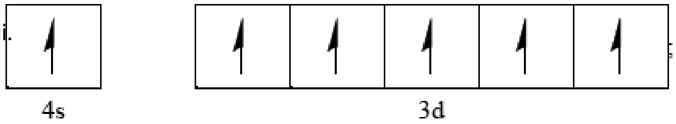
State what the term *spontaneous* means when used in a chemistry context.

Markscheme

a.i. the electron configuration (of argon) / $1s^22s^22p^63s^23p^6$;

a.ii. $x = 1$ **and** $y = 5$;

a.iii.



Accept all six arrows pointing down rather than up.

b.i. the concentration (of nitrogen(II) oxide);

*Award **[0]** if reference made to equilibrium.*

b.ii. $mol^{-2}dm^6s^{-1} / dm^6mol^{-2}s^{-1}$;

Accept $(mol^{-1} dm^3)2s^{-1}$.

c.i. complex (ion) / the charge is delocalized over all that is contained in the brackets;

c.ii. colour is due to energy being absorbed when electrons are promoted within the split d orbitals;

the colour observed is the complementary colour to the energy absorbed / *OWTTE*;

Accept either answer for first mark.

changing the ligand / coordination number / geometry changes the amount the d orbitals are split/energy difference between the d orbitals / *OWTTE*;

d. the reaction gives out (Gibbs Free) energy that can do work;

ΔG for the reaction has a negative value;

a reaction that occurs without adding energy (beyond that required to overcome energy barrier);

Examiners report

a.i. Most candidates were familiar with the use of square brackets to represent noble gas electron configurations and concentrations in rate expressions and it was encouraging to see candidates give a correct orbital diagram with the d electrons unpaired.

a.ii. A significant number of students were unaware of the exceptional nature of the electron configuration for chromium.

a.iii. A significant number of students were unaware of the exceptional nature of the electron configuration for chromium, but were able to gain the mark in (a) (iii) with ecf.

b.i. The understanding of the use of square bracket to represent complex ions was limited.

b.ii. Many candidates omitted the s^{-1} in the units for the rate constant.

c.i. [N/A]

c.ii. (c) (ii) proved to be more challenging with many candidates mixing up sub-shells with orbitals and absorption with emission spectra.

d. Many candidates were familiar with the use of the term *spontaneous* when used in a chemical 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]

Markscheme

a.i. *Group*: number of valence/outer energy level electrons same;

Period: electrons are in same valence/outer energy level;

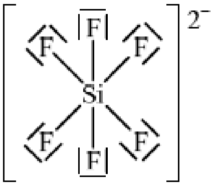
Accept number of energy levels containing electrons occupied.

Accept shell for energy level.

a.ii. 4;

Allow the mark if the correct individual orbitals (e.g. 2s etc.) are listed.

b.i.



;

octahedral/octahedron/square bipyramidal;

90° / 90° **and** 180°;

b.ii.

;

linear;

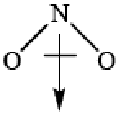
180°;

Allow dots, crosses or lines in Lewis structures.

Penalize missing charge, missing bracket once only in (i) and (ii).

Lone pairs required for BOTH (i) and (ii).

d. NO_2:



*Award **[1]** for correct representation of the bent shape **and [1]** for showing the net dipole moment, or explaining it in words (unsymmetrical distribution of charge).*

CO_2:

CO_2 :

*Award **[1]** for correct representation of the linear shape **and** for showing the two equal but opposite dipoles or explaining it in words (symmetrical distribution of charge).*

For both species, allow either arrow or arrow with bar for representation of dipole moment.

Allow correct partial charges instead of the representation of the vector dipole moment.

Ignore incorrect bonds.

Lone pairs not needed.

f.ii. mixing/joining together/combining/merging of atomic orbitals to form molecular /new orbitals / orbitals of equal energy;

f.iii. $sigma$ *bond*:

end-on/axial overlap with electron density between the two atoms/nuclei;

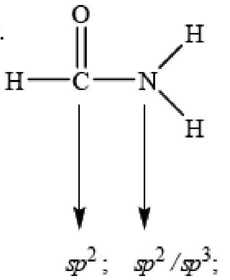
π *bond*:

sideways/parallel overlap with electron density above **and** below internuclear axis/$sigma$ bond;

Marks can be scored from a suitable diagram.

*Award **[1 max]** for stating end-on/axial overlap for $sigma$ and sideways/parallel overlap for π only i.e. without mentioning electron density OR stating electron density between the two atoms/nuclei for $sigma$ above and below internuclear axis/$sigma$ bond for π i.e. without mentioning overlap.*

f.iv.



Correct answer is actually sp^2 for nitrogen because of delocalization/planar geometry.

Accept sp^3.

Examiners report

a.i. Part (a) was very poorly answered which was surprising at HL. Most candidates described groups correctly but only a small majority stated that for a period the electrons are in the same valence level.

a.ii.Part (ii) was well answered.

b.i. For (b) VSEPR theory in general was well answered. The most common mistakes involved candidates failing to include square brackets or lone pairs of electrons or charges. Four G2 comments stated that expanded octets are not on the syllabus. However, AS 14.1.1 states explicitly that candidates should be able to predict the shape and bond angles of species of five and six negative charge centres. Four examples are included in the teachers note, including $\mathrm{SF_6}$, but it has to emphasized again, as in previous subject reports that examples should not be confined in teaching programmes to just these four examples. Even $\mathrm{SF_6}$ is a clear example of an expanded octet type structure, as is $\mathrm{SiF_6^{2-}}$, as asked in this question.

b.ii.There were five other G2 comments again stating the fact that $\mathrm{NO_2^+}$ is off-syllabus. Based on AS 4.2.7, this example is clearly on the syllabus as the AS states that candidates should be able to predict the shape and bond angles of species of two, three and four negative charge centres. All the examples in the teachers note should be covered at a minimum in the teaching programme, but these are not the only examples.

d. There were seven G2 comments referring to (d); some respondents felt that the candidates had to answer the question by determining the shape of both $\mathrm{NO_2}$ and$\mathrm{CO_2}$ using VSEPR Theory. This is a classic example of candidates reading the question carefully and not making unnecessary assumptions in relation to what is being asked. Only three marks are allocated to this question and hence this should be another clue as to suggest that the answer can be given in a concise manner. All candidates had to do was determine the fact that both species are XY2 species (not XYZ even) and hence can only be one of two geometries, either linear or bent. $\mathrm{CO_2}$ must be non-polar since it is a linear geometry and hence the two dipole moments cancel each other out, yielding a net dipole moment of zero. In the case of $\mathrm{NO_2}$, the geometry must be bent, and therefore there is a net dipole moment meaning it is a polar molecule. A simple diagram of the two species with the two bond dipole moments in each case and the resultant net dipole moment (in the case of $\mathrm{NO_2}$) would have scored both marks. There was no need to show lone pairs of electrons or isolated electrons etc. to answer this question, as candidates were not asked to write Lewis structures etc. Some candidates wasted time here trying to work these out and even some candidates thought that there might even be a mistake in the question and tried to answer the question with $\mathrm{NO_2^-}$, because this is an example given in the teachers note in AS 14.3.1, based on delocalization.

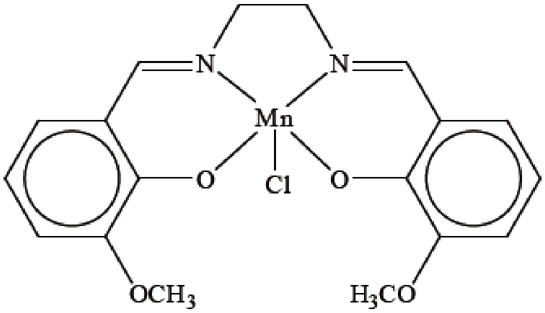
The very best candidates did draw dipole moments, as the question did ask for diagrams, when explaining polarity, as opposed to simply a description in words.

f.ii. Hybridization was usually well answered in part (ii), but sometimes candidates did not score the mark due to lack of specific subject vocabulary.

f.iii. Although candidates often had some understanding of sigma and pi bonding, very few mentioned electron density in (iii).

f.iv. For (iv) one G2 comment stated that the hybridization of N in $\mathrm{HCONH_2}$ will in fact be $\mathrm{sp^2}$ due to the planar nature of the $\mathrm{NH_2}$ group here in this example, which is in fact correct, although it is unlikely that candidates at this level would know this. Nearly all candidates gave $\mathrm{sp^3}$ hybridization for N, which they based on a perceived pyramidal type geometry, like in ammonia. For this reason, during GA, we decided to allow both hybridizations, even though the correct answer is actually $\mathrm{sp^2}$ in this example.

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]

Markscheme

a. $\mathrm{1s^2 2s^2 2p^6 3s^2 3p^6 3d^4}$ / $\mathrm{[Ar]3d^4}$;

b. ligand;

dative/coordinate (covalent);

Do not accept “covalent”.

c. variable oxidation state/number;

   catalytic properties;

d. d sublevel/orbitals split (into two levels by ligands);

   electrons absorb light/photons and move to the higher energy orbital;
   frequency of light/photons absorbed in the visible region;

Examiners report

a. Very few candidates could interpret the electron structure of manganese from its oxidation state, though the term “ligand” and the nature of its bond to metal ions were almost universally known. The general properties of transition metals seemed to have been well memorized, even though they were not always correctly applied. The splitting of the d sub-shell was generally known, though a worrying number of students believe that transition metal ions emit coloured light.

b. Very few candidates could interpret the electron structure of manganese from its oxidation state, though the term “ligand” and the nature of its bond to metal ions were almost universally known. The general properties of transition metals seemed to have been well memorized, even though they were not always correctly applied. The splitting of the d sub-shell was generally known, though a worrying number of students believe that transition metal ions emit coloured light.

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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]

Markscheme

a. cobalt has a greater proportion of heavier isotopes / *OWTTE* / cobalt has greater number of neutrons;

b. 27 protons **and** 25 electrons;

c. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^7 / [Ar]\ 3d^7$;

Examiners report

a. Candidates did reasonably well on this question. Many candidates got (a) correct.

b. Most candidates got the correct number of protons and electrons in the Co^{2+} ion in part (b).

c. In (c), a small minority of candidates tried to answer this question with a 2,8,15 type electron arrangement which showed weakness at HL and many candidates did not realise that electrons come out of the 4s level first before the 3d in part (c).

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 $K_2Cr_2O_7$ and 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 Cr_2O_3 and CrO_3. [2]

Cr_2O_3:
CrO_3:

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

c.ii. $Cr_2O_7^{2-}(aq)$ and $I^-(aq)$ ions react together in the **presence of acid** to form $Cr^{3+}(aq)$ and $IO_3^-(aq)$ 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 $[Cr(H_2O)_6]^{3+}$ 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]

Markscheme

a. *Oxidation:* increase in oxidation number **and** *Reduction:* decrease in oxidation number / *OWTTE*;

b. *Cr_2O_3*:

chromium(III) oxide;

Do not award mark for chromium oxide.

CrO_3:

chromium(VI) oxide;

Do not award mark for chromium oxide.

Do not award any marks if chromium oxide without Roman numerals is given for both.

c.i. substance reduced / causes other substance to be oxidized / increase oxidation number of another species / gains electrons / *OWTTE*;

c.ii. *Oxidizing agent:*

$\mathrm{Cr_2O_7^{2-}}$ / dichromate (ion);

$\mathrm{Cr_2O_7^{2-}(aq) + I^-(aq) + 8H^+(aq) \rightarrow 2Cr^{3+}(aq) + IO_3^-(aq) + 4H_2O(l)}$

*Award **[1]** for coefficients: $Cr_2O_7^{2-}(aq)$, $I^-(aq)$, $2Cr^{3+}(aq)$, $IO^{3-}(aq)$.*

*Award **[1]** for coefficients: $8H^+(aq)$, $4H_2O(l)$.*

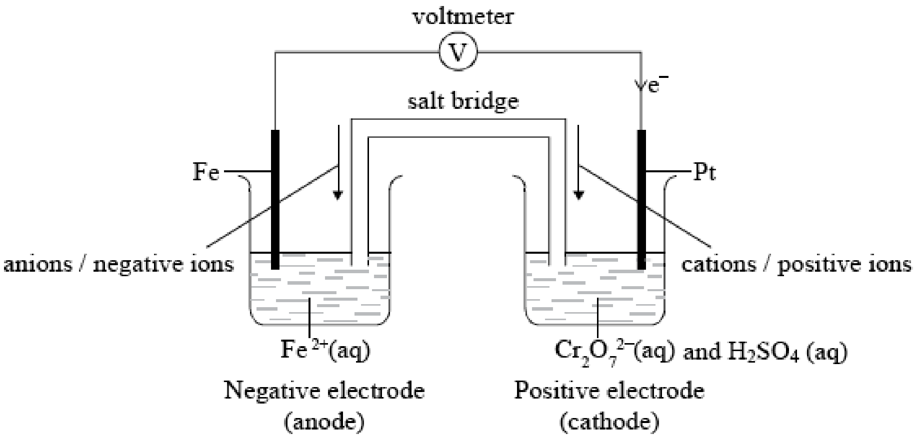
*Award **[1 max]** if coefficients of reactants only correct i.e. $Cr_2O_7^{2-}$, I^- and $8H^+$.*

*Award **[1 max]** if coefficients of products only correct i.e. $2Cr^{3+}$, IO^{3-} and $4H_2O$.*

*Award **[1 max]** for correct reactants and products.*

Ignore state symbols.

d.i.



Voltaic cell showing:

labelled positive electrode (cathode) **and** negative electrode (anode);

direction of electrons in external circuit **and** direction of ions in salt bridge;

Award mark if correct direction of electrons is indicated but e^- not labelled in external circuit.

Allow e instead of e^-.

Cations/positive ions and anions/negative ions must be identified in salt bridge. Allow correct movement of ions in electrolyte instead of movement of ions in salt bridge (e.g. Fe^{2+} from Fe at negative electrode/anode etc.).

If both movement of ions in salt bridge and movement of ions in electrolyte is given but one is incorrect do not award mark.

Positive electrode (cathode):

$\mathrm{Cr_2O_7^{2-}(aq) + 14H^+(aq) + 6e^- \rightarrow 2Cr^{3+}(aq) + 7H_2O(l)}$;

Negative electrode (anode):

$\mathrm{Fe(s) \rightarrow Fe^{2+}(aq) + 2e^-}$;

Penalize once only.

Penalize once only if electrodes or equations reversed.

For both electrodes allow e instead of e⁻.

Overall cell reaction:

$\mathrm{Cr_2O_7^{2-}(aq) + 3Fe(s) + 14H^+(aq) \rightarrow 2Cr^{3+}(aq) + 3Fe^{2+}(aq) + 7H_2O(l)}$;

Ignore state symbols throughout (d) (i).

d.ii. potential under standard conditions relative to standard hydrogen electrode/SHE;

Reference must be made to standard conditions.

Instead of standard conditions allow either solute concentration of 1 mol dm^{-3}/1 M/1 mol L^{-1} or 100 kPa/10^5 Pa for gases.

Allow 1 bar for 100 kPa/10^5 Pa.

Allow 1 atm/1.01 × 10^5 Pa.

Allow voltage instead of potential.

d.iii. $(+)1.78\ \mathrm{(V)}$;

e.i. catalysts;

variable oxidation state/numbers;

Allow variable valency.

magnetic (properties);

(form) coloured ions/compounds;

Allow just coloured.

(form) complexes/complex ions;

Allow other metallic physical properties such as high densities/high melting points etc.

Allow partially filled/incomplete d subshell/sub-level.

e.ii. dative (covalent)/coordinate;

Lewis base / (species/ion/molecule with) lone/non-bonding pair;

e.iii. partially filled/incomplete d subshell/sub-level/orbitals;

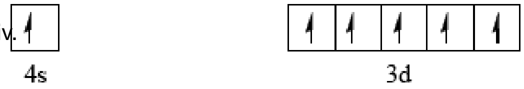
d orbitals split (into two sets of different energies);

colour due to electron transition between (split) d orbitals / frequencies of visible light absorbed by electrons moving from lower to higher d levels;

colour due to remaining frequencies / complementary colour seen;

Allow wavelength as well as frequency.

e.iv.



Accept half-arrows or full arrows and boxes in reverse order.

Do not penalize if additional sub-levels are shown, if sub-levels are not labelled or if no boxes are drawn (providing system of arrows correct).

Do not award mark if sub-levels are incorrectly labelled.

Orbital diagram may also be represented with sub-levels shown at different relative energy positions.

f. *Positive electrode (anode):* chromium;

Allow lead/titanium/platinum/graphite.

Negative electrode (cathode): object to be plated;

Allow specific example here e.g. spoon.

Electrolyte: $\mathrm{Cr^{3+}(aq)}$;

Allow (mixture of) $\mathrm{Cr^{3+}(aq)}$ ***and*** *CrO_4^{2-}(aq)/chromate/chromic acid/H_2CrO_4.*

Ignore state symbols.

Allow any soluble salt of Cr^{3+}.

Examiners report

a. Candidates generally knew that oxidation involves an increase in oxidation number and reduction a decrease.

b. Some forgot to include the Roman Numerals here and a large majority simply got the Roman Numeral incorrect. One G2 comment suggested that it would have been better if systematic was included in the question which is a fair point, though typically candidates simply put chromium oxide for both compounds which showed misunderstanding of what was really required.

c.i. The definition of an oxidizing agent was well answered.

c.ii. Most candidates knew that the dichromate ion acted as the oxidizing agent but many made lots of errors in deducing the balanced chemical equation.

d.i. Only the best candidates scored all five marks, though most candidates scored at least two marks. Some candidates mixed up the cathode and anode. Equilibrium signs were often written and very few gave the correct direction of the movement of ions. Some G2 comments stated that is was not clear what ion movement was required – flow of ions through the salt bridge or just movement of ions towards the electrodes in the electrolyte. In fact most candidates could not write either and the markscheme in fact allowed credit for either of these to be fair to candidates.

d.ii. Standard conditions often was omitted.

d.iii. (iii) was well answered.

e.i. Most candidates scored full marks here.

e.ii. Most candidates scored full marks here.

e.iii. Many candidates scored two out of three marks.

e.iv. Many candidates put two electrons in the 4s level and four electrons in the 3d level which was incorrect in the orbital diagram.

f. Candidates often scored two out of three marks here with the most common error relating to the electrolyte.

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.

Markscheme

Co-60 emits (penetrating) gamma radiation/rays / *OWTTE*;

Allow because Co-60 emits radiation which kills/treats cancer cells.

Do not allow answers such as Co-60 is radioactive or Co-60 treats cancer as single statements.

Examiners report

The top students mentioned gamma rays and again this proved to be a good discriminator. One G2 comment stated that this question was not strictly part of AS 2.1.7. However, this is both an Aim 8 AS and Objective 3 and it is expected that candidates would be exposed to this degree of discussion.

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.

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

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.

Markscheme

a. $63x + 65(100 - x) = 63.55 \times 100$;

$(x =)\ 72.50(\%)$;

*Award **[2]** for correct final answer.*

b. $\mathrm{1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1 / 1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10}}$;

Do not accept upper case letters or numbers as subscripts.

c. colour is due to movement of electrons (between d orbitals) / *OWTTE*;

copper(I) has a full d sub-shell(, hence electrons cannot move) / copper(II) has an incomplete d sub-shell(, hence electrons can move) / *OWTTE*;

d. (i) $\left(E^{\ominus}_{\text{cell}} = 0.15 - 0.52 =\right) - 0.37\ (\text{V})$

choosing correct $E^{\ominus}_{\text{cell}}$ values;

combining in correct way;

Award ***[2]*** *for correct final answer*.

Award ***[1]*** *for –0.18 (0.34 instead of 0.15) and –0.19 (0.34 instead of 0.52).*

(ii) not spontaneous **because** $E^{\ominus}$ negative / *OWTTE*;

Examiners report

a. This question in general was well answered, with an encouraging number of students being able to both calculate the proportions of the two isotopes of copper and state its atypical electron configuration. Responses to part (c) often centred around the splitting of d-orbitals rather than their completeness and a disturbing number of answers implied, or stated, that transition metals emit, rather than absorb light. In the final part, as might have been predicted, a significant number of students used the electrode potential for $\text{Cu}^{2+}/\text{Cu}\ (+0.34\ \text{V})$, rather than those required, but a number of them managed to gain some credit by combining this with the other potential in a valid manner and correctly predicting the spontaneity that it would imply.

b. This question in general was well answered, with an encouraging number of students being able to both calculate the proportions of the two isotopes of copper and state its atypical electron configuration. Responses to part (c) often centred around the splitting of d-orbitals rather than their completeness and a disturbing number of answers implied, or stated, that transition metals emit, rather than absorb light. In the final part, as might have been predicted, a significant number of students used the electrode potential for $\text{Cu}^{2+}/\text{Cu}\ (+0.34\ \text{V})$, rather than those required, but a number of them managed to gain some credit by combining this with the other potential in a valid manner and correctly predicting the spontaneity that it would imply.

c. This question in general was well answered, with an encouraging number of students being able to both calculate the proportions of the two isotopes of copper and state its atypical electron configuration. Responses to part (c) often centred around the splitting of d-orbitals rather than their completeness and a disturbing number of answers implied, or stated, that transition metals emit, rather than absorb light. In the final part, as might have been predicted, a significant number of students used the electrode potential for $\text{Cu}^{2+}/\text{Cu}\ (+0.34\ \text{V})$, rather than those required, but a number of them managed to gain some credit by combining this with the other potential in a valid manner and correctly predicting the spontaneity that it would imply.

d. This question in general was well answered, with an encouraging number of students being able to both calculate the proportions of the two isotopes of copper and state its atypical electron configuration. Responses to part (c) often centred around the splitting of d-orbitals rather than their completeness and a disturbing number of answers implied, or stated, that transition metals emit, rather than absorb light. In the final part, as might have been predicted, a significant number of students used the electrode potential for $\text{Cu}^{2+}/\text{Cu}\ (+0.34\ \text{V})$, rather than those required, but a number of them managed to gain some credit by combining this with the other potential in a valid manner and correctly predicting the spontaneity that it would imply.

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]

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

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

Markscheme

a. series of lines/lines;

electron transfer/transition between higher energy level to lower energy level / electron transitions into first energy level causes UV series / transition into second energy level causes visible series / transition into third energy level causes infrared series;

convergence at higher frequency/energy/short wavelength;

Allow any of the above points to be shown on a diagram.

b. $[\mathrm{Fe(CN)_6}]^{4-} = +2$;

$[\mathrm{FeCl_4}]^{-} = +3$;

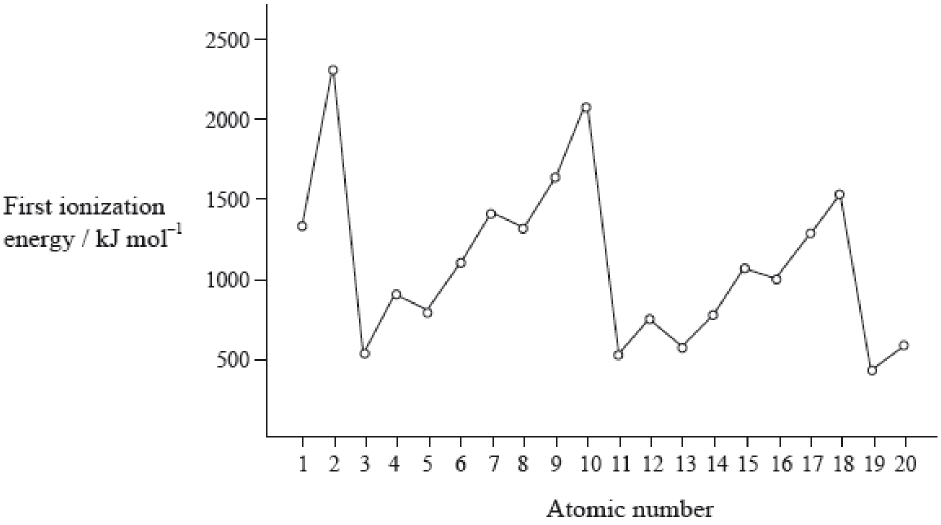
*Award **[1 max]** if 2+ and 3+, 2 and 3 or II and III stated.*

Examiners report

a. In the emission spectrum of hydrogen some candidates missed stating about convergence at high energy/frequency while some other candidates forgot to write that it is a line spectrum.

b. The majority of candidates deduced the oxidation number of iron in the complex ions correctly although some candidates still wrote 2+ and 3+ which deprived them of one mark.

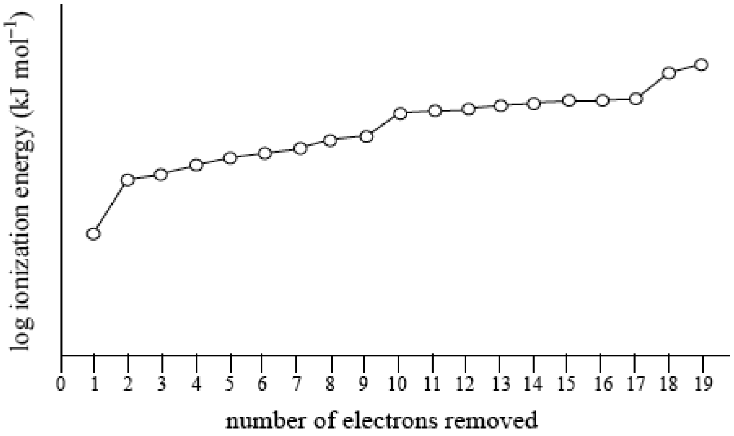
The graph of the first ionization energy plotted against atomic number for the first twenty elements shows periodicity.



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, $\mathrm{Cu^{+}}$. [2]

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

Markscheme

b.ii. (evidence for main levels)

highest values for noble gases / lowest values for alkali metals / *OWTTE*;

general increase across a period;

(evidence for sub-levels)

drop in I.E. from Be to B/Mg to Al/Group 2 to Group 3;

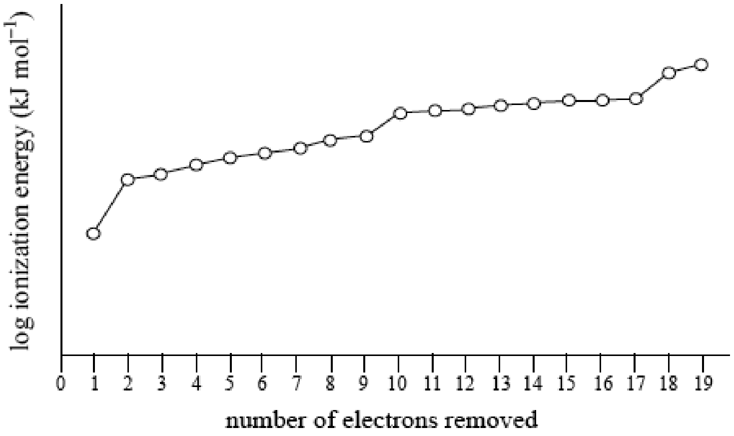
drop in I.E. from N to O/P to S/Group 5 to Group 6;

b.iii. $\mathrm{M^{+}(g) \rightarrow M^{2+}(g) + e^{-}}$ / *OWTTE* ;

Accept e instead of e⁻.

b.iv. Rough sketch to show:

Graph of successive ionization energies for potassium



correct use of axes **and** one electron relatively easy to remove;

a jump in value then eight, another jump to another eight **and** finally another jump for the remaining two electrons ;

electronic configuration of $\mathrm{K} = 1s^2 2s^2 2p^6 3s^2 3p^6 4s^1$ / first electron due to removal of $4s^1$, next eight due to third level/$3s^2 3p^6$, next eight due to second level/$2s^2 2p^6$ and last two due to removal of first level/$1s^2$;

the more electrons removed the more the positive nucleus attracts the remaining electrons and each main energy level is closer to the nucleus / *OWTTE*;

c.i. $(\mathrm{Cu})\ 1s^2 2s^2 2p^6 3s^2 3p^6 4s^1 3d^{10} / 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10} 4s^1$;

Do not accept [Ar]$4s^1 3d^{10}$.

$(\mathrm{Cu}^+)\ 1s^2 2s^2 2p^6 3s^2 3p^6 3d^{10}$;

Do not accept [Ar]$3d^{10}$.

c.ii. Cu^{2+} has an incomplete d sub-level **and** Sc^{3+} has no d electrons;

the d sub-level is split so the d electrons (in copper) can be excited by visible light / *OWTTE*;

Examiners report

b.ii. Many candidates had difficulty correlating the graph of first ionization energy to main energy levels and sub-levels.

b.iii. [N/A]

b.iv. Commonly the graph looked very similar to the graph provided of first ionization energy against atomic number. Even the few candidates who seemed to understand the ideas involved with successive ionization energies drew only partial graphs and did not continue for the removal of all 19 electrons. Some teachers commented on the G2 forms that sketching the graph is beyond the scope of the course but it is clearly covered by AS 12.1.2.

c.i. In part (c), few candidates could correctly write the electron configurations of Cu and Cu^+, with many giving a full 4s orbital and only 9 electrons in the 3d orbitals. Candidates who managed to correctly write the electron configuration of Cu often removed a 3d electron when creating Cu^+.

c.ii. Many candidates could explain why aqueous solutions of copper(II) compounds are coloured but those of scandium(III) compounds are not, but some candidates responded very weakly.

Calcium carbide, CaC_2, is an ionic solid.

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

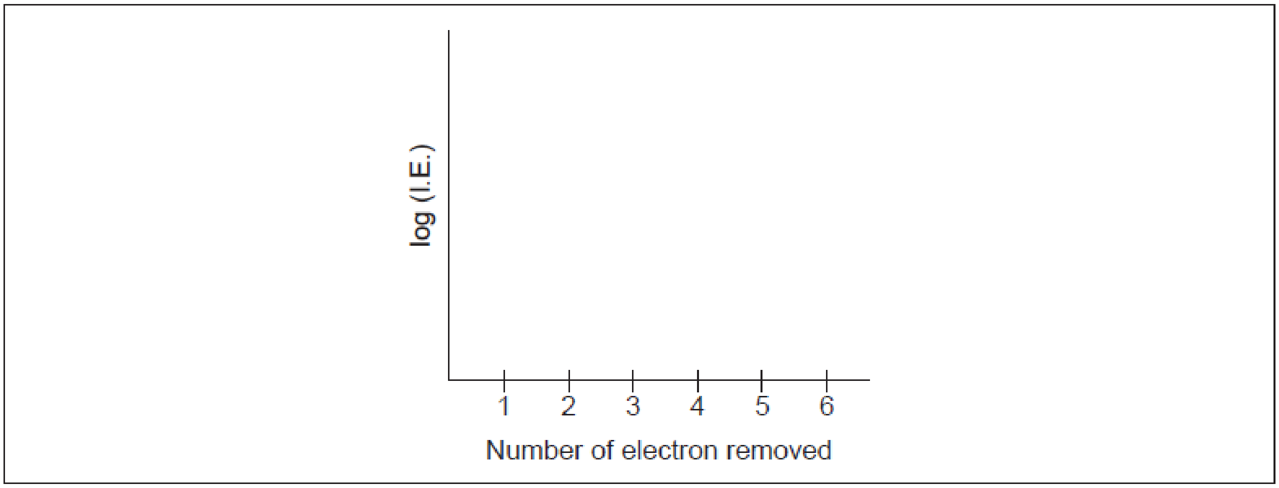
b. Describe how the relative atomic mass of a sample of calcium could be determined from its mass spectrum. [2]

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):

. . . .

Markscheme

a. electrostatic attraction ***AND*** oppositely charged ions

[1 mark]

b. multiply relative intensity by «*m/z*» value of isotope

OR

find the frequency of each isotope

sum of the values of products/multiplication «from each isotope»

OR

find/calculate the weighted average

Award ***[1 max]*** *for stating "m/z values of isotopes* ***AND*** *relative abundance/intensity" but not stating these need to be multiplied.*

[2 marks]

c. «promoted» electrons fall back to lower energy level

energy difference between levels is different

Accept "Na and Ca have different nuclear charge" for M2.

[2 marks]

d.i. *Any two of:*

stronger metallic bonding

smaller ionic/atomic radius

two electrons per atom are delocalized

OR

greater ionic charge

greater atomic mass

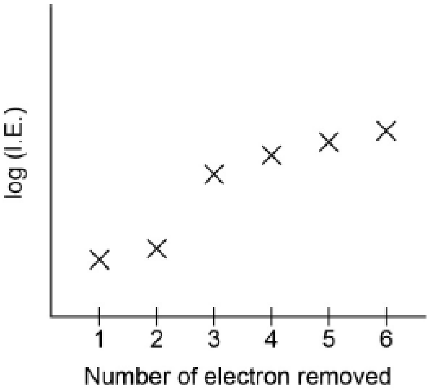
Do ***not*** *accept just "heavier" or "more massive" without reference to atomic mass.*

[2 marks]

d.ii. delocalized/mobile electrons «free to move»

[1 mark]

e.



general increase

only one discontinuity between "IE2" and "IE3"

[2 marks]

f. pH > 7

Accept any specific pH value or range of values above 7 and below 14.

[1 mark]

g.i. *sigma (σ):*

overlap «of atomic orbitals» along the axial/internuclear axis

OR

head-on/end-to-end overlap «of atomic orbitals»

pi (π):

overlap «of p-orbitals» above and below the internuclear axis

OR

sideways overlap «of p-orbitals»

Award marks for suitable diagrams.

[2 marks]

g.ii *sigma (σ):* 3

AND

pi (π): 2

[1 mark]

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d.i. [N/A]
d.ii. [N/A]
e. [N/A]
f. [N/A]
g.i. [N/A]
g.ii. [N/A]

Iron rusts in the presence of oxygen and water. Rusting is a redox process involving several steps that produces hydrated iron(III) oxide,

$\mathrm{Fe_2O_3 \bullet nH_2O}$, as the final product.

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

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

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

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. State **two other** examples of catalyzed reactions giving the transition metal or its compound acting as catalyst. [2]

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]

Markscheme

a. (i) oxidation **and** (iron/Fe) loses electrons/increases in oxidation number/state;

(ii) $\underset{\boxed{0}}{O_2}(aq) + 4e^- + 2\underset{\boxed{I}}{H_2}\underset{\boxed{-II}}{O}(l) \rightarrow 4\underset{\boxed{-II}}{O}\underset{\boxed{I}}{H}^-(aq)$;

*Award **[2]** for five correct.*

*Award **[1]** for four correct.*

Accept use of oxidation states (0, +1, –2, –2, +1) for oxidation numbers.

Penalize once for incorrect notation (eg, 2, 2–).

(iii) $O_2(aq) + 2H_2O(l) + 2Fe(s) \rightarrow 2Fe^{2+}(aq) + 4OH^-(aq)$;

Ignore state symbols.

(iv) Fe/iron;

b. needs to break strong <u>hydrogen bonds/H–bonds</u> between water molecules (to dissolve) / oxygen cannot form <u>hydrogen bonds/H–bonds</u> with water;

oxygen can only form (weak) van der Waals'/vdW/LDF/London/dispersion forces with water;

c. groups indicate the number of electrons in the highest energy level/outer/valence shell;

periods indicate the number of (occupied) energy levels/shells (in the atom);

d. V_2O_5 catalyses oxidation of SO_2 / V_2O_5 is a catalyst in the Contact Process;

Fe catalyses the reaction between N_2 and H_2 / Fe is a catalyst in the Haber Process;

Ni/Pd/Pt catalyses hydrogenation / manufacture of margarine / addition of hydrogen to C=C / conversion of alkenes to alkanes;

Pd/Pt is a catalyst in catalytic converters / Pd/Pt catalyzes reaction of NO_2 and CO/NO_2 and (unburnt) fuel/exhaust gases;

Accept other correct examples.

Accept formulas or names of substances.

e. (i) $H_2O(l) \rightleftharpoons H^+(aq) + OH^-(aq) / 2H_2O(l) \rightleftharpoons H_3O^+(aq) + OH^-(aq)$;

$\rightleftharpoons$ and state symbols are necessary for the mark.

(ii) $K_w = [H^+][OH^-] / K_w = [H_3O^+][OH^-]$;

(iii) at higher temperatures ionization increases / at higher temperatures equilibrium shifts to right;

ionization is endothermic;

Do not allow ECF for M2.

(iv) $5.13 \times 10^{-13} = [H_3O^+]^2/[H^+]^2/[H_3O^+]/[H^+] = 7.16 \times 10^{-7}\ (\text{mol}\,\text{dm}^{-3})$;

$\text{pH} = 6.14/6.15$;

*Award **[2]** for correct final answer.*

f. (i) chlorine/Cl_2 (is produced at the positive electrode/anode);

according to electrochemical series/ E° values/ease of oxidation OH^-/H_2O reacts/oxygen is released / *OWTTE* / at low chloride concentration OH^-/H_2O reacts/oxygen is released;

high concentration makes Cl^- oxidize/react in preference to OH^-/H_2O / *OWTTE*;

(ii) *Negative electrode (cathode):*

$2H^+(aq) + 2e^- \rightarrow H_2(g)/H^+(aq) + e^- \rightarrow \frac{1}{2}H_2(g)/2H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq);$

Positive electrode (anode):

$2Cl^-(aq) \rightarrow Cl_2(g) + 2e^-/Cl^-(aq) \rightarrow \frac{1}{2}Cl_2(g) + e^-/2Cl^-(aq) - 2e^- \rightarrow Cl_2(g)/$

$Cl^-(aq) - e^- \rightarrow \frac{1}{2}Cl_2(g);$

Ignore state symbols.

Accept e instead of e⁻.

*Award **[1]** if half-equations are correct but placed at the wrong electrodes.*

g. bracelet/object to be electroplated is the cathode/negative electrode;

silver anode/positive electrode;

Accept Pt anode.

Electrolyte: liquid $Na[Ag(CN_2)]$/sodium dicyanoargentate/$[Ag(CN)_2]^-$/ solution of an appropriate silver salt;

Accept AgNO$_3$/silver nitrate.

All marks can be scored with a labelled diagram.

Examiners report

a. (i) Very well answered.

(ii) Most candidates answered correctly. The most common mistakes were doubling the oxidation number of H in H_2O, and entering a wrong oxidation number for elemental oxygen.

(iii) A well-answered question.

b. The aqueous solubility of oxygen gas was often poorly explained, with the discussion focussing on the intermolecular forces found in each substance separately and then stating that "like dissolves like".

c. Well answered by most candidates.

d. The majority of candidates were able to give two valid examples of transition metals or their compounds acting as catalysts.

e. (i) Very well answered.

(ii) Well answered.

(iii) About half of the candidates were able to gain full marks. Some candidates found difficulty in connecting the increase in K_w to the position of equilibrium.

(iv) About half of the candidates were able to calculate the pH from the K_w value.

f. (i) Many candidates identified chlorine as the product, but the other two marks were more discriminating. Some candidates clarified that Cl^- was oxidized in preference to OH- because of its high concentration, but very few related the situation to the electrochemical series.

(ii) This was poorly answered by many candidates. Common mistakes included releasing sodium at the cathode, reversing electrodes and unbalanced redox half-reactions where the electrons were sometimes on the wrong side of the equation.

g. Very well answered. Most candidates determined both electrodes correctly. The main difficulty for some candidates was choosing a suitable electrolyte.

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 $\mathrm{PCl_3}$ according to the Lewis theory. [2]

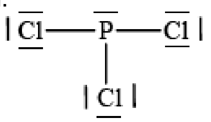
e. Explain the delocalization of π electrons using the $\mathrm{O_3}$ molecule as an example, including **two** facts that support the delocalization. [4]

Markscheme

c.i. $\mathrm{1s^2 2s^2 2p^6 3s^2 3p^3}$;

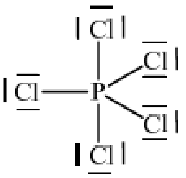
c.ii.

PCl₃



;

PCl₅

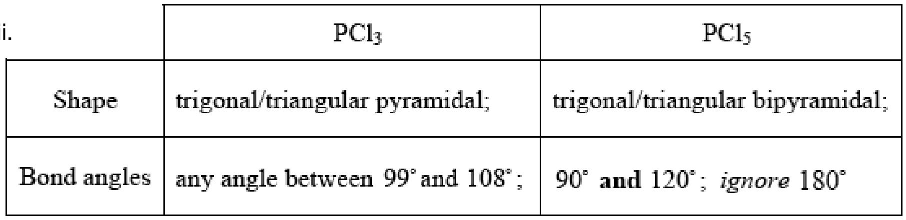


;

Penalize missing lone pairs on chlorine only once.

Accept any combination of lines, dots or crosses to represent electron pairs.

c.iii.



	PCl_3	PCl_5
Shape	trigonal/triangular pyramidal;	trigonal/triangular bipyramidal;
Bond angles	any angle between 99° and 108°;	90° **and** 120°; *ignore* 180°

Shape and bond angle must be consistent with the number of electron domains given in the diagram in (ii).

c.iv. sp^3 (hybridization);

c.v. PCl_5 has higher melting point than PCl_3;

PCl_5 has stronger intermolecular/London/dispersion/van der Waals' forces;

(because of) more electrons/greater mass;

Accept the opposite argument for PCl_3.

*Award **[1 max]** for answers suggesting PCl_3 has higher melting point because it is polar and PCl_5 is not.*

d.i. electron pair acceptor;

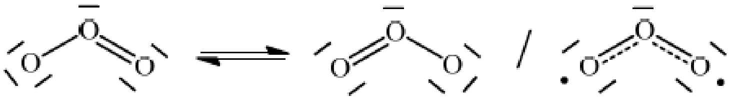
d.ii. Lewis base;

has non-bonding/lone pair of electrons;

No ECF from (i).

e. overlap of p orbitals / p electrons of double/π bond and non-bonding/lone pair on oxygen interact / *OWTTE*;

π electrons not localized / different resonance structures possible /


;

both bonds/O–O and O=O have equal length / *OWTTE*;

both bonds/O–O and O=O have equal bond energy / *OWTTE*;

Examiners report

c.i. The electron configuration of phosphorus was successfully answered (even by apparently weaker candidates) and there were many good answers for the Lewis structures. Candidates would do well to draw the "dots" clearly remembering that their answer will be scanned. They should group the electron dots neatly in pairs (much easier for the examiner to count, for one thing) or use a line to represent an electron pair. The usual errors occurred namely missing lone pairs on P and/or Cl atoms.

c.ii. The electron configuration of phosphorus was successfully answered (even by apparently weaker candidates) and there were many good answers for the Lewis structures. Candidates would do well to draw the "dots" clearly remembering that their answer will be scanned. They should group the electron dots neatly in pairs (much easier for the examiner to count, for one thing) or use a line to represent an electron pair. The usual errors occurred namely missing lone pairs on P and/or Cl atoms.

c.iii. The shapes and angles in (iii) were patchy but there were also some impressive answers.

c.iv About half knew that sp^3 was the answer to (iv) and in (v) about half based their explanation on the dipole moment in $\mathrm{PCl_3}$. (One mark was allowed for those who recognized that $\mathrm{PCl_3}$ would be polar whilst $\mathrm{PCl_5}$ would not – thus suggesting that $\mathrm{PCl_3}$ had the higher melting point.) Candidates were expected to know the order of melting points as this had been studied in 13.1.1. Very few were able to write a balanced equation for the reaction of $\mathrm{PCl_5}$ with water.

c.v. About half knew that sp^3 was the answer to (iv) and in (v) about half based their explanation on the dipole moment in $\mathrm{PCl_3}$. (One mark was allowed for those who recognized that $\mathrm{PCl_3}$ would be polar whilst $\mathrm{PCl_5}$ would not – thus suggesting that $\mathrm{PCl_3}$ had the higher melting point.) Candidates were expected to know the order of melting points as this had been studied in 13.1.1. Very few were able to write a balanced equation for the reaction of $\mathrm{PCl_5}$ with water.

d.i. Many failed to note that a Lewis acid is an electron *pair* acceptor and the definition was often muddled with that of Brønsted-Lowry.

d.ii. Some, in (d) (ii), treated the P and Cl atoms separately.

e. In (e) there was little discussion of overlap of p orbitals, some of resonance but hardly any evidence in terms of equal bond length and equal bond strength. The bonding in an ozone molecule was not well-understood.

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

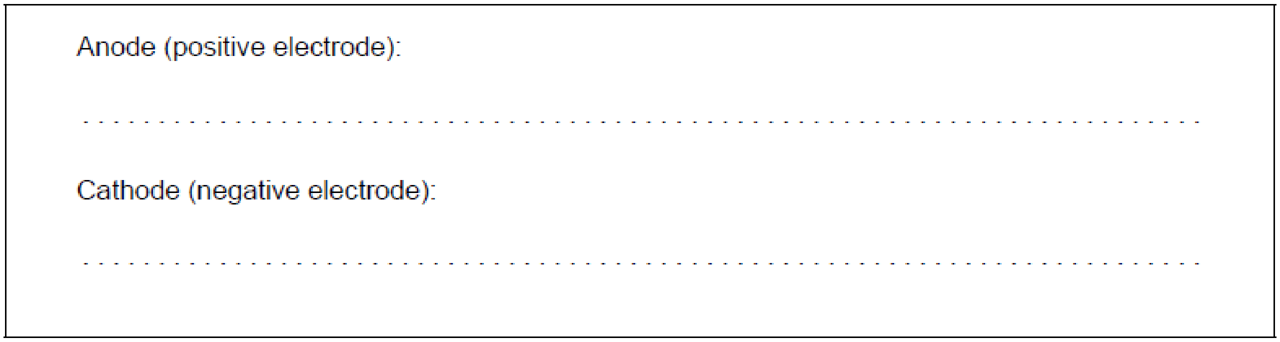
c. Magnesium ions produce no emission or absorption lines in the visible region of the electromagnetic spectrum. Suggest why most magnesium compounds tested in a school laboratory show traces of yellow in the flame. [1]

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.

Markscheme

c. contamination with sodium/other «compounds»

d. i

energy levels are closer together <u>at high energy / high frequency / short wavelength</u>

ii
ionisation energy

i. i)

Anode (positive electrode):

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

Cathode (negative electrode):

$Mg^{2+} + 2e^- \rightarrow Mg\ (l)$

Penalize missing/incorrect state symbols at Cl_2 and Mg once only.

*Award **[1 max]** if equations are at wrong electrodes.*

Accept Mg (g).

ii)

reduction

iii)

Anode (positive electrode):
oxygen/O_2
OR
hydogen ion/proton/H^+ ***AND*** oxygen/O_2
Cathode (negative electrode):
hydrogen/H_2
OR
hydroxide «ion»/OH^- ***AND*** hydrogen/H_2

*Award **[1 max]** if correct products given at wrong electrodes.*

j. *Any two of:*

«inert» Pt electrode
OR
platinum black conductor

1 mol dm^{-3} H^+ (aq)

H_2 (g) at 100 kPa

Accept 1 atm H_2 (g).
Accept 1 bar H_2 (g)
Accept a labelled diagram.
Ignore temperature if it is specified.

k. i

Mg(s) + Cu^{2+} (aq) → Mg^{2+} (aq) + Cu(s)

ii

«+0.34V – (–2.37V) = +»2.71 «V»

iii

cell potential increases

reaction «in Q4(k)(i)» moves to the right
OR
potential of the copper half-cell increases/becomes more positive

Accept correct answers based on the Nernst equation

Examiners report

c. [N/A]
d. [N/A]
i. [N/A]
j. [N/A]
k. [N/A]

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]

Markscheme

a. $1s^22s^22p^63s^23p^63d^{10}4s^1/1s^22s^22p^63s^23p^64s^13d^{10}$;

b. *Physical:*

^{63}Cu lower boiling point/melting point/density/greater rate of diffusion than ^{65}Cu;

Accept converse argument.

Do not accept “different mass”.

Chemical:

(properties identical because) same electron configuration/arrangement of electrons;

*Accept “same number of protons **and** electrons”.*

Do not accept “same number of electrons” OR “same valence (electrons)” OR “same atomic number” only.

c. electrostatic attraction;

between (a lattice of) cations/positive ions **and** delocalized/sea of electrons;

Do not award any mark for only stating “metallic bonding”.

Examiners report

a. Most were able to quote the electron configuration of copper correctly; but some gave [Ar] $4s^1\ 3d^9$ when they were specifically asked for the *full* configuration. A few, inevitably gave $3d^9\ 4s^2$. In (b), few related the difference in mass to a *property* and most did not give the comparison; “the same number of electrons and protons” was more popular than “the same electron configuration”. The descriptions of metallic bonding were disappointing; the mark for electrostatic attraction was rarely scored and many confused “nuclei” with “cations/positive ions”.

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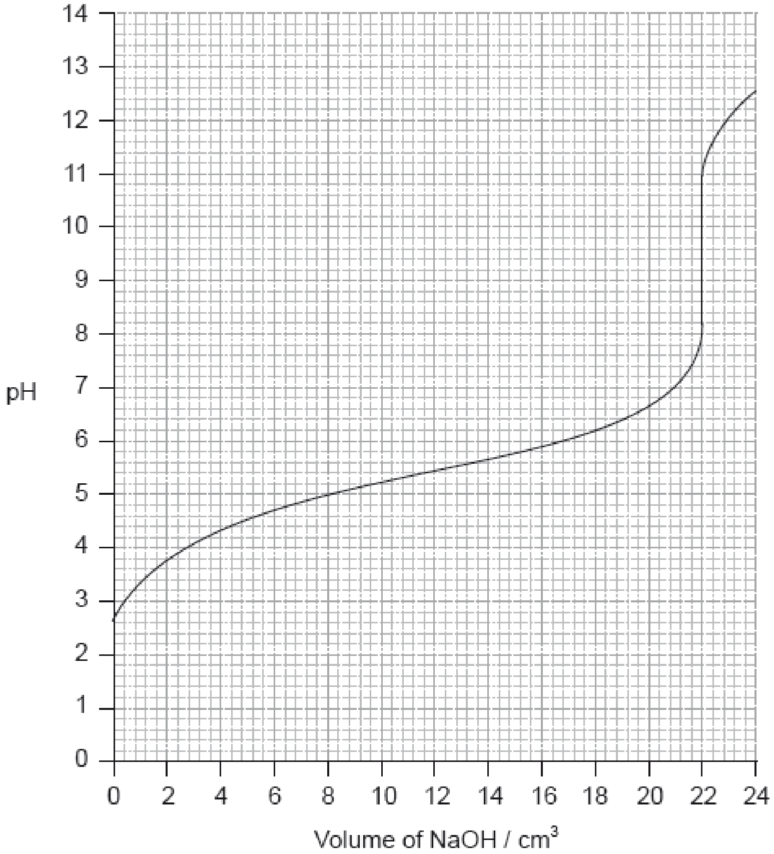
Acids can be described as strong or weak.

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 mol dm^{-3} HCl(aq) and 0.10 mol dm^{-3} $\text{CH}_3\text{COOH(aq)}$.

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 cm^3 solution. [4]

c.i. Determine the pH at the equivalence point of the titration and the $\text{p}K_\text{a}$ 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

Markscheme

a. (i) weak acids dissociate only partially **and** strong acids (are assumed to) dissociate fully;

(ii) measuring electrical conductivity **and** strong acids have greater electrical conductivity/weak acids have lower electrical conductivity;

Do not accept conductivity for electrical conductivity.

Accept explanation in terms of lightbulb in circuit.

measure pH/use universal indicator **and** pH higher for weak acid/pH lower for strong acid;

conduct titration with a strong base **and** equivalence point higher for weak acid / buffer region for weak acid;

adding a reactive metal/carbonate/hydrogen carbonate **and** stronger effervescence/faster reaction with strong acids;

Accept converse argument.

Accept correct example.

adding a strong base **and** strong acid would increase more in temperature/weak acids increase less in temperature;

Accept correct example.

*Award **[1 max]** for three suitable tests without correct results.*

Accept specific examples with given strong acid and weak acid.

*Accept "addition of $AgNO_3(aq)$ **and** white precipitate with HCl (aq)".*

Do not accept "smell".

b. $\frac{1.40}{60.06} = 0.0233\ (\mathrm{mol})$ **and** $\frac{0.0233}{0.500} = 0.0466\ (\mathrm{mol\,dm^{-3}})$;

$(\mathrm{p}K_\mathrm{a} = 4.76) K_\mathrm{a} = 1.7 \times 10^{-5}$;

$[\mathrm{H^+}] = \sqrt{K_\mathrm{a}[\mathrm{HA}]} = 8.9 \times 10^{-4}$;

Accept 9.0×10^{-4}.

$\mathrm{pH} = 3.05$;

*Award **[4]** for correct final answer.*

Accept alternative methods.

c.i. *Equivalence point*: pH of 9.5;

Accept values between 9 and 10.

$\mathrm{p}K_\mathrm{a} = \mathrm{pH}$ at half equivalence point;

$\mathrm{p}K_\mathrm{a} = 5.4$;

Accept any value between 5.2 and 5.6.

*Award **[2]** for M2 and M3 if correct $\mathrm{p}K_a$ given without explanation.*

c.ii. phenolphthalein;

c.iii. $\mathrm{HIn(aq)} \rightleftharpoons \mathrm{H^+(aq)} + \mathrm{In^-(aq)}$ **and** HIn and $\mathrm{In^-}$ have different colours;

Ignore state symbols.

equilibrium shifts depending on addition of $\mathrm{H^+}$ and $\mathrm{OH^-}$ / more HIn in acid/low pH / more $\mathrm{In^-}$ in alkali/high pH;

d.i. $\mathrm{CH_2ClCOO^-}$;

d.ii. stronger because $\mathrm{p}K_\mathrm{a}$ of chloroethanoic acid is $<$ $\mathrm{p}K_\mathrm{a}$ of ethanoic acid;

d.iii. *Concentration of acid*: $\frac{0.030}{0.300} = 0.10\ (\mathrm{mol\,dm^{-3}})$;

Concentration of base/salt: $\frac{0.020}{0.300} = 0.067\ (\mathrm{mol\,dm^{-3}})$;

$[\mathrm{H^+}] = \frac{K_\mathrm{a} \times [\mathrm{HA}]}{[\mathrm{A^-}]} / \frac{1.3 \times 10^{-3} \times 0.10}{0.067} / 1.9 \times 10^{-3}\ (\mathrm{mol\,dm^{-3}})$;

$\mathrm{pH} = 2.72$;

*Award **[4]** for correct final answer.*

Accept 2.69, 2.70 or 2.7.

Alternative for M3 and M4 if Henderson-Hasselbalch equation used:

M3: $pH = pK_a + log\frac{[base]}{[acid]}$ / $2.87 + log\left(\frac{0.067}{0.10}\right)$

M4: $pH = 2.70$.

*Award **[1 max]** for* $n_{acid}(= 100 \times 0.50 \div 1000) = 0.050 mol$ ***and***

$n_{base}(= 200 \times 0.10 \div 1000) = 0.020 mol$.

e. Cl has 7 valence electrons **and** is in group 7;

Accept "group 17" as suggested by IUPAC.

Cl has 3 occupied (electron) shells/energy levels **and** so is in period 3;

f.

Molecule	Shape	Bond angle	Polarity
SCl_2	bent/angular/ v-shaped	< 109.5° *Accept 100° – 108°.* *Literature value is 103°.*	polar
$SClF_5$	Octahedral *Accept square bipyramidal.*	90° (180°)	polar

Do not accept ECF for bond angles and polarities from incorrect shapes.

*Award **[3]** for all six correct.*

*Award **[2]** for four or five correct.*

*Award **[1]** for two or three correct.*

Examiners report

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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.

$$2\mathrm{NO}\ (g) + \mathrm{Cl_2}\ (g) \rightarrow 2\mathrm{NOCl}\ (g)$$

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]

Markscheme

b. electron transfer/transition between high«er» energy level to low«er» energy level

OR

electron transitions into first energy level causes UV series

OR

transition into second energy level causes visible series

OR

transition into third energy level causes infrared series

Accept any of the points shown on a diagram.

c. 24 x 0.786 + 25 x 0.101 + 26 x 0.113

24.33

Award **[2]** for correct final answer.
Award **[0]** for 24.31 with no working (data booklet value).

d.i. carbon: «$\frac{0.4490\text{ g}}{44.01\text{ g mol}^{-1}}$ =» 0.01020 «mol» / 0.1225 «g»

OR

hydrogen: «$\frac{0.1840 \times 2}{18.02\ g\ mol^{-1}}$ =» 0.02042 «mol» / 0.0206 «g»

oxygen: «0.1595 – (0.1225 + 0.0206)» = 0.0164 «g» / 0.001025 «mol»

empirical formula: $C_{10}H_{20}O$

*Award **[3]** for correct final answer.*

*Do **not** award M3 for a hydrocarbon.*

d.ii. «temperature =» 423 K

OR

$M = \frac{mRT}{pV}$

«$M = \frac{0.150\text{ g} \times 8.31\text{ JK}^{-1}\text{ mol}^{-1} \times 423\text{ K}}{100.2\text{ kPa} \times 0.0337\text{ dm}^3}$ =» 156 «g mol^{-1}»

*Award **[1]** for correct answer with no working shown.*

*Accept "pV = nRT **AND** n = $\frac{m}{M}$" for M1.*

d.iii. $C_{10}H_{20}O$

[1 Mark]

e.i. *Cl_2:* first

NO: second

e.ii. rate = *k* $[NO]^2\ [Cl_2]$

e.iii. 180 / 1.80 x 10^2 «$dm^6\ mol^{-2}\ min^{-1}$»

Examiners report

b. [N/A]
c. [N/A]
d.i. [N/A]
d.ii. [N/A]
d.iii. [N/A]
e.i. [N/A]
e.ii. [N/A]
e.iii. [N/A]

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.

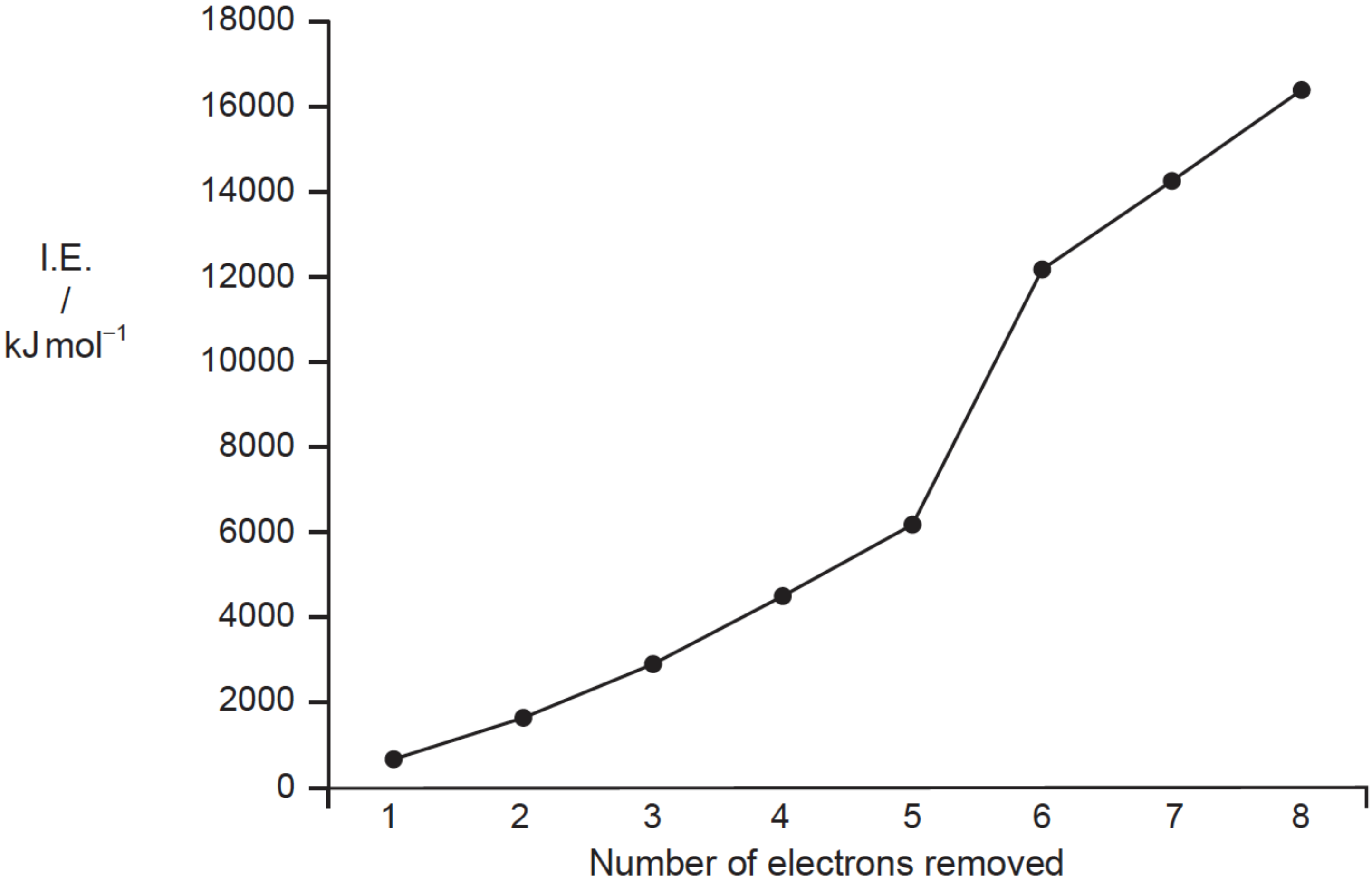
c. Outline, giving the **full** electron configuration of the vanadium atom, what is meant by the term transition metal. [2]

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.

Markscheme

a. (i)

same charge ***AND*** same/similar ionic radius

(ii)
enthalpy of hydration «= −1483 + 2 (−359)» = −2201 «kJmol^{-1}»
enthalpy of solution «= 2170 − 2201» = −31 «kJmol^{-1}»

*Award **[2]** for correct final answer.*

*Award **[1 max]** for +31 «kJmol^{-1}».*

*Award **[1 max]** for ±4371.*

(iii)
hydrochloric acid shifts equilibrium to left
OR
hydrochloric acid prevents the basic chloride forming/precipitating

*Accept "hydrochloric acid reacts with «basic» chloride" **OR** "hydrochloric acid suppresses salt hydrolysis".*

b. (i)

$E^{\ominus}$ «= 0.34 – 0.15» = 0.19«V»

$\Delta GO^{\ominus}$«= – $nFE^{\ominus}$ = –2 × 96500 × 0.19» = –36670 / –37000«J» / – 37«kJ»

Accept –18335 «J» or –18 «kJ» as equation not specified.

(ii)

yes ***AND*** $\Delta G^{\ominus}$ is negative

OR

yes ***AND*** $E^{\ominus}$ for the cell is positive

OR

yes ***AND*** Sn^{2+} (aq) is a stronger reducing agent than V^{3+}(aq)

OR

yes ***AND*** $E^{\ominus}$ SN^{4+} (aq) is more negative that $E^{\ominus}$ or VO^{2+} (aq)

OR

yes ***AND*** VO^{2+} (aq) is a stronger oxidizing agent than Sn^{4+} (aq)

OR

yes ***AND*** $E^{\ominus}$ for VO^{2+} (aq) is more positive than $E^{\ominus}$ for SN^{4+} (aq)

Do ***not*** *accept reference to anti-clockwise rule.*

c. $1s^2 2s^2 2p^6 3s^2 3p^6 3d^3 4s^2$

OR

$1s^2 2s^2 2p^6 3s^2 3p^6 4s^2 3d^3$

incomplete d «sub-» level/orbital/shell «in its compounds/ions»

d. (i)

give/donate a lone/non-bonding electron pair

Accept "through the formation of a dative/ coordinate bond".

Accept "by acting as Lewis bases".

Do not accept "act as ligands".

(ii)
«more chlorido ligands» smaller energy gap between split d-orbitals
OR
Cl^- is lower than H_2O in spectrochemical series
OR
Cl^- is a weaker ligand/has lower charge density

the absorption will move to longer wavelengths

OR

the absorption wavelength will increase

Do not accept answers in terms of change of frequency.

e. (i)

First: 4s ***AND*** *Second:* 4s ***AND*** *Third:* 3d ***AND*** *Fourth:* 3d

Do ***not*** *apply* ***ECF*** *from (c).*

(ii)
«in the same sub-shell and a» decrease in electron-electron repulsion
OR
«in the same sub-shell and» as more electrons removed, the pull of of the nucleus/positive ions holds the remaining electrons more tightly

Do ***not*** *accept "greater nuclear charge/ effective nuclear charge".*

(iii)
electron 5 is lost from the 3d orbital
OR
electron 5 is lost from the valence shell

electron 6 is lost from a 3p orbital

OR

electron 6 is lost from a «complete» inner shell

3p orbital/complete inner shell experiences a much larger effective nuclear charge
OR
3p orbital/complete inner shell is less well shielded
OR
3p orbital/complete inner shell is nearer the nucleus

Award ***[1 max]*** *(for M1/M2) (****ECF****) if candidate recognises electrons 5 and 6 are from different levels.*

(iv)
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Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]
e. [N/A]