SL Paper 2

a.i. Define the term *isotopes*. [1]

a.ii. A sample of silicon contains three isotopes. [2]

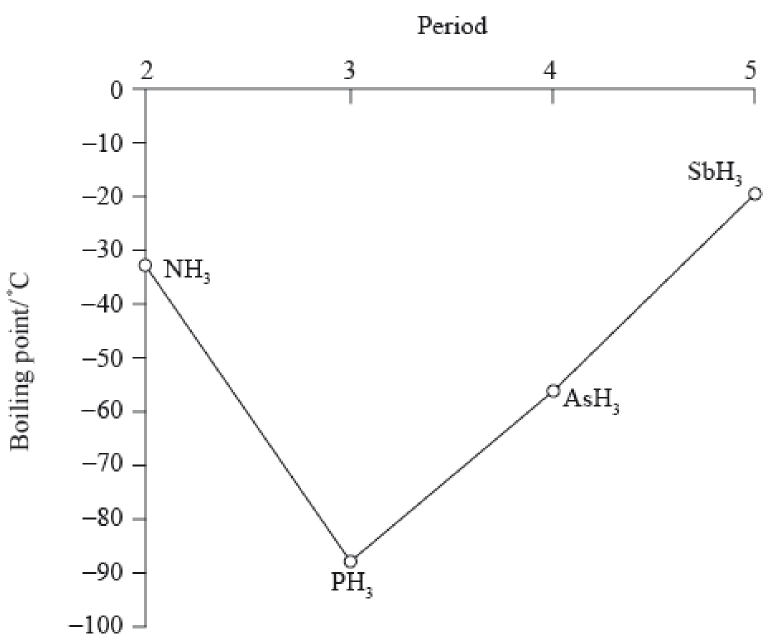
Isotope	Percentage abundance / %
^{28}Si	92.23
^{29}Si	4.68
^{30}Si	3.09

Calculate the relative atomic mass of silicon using this data.

a.iii. Describe the structure and bonding in silicon dioxide and carbon dioxide. [4]

b.i. Draw the Lewis structure of NH3, state its shape and deduce and explain the H–N–H bond angle in NH_3. [4]

b.ii. The graph below shows the boiling points of the hydrides of group 5. Discuss the variation in the boiling points. [4]



c. Explain, using diagrams, why CO and NO_2 are polar molecules but CO_2 is a non-polar molecule. [5]

Markscheme

a.i. atoms of the same element with the same atomic number/*Z*/same number of protons, but different mass numbers/*A*/different number of neutrons;

a.ii. $(0.9223 \times 28) + (0.0468 \times 29) + (0.0309 \times 30)$;

28.1/28.11;

Working must be shown to get ***[2]****, do not accept 28.09 on its own (given in the data booklet).*

a.iii *Silicon dioxide*

single covalent (bonds);

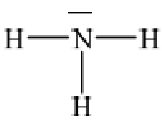
network/giant covalent/ macromolecular / repeating tetrahedral units;

Carbon dioxide

double covalent (bonds);

(simple / discrete) molecular;

Marks may be obtained from suitable structural representations of SiO_2 and CO_2.

b.i.  ;

Allow crosses or dots for lone-pair.

trigonal/triangular pyramidal;

($\sim$)107° / less than 109.5°;

Do not allow ECF.

LP-BP repulsion $>$ BP-BP repulsion / one lone pair and three bond pairs / lone pairs/non-bonding pairs repel more than bonding-pairs;

Do not accept repulsion between atoms.

b.ii boiling points increase going down the group (from $\mathrm{PH_3}$ to $\mathrm{AsH_3}$ to $\mathrm{SbH_3}$);

M_r/number of electrons/molecular size increases down the group;

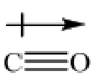
Accept electron cloud increases down the group for the second marking point.

greater dispersion/London/van der Waal's forces;

$\mathrm{NH_3}$/ammonia has a higher boiling point than expected due to the hydrogen bonding between the molecules;

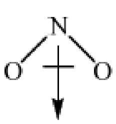
Do not accept hydrogen bonding alone.

c. *CO*:



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

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:

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

For all three molecules, 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.

Examiners report

a.i. In general the definition of isotopes was correct in (a) (i), but there are still some candidates who stated “isotopes are elements” and not “atoms of the same element”.

a.ii. Nearly everybody gave the correct answer of 28.1 for the relative atomic mass of silicon in (ii).

a.iii. Part (a) (iii) proved to be very difficult for the candidates. There was a lot of confusion about the two molecules; some candidates stated that they had the same double bond. Not many candidates mentioned the giant covalent structure for the silicon dioxide or the simple molecular structure for the carbon dioxide.

b.i. In (b) (i) the majority of candidates drew the Lewis structure of the ammonia molecule correctly showing the lone pair of electrons and the correct shape and angle and (ii) was well answered by most candidates.

b.ii. They realised that $\mathrm{NH_3}$ had a higher boiling point than $\mathrm{PH_3}$ because of the intermolecular hydrogen bonding present in $\mathrm{NH_3}$.

c. For (c) most answers given here showed diagrams of the three molecules, including distribution of charges, bonding and shapes. Some candidates gave very good answers showing a good understanding of the polarity of molecules.

Boron is most often encountered as a component in borosilicate glass (heat resistant glass).

The naturally occurring element contains two stable isotopes, ${}^{10}_{5}\mathrm{B}$ and ${}^{11}_{5}\mathrm{B}$.

a. State the number of protons, neutrons and electrons in an atom of ${}^{11}_{5}\mathrm{B}$. [1]

	Protons	Neutrons	Electrons
${}^{11}_{5}\mathrm{B}$			

b. The relative atomic mass of boron is 10.8, to three significant figures. Calculate the percentage of ${}^{10}_{5}\mathrm{B}$ in the naturally occurring element. [2]

c. Isotopes of boron containing 7 and 8 neutrons also exist. Suggest why releasing isotopes containing more neutrons than the stable isotope into the environment can be dangerous. [1]

d. (i) State the formula of the compound that boron forms with fluorine. [3]

(ii) Explain why this compound acts as a Lewis acid.

Markscheme

a.

	Protons	Neutrons	Electrons
${}^{11}_{5}\mathrm{B}$	5	6	5

;

b. $10x + 11(100 - x) = 10.8 \times 100$;

$(x =)20\%$;

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

Do not allow ECF.

c. radioactive/radioisotope(s)/give out radiation;

Accept answers that outline the effects of radioactive pollution of the environment.

Do not accept “unstable”.

d. (i) BF_3;

(ii) incomplete valence shell / electron deficient / *OWTTE*;

capable of accepting an electron pair;

Examiners report

a. This question in general was well answered. Most candidates were able to identify the elementary particles of atomic boron with an encouraging number of students calculating the proportions of the two isotopes. A significant number did leave the question blank however although it should be a familiar example. Most candidates were able to state the formula of boron trifluoride and describe the action of Lewis acids although only a minority could explain its behaviour in terms of boron’s incomplete octet.

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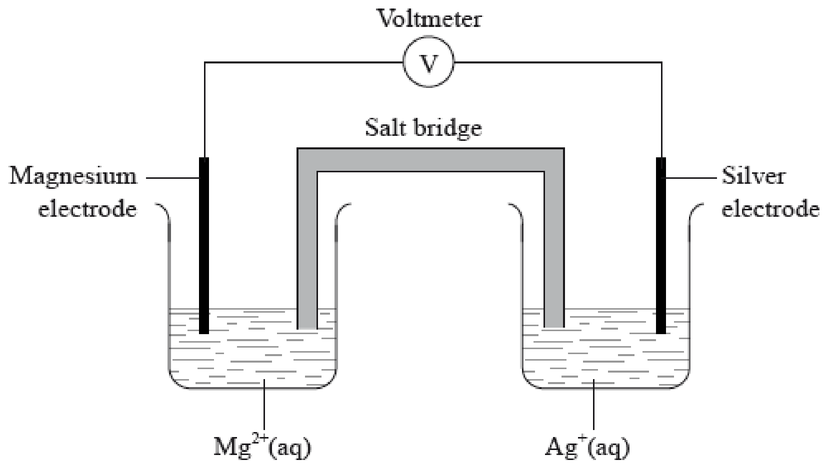
Iron rusts in the presence of oxygen and water. Rusting is a redox process involving several steps that produces hydrated iron(III) oxide, $Fe_2O_3 \bullet nH_2O$, as the final product.

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

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

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

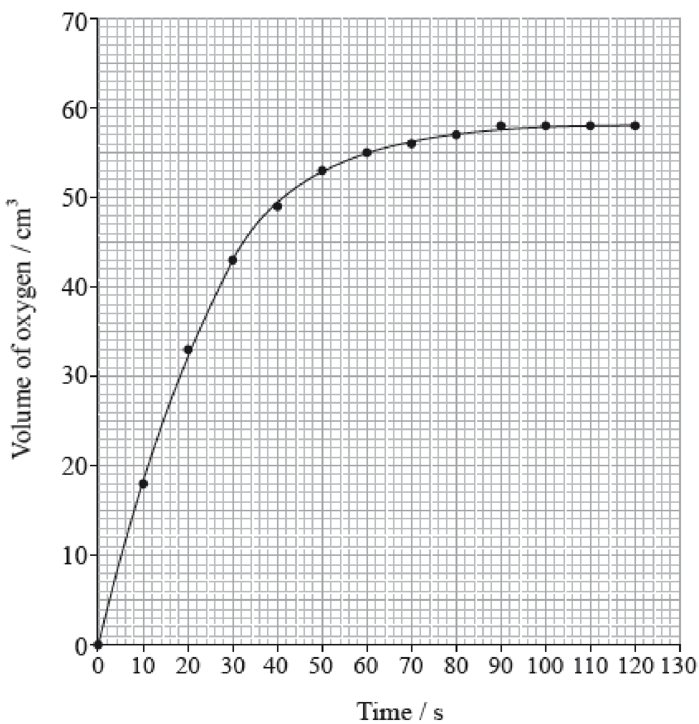
A voltaic cell is made from a half-cell containing a magnesium electrode in a solution of magnesium nitrate and a half-cell containing a silver electrode in a solution of silver(I) nitrate.



Hydrogen peroxide decomposes according to the equation below.

$$2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$$

The rate of the decomposition can be monitored by measuring the volume of oxygen gas released. The graph shows the results obtained when a solution of hydrogen peroxide decomposed in the presence of a CuO catalyst.



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. (i) Given that magnesium is more reactive than silver, deduce the half-equations for the reactions occurring at each electrode, including state symbols. [3]

Negative electrode (anode):

Positive electrode (cathode):

(ii) Outline **one** function of the salt bridge.

d. (i) State the property that determines the order in which elements are arranged in the periodic table. [3]

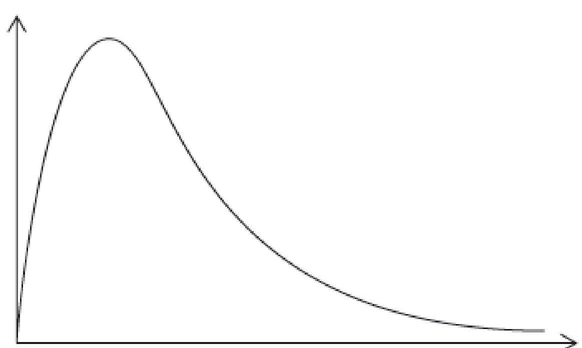
(ii) State the relationship between the electron arrangement of an element and its group and period in the periodic table.

e. (i) The experiment is repeated with the same amount of a more effective catalyst, MnO_2, under the same conditions and using the same concentration and volume of hydrogen peroxide. On the graph above, sketch the curve you would expect. [7]

(ii) Outline how the initial rate of reaction can be found from the graph.

(iii) Outline a different experimental procedure that can be used to monitor the decomposition rate of hydrogen peroxide.

(iv) A Maxwell–Boltzmann energy distribution curve is drawn below. Label both axes and explain, by annotating the graph, how catalysts increase the rate of reaction.



Markscheme

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

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

0 I −II −II I

*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. oxygen is non-polar;

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. (i) *Negative electrode (anode):*

$Mg(s) \rightarrow Mg^{2+}(aq) + 2e^- / \frac{1}{2}Mg(s) \rightarrow \frac{1}{2}Mg^{2+}(aq) + e^- /$

$Mg(s) - 2e^- \rightarrow Mg^{2+}(aq) / \frac{1}{2}Mg(s) - e^- \rightarrow \frac{1}{2}Mg^{2+}(aq)$;

Accept equations for the oxidation of water/hydroxide ions.

Positive electrode (cathode):

$Ag^+(aq) + e^- \rightarrow Ag\ (s)$;

Accept Ag equation doubled so that both electrodes involve 2 electrons.

Accept e instead of e⁻.

*Award **[1 max]** if both equations are correct but the state symbols are missing/incorrect.*

*Award **[1 max]** if both equations are reversed but state symbols correct.*

(ii) provides ions that flow into electrolytes/half-cells / maintains electrical neutrality of solutions/electrolytes / provides electrical continuity by providing path for migrating ions;

Accept completes the (electrical) circuit / allows current to flow / OWTTE.

d. (i) atomic number / number of protons;

Accept number of electrons in a (neutral) <u>atom</u>.

(ii) 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);

e. (i) steeper curve with a similar shape that reaches same maximum volume of O_2;

(ii) (draw a) tangent to the curve at origin/time = 0/start of reaction;

(calculate) the gradient/slope (of the tangent);

(iii) measure/monitor mass/pressure/$[H_2O_2]$;

Accept measure/monitor temperature of system.

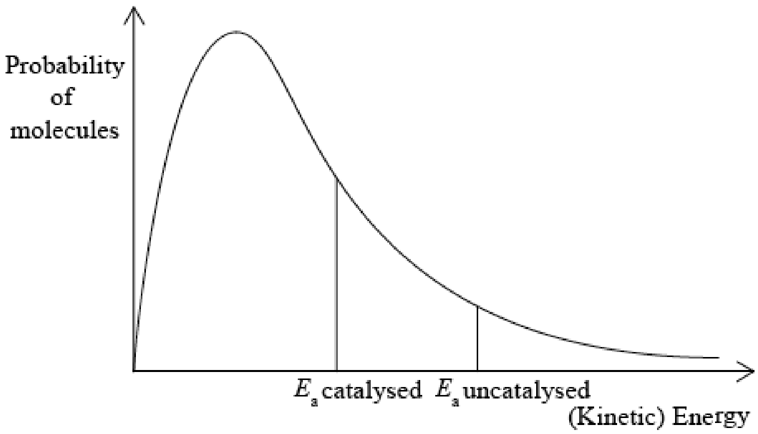
(iv) *y-axis*: probability / fraction of molecules/particles / probability density

Allow "number of particles/molecules" on y-axis.

and

x-axis: (kinetic) energy;

Accept “speed/velocity” on x-axis.



correct relative position of E_a catalysed and E_a uncatalysed;

more/greater proportion of molecules/collisions have the lower/required/catalysed E_a (and can react upon collision);

M3 can be scored by shading and annotating the graph.

Accept a greater number/proportion of successful collisions as catalyst reduces E_a.

Examiners report

a. In Part (a) almost all candidates could correctly identify the equation as an oxidation reaction and justify their choice. Assigning oxidation numbers to particular species proved slightly trickier, with many not knowing that elements always have an oxidation state of zero.

Combining the half equations also provided a bit of challenge with many equations having residual electrons, though most students could correctly identify the reducing agent. The aqueous solubility of oxygen gas in Part (b) was poorly explained, with the discussion being most frequently in terms of polarity rather than invoking hydrogen bonding. The electrolysis question in Part (c) was generally well answered, though most relied on “completing the circuit” to obtain the salt bridge mark with few showing any comprehension of the way in which this was achieved. Both the property responsible for the ordering of the periodic table and the relationship of electronic structure to position in the periodic table, required for Part (d), were well known and it was rare for a student not to gain full marks. Similarly in Part (e), most students correctly drew the curve that would result from a more effective catalyst. Many also seemed to be aware of the basic idea of how to find the reaction rate, though correct use of the terms “tangent” and “gradient” was rare and many failed to note it referred to “initial rate”. Most students could also identify an appropriate alternative method for monitoring the rate. In the final section most students could accurately label the axes of a Maxwell-Boltzmann curve and many could also use it to explain the effect of a catalyst, though some weaker students confused this with the effect of temperature and constructed a second curve.

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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.

Phosphorus(V) oxide, $\mathrm{P_4O_{10}}$ $(M_\mathrm{r} = 283.88)$, reacts vigorously with water $(M_\mathrm{r} = 18.02)$, according to the equation below.

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

a.i. Calculate the relative atomic mass of this sample of magnesium correct to **two** decimal places. [2]

a.iii Predict the relative atomic radii of the three magnesium isotopes, giving your reasons. [2]

b. Describe the bonding in magnesium. [2]

c. State an equation for the reaction of magnesium oxide with water. [1]

d.i. A student added 5.00 g of P_4O_{10} to 1.50 g of water. Determine the limiting reactant, showing your working. [2]

d.ii. Calculate the mass of phosphoric(V) acid, H_3PO_4, formed in the reaction. [2]

d.iii. State a balanced equation for the reaction of aqueous H_3PO_4 with excess aqueous sodium hydroxide, including state symbols. [2]

d.iv. State the formula of the conjugate base of H_3PO_4. [1]

e. (i) Deduce the Lewis structure of PH_4^+. [4]

(ii) Predict, giving a reason, the bond angle around the phosphorus atom in PH_4^+.

(iii) Predict whether or not the P–H bond is polar, giving a reason for your choice.

Markscheme

a.i. $\left(\frac{(77.44\times24)+(10.00\times25)+(12.56\ 26)}{100}\right)$;

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).

a.iii. 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. (lattice of) positive ions/cations **and** mobile/free/delocalized electrons;

Accept "sea of electrons" instead of "delocalized electrons".

Award M1 for a suitable diagram.

electrostatic attraction (between ions and delocalized electrons);

c. $MgO + H_2O \rightarrow Mg(OH)_2/Mg^{2+} + 2OH^-$;

Accept reversible arrow.

d.i. P_4O_{10}: $\left(\frac{5.00}{283.88} =\right)$ 0.0176 (mol) **and** H_2O: $\left(\frac{1.50}{18.02} =\right)$ 0.0832 (mol);

H_2O is the limiting reactant **and** reason related to stoichiometry;

d.ii. $\frac{0.0832\times4}{6}$/0.0555 (mol);

$(0.0555 \times 98.00 =)$ 5.44 g;

The unit is needed for M2.

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

Do not penalize slight numerical variations due to premature rounding.

d.iii. $H_3PO_4(aq) + 3NaOH(aq) \rightarrow Na_3PO_4(aq) + 3H_2O(l)$

correct products and balancing;

correct state symbols;

Accept valid ionic equations.

d.iv. $H_2PO_4^-$;

e.

(i)  ;

Accept dots, crosses or lines for pairs of electrons.

No need to distinguish the dative covalent bond from the other bonds.

Charge is required for the mark.

Do not penalize missing square brackets.

(ii) $109^\circ 27' / 109.5^\circ / 109^\circ$;

4 electron domains/pairs/(negative) charge centres (around central atom/P);

Accept ion is tetrahedral / electron pairs/domains repel each other.

(iii) non-polar **and** P and H have the same electronegativity / *OWTTE*;

Accept slightly polar as precise electronegativities of P and H are not identical / OWTTE.

Examiners report

a.i. In Part (a) most candidates gained full marks, with the most common error being a failure to quote the answer to the precision specified, but the explanations of deflection, and more particularly detection, in the mass spectrometer were weak. The prediction of relative atomic radii of the isotopes, something that required the application of reason rather than recall, also proved much more challenging. Part (b) revealed that many candidates have a very weak understanding of the metallic bond with many thinking the bonding was ionic.

Even when they knew about a cation lattice and delocalized electrons, a mark was frequently dropped by failing to specify that the attraction between them was electrostatic. Most candidates wrote the correct equation in Part (c), but it is still disturbing that some students at this level cannot write even the most straightforward chemical equation. In Part (d) many students proved capable of carrying out routine stoichiometric calculations to identify the limiting reactant and use the result to find the mass of the product.

Even if the final result was incorrect quite frequently students gained some credit through the application of ECF. Only the better candidates could write an equation for the neutralisation of phosphoric(V) acid and even the routine derivation of a conjugate base from the formula of the acid proved difficult for many. In Part (e) most students could manage the correct Lewis structure, though some lost the mark through omitting the charge. Many candidates also scored well on the shape of the ion and the polarity of the P-H bond.

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Even when they knew about a cation lattice and delocalized electrons, a mark was frequently dropped by failing to specify that the attraction between them was electrostatic. Most candidates wrote the correct equation in Part (c), but it is still disturbing that some students at this level cannot write even the most straightforward chemical equation. In Part (d) many students proved capable of carrying out routine stoichiometric calculations to identify the limiting reactant and use the result to find the mass of the product.

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

a.i. Define the term *isotopes of an element*. [1]

a.ii. Calculate the percentage abundance of **each** isotope, given that the relative atomic mass of B is 10.81. [2]

c.i. Deduce the Lewis structures of NH_3 and BF_3. [2]

NH_3 BF_3

c.ii. Describe how covalent bonds are formed. [1]

c.iii. Compare the shapes of the two molecules and explain the difference using valence shell electron pair repulsion theory (VSEPR). [4]

c.iv. Predict and explain whether the molecules NH_3 and BF_3 are polar molecules. [2]

Markscheme

a.i. atoms of the same element/with the same number of protons/with same atomic

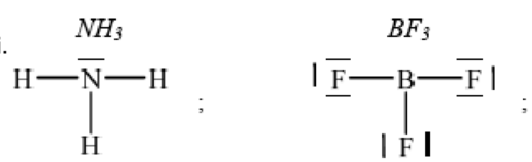
number but different number of neutrons/mass number/mass;

a.ii. $10x + 11(1 - x) = 10.81,\ x = 0.19$;

Accept similar method.

^{10}B: 19% **and** *^{11}B:* 81%;

c.i.



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

c.ii. sharing of electrons between atoms;

c.iii. NH_3*:* (trigonal/triangular) pyramidal;

BF_3*:* trigonal/triangular planar;

NH_3 has 4 negative centres of charge/three bonding pairs and one lone pair **and** BF_3 has 3 negative centres of charge/three bonding pairs / *OWTTE*;

(bond angles) 107° in NH_3 **and** 120° in BF_3;

Accept 107.5° for NH_3.

c.iv. BF_3 not polar as no net dipole moment / BF bond polarities cancel each other out / symmetrical distribution of charge;

NH_3 polar as net dipole moment present / NH bond polarities do not cancel each other out / unsymmetrical distribution of charge;

Accept suitable diagram showing dipole moments.

Do not accept electronegativities cancel out.

Examiners report

a.i. Few candidates defined isotopes in terms of atoms.

a.ii. The percentage abundance was generally done well.

c.i. The Lewis structure of NH_3 was well answered, though many forgot the non-bonding electron pairs of fluorine.

c.ii. The covalent bond was often just described as electron sharing between non-metals.

c.iii. Shapes of molecules and angles were often well known, but the explanation using the VSEPR theory was very weak, with many students not being able to describe the bonding and lone pairs in terms of negative charge centres.

c.iv. Polarity was very poorly understood, with almost no candidates actually talking about polarity of bonds or showing an understanding of the impact of symmetry on the overall dipole moment.

Lithium and boron are elements in period 2 of the periodic table. Lithium occurs in group 1 (the alkali metals) and boron occurs in group 3. Isotopes exist for both elements.

Every element has its own unique line emission spectrum.

a. (i) Define the terms *atomic number*, *mass number* and *isotopes of an element*. [10]

Atomic number:

Mass number:

Isotopes of an element:

(ii) Distinguish between the terms *group* and *period*.

(iii) Deduce the electron arrangements of the lithium ion, Li^+, and the boron atom, B.

Li^+:

B:

(iv) Naturally occurring boron exists as two isotopes with mass numbers of 10 and 11. Calculate the percentage abundance of the lighter isotope, using this information and the relative atomic mass of boron in Table 5 of the Data Booklet.

v) Lithium exists as two isotopes with mass numbers of 6 and 7. Deduce the number of protons, electrons and neutrons for each isotope.

Mass number (A)	Number of protons	Number of electrons	Number of neutrons
6			
7			

b. (i) Distinguish between a *continuous spectrum* and a *line spectrum*. [6]

(ii) Draw a diagram to show the electron transitions between energy levels in a hydrogen atom that are responsible for the two series of lines in the ultraviolet and visible regions of the spectrum. Label your diagram to show **three** transitions for each series.

c. (i) Explain why metals are good conductors of electricity and why they are malleable. [4]

(ii) Iron is described as a transition metal. Identify the **two** most common ions of iron.

iii) Deduce the chemical formulas of lithium oxide and iron(II) oxide.

Lithium oxide:

Iron(II) oxide:

Markscheme

a. (i) *Atomic number*:

number of protons (in nucleus/atom);

Mass number:

(sum of) number of protons **and** neutrons (in nucleus/atom);

Isotopes of an element:

atoms of same element / atoms with same number of protons/atomic number/Z but different number of neutrons/mass number/*A*;

Penalize once only use of the term element in the three definitions, for example, number of protons in an element or number of protons and neutrons in an element or element with the same atomic number but different mass number.

(ii) *Group*: (elements in vertical) columns in periodic table **and** *Period*: (elements in horizontal) rows in periodic table;

Allow elements in same group have similar chemical properties ***and*** *within a period, atoms have same number of shells/energy levels (but number of electrons in valence/outer shell increases).*

Allow groups distributed vertically ***and*** *periods distributed horizontally / OWTTE.*

Allow group number gives number of valence/outer shell electrons (for maingroup elements) ***and*** *period gives same number of shells/energy levels.*

(iii) *Li^+:* $2/1s^2$;

B: $2,3/1s^2 2s^2 2p^1$;

(iv) correct mathematical expression set-up (e.g. $\left(\frac{x}{100}\right)(10)+\left[\frac{(100-x)}{(100)}\right](11)=10.81$);

19%;

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

(v)

Mass number (A)	Number of protons	Number of electrons	Number of neutrons
6	3	3	3 ;
7	3	3	4 ;

*Award **[1 max]** for correct number of neutrons for both isotopes if numbers of protons or electrons is not given.*

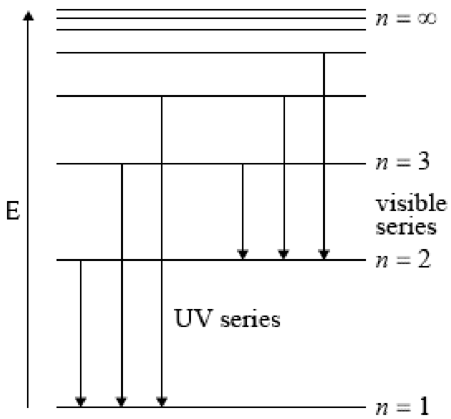
*Award **[1 max]** for correct number of protons and electrons for both isotopes if number of neutrons is not given or if numbers of neutrons are incorrect.*

b. (i) *Continuous spectrum:* radiation spread over all wavelengths/frequencies/energies/colours / *OWTTE*;

Line spectrum: radiation (absorbed/emitted) at certain/specific wavelengths/frequencies/energies/colours / *OWTTE*;

Allow series of (separate/discrete) lines which converge/get closer together at high energy / OWTTE.

(ii)



showing *y*-axis labelled as energy/E **or** labelling at least two energy levels

($n = 1, n = 2$ *etc*. but not for $n = 0$);

showing energy levels converging;

showing jumps to $n = 1$ for ultraviolet series;

showing jumps to $n = 2$ for visible series;

UV and visible must be labelled.

c. (i) metals have delocalized electrons / sea of electrons which are mobile/can move / *OWTTE*;

layers/positive ions/cations/atoms slide past/over each other / *OWTTE*;

Do not accept nuclei for M2.

(ii) Fe^{2+} **and** Fe^{3+} ;

(iii) *Lithium oxide*: Li_2O **and** *Iron(II) oxide*: FeO;

Examiners report

a. Many candidates defined the atomic number, mass number and isotopes correctly although the weaker candidates incorrectly used the term element instead of atom and others defined mass number in terms of molar mass instead of sum of protons and neutrons in the nucleus. Distinguishing between a group and a period and deducing the electron arrangements of Li^+ and boron was handled well by majority of candidates. Many candidates struggled to calculate the percentage abundance of the lighter isotope whereas in part (v), most candidates correctly deduced the number of protons, neutrons and electrons in the two isotopes of lithium.

b. Distinguishing between a continuous and line spectrum in part (b) proved difficult for many candidates. Similarly, drawing a diagram to show the electron transitions between energy levels in a hydrogen atom was challenging for many candidates. Common errors seen were: starting incorrectly at $n = 0$, not showing convergence or mixed up between the ultraviolet and visible lines.

c. In Part (c), although the explanation of why metals are good conductors of electricity was answered well, some candidates did not refer to delocalized or sea of electrons. Explanation of why metals are malleable proved to be difficult for many candidates. Identifying the two most common ions of iron and deducing chemical formulas was correctly answered by majority of the candidates.

Iron has three main naturally occurring isotopes which can be investigated using a mass spectrometer.

b. A sample of iron has the following isotopic composition by mass. [2]

Isotope	^{54}Fe	^{56}Fe	^{57}Fe
Relative abundance / %	5.95	91.88	2.17

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

c. Calculate the number of electrons in the ion $^{56}Fe^{2+}$. [1]

d. Describe the bonding in iron and explain the electrical conductivity and malleability of the metal. [4]

Markscheme

b. $\frac{(54 \times 5.95)+(56 \times 91.88)+(57\ 2.17)}{100}$;

55.90;

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

Answer must be to 2 d.p.

c. 24;

d. metallic (bonding);

positive ions/cations **and** delocalized/sea of electrons;

electrostatic attraction between the two;

*Award **[2 max]** for description of bonding*

Conductivity:

electrons delocalised/free to move;

Malleability:

atoms/ions/cations can move without breaking bonds / atoms/ions/cations can slide past each other;

Examiners report

b. Most candidates could correctly calculate the relative atomic mass although a few lost a mark by giving their answers to 1 or 3 decimal places.

c. Most candidates correctly calculated the number of electrons, but the most frequent incorrect answers were 28 and 54.

d. The explanation of iron"s properties was well answered in terms of metallic bonding and most candidates correctly described its electrical conductivity as due to free flowing electrons. However, only a few could explain malleability in terms of the layers of ions being able to slide over each other.

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c. The relative atomic mass of naturally occurring copper is 63.55. Calculate the abundances of $^{63}\mathrm{Cu}$ and $^{65}\mathrm{Cu}$ in naturally occurring copper. [2]

d. The isotopes of some elements are radioactive. State a radioisotope used in medicine. [1]

e. State a balanced equation for the reaction of sodium with water. Include state symbols. [2]

f. With reference to electronic arrangements, suggest why the reaction between rubidium and water is more vigorous than that between sodium and water. [2]

g. Describe and explain what you will see if chlorine gas is bubbled through a solution of [3]

(i) potassium iodide.

(ii) potassium fluoride.

Markscheme

c. $63x + 65(1 - x) = 63.55$;

(or some other mathematical expression).

$^{63}\mathrm{Cu} = 72.5\%$ **and** $^{65}\mathrm{Cu} = 27.5\%$;

*Allow ^{63}Cu = 0.725 **and** ^{65}Cu = 0.275.*

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

d. ^{60}Co /^{131}I /^{125}I;

Must contain correct mass numbers.

Allow other formats such as cobalt-60, Co-60 etc.

Award no marks if a correct radioisotope is given with an incorrect radioisotope.

Allow any other radioisotope if you can verify its use.

e. $2\mathrm{Na(s)} + 2\mathrm{H_2O(l)} \rightarrow 2\mathrm{NaOH(aq)} + \mathrm{H_2(g)}$ / $\mathrm{Na(s)} + \mathrm{H_2O(l)} \rightarrow \mathrm{NaOH(aq)} + \frac{1}{2}\mathrm{H_2(g)}$

*Award **[1]** for correct balanced equation.*

*Award **[1]** for correct state symbols for sodium, water, sodium hydroxide and hydrogen.*

Second mark is not dependent on equation being correctly balanced.

f. (Rb more reactive because) electron lost further from nucleus so less tightly held;

Rb electron is in 5th energy level **and** (Na less reactive) as electron lost in 3rd energy level / *OWTTE*;

*Allow **[1 max]** for electron arrangements of Na (e.g. 2,8,1) and Rb if second mark is not scored.*

g. (i) solution becomes yellow/orange/brown/darker;

chlorine is more reactive than iodine (and displaces it from solution) / *OWTTE*;

Allow correct equation ($KI + Cl_2 \rightarrow KCl + I_2$) for second mark or stating that iodine/I_2 is formed.

(ii) no colour change/nothing happens as fluorine is more reactive than chlorine / *OWTTE*;

Examiners report

c. Candidates who knew how to calculate the abundances of Cu-63 and Cu-65 generally scored full marks, but many had no idea at all on how to approach the question in (c).

d. Surprisingly very few candidates were able to state a radioisotope used in medicine. C-13 and C-14 were often given and sometimes elements were suggested but with no specified mass number.

e. Approximately 25% of candidates got the equation mark, but many gave incorrect state symbols. A significant number of candidates wrote equations with the formation of Na_2O or even atomic H.

f. Some of the weaker candidates explained the reactivity by referring to the change in reactivity down group 1 with no further explanation. Many referred to the increased number of shells in Rb or the increased distance the valence electron is from the nucleus, but some did not go on to explain that this affected its attraction/ease of loss. Very few candidates scored the marks for reference to valence electrons being in the third and fifth shells respectively.

g. The colour change in (i) was usually known. There was rarely any explanation in (ii) as to why there is no observable reaction with the fluoride.

Calcium carbide, CaC_2, is an ionic solid.

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

b. State the electron configuration of the Ca^{2+} ion. [1]

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. 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.

Markscheme

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

[1 mark]

b. $1s^22s^22p^63s^23p^6$

OR

[Ar]

[1 mark]

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. pH > 7

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

[1 mark]

Examiners report

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

^{131}I is a radioactive isotope of iodine.

a.i. Define the term *isotope*. [1]

a.ii. Determine the number of neutrons in one atom of iodine-131. [1]

Markscheme

a.i. atoms which have same atomic number but different mass number / atoms of the same element which have different numbers of neutrons / atoms with the same number of protons but different numbers of neutrons / atom of an element with a fixed number of protons but a number of neutrons which can be variable;

a.ii. 78;

Examiners report

a.i. In (a)(i), the word *atoms* was frequently omitted from the definition; it is accepted that it would have been preferable to ask for the definition of *isotopes of an element* as specified in the syllabus.

a.ii. The answer in (ii) was generally correct.

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.

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 $108\ g\ mol^{-1}$.

a. Draw the structure of 2-methylbut-2-ene. [1]

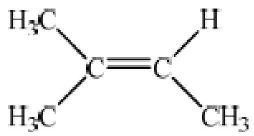
b. State the other substances required to convert 2-methylbut-2-ene to 2-methylbutan-2-ol. [2]

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

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

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

Markscheme

a.  / $(CH_3)_2C{=}CH{-}CH_3$;

Accept condensed formula such as $(CH_3)_2CCHCH_3$.

b. water/H_2O;

Accept steam.

(concentrated) sulfuric acid/H_2SO_4 (catalyst);

Accept phosphoric acid/H_3PO_4.

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

c. not react;

tertiary alcohol (not easily oxidized);

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 H-bonds (to water) / 2-methylbut-2-ene cannot form H-bonds (to water);

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.

Examiners report

a. This was the second most popular question answered in Section B. This question was focussed on organic chemistry and attempted by many candidates.

Most candidates were able to draw the correct structure of 2-methylbut-2-ene in part (a). In part (b), water and sulfuric acid were stated correctly as the reagents. In part (c), most candidates knew that tertiary alcohols do not react. In part (d), the most common mistake was some candidates thinking that the hydroxyl group in an alcohol was a hydrogen bond. Some other candidates could not write that the alcohol forms hydrogen bonds with water. In part (e), many candidates got S_N1, though an odd few candidates identified the mechanism as S_N2. In part (e) (ii), the mechanisms proved a problem for several candidates. The use of curly arrows in reaction mechanisms continues to be poorly understood, the arrow often pointing in the wrong direction. Candidates must take care to accurately draw the position of the curly arrows illustrating the movement of electrons. Some candidates forgot to include the lone pair for the curly arrow going from the lone pair on O to C^+. Some candidates had the lone pair incorrectly located on the H and others had the curly arrow going to an atom instead of between the O and the C^+. Part (iii) was well answered.

Part (f) proved challenging for candidates and very few referred to chlorines isotopes. In addition, the majority of candidates did not state that the same rate could be applied as the isotopes have the same chemical properties. In part (g), many candidates scored three out of five marks. Some candidates forgot to state that the sample is converted to the gaseous state for the vaporization stage. Many candidates although knew about detection but only few stated that the ions hit the counter and an electrical signal is generated.

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Part (f) proved challenging for candidates and very few referred to chlorines isotopes. In addition, the majority of candidates did not state that the same rate could be applied as the isotopes have the same chemical properties. In part (g), many candidates scored three out of five marks. Some candidates forgot to state that the sample is converted to the gaseous state for the vaporization stage. Many candidates although knew about detection but only few stated that the ions hit the counter and an electrical signal is generated.

d. This was the second most popular question answered in Section B. This question was focussed on organic chemistry and attempted by many

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Rubidium contains two stable isotopes, $^{85}\mathrm{Rb}$ and $^{87}\mathrm{Rb}$. The relative atomic mass of rubidium is given in Table 5 of the Data Booklet.

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

c. State the number of electrons and the number of neutrons present in an atom of $^{87}\mathrm{Rb}$. [2]

Number of electrons:

Number of neutrons:

Markscheme

a. (let $x = \text{fraction of } ^{85}\mathrm{Rb}$)

$\frac{(x\times85)+[(100-x)\times87]}{100} = 85.47$;

$^{85}\mathrm{Rb} = 76.5\%$ **and** $^{87}\mathrm{Rb} = 23.5\%$;

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

c. 37 (electrons);

50 (neutrons);

Examiners report

a. This question was answered very well by those that knew the correct mathematical technique; however some candidates did not have any idea how to tackle this problem.

c. The vast majority of candidates could correctly state the number of electrons and neutrons present in Rubidium- 87.

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

Deduce the missing information and complete the following table.

Symbol	$^{59}Co^{3+}$	^{60}Co	
Number of protons	27		53
Number of neutrons		33	72
Number of electrons		27	53

Markscheme

Symbol	$^{59}Co^{3+}$	^{60}Co	^{125}I
Number of protons	27	27	53
Number of neutrons	32	33	72
Number of electrons	24	27	53

*Award **[2]** for all four correct.*

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

Examiners report

This was generally well answered and sub-atomic particles were well known although some gave 53 instead of 125 and Co was often given instead of I.

Chlorine occurs in Group 7, the halogens.

Two stable isotopes of chlorine are ^{35}Cl and ^{37}Cl with mass numbers 35 and 37 respectively.

Chlorine has an electronegativity value of 3.2 on the Pauling scale.

Chloroethene, $H_2C{=}CHCl$, the monomer used in the polymerization reaction in the manufacture of the polymer poly(chloroethene), PVC, can be synthesized in the following two-stage reaction pathway.

$$\text{Stage 1:} \quad C_2H_4(g) + Cl_2(g) \rightarrow ClCH_2CH_2Cl(g)$$
$$\text{Stage 2:} \quad ClCH_2CH_2Cl(g) + HC{=}CHCl(g) + HCl(g)$$

a.i. Define the term *isotopes of an element*. [2]

a.ii. Calculate the number of protons, neutrons and electrons in the isotopes ^{35}Cl and ^{37}Cl. [2]

Isotope	Number of protons	Number of neutrons	Number of electrons
^{35}Cl			
^{37}Cl			

a.iii Using the mass numbers of the two isotopes and the relative atomic mass of chlorine from Table 5 of the Data Booklet, determine the percentage abundance of each isotope. [2]

Percentage abundance ^{35}Cl:

Percentage abundance ^{37}Cl:

b.i. Define the term *electronegativity*. [1]

b.ii. Using Table 7 of the Data Booklet, explain the trends in electronegativity values of the Group 7 elements from F to I. [2]

b.iii. State the balanced chemical equation for the reaction of potassium bromide, KBr(aq), with chlorine, Cl_2(aq). [1]

b.iv. Describe the colour change likely to be observed in this reaction. [1]

c.ii. Determine the enthalpy change, ΔH, in kJ mol^{-1}, for stage 1 using average bond enthalpy data from Table 10 of the Data Booklet. [3]

c.iii. State whether the reaction given in stage 1 is exothermic or endothermic. [1]

c.iv. Draw the structure of poly(chloroethene) showing **two** repeating units. [1]

c.v. Suggest why monomers are often gases or volatile liquids whereas polymers are solids. [2]

Markscheme

a.i. <u>atoms</u> of same element / atoms with same number of protons/atomic number/Z;

Do not allow elements instead of atoms in second alternative.

(but) different numbers of neutrons/mass number/*A*;

a.ii.

Isotope	Number of protons	Number of neutrons	Number of electrons	
^{35}Cl	17	18	17	;
^{37}Cl	17	20	17	;

*Allow **[1 max]** for 17 p, 17 e for both if n's are omitted or incorrect.*

*Allow **[1 max]** for ^{35}Cl: 18 n **and** ^{37}Cl: 20 n if p's and e's are omitted.*

a.iii. $(\text{for } ^{35}\text{Cl} : x\%)\ 35x + 3700 - 37x = 3545$;

Allow other alternative mathematical arrangements.

$^{35}\text{Cl} = 77.5\%$ **and** $^{37}\text{Cl} = 22.5\%$;

*Award **[1 max]** for correct percentages if no correct working is shown.*

b.i. ability of atom/nucleus to attract bonding/shared pair of electrons / attraction of nucleus for bonding/shared pair of electrons / *OWTTE*;

Do not allow element instead of atom/nucleus.

b.ii. increasing atomic radii (down the group) / *OWTTE*;

so reduced attraction (for the bonding electrons) / *OWTTE*;

screening/shielding effect of inner electrons / *OWTTE*;

Allow more energy levels/electron shells for M1.

Do not accept decrease in nuclear charge.

b.iii. $2\text{KBr(aq)} + \text{Cl}_2\text{(aq)} \rightarrow 2\text{KCl(aq)} + \text{Br}_2\text{(aq)}$;

Ignore state symbols.

Allow ionic equation.

b.iv colourless/pale yellow/green to yellow/orange/brown;

Start and end colours must both be mentioned.

c.ii *Bonds breaking*:

1 × (C=C) + 4 × (C–H) + 1 × (Cl–Cl)

$= (1)(612) + (4)(413) + (1)(243) / = (+)2507 \text{ (kJ mol}^{-1}\text{)};$

Bonds forming:

1 × (C–C) + 4 × (C–H) + 2 × (Cl–Cl)

$= (1)(347) + (4)(413) + (2)(346) / = -2691 \text{ (kJ mol}^{-1}\text{)};$

Enthalpy change:

$(2507 - 2691 =) \; -184 \text{ (kJ mol}^{-1}\text{)};$

OR

Bonds breaking:

1 × (C=C) + 1 × (Cl–Cl)

$= (1)(612) + (1)(243) / = (+)855 \text{ (kJ mol}^{-1}\text{)};$

Bonds forming:

1 × (C–C) + 2 × (C–Cl)

$= (1)(347) + (2)(346) / = -1039 \text{ (kJ mol}^{-1}\text{)};$

Enthalpy change:

$(855 - 1039 =) \; -184 \text{ (kJ mol}^{-1}\text{)};$

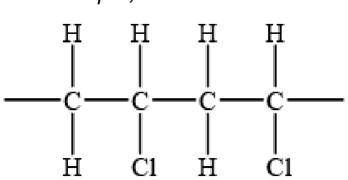
*Award **[3]** for correct final answer*.

c.iii exothermic;

Do not award mark unless based on some value for part (iii).

c.iv representation of PVC showing two repeating units;

For example,



Brackets not necessary but continuation bonds must be given.

No penalty if chlorines are not on same side.

No penalty if chlorines are on two middle C atoms or on two end C atoms.

c.v. monomers are smaller molecules / monomers have smaller mass / smaller surface area than polymers;

weaker/fewer intermolecular/London/dispersion/van der Waals’ forces (of attraction);

Allow reverse argument.

Allow abbreviation for London/dispersion as FDL or for van der Waals’ as vdW.

Award zero if reference is made to breaking of bonds.

Examiners report

a.i. This was by far the most popular choice of question in Section B. Again, part a) (i) proved challenging as many candidates failed to refer to atoms in their definition and scored only 1 mark out of 2.

a.ii. In a) (ii) most candidates could state the numbers of protons, neutrons and electrons in the isotopes of chlorine. Those who got this wrong gave answers which indicated a complete lack of understanding of atomic structure.

a.iii. In a) (iii) some candidates remembered the percentage abundance of chlorine isotopes but could not do the calculation.

b.i. Part b) (i) required another definition. Again, many candidates lost marks for inarticulate responses.

b.ii. The explanation in b) (ii) of trends in electronegativity values was reasonably well done, with most candidates scoring at least one mark out of two.

b.iii. However, writing a balanced equation in b) (iii) was poorly done with many candidates not knowing the formula of KCl, and not knowing what products would be formed. This is clearly on the syllabus in 3.3.1.

b.iv. Almost no-one knew the colours of aqueous chlorine and aqueous bromine in b) (iv).

c.ii. In part c) (ii) the calculation of ΔH using bond enthalpies was done well. Some candidates failed to use the C=C bond enthalpy value and some did not recall that bond breaking is endothermic and bond formation exothermic.

c.iii. Nearly everyone scored a mark in c) (iii) as follow-through marks were awarded.

c.iv. Drawing two repeating units of poly(chloroethene) presented difficulties in c) (iv). Some candidates tried to draw the monomers joined through the chlorine atoms.

c.v. In c) (v) most candidates scored at least one out of two for explaining why monomers have a much lower melting point than polymers.

Carbon and silicon belong to the same group of the periodic table.

Both silicon and carbon form oxides.

b. State the period numbers of both carbon and silicon. [1]

c. Describe and compare **three** features of the structure and bonding in the three allotropes of carbon: diamond, graphite and C_{60} fullerene. [6]

d.i. Draw the Lewis structure of CO_2 and predict its shape and bond angle. [2]

d.ii. Describe the structure and bonding in SiO_2. [2]

d.iii. Explain why silicon dioxide is a solid and carbon dioxide is a gas at room temperature. [2]

e. Describe the bonding within the carbon monoxide molecule. [2]

f. Silicon has three stable isotopes, ^{28}Si, ^{29}Si and ^{30}Si. The heaviest isotope, ^{30}Si, has a percentage abundance of 3.1%. Calculate the percentage abundance of the lightest isotope to one decimal place. [2]

Markscheme

b. C: 2 **and** Si: 3;

c. *Award **[2 max]** for three of the following features:*

Bonding

*Graphite **and** C_{60} fullerene:* covalent bonds **and** van der Waals'/London/dispersion forces;

Diamond: covalent bonds (and van der Waals'/London/dispersion forces);

Delocalized electrons

*Graphite **and** C_{60} fullerene:* delocalized electrons;

Diamond: no delocalized electrons;

Structure

Diamond: network/giant structure / macromolecular / three-dimensional structure **and** *Graphite:* layered structure / two-dimensional structure / planar;

C_{60} fullerene: consists of molecules / spheres made of atoms arranged in hexagons/pentagons;

Bond angles

Graphite: 120° **and** *Diamond:* 109°;

C60 fullerene: bond angles between 109–120°;

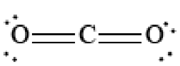
*Allow Graphite: sp^2 **and** Diamond: sp^3.*

*Allow C_{60} fullerene: sp^2 **and** sp^3.*

Number of atoms each carbon is bonded to

*Graphite **and** C_{60} fullerene:* each C atom attached to 3 others;

Diamond: each C atom attached to 4 atoms / tetrahedral arrangement of C (atoms);

d.i. 

linear **and** 180°;

Accept crosses, lines or dots as electron pairs.

d.ii. network/giant structure / macromolecular;

each Si atom bonded covalently to 4 oxygen atoms **and** each O atom bonded covalently to 2 Si atoms / single covalent bonds;

*Award **[1 max]** for answers such as network-covalent, giant-covalent or macromolecular-covalent.*

Both M1 and M2 can be scored by a suitable diagram.

d.iii. *Silicon dioxide:* strong/covalent bonds in network/giant structure/macromolecule;

Carbon dioxide: weak/van der Waals'/dispersion/London forces between molecules;

e. triple (covalent) bond;

one electron pair donated by oxygen to carbon atom / dative (covalent)/coordinate (covalent) bond;

*Award **[1 max]** for representation of* C≡O.

*Award **[2]** if CO shown with dative covalent bond.*

f. $2809 = 3.10 \times 30 + 28x + 29(96.9 - x)$;

$\% \, ^{28}\text{Si} = (93 + 2810.1 - 2809) = 94.1\%$;

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

Examiners report

b. Part (b) was exceptionally well done.

c. Many candidates struggled with Part (c) not being able to clearly identify the bonding and structure in the allotropes of carbon. Candidates often incorrectly discussed the properties of the allotropes.

d.i. In Part (d), candidates were competent at drawing carbon dioxide but struggled to identify the bonding and structure in silicon dioxide.

d.ii. Most candidates incorrectly identifying silicon dioxide as molecular compound.

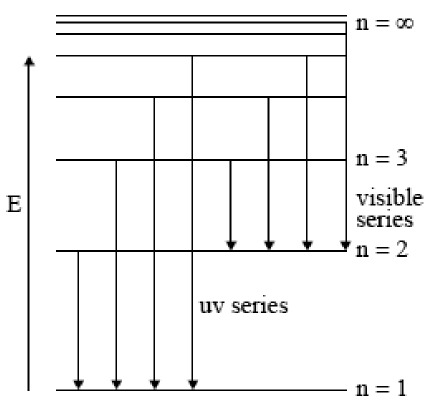
d.iii. Candidates also struggled to explain why CO_2 was a gas and SiO_2 was a solid a room temperature and again commented on the properties of the compounds rather than the structure and bonding.

e. In part (e) many candidates failed to state that a dative bond was present in CO.

f. Although the calculation in (f) was more challenging than similar questions in the past, it was managed by many candidates.

Draw and label an energy level diagram for the hydrogen atom. In your diagram show how the series of lines in the ultraviolet and visible regions of its emission spectrum are produced, clearly labelling each series.

Markscheme



showing *y*-axis labelled as energy/E / labelling at least two energy levels;

showing a minimum of four energy levels/lines with convergence;

showing jumps to n = 1 for ultraviolet series;

showing jumps to n = 2 for visible light series;

Must show at least two vertical lines per series to score M3 and M4 but penalize once only.

For M3, M4 if transition not shown from higher to lower energy level penalize only once.

Examiners report

Although this generally proved to be the second most difficult question in Section A there were some excellent diagrams with some even linking a correct energy level diagram with a correct line emission spectrum. Candidates in some schools, however, appeared not to have encountered these ideas at all. Common errors were to label the first energy level as n = 0 rather than n = 1 and to only include one transition for each series. Sometimes the arrows showed the absorption rather than the required emission transition.

A sample of vaporized elemental magnesium is introduced into a mass spectrometer.

One of the ions that reaches the detector is $^{26}\mathrm{Mg}^{+}$.

a. Calculate the number of protons, neutrons and electrons in the $^{26}\mathrm{Mg}^{+}$ ion. [2]

d. The sample contained the three isotopes $^{24}\mathrm{Mg}$, $^{25}\mathrm{Mg}$ and $^{26}\mathrm{Mg}$. The relative percentage abundances of $^{25}\mathrm{Mg}$ and $^{26}\mathrm{Mg}$ are 10.00% and 11.01% respectively. Calculate the relative atomic mass (A_r) of magnesium, accurate to **two** decimal places. [2]

Markscheme

a. *Protons:* 12

Neutrons: 14

Electrons: 11

*Award **[2]** for three correct answers.*

*Award **[1]** for two correct answers.*

*Award **[0]** for one correct answer.*

d. $^{24}\mathrm{Mg} = (100 - 10.00 - 11.01 =)\ 78.99\%$;

$A_r = (24 \times 0.7899 + 25 \times 0.1000 + 26 \times 0.1101 =)\ 24.32$;

*Award **[2]** for correct final answer which must be to two decimal places.*

Do not accept data booklet value of 24.31.

Examiners report

a. The question on the structure of atoms generally scored well. The workings of the mass spectrometer was less well known; with many getting confused with the role of the magnetic and electric fields. The calculation of the A_r was done very well.

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a. State the relative mass and charge of the subatomic particles of an atom. [2]

	Relative mass	Relative charge
Proton	....	+1
Electron	5×10^{-4}	....
Neutron	....	....

b. (i) Calculate the number of neutrons and electrons in one atom of ^{65}Cu. [3]

Neutrons:

Electrons:

(ii) State one difference in the physical properties of the isotopes ^{63}Cu and ^{65}Cu and explain why their chemical properties are the same.

Physical:

Chemical:

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

d. Suggest **two** properties of copper that make it useful and economically important. [1]

Markscheme

a.

	Relative mass	Relative charge
Proton	1	+1
Electron	5×10^{-4}	–1
Neutron	1	0

;

*Award **[2]** for all four correct.*

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

b. (i) *Neutrons:* 36 **and** *Electrons:* 29;

(ii) *Physical:*

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

Accept converse arguments.

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".

d. *Award **[1]** for any **two** of:*

malleable / ductile / conducts electricity / conducts heat / durable / strong / resistant to corrosion / low reactivity;

Examiners report

a. This question focused on atomic structure and metals was very accessible. Many students could correctly state relative mass and charge of the subatomic particles but it was disappointing to see the number of students who could not. Units were not penalized which meant that more students gained marks than would otherwise have been the case. Many students could calculate the protons and neutrons in the copper isotope but few could explain how the physical properties would vary (mass is not a property) and few could clearly explain why the chemical properties were identical. Explanations were often far too vague. Two properties of copper were asked for in and many could give one, again answers were often very vague, such as "it conducts" without specifying what it was conducting.

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

b. Deduce the numbers of protons and electrons in the K^+ ion. [1]

Markscheme

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

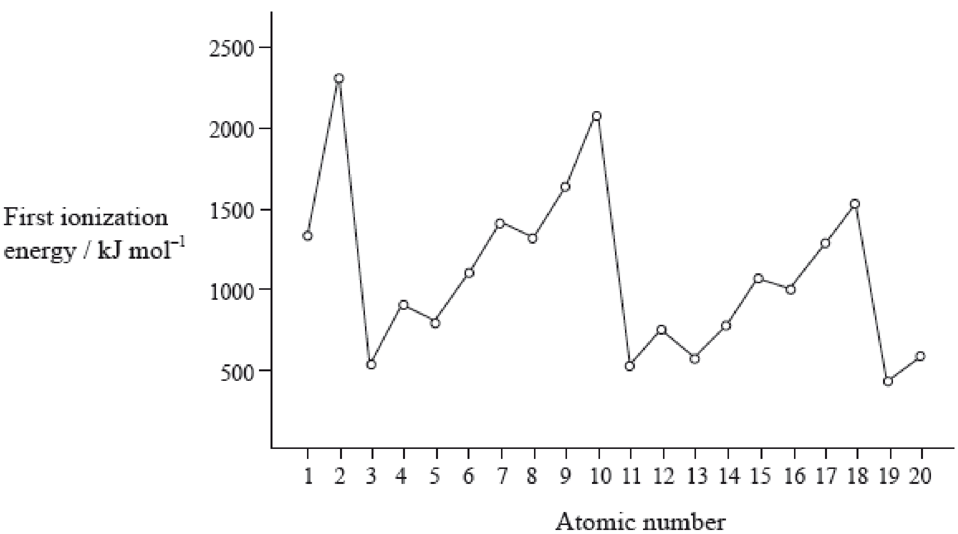
b. 19 protons **and** 18 electrons;

Examiners report

a. This question was the best answered on the paper and generally well answered question. In part (a) candidates sometimes incorrectly used the term relative atomic mass instead of relative isotopic mass when referring to the mass of an isotope.

b. Most candidates correctly deduced the number of protons and electrons in the K^+ ion, however some candidates did not read the question carefully and deduced the number of subatomic particles in the K atom.

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



a.iii Strontium exists as four naturally-occurring isotopes. Calculate the relative atomic mass of strontium to two decimal places from the following data. [2]

Isotope	Percentage abundance
Sr-84	0.56
Sr-86	9.90
Sr-87	7.00
Sr-88	82.54

b.i. Define the term *first ionization energy* and state what is meant by the term *periodicity*. [2]

b.ii. State the electron arrangement of argon and explain why the noble gases, helium, neon and argon show the highest first ionization energies for their respective periods. [3]

b.iii. A graph of atomic radius plotted against atomic number shows that the atomic radius decreases across a period. Explain why chlorine has a smaller atomic radius than sodium. [1]

b.iv. Explain why a sulfide ion, S^{2-}, is larger than a chloride ion, Cl^{-}. [1]

b.v. Explain why the melting points of the Group 1 metals $(Li \rightarrow Cs)$ decrease down the group whereas the melting points of the Group 7 elements $(F \rightarrow I)$ increase down the group. [3]

Markscheme

a.iii. $A_r = \frac{[(0.56\times84)+(9.90\times86)+(7.00\times87)+(82.54\times88)]}{100}$;

$= 87.71$;

*Award **[1 max]** if answer not given to two decimal places.*

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

Apply –1(U) if answer quoted in g or g mol^{-1}.

b.i. first ionization energy: $M(g) \rightarrow M^{+}(g) + e^{-}/e$ / the (minimum) energy ($in\ kJ\ mol^{-1}$) to remove one electron from a gaseous atom / the energy required to remove one mole of electrons from one mole of gaseous atoms;

periodicity: repeating pattern of (physical and chemical) properties;

b.ii. 2.8.8/sp version;

Accept any two of the following:

the outer energy level/shell is full;

the increased charge on the nucleus;

great(est) attraction for electrons;

b.iii. 17 p in Cl nucleus attract the outer level more than 11 p in Na nucleus / greater nuclear charge attracts outer level more;

Allow converse for Na.

Do not accept larger nucleus.

b.iv. S^{2-} has one proton less/ smaller nuclear charge so outer level held less strongly / *OWTTE*;

Allow converse for chloride.

Do not accept larger nucleus.

b.v. the radii of the metal atoms increase (from $Li \rightarrow Cs$) (so the forces of attraction are less between them) / *OWTTE*;

the forces of attraction between halogen molecules are van der Waals;

forces increase with increasing mass/number of electrons;

Examiners report

a.iii.The type of calculation in (a)(iii)is well understood. In the cases where both marks were not awarded, this was due to arithmetic error, not reading the question properly and providing an answer to other than two decimal places, or giving some unit such as grams.

b.i. Part (b)(i) resulted in very few marks being awarded; the requirements to refer to a gaseous atom and the idea of repetition in periodicity were sufficient to prevent otherwise reasonable answers from scoring.

b.ii.The electron configuration was usually known in (b)(ii), as was the fact that there is a full outer electron shell. The third mark was less frequently awarded, with candidates often using the simplistic ‘it is full so it doesn’t want to lose electrons’ argument.

b.iii.(b)(iii) was commonly correct but (b)(iv) was less well answered as many candidates failed to realise that these ions are isoelectronic and gave an answer relating to sulphide having more electrons with a consequent increase in repulsions.

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b.v.Part (b)(v) was poorly answered. Very few scored the first mark, many answers referring to some sort of ionization process. A handful of candidates scored the second mark for a reference to van der Waals forces but explanations for an increase were very weak. A number of candidates lost marks by referring to the breaking of covalent bonds rather than overcoming intermolecular forces.

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

a. State the nuclear symbol notation, ${}^{A}_{Z}X$, for magnesium-26. [1]

b. Mass spectroscopic analysis of a sample of magnesium gave the following results: [2]

	% abundance
Mg-24	78.60
Mg-25	10.11
Mg-26	11.29

Calculate the relative atomic mass, A_r, of this sample of magnesium to two decimal places.

c. Magnesium burns in air to form a white compound, magnesium oxide. Formulate an equation for the reaction of magnesium oxide with water. [1]

d. Describe the trend in acid-base properties of the oxides of period 3, sodium to chlorine. [2]

e. In addition to magnesium oxide, magnesium forms another compound when burned in air. Suggest the formula of this compound [1]

f. Describe the structure and bonding in solid magnesium oxide. [2]

g. Magnesium chloride can be electrolysed. [2]

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 922 K and 987 K respectively.

Anode (positive electrode):

Cathode (negative electrode):

Markscheme

a. $^{26}_{12}\mathrm{Mg}$

b. «Ar =»$\frac{24\times78.60+25\times10.11+26\times11.29}{100}$

«= 24.3269 =» 24.33

*Award **[2]** for correct final answer.*
*Do **not** accept data booklet value (24.31).*

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

OR

$MgO(s) + H_2O(l) \rightarrow Mg^{2+}(aq) + 2OH^{-}(aq)$

Accept $\rightleftharpoons$.

d. from basic to acidic

through amphoteric

Accept "alkali/alkaline" for "basic".
*Accept "oxides of Na and Mg: basic **AND** oxide of Al: amphoteric" for M1.*
Accept "oxides of non-metals/Si to Cl acidic" for M2.
*Do **not** accept just "become more acidic"*

e. Mg_3N_2

Accept MgO_2, $Mg(OH)_2$, $Mg(NOx)_2$, $MgCO_3$.

f. «3-D/giant» regularly repeating arrangement «of ions»

OR

lattice «of ions»

Accept "giant" for M1, unless "giant covalent" stated.

electrostatic attraction between oppositely charged ions
OR
electrostatic attraction between Mg^{2+} and O^{2-} ions
*Do **not** accept "ionic" without description.*

g. *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).

Examiners report

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

e. [N/A]
f. [N/A]
g. [N/A]

There are many oxides of silver with the formula Ag_xO_y. All of them decompose into their elements when heated strongly.

a.i. After heating 3.760 g of a silver oxide 3.275 g of silver remained. Determine the empirical formula of Ag_xO_y. [2]

a.ii. Suggest why the final mass of solid obtained by heating 3.760 g of Ag_xO_y may be greater than 3.275 g giving one design improvement for your proposed suggestion. Ignore any possible errors in the weighing procedure. [2]

b. Naturally occurring silver is composed of two stable isotopes, ^{107}Ag and ^{109}Ag. [1]

The relative atomic mass of silver is 107.87. Show that isotope ^{107}Ag is more abundant.

c.i. Some oxides of period 3, such as Na_2O and P_4O_{10}, react with water. A spatula measure of each oxide was added to a separate 100 cm^3 flask containing distilled water and a few drops of bromothymol blue indicator. [3]

The indicator is listed in section 22 of the data booklet.

Deduce the colour of the resulting solution and the chemical formula of the product formed after reaction with water for each oxide.

Flask containing	Colour of solution	Product formula
Na_2O	. . . .	. . . .
P_4O_{10}	. . . .	. . . .

c.ii. Explain the electrical conductivity of molten Na_2O and P_4O_{10}. [2]

d. Outline the model of electron configuration deduced from the hydrogen line emission spectrum (Bohr's model). [2]

Markscheme

a.i. n(Ag) = «$\frac{3.275 \text{ g}}{107.87 \text{ g mol}}$ =» 0.03036 «mol»

AND

n(O) = «$\frac{3.760 \text{ g} - 3.275 \text{ g}}{16.00 \text{ g mol}^{-1}} = \frac{0.485}{16.00}$ =» 0.03031 «mol»

«$\frac{0.03036}{0.03031} \approx 1$ / ratio of Ag to O approximately 1 : 1, so»

AgO

Accept other valid methods for M1.

*Award **[1 max]** for correct empirical formula if method not shown.*

[2 marks]

a.ii. temperature too low

OR

heating time too short

OR

oxide not decomposed completely

heat sample to constant mass «for three or more trials»

Accept "not heated strongly enough".

If M1 as per markscheme, M2 can only be awarded for constant mass technique.

Accept "soot deposition" (M1) and any suitable way to reduce it (for M2).

Accept "absorbs moisture from atmosphere" (M1) and "cool in dessicator" (M2).

*Award **[1 max]** for reference to impurity **AND** design improvement.*

[2 marks]

b. A_r closer to 107/less than 108 «so more ^{107}Ag»

OR

A_r less than the average of (107 + 109) «so more ^{107}Ag»

Accept calculations that gives greater than 50% ^{107}Ag.

[1 mark]

c.i.

Flask containing	Colour of solution	Product formula
Na_2O	blue ***AND*** yellow ✓	NaOH ✓
P_4O_{10}		H_3PO_4 ✓

Do not accept name for the products.

Accept "$Na^+ + OH^-$" for NaOH.

Ignore coefficients in front of formula.

[3 marks]

c.ii. «molten» Na_2O has mobile ions/charged particles ***AND*** conducts electricity

«molten» P_4O_{10} does not have mobile ions/charged particles ***AND*** does not conduct electricity/is poor conductor of electricity

*Do **not** award marks without concept of mobile charges being present.*

*Award **[1 max]** if type of bonding or electrical conductivity correctly identified in each compound.*

*Do **not** accept answers based on electrons.*

*Award **[1 max]** if reference made to solution.*

[2 marks]

d. electrons in discrete/specific/certain/different shells/energy levels

energy levels converge/get closer together at higher energies
OR
energy levels converge with distance from the nucleus

Accept appropriate diagram for M1, M2 or both.

Do not give marks for answers that refer to the lines in the spectrum.

[2 marks]

Examiners report

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

Titanium is a transition metal.

$TiCl_4$ reacts with water and the resulting titanium(IV) oxide can be used as a smoke screen.

a. Describe the bonding in metals. [2]

b. Titanium exists as several isotopes. The mass spectrum of a sample of titanium gave the following data: [2]

Mass number	% abundance
46	7.98
47	7.32
48	73.99
49	5.46
50	5.25

Calculate the relative atomic mass of titanium to two decimal places.

c. State the number of protons, neutrons and electrons in the $^{48}_{22}\mathrm{Ti}$ atom. [1]

Protons:

. . . .

Neutrons:

. . . .

Electrons:

. . . .

d.i. State the full electron configuration of the ${}^{48}_{22}\mathrm{Ti}^{2+}$ ion. [1]

d.ii. Explain why an aluminium-titanium alloy is harder than pure aluminium. [2]

e.i. State the type of bonding in potassium chloride which melts at 1043 K. [1]

e.ii. A chloride of titanium, $TiCl_4$, melts at 248 K. Suggest why the melting point is so much lower than that of KCl. [1]

f.i. Formulate an equation for this reaction. [2]

f.ii. Suggest **one** disadvantage of using this smoke in an enclosed space. [1]

Markscheme

a. electrostatic attraction

between «a lattice of» metal/positive ions/cations ***AND*** «a sea of» delocalized electrons

Accept mobile electrons.

*Do **not** accept “metal atoms/nuclei”.*

[2 marks]

b. $\frac{(46\times7.98)+(47\times7.32)+(48\times73.99)+(49\times5.46)+(50\times5.25)}{100}$

= 47.93

Answer must have two decimal places with a value from 47.90 to 48.00.

Award [2] for correct final answer.

Award [0] for 47.87 (data booklet value).

[2 marks]

c. *Protons:* 22 ***AND*** *Neutrons:* 26 ***AND*** *Electrons:* 22

[1 mark]

d.i.

$1s^22s^22p^63s^23p^63d^2$

[1 mark]

d.ii. titanium atoms/ions distort the regular arrangement of atoms/ions

OR

titanium atoms/ions are a different size to aluminium «atoms/ions»

prevent layers sliding over each other

Accept diagram showing different sizes of atoms/ions.

[2 marks]

e.i. ionic

OR

«electrostatic» attraction between oppositely charged ions

[1 mark]

e.ii. «simple» molecular structure

OR

weak«er» intermolecular bonds

OR

weak«er» bonds between molecules

Accept specific examples of weak bonds such as London/dispersion and van der Waals.

*Do **not** accept "covalent".*

[1 mark]

f.i. $TiCl_4(l) + 2H_2O(l) \rightarrow TiO_2(s) + 4HCl(aq)$

correct products

correct balancing

Accept ionic equation.

Award M2 if products are HCl and a compound of Ti and O.

[2 marks]

f.ii. HCl causes breathing/respiratory problems

OR

HCl is an irritant

OR

HCl is toxic

OR

HCl has acidic vapour

OR

HCl is corrosive

Accept "TiO_2 causes breathing problems/is an irritant".

Accept "harmful" for both HCl and TiO_2.

Accept "smoke is asphyxiant".

[1 mark]

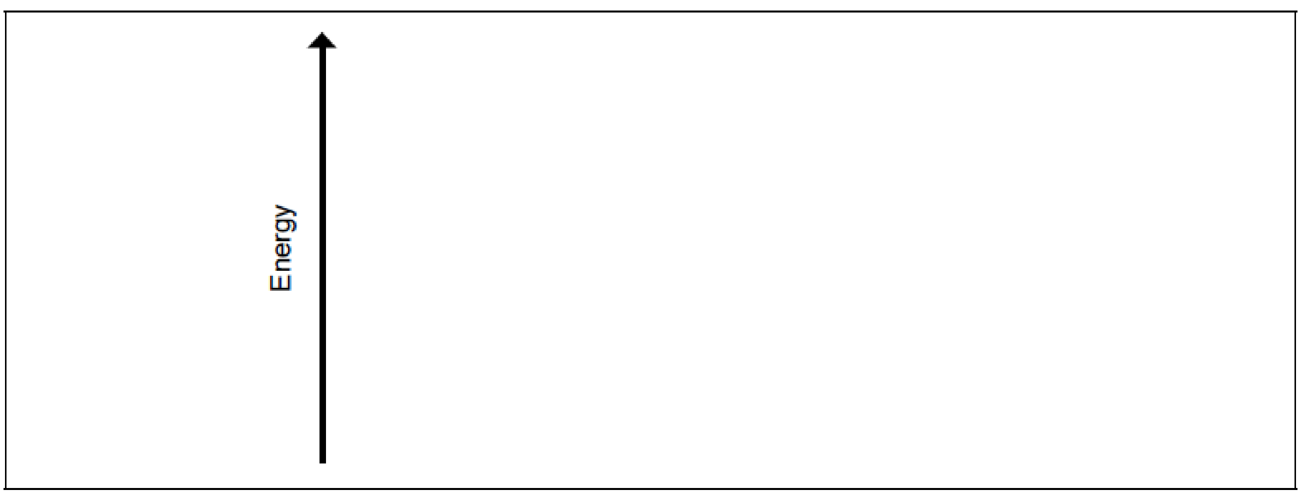
Examiners report

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

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

Elements show trends in their physical properties across the periodic table.

a.i. Draw the first four energy levels of a hydrogen atom on the axis, labelling n = 1, 2, 3 and 4. [1]



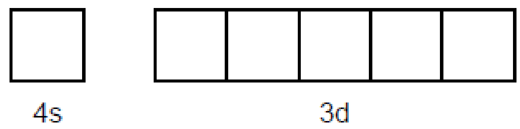
a.ii. Draw the lines, on your diagram, that represent the electron transitions to n = 2 in the emission spectrum. [1]

b.i. Outline why atomic radius decreases across period 3, sodium to chlorine. [1]

b.ii. Outline why the ionic radius of K^+ is smaller than that of Cl^-. [2]

c.i. Copper is widely used as an electrical conductor. [1]

Draw arrows in the boxes to represent the electronic configuration of copper in the 4s and 3d orbitals.



c.ii. Impure copper can be purified by electrolysis. In the electrolytic cell, impure copper is the anode (positive electrode), pure copper is the cathode (negative electrode) and the electrolyte is copper(II) sulfate solution. [2]

Formulate the half-equation at each electrode.

Anode (positive electrode):

. . . .

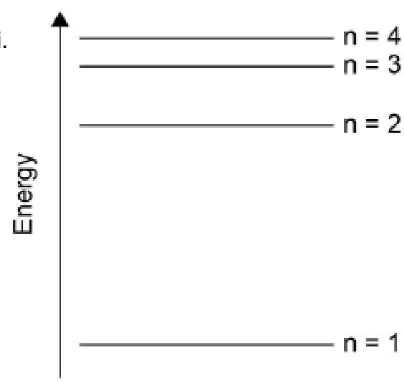
Cathode (negative electrode):

. . . .

c.iii Outline where and in which direction the electrons flow during electrolysis. [1]

Markscheme

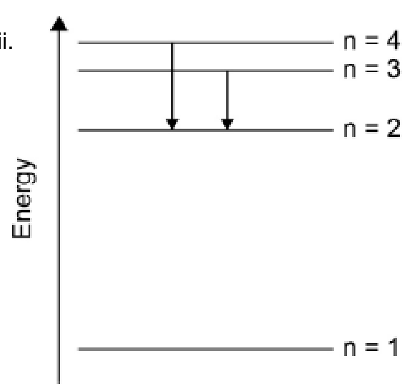
a.i.



4 levels showing convergence at higher energy

[1 mark]

a.ii.



arrows (pointing down) from n = 3 to n = 2 ***AND*** n = 4 to n = 2

[1 mark]

b.i. same number of shells/«outer» energy level/shielding ***AND*** nuclear charge/number of protons/Z_{eff} increases «causing a stronger pull on the outer electrons»

[1 mark]

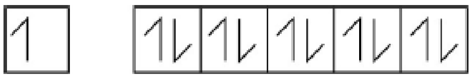
b.ii. K^+ 19 protons ***AND*** Cl^- 17 protons

OR

K^+ has «two» more protons

same number of electrons/isoelectronic «thus pulled closer together»

[2 marks]

c.i. 

[1 mark]

c.ii. *Anode (positive electrode):*

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

Cathode (negative electrode):

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

Accept $Cu(s) - 2e^- \rightarrow Cu^{2+}(aq)$.

Accept $\rightleftharpoons$ *for* $\rightarrow$

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

[2 marks]

c.iii. «external» circuit/wire ***AND*** from positive/anode to negative/cathode electrode

Accept "through power supply/battery" instead of "circuit".

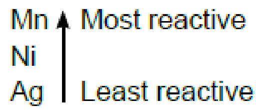
[1 mark]

Examiners report

a.i. [N/A]
a.ii. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]
c.iii. [N/A]

Trends in physical and chemical properties are useful to chemists.

The Activity series lists the metal in order of reactivity.



a. Explain the general increasing trend in the first ionization energies of the period 3 elements, Na to Ar. [2]

b. Explain why the melting points of the group 1 metals (Li → Cs) decrease down the group. [2]

c. State an equation for the reaction of phosphorus (V) oxide, P_4O_{10} (s), with water. [1]

d. Describe the emission spectrum of hydrogen. [2]

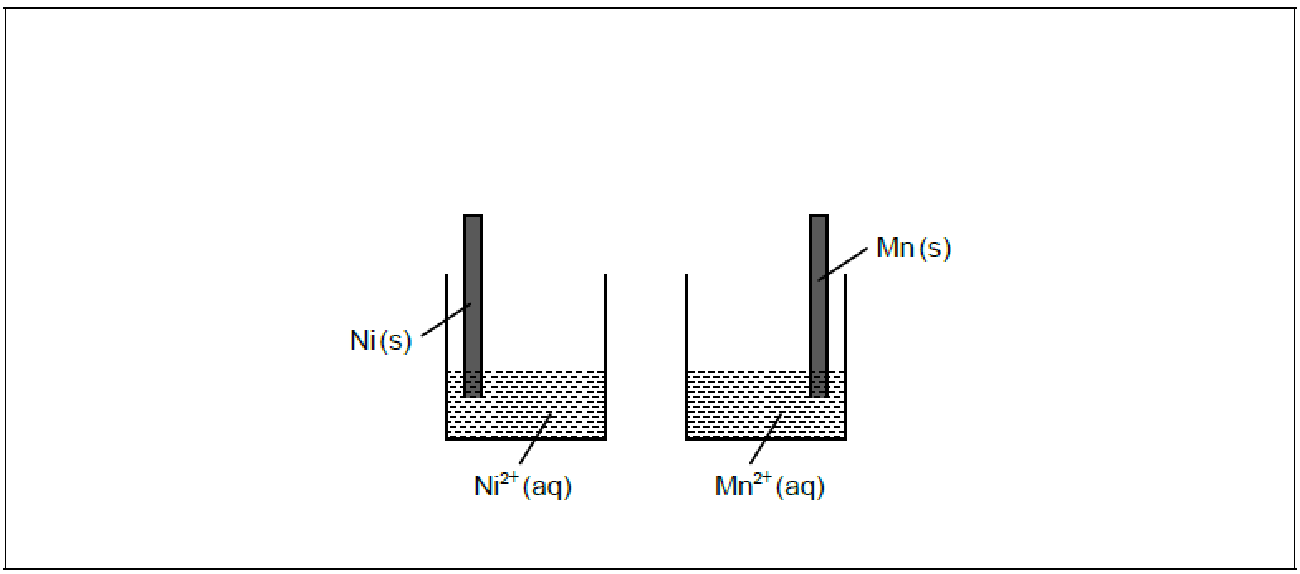
e.i. Identify the strongest reducing agent in the given list. [1]

e.ii. A voltaic cell is made up of a Mn^{2+}/Mn half-cell and a Ni^{2+}/Ni half-cell. [1]

Deduce the equation for the cell reaction.

e.iii. The voltaic cell stated in part (ii) is partially shown below. [2]

Draw and label the connections needed to show the direction of electron movement and ion flow between the two half-cells.



Markscheme

a. increasing number of protons

OR

increasing nuclear charge

«atomic» radius/size decreases

OR

same number of shells

OR

similar shielding «by inner electrons»

«greater energy needed to overcome increased attraction between nucleus and electrons»

b. atomic/ionic radius increases

smaller charge density

OR

force of attraction between metal ions and delocalised electrons decreases

*Do **not** accept discussion of attraction between valence electrons and nucleus for M2.*

Accept "weaker metallic bonds" for M2.

c. P_4O_{10} (s) + $6H_2O$ (l) → $4H_3PO_4$ (aq)

Accept "P_4O_{10} (s) + $2H_2O$ (l) → $4HPO_3$ (aq)" (initial reaction).

d. «series of» lines

OR

only certain frequencies/wavelengths

convergence at high«er» frequency/energy/short«er» wavelength

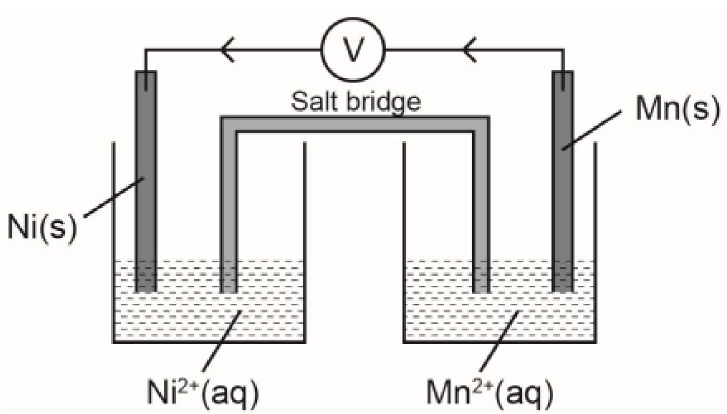
M1 and/or M2 may be shown on a diagram.

e.i. Mn

e.ii. Mn (s) + Ni^{2+} (aq) → Ni (s) + Mn^{2+} (aq)

e.iii. wire between electrodes AND labelled salt bridge in contact with both electrolytes

anions to right (salt bridge)
OR
cations to left (salt bridge)
OR
arrow from Mn to Ni (on wire or next to it)



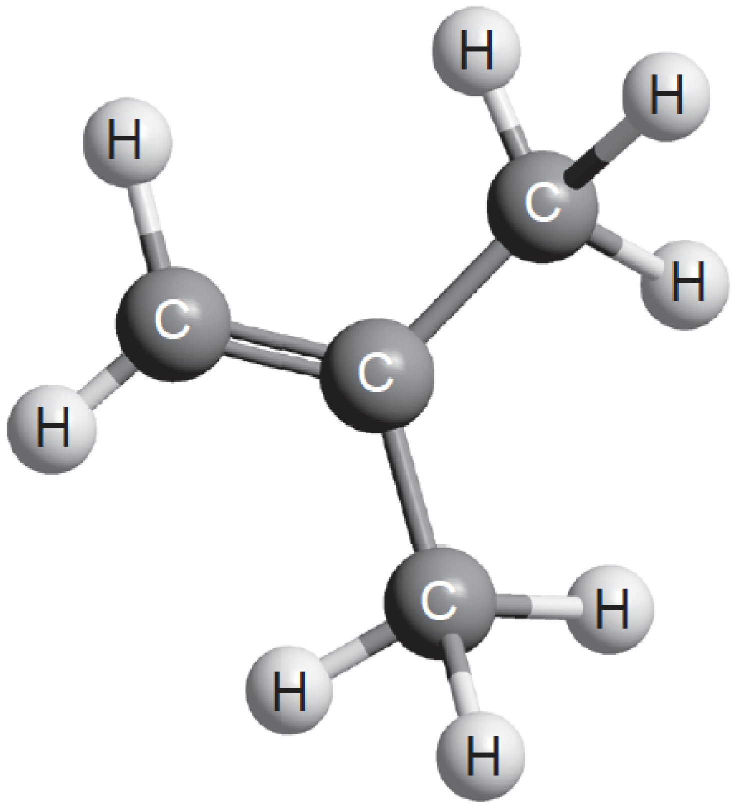
*Electrodes can be connected directly or through voltmeter/ammeter/light bulb, but **not** a battery/power supply.*

Accept ions or a specific salt as the label of the salt bridge.

Examiners report

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

Alkenes are widely used in the production of polymers. The compound **A**, shown below, is used in the manufacture of synthetic rubber.



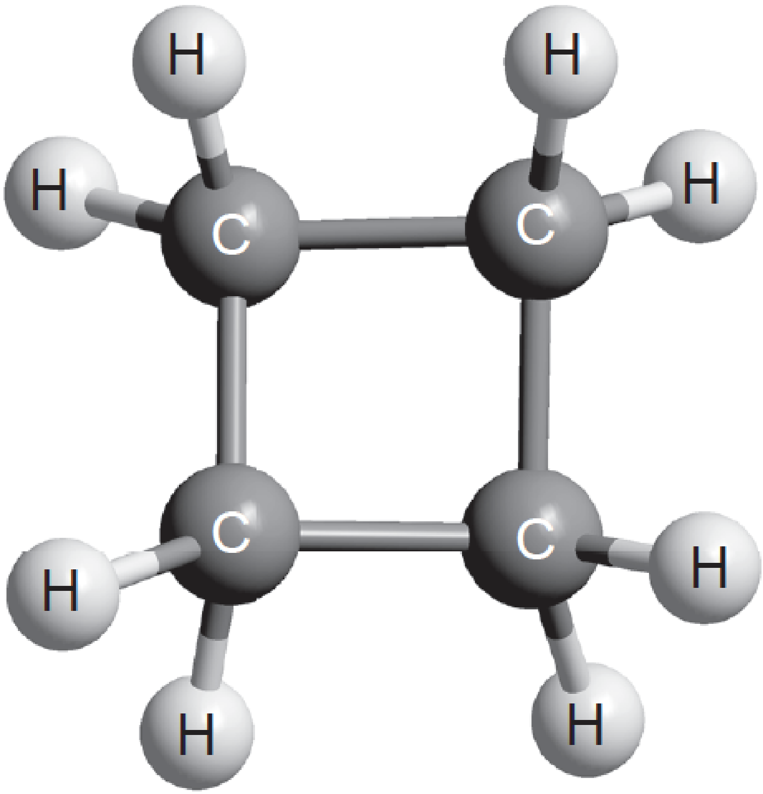
A

a. (i) State the name, applying IUPAC rules, of compound **A**. [3]

(ii) Draw a section, showing three repeating units, of the polymer that can be formed from compound **A**.

(iii) Compound **A** is flammable. Formulate the equation for its complete combustion.

b. Compound **B** is related to compound **A**. [5]



B

(i) State the term that is used to describe molecules that are related to each other in the same way as compound **A** and compound **B**.

(ii) Suggest a chemical test to distinguish between compound **A** and compound **B**, giving the observation you would expect for each.

Test:

Observation with **A**:

Observation with **B**:

(iii) Spectroscopic methods could also be used to distinguish between compounds **A** and **B**.

Predict one difference in the IR spectra **and** one difference in the ^{1}H NMR spectra of these compounds, using sections 26 and 27 of the data booklet.

IR spectra:

^{1}H NMR spectra:

c. A sample of compound **A** was prepared in which the ^{12}C in the CH_2 group was replaced by ^{13}C. [3]

(i) State the main difference between the mass spectrum of this sample and that of normal compound **A**.

(ii) State the structure of the nucleus and the orbital diagram of ^{13}C in its ground state.

No. protons . . . . No. neutrons . . . .

Orbital diagram ☐ 1s ☐ 2s ☐☐☐ 2p

d. Draw a 1s atomic orbital and a 2p atomic orbital. [1]

1s: 2p:

Markscheme

a. (i)

methylpropene

(ii)
$-CH_2-C(CH_3)_2-CH_2-C(CH_3)_2-CH_2-C(CH_3)_2-$

Must have continuation bonds at both ends.

Accept any orientation of the monomers, which could give methyl side-chains on neighbouring atoms etc.

(iii)
C_4H_8 (g) + $6O_2$ (g) → $4CO_2$ (g) + $4H_2O$(l)

b. (i)

«structural/functional group» isomer«s»

(ii)

Test:

«react with» bromine/Br_2 «in the dark»

OR

«react with» bromine water/Br_2 (aq) «in the dark»

A: from yellow/orange/brown to colourless ***AND*** B: colour remains/slowly decolourized

Accept other correct reagents, such as manganate(VII) or iodine solutions, and descriptions of the corresponding changes observed.
Accept "decolourized" for A and "not decolourized/unchanged" for B.
Do ***not*** *accept "clear/transparent" instead of "colourless".*

(iii)

IR: **A** would absorb at 1620–1680cm^{-1} ***AND*** **B** would not

^{1}H NMR: **A** would have 2 signals ***AND*** **B** would have 1 signal
OR
A would have a signal at 4.5–6.0 ppm ***AND*** **B** would not
OR
A would have a signal at 0.9–1.0 ppm ***AND*** **B** would not
OR
B would have a signal at 1.3–1.4 ppm ***AND*** **A** would not

Accept "peak" for "signal".

*Award **[1 max]** if students have a correct assignation of a signal, but no comparison, for **both** IR and NMR.*
Accept “B would have a signal at 2.0 ppm” as shown in its ^{1}H NMR spectrum.

c. (i)

«molecular ion» peak at «m/z =» 57, «not 56»

OR

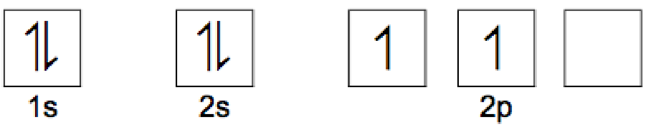
«molecular ion» peak at one «m/z» higher

OR

will not have a «large» peak at 56

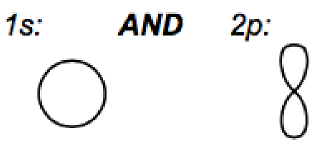
Accept a peak at m/z one greater than the ^{12}C one for any likely fragment.

(ii)
protons: 6 ***AND*** neutrons: 7



Accept full arrows.

d.



Accept p orbitals aligned on y– and z–axes, or diagrams correctly showing all three p-orbitals.
*Do **not** accept p-orbitals without a node.*

Examiners report

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