APOLLO

Chemistry
HL Workbook

First assessment 2025
Whole questions arranged by syllabus topic.
Original question and scheme crops preserve source diagrams.

APOLLO

Measuring enthalpy changes

8 questions

22. Which equation correctly shows **both** enthalpy of formation, $\Delta H^{\ominus}_{f}$, of a compound and enthalpy of combustion, $\Delta H^{\ominus}_{c}$, of its elements?

A. $CO(g) + ½O_2(g) \rightarrow CO_2(g)$

B. $½N_2(g) + 1½H_2(g) \rightarrow NH_3(g)$

C. $2S(s) + 3O_2(g) \rightarrow 2SO_3(g)$

D. $H_2(g) + ½O_2(g) \rightarrow H_2O(l)$

23. 0.050 mol of sodium hydrogencarbonate was added to 50 cm^3 of 2.0 mol dm^{-3} solution of citric acid.

$$C_6H_8O_7(aq) + 3NaHCO_3(s) \rightarrow C_6H_5O_7Na_3(aq) + 3CO_2(g) + 3H_2O(l)$$

The initial temperature of the solution was 298 K and the final temperature was 297 K.
What is the enthalpy of this reaction in kJ mol^{-1}? ($c_w = 4.18$ J g^{-1} K^{-1}, $Q = mc\Delta T$)

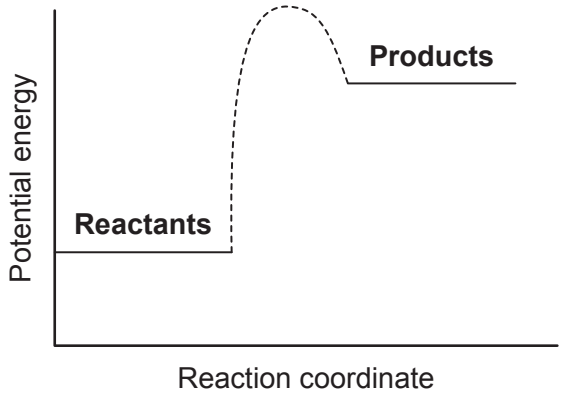
A. +4.18

B. −4.18

C. +12.5

D. −12.5

18. What is the correct interpretation of this energy profile?



	Relative stability	Temperature of surroundings
A.	reactants more stable than products	decreases
B.	reactants more stable than products	increases
C.	reactants less stable than products	decreases
D.	reactants less stable than products	increases

20. Which statement about an exothermic reaction is correct?

A. Temperature decreases and the products have higher enthalpy than the reactants.

B. Temperature decreases and the products have lower enthalpy than the reactants.

C. Temperature increases and the products have higher enthalpy than the reactants.

D. Temperature increases and the products have lower enthalpy than the reactants.

21. The energy from burning 0.321 g of methanol causes the temperature of 200 cm^3 of water to rise by 5.00 K. What is the enthalpy of combustion of the methanol in $kJ\,mol^{-1}$?

Specific heat capacity of water: $4.18\,J\,g^{-1}K^{-1}$, M_r methanol $= 32.05\,g\,mol^{-1}$

$$Q = mc\Delta T$$

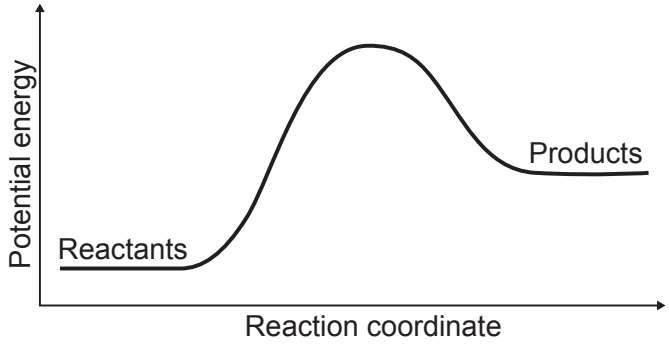
A. –417

B. –579

C. –23 200

D. –417 000

20. The potential energy profile of a reaction is shown.



Which reaction has this energy profile?

A. $N_2(g) + O_2(g) \rightarrow 2NO(g)$

B. $2H(g) \rightarrow H_2(g)$

C. $NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$

D. $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

2. A student was asked to identify an unknown metal with a mass of 1.28 g using calorimetry. The metal was placed in beaker **A** with boiling water at 100.00 °C until the metal reached the same temperature as the water. The metal was then quickly transferred to beaker **B** with 5.65 g of water which had an initial temperature of 25.00 °C. The final temperature of the water in beaker **B** and the metal was 26.77 °C.

Data for unknown metal sample	
Mass of unknown metal / g	1.28
Initial temperature of metal / °C	100.00
Mass of cool water in beaker **B** / g	5.65
Initial temperature of water in beaker **B** / °C	25.00
Final temperature of water in beaker **B** and metal / °C	26.77

(a) Determine the amount of energy transferred from the metal to the water in beaker **B** using sections 1 and 2 of the data booklet. [2]

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(b) Determine the specific heat capacity of the metal assuming the heat absorbed by the water in beaker **B** in (a) is equal to the heat released by the metal.

Use section 1 of the data booklet.

If you did not get an answer to (a) use 40.5 J although this is not the correct answer. [2]

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(Question 2 continued)

(c) State the name of the unknown metal using the table. [1]

Metal	Specific heat capacity ($J\,g^{-1}\,K^{-1}$)
Lead	0.129
Silver	0.235
Iron	0.449
Aluminium	0.897

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(d) Deduce **two** sources of systematic error for this experiment based on the results. [2]

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(e) State another physical property that could be used to identify the metal without damaging the sample. [1]

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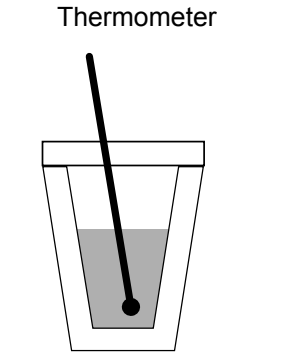
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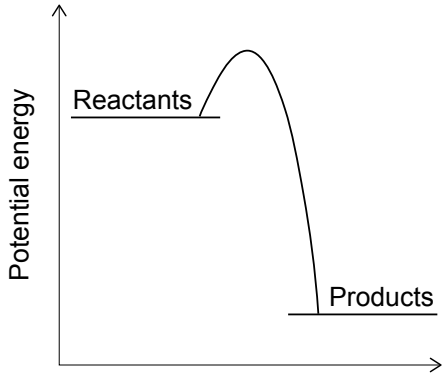
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Question 2 - working space

20. The potential energy profile for a “coffee cup” calorimetry experiment is shown.



Coffee cup calorimeter



What is the correct interpretation of this reaction?

	Temperature	Type of reaction
A.	increases	exothermic
B.	increases	endothermic
C.	decreases	exothermic
D.	decreases	endothermic

Turn over

APOLLO

Energy cycles in reactions

7 questions

24. The table shows enthalpy of combustion data for several substances.

Substance	$\Delta H^{\ominus}_c$ (kJ mol^{-1})
C_2H_6	−1561
C_2H_4	−1411
H_2	−286

Which expression would give the enthalpy for the following reaction?

$$C_2H_4(g) + H_2(g) \rightarrow C_2H_6(g)$$

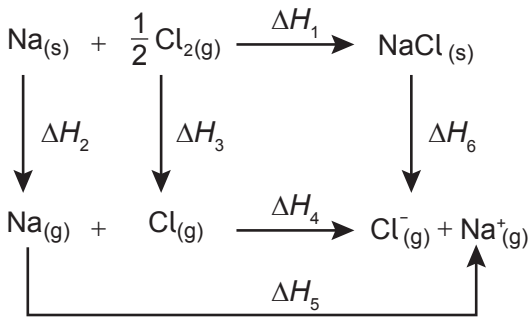
A. $-1561 + 286 - 1411$

B. $-1411 - 286 + 1561$

C. $-1411 + 286 + 1561$

D. $-1561 - 286 - 1411$

22. Which energy change on the diagram below represents the electron affinity of chlorine?



A. ΔH_2

B. ΔH_3

C. ΔH_4

D. ΔH_5

21. What is the enthalpy change for the reaction in $kJ\,mol^{-1}$?

$$C_2H_2(g) + 2H_2(g) \rightarrow C_2H_6(g)$$

	ΔH_c^θ / kJ mol^{-1}
$C_2H_2(g)$	−1301
$H_2(g)$	−286
$C_2H_6(g)$	−1561

A. $-1561 - 2(-286) - 1301$

B. $-1561 + 2(-286) - 1301$

C. $-1301 + 2(-286) + 1561$

D. $-1301 - 2(-286) + 1561$

22. Which equation represents the enthalpy change of atomisation, ΔH^{θ}_{at} , of bromine?

A. $Br_2(l) \rightarrow Br_2(g)$

B. $1/2Br_2(g) \rightarrow Br(g)$

C. $1/2Br_2(l) \rightarrow Br(g)$

D. $Br_2(g) \rightarrow 2Br(g)$

20. Consider these equations:

$$S(s) + O_2(g) \rightarrow SO_2(g) \qquad \Delta H^{\ominus} = x \text{ kJ mol}^{-1}$$

$$2SO_2(g) + O_2(g) \rightarrow 2SO_3(g) \qquad \Delta H^{\ominus} = y \text{ kJ mol}^{-1}$$

What is the value of $\Delta H^{\ominus}$, in kJ mol^{-1}, for this reaction?

$$S(s) + \frac{3}{2} O_2(g) \rightarrow SO_3(g)$$

A. $x + y$

B. $x + \frac{1}{2} y$

C. $x - \frac{1}{2} y$

D. $x - y$

21. What is the enthalpy change for the reaction in kJ mol^{-1}?

$$\text{CO}_2(\text{g}) + \text{H}_2(\text{g}) \rightarrow \text{CO}(\text{g}) + \text{H}_2\text{O}(\text{g})$$

$$2\text{CO}(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{CO}_2(\text{g}) \qquad \Delta H = -566\,\text{kJ mol}^{-1}$$

$$2\text{H}_2(\text{g}) + \text{O}_2(\text{g}) \rightarrow 2\text{H}_2\text{O}(\text{l}) \qquad \Delta H = -572\,\text{kJ mol}^{-1}$$

$$\text{H}_2\text{O}(\text{g}) \rightarrow \text{H}_2\text{O}(\text{l}) \qquad \Delta H = -44\,\text{kJ mol}^{-1}$$

A. -1182

B. -899

C. -41

D. $+41$

23. Which are endothermic processes in a Born–Haber cycle for the formation of an ionic compound?

I. Enthalpy of atomization

II. First electron affinity

III. First ionization energy

A. I and II only

B. I and III only

C. II and III only

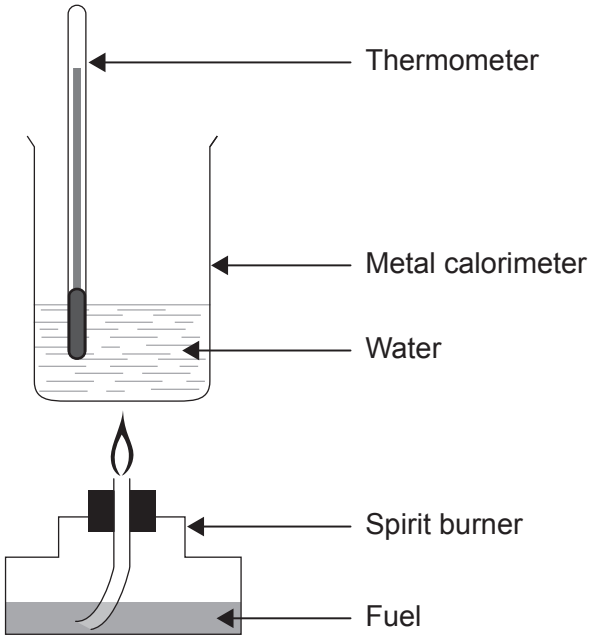
D. I, II and III

APOLLO

Energy from fuels

9 questions

19. What is the standard enthalpy change, $\Delta H^{\ominus}_{\text{combustion}}$, according to the data?



Amount of fuel burned = 0.110 mol
Mass of water = 200 g
Initial temperature of water = 21.0 °C
Final temperature of water = 25.0 °C
Specific heat capacity of water, $c_w = 4.18\,\text{J g}^{-1}\,\text{K}^{-1}$
$Q = mc\Delta T$

A. $-2110\,\text{kJ mol}^{-1}$

B. $-30.4\,\text{kJ mol}^{-1}$

C. $+30.4\,\text{kJ mol}^{-1}$

D. $+2110\,\text{kJ mol}^{-1}$

20. What is the coefficient of oxygen when the equation for the complete combustion of ethanol is balanced using the smallest whole numbers?

$$\_\_C_2H_5OH + \_\_O_2 \rightarrow \_\_CO_2 + \_\_H_2O$$

A. 1

B. 2

C. 3

D. 7

Turn over

9. Ethanol is a biofuel that is made from glucose. Glucose is formed by the biological fixation of carbon through photosynthesis.

(a) State the equation for photosynthesis. [1]

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(b) (i) Outline **two** advantages of using ethanol as a fuel instead of gasoline (petrol). [2]

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(ii) Calculate the enthalpy change for the combustion of ethanol in $kJ\,mol^{-1}$. Use section 12 of the data booklet. [3]

$$C_2H_5OH(l) + 3O_2(g) \rightarrow 2CO_2(g) + 3H_2O(g)$$

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(Question 9 continued)

(c) Calculate the increase in temperature in a sample of 500.0 cm^3 of water heated by the combustion of 4.00 g of ethanol. Use sections 2 and 14 of the data booklet. [2]

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(d) Explain this trend in the atomic radii of the atoms in the ethanol molecule [3]

$H < O < C$.

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Question 9 - working space

23. Which of the following statements best describes an environmental implication associated with the use of fossil fuels?

A. Increased biodiversity due to the establishment of habitats through mining

B. Decreased emission of greenhouse gases leading to global cooling

C. Enhanced soil fertility due to the deposition of coal dust

D. Acid rain formation from the release of sulfur dioxide and nitrogen oxides

19. What is the sum of the coefficients when 1 mol of propan-1-ol, C_3H_7OH, undergoes complete combustion?

$$\_\_C_3H_7OH(l) + \_\_O_2(g) \rightarrow \_\_CO_2(g) + \_\_H_2O(l)$$

A. 11.5

B. 12

C. 12.5

D. 13

21. Which statement is a disadvantage of using biofuels instead of fossil fuels?

A. Land is used that could be used to grow food.

B. Combustion releases more energy per mol of fuel.

C. Emissions of CO_2 to the atmosphere are lower overall.

D. Crop waste can be used as a fuel.

22. Which products may form when propane undergoes incomplete combustion?

A. CO_2 and H_2 only

B. CO, C and H_2

C. CO_2, H_2O and H_2

D. CO_2, CO and C

22. Which is a renewable energy source?

A. natural gas

B. uranium

C. coal

D. wood

5. Heptadecane, $C_{17}H_{36}$, can be extracted from crude oil or cactus plants.

(a) Write an equation for the complete combustion of $C_{17}H_{36}$. [1]

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(b) The enthalpy of combustion of $C_{17}H_{36}$ is $-11\,350\,kJ\,mol^{-1}$.

(i) Calculate the maximum energy produced when 2.00 g of $C_{17}H_{36}$ is combusted. [2]

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(ii) Determine the maximum temperature change when 500.0 cm^3 of water is heated by a 2.00 g sample of $C_{17}H_{36}$. [2]

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(iii) Outline **two** assumptions made in the calculation in (b)(ii). [2]

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(Question 5 continued)

(c) Explain why biofuels contribute less to climate change than fossil fuels. [1]

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(d) Heptadecane can be broken down into smaller molecules. Consider the reaction:

$$C_{17}H_{36}(g) \rightarrow 2\ C_2H_4(g) + C_{13}H_{28}(g)$$

(i) Determine the standard enthalpy change, $\Delta H^{\ominus}$, for the reaction stated, using section 12 of the data booklet. [3]

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(ii) Determine the enthalpy change of reaction. Use the data provided and section 13 of the data booklet. [2]

$$\Delta H_f\ (C_{17}H_{36}) = -393.9\,\text{kJ mol}^{-1}$$

$$\Delta H_f\ (C_{13}H_{28}) = -311.5\,\text{kJ mol}^{-1}$$

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(Question 5 continued)

(iii) Comment on the difference between the two values calculated in (d)(i) and (d)(ii). [1]

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(iv) Predict the sign of the entropy change of the reaction, giving a reason. [1]

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(v) Discuss, with reference to (d)(ii) and (d)(iv), how temperature affects the spontaneity of the reaction. [2]

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(e) Ethene can be converted to ethanol in one reaction. State the equation for this reaction. [1]

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(This question continues on the following page)

(Question 5 continued)

(f) Ethanol reacts with oleic acid to produce ethyl oleate.

$$C_{17}H_{33}COOH(l) + CH_3CH_2OH(l) \rightleftharpoons C_{17}H_{33}COOCH_2CH_3(l) + \mathbf{X}(l)$$

(i) Identify the type of reaction and the side product **X**(l). [1]

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(ii) Calculate the atom economy of the reaction. [1]

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(iii) Discuss why the atom economy of a reaction is an important consideration when evaluating the impact of a reaction in an industrial process. [2]

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(iv) Deduce the equilibrium constant expression, K_c, for the reaction. Assume that the reaction is homogeneous. [1]

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(Question 5 continued)

(g) The equilibrium constant, K_c, is 9.3×10^{-5} at 75 °C.

(i) Determine the amount of ethyl oleate present in the reaction mixture at equilibrium when 0.10 mol dm^{-3} of oleic acid reacts with 0.10 mol dm^{-3} of ethanol at 75 °C and state any assumptions you have made in your calculation. [2]

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(ii) State **one** method of increasing the yield. [1]

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will not be marked.

Question 5 - working space

APOLLO

Entropy and spontaneity (Additional higher level)

9 questions

25. Which of the following reactions will have the largest positive change in entropy?

A. $CaCO_3(s) + 2HCl(aq) \rightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

B. $CaO(s) + CO_2(g) \rightarrow CaCO_3(s)$

C. $I_2(g) + H_2(g) \rightarrow 2HI(g)$

D. $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

21. Which change results in a decrease in entropy?

A. $N_2H_4(l) \rightarrow N_2(g) + 2H_2(g)$

B. $K_2Cr_2O_7(s) \rightarrow K_2Cr_2O_7(aq)$

C. $MgCO_3(s) \rightarrow MgO(s) + CO_2(g)$

D. $2H_2(g) + O_2(g) \rightarrow 2H_2O(g)$

22. Which value indicates an equilibrium reaction?

A. $\Delta S = 0\,\text{J}\,\text{K}^{-1}\,\text{mol}^{-1}$

B. $\Delta G = 0\,\text{kJ}\,\text{mol}^{-1}$

C. $\Delta H = 0\,\text{kJ}\,\text{mol}^{-1}$

D. $\Delta T = 0\,\text{K}$

23. In which reaction does entropy decrease?

A. $KBr(s) \rightarrow KBr(aq)$

B. $NH_3(g) + HCl(g) \rightarrow NH_4Cl(s)$

C. $Mg(s) + H_2SO_4(aq) \rightarrow MgSO_4(aq) + H_2(g)$

D. $CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$

24. What are the signs of ΔH and ΔS for a reaction that is non-spontaneous at low temperatures but spontaneous at high temperatures?

	ΔH	ΔS
A.	+	−
B.	−	−
C.	+	+
D.	−	+

5. Ethyne, C_2H_2, is a useful raw material in the synthesis of organic compounds.

(a) (i) Calculate the standard enthalpy change, in $kJ\,mol^{-1}$, of the complete hydrogenation of ethyne to produce ethane. Use section 14 of the data booklet. [2]

$$C_2H_2(g) + 2\,H_2(g) \rightarrow C_2H_6(g)$$

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(ii) Calculate the temperature at which this reaction is no longer spontaneous. [2]

Use your answer to part (a)(i) and section 1 of the data booklet.

The standard entropy change of this reaction is $\Delta S^{\ominus} = -233\,J\,K^{-1}\,mol^{-1}$.

If you did not obtain an answer to part (a)(i) then use the value $-80.0\,kJ\,mol^{-1}$, although this is not the correct answer.

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(Question 5 continued)

(b) $140.0\,cm^3$ of ethyne are reacted with $160.0\,cm^3$ of hydrogen in a container at 420 K and 1.00×10^5 Pa. Ethane is the only product.

Determine the maximum possible volume of ethane formed under these conditions of temperature and pressure. [2]

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(c) (i) Draw the Lewis formula of C_2H_2. [1]

(ii) State the hybridization of the carbon atom in C_2H_2. [1]

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Question 5 - working space

24. Which reaction is predicted to occur with the largest decrease in entropy?

A. $N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

B. $N_2(g) + 2O_2(g) \rightarrow 2NO_2(g)$

C. $6CO_2(g) + 6H_2O(g) \rightarrow C_6H_{12}O_6(s) + 6O_2(g)$

D. $CO(g) + 2H_2(g) \rightarrow CH_3OH(l)$

28. What is the value of the Gibbs energy change, ΔG, in $kJ\,mol^{-1}$, for the reaction between hydrogen and iodine gases at 30 °C?

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad K = 40.2$$

$$\Delta G = -RT \ln K \qquad R = 8.31\,J\,K^{-1}\,mol^{-1}$$

A. −9300

B. −921

C. −9.30

D. −0.921

24. What is correct as a system approaches equilibrium?

A. Q remains constant.

B. K_c increases.

C. $\Delta G^{\ominus}$ becomes more negative.

D. ΔG approaches zero.

APOLLO

How much? The amount of chemical change

11 questions

26. Chloroethane is produced by the reaction of ethane with chlorine.

$$C_2H_6(g) + Cl_2(g) \rightarrow C_2H_5Cl(g) + HCl(g)$$

($C_2H_6 = 30.08\,g\,mol^{-1}$, $Cl_2 = 70.90\,g\,mol^{-1}$, $C_2H_5Cl = 64.52\,g\,mol^{-1}$, $HCl = 36.46\,g\,mol^{-1}$)

$$\%\ \text{atom economy} = \frac{\text{molar mass of desired product}}{\text{molar mass of all reactants}} \times 100$$

What is the atom economy for this reaction?

A. 15.7 %

B. 46.6 %

C. 63.9 %

D. 99.9 %

27. 75 cm^3 of propane was completely combusted in 400 cm^3 of oxygen according to the following equation.

$$CH_3CH_2CH_3(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(l)$$

What is the volume of unreacted oxygen remaining at the original conditions?

A. 25 cm^3.

B. 50 cm^3.

C. 75 cm^3.

D. 150 cm^3.

23. What are the limiting reactant and theoretical yield of hydrogen when 0.20 mol of magnesium reacts with 0.20 mol of hydrochloric acid?

$$Mg(s) + 2HCl(aq) \rightarrow MgCl_2(aq) + H_2(g)$$

	Limiting reactant	Theoretical yield of H_2 / mol
A.	Mg	0.10
B.	Mg	0.20
C.	HCl	0.05
D.	HCl	0.10

25. Which process to produce ethanol has an atom economy of 100?

A. $C_2H_4 + H_2O \rightarrow C_2H_5OH$

B. $C_6H_{12}O_6 \rightarrow 2C_2H_5OH + 2CO_2$

C. $CH_3COOC_2H_5 + NaOH \rightarrow C_2H_5OH + CH_3COONa$

D. $CH_3COOC_2H_5 + H_2O \rightleftharpoons C_2H_5OH + CH_3COOH$

30. How many moles of oxygen are needed for the complete combustion of 11.5 g of $C_3H_8(g)$?

M_r propane $= 44.1\,g\,mol^{-1}$

A. 10.4

B. 5.20

C. 2.60

D. 1.30

33. Which equation correctly describes a chemical reaction?

A. $2HCl + Na_2CO_3 \rightarrow 2NaCl + CO_2 + H_2O$

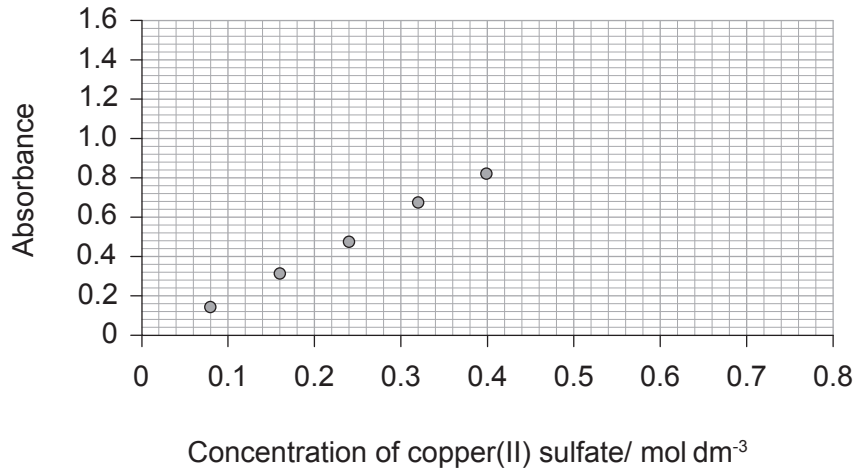
B. $Cu + 2HCl \rightarrow CuCl_2 + H_2$

C. $NaOH + HCl \rightarrow NaCl + H_2$

D. $2HCl + Ca(HCO_3)_2 \rightarrow CaCl_2 + 2H_2O$

3. A colorimetry experiment was conducted on a series of solutions of copper(II) sulfate, $CuSO_4$. The absorbance versus concentration data were graphed.

(a) Draw a best fit line in the graph below, extrapolating beyond the data given. [2]



(b) State the mathematical relationship between absorbance and concentration. [1]

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(c) The instrument used can collect absorbance or percent transmittance at a specific wavelength. Outline why a specific wavelength must be selected. [1]

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(Question 3 continued)

(d) Deduce the equation that relates the absorbance to concentration including the value of the constant. [2]

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(e) Estimate the absorbance value of a 0.600 mol dm^{-3} $CuSO_4$ solution. [1]

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(f) Predict the difference, if any, between reading the absorbance value for the 0.600 mol dm^{-3} $CuSO_4$ solution from the graph and calculating it using the equation in (d). [1]

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(g) The copper(II) sulfate solution is blue. Deduce the optimum wavelength to use for colorimetry, using section 15 of the data booklet. [1]

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Question 3 - working space

Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

2. In a separate experiment, the rate of a reaction was studied using colorimetry. During the reaction, the mixture changed colour from orange to green.

Before the investigation could be carried out, it was necessary to construct a calibration curve for the colorimeter.

(a) Describe how a standard aqueous solution can be prepared. [3]

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(b) Describe how this solution can be used to construct a calibration curve. [3]

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(c) Explain how this curve can be used to determine the unknown concentration. [1]

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Question 2 - working space

4. 3.162 g of calcium carbonate, $CaCO_3(s)$, is reacted with 20.0 cm^3 of 4.00 mol dm^{-3} hydrochloric acid, HCl(aq).

(a) (i) Write an equation for the reaction, including all state symbols. [2]

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(ii) Deduce which reactant is limiting. Use sections 1, 4 and 7 of the data booklet. [2]

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(iii) Calculate the volume, in dm^3 at STP, of the gas produced. Use section 2 of the data booklet. [1]

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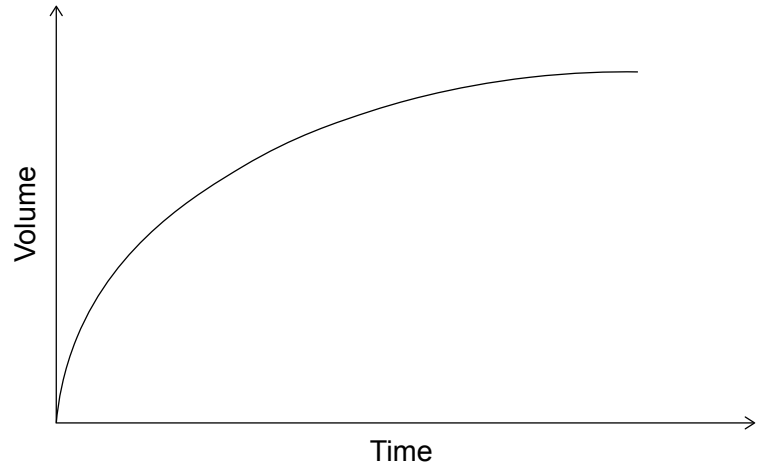
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(Question 4 continued)

(b) The rate of this reaction can be experimentally determined by measuring the volume of gas produced as time progresses.

(i) Sketch another curve for the reaction taking place with the acid at a higher temperature and all other conditions unchanged. [1]



(ii) Outline why the reaction rate would be lower if ethanoic acid, CH_3COOH, were used instead of hydrochloric acid. [1]

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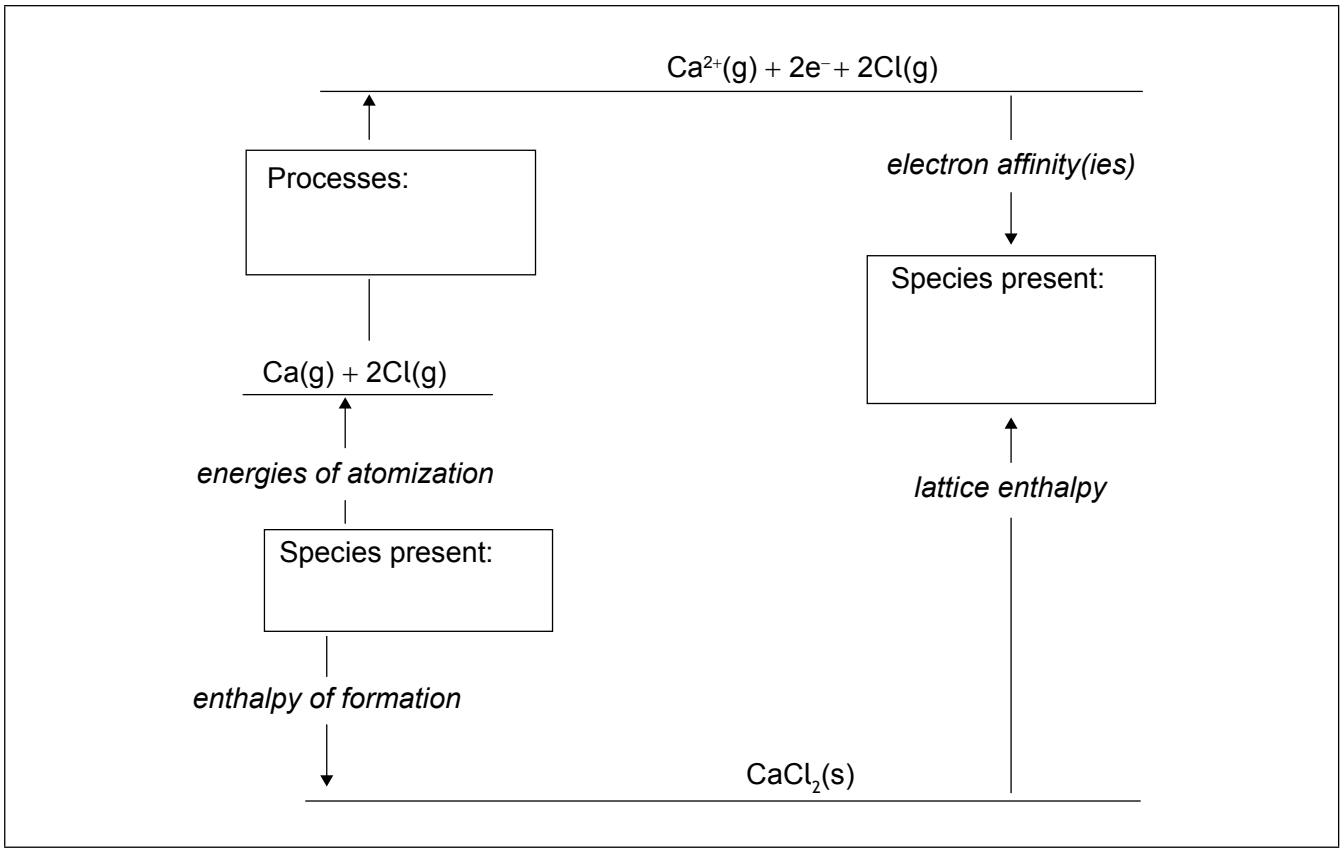
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(Question 4 continued)

(c) Calcium carbonate and calcium chloride are ionic compounds.

(i) Annotate the Born–Haber cycle for calcium chloride, $CaCl_2$, by filling the names of processes and formulas of species, including state symbols, in the boxes. [3]



(ii) Outline why the lattice enthalpy of calcium chloride is lower than the lattice enthalpy of magnesium chloride. [1]

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Question 4 - working space

4. What is the volume, in dm^3, of ethane gas, $C_2H_6(g)$, produced when $0.25\,dm^3$ of ethyne, $C_2H_2(g)$, reacts with $0.40\,dm^3$ of hydrogen gas, $H_2(g)$?

All volumes are measured under the same conditions.

$$C_2H_2(g) + 2H_2(g) \rightarrow C_2H_6(g)$$

A. 0.20

B. 0.25

C. 0.40

D. 0.45

24. What is the theoretical yield, in g, of ethanamide, CH_3CONH_2, that can be produced from the reaction of 4.00 g of ammonium carbonate, $(NH_4)_2CO_3$, with excess ethanoic acid, CH_3COOH?

$$2CH_3COOH(l) + (NH_4)_2CO_3(s) \rightarrow 2CH_3COONH_4(aq) + H_2O(l) + CO_2(g)$$

$$CH_3COONH_4(aq) \rightarrow CH_3CONH_2(s) + H_2O(l)$$

$$M_r(NH_4)_2CO_3 = 96.11$$

$$M_r CH_3CONH_2 = 59.08$$

A. 1.23

B. 2.46

C. 4.92

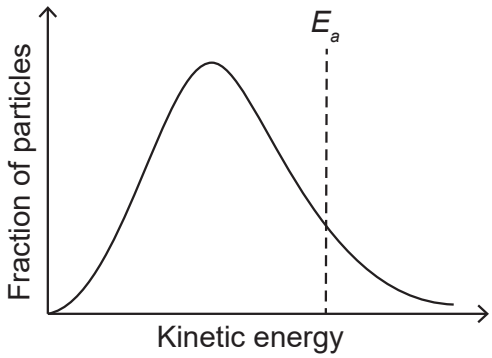
D. 6.51

APOLLO

How fast? The rate of chemical change

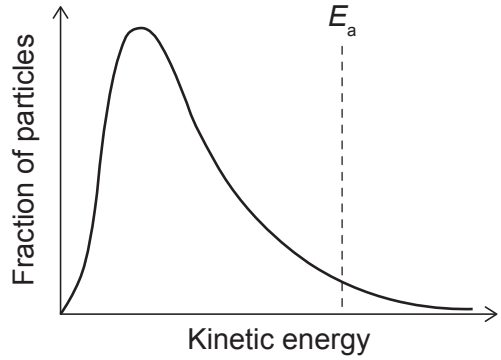
24 questions

28. Consider the following Maxwell-Boltzmann distribution.

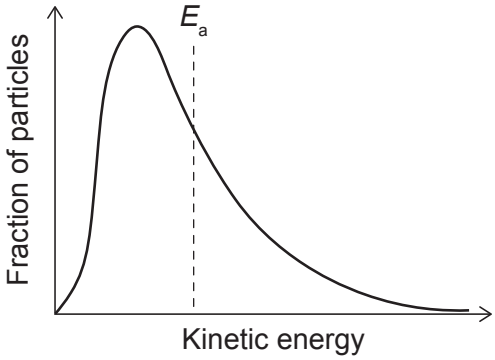


Which represents the distribution and value of activation energy at a lower temperature?

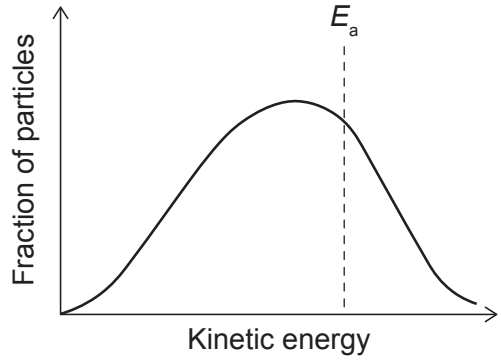
A.



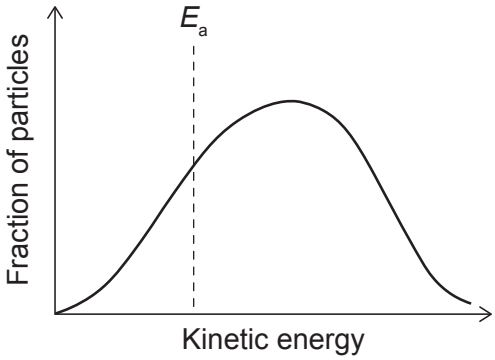
B.



C.



D.



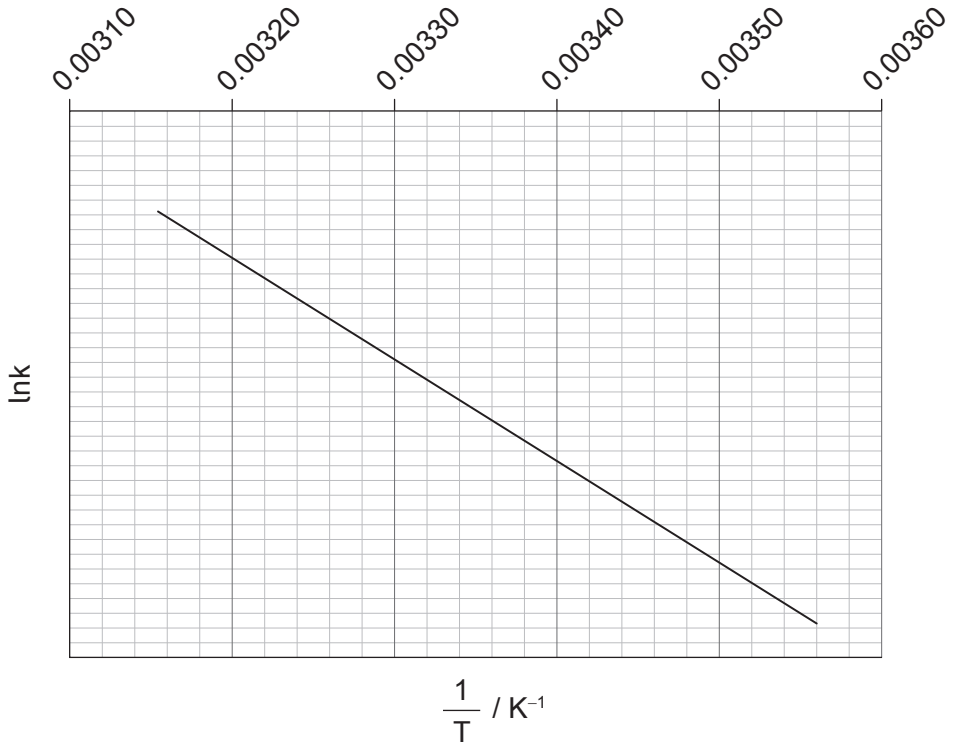
30. The following results were obtained from the acid-catalysed reaction between iodine, I_2, and propanone, CH_3COCH_3.

Experiment	Initial $[CH_3COCH_3]$ ($mol\,dm^{-3}$)	Initial $[I_2]$ ($mol\,dm^{-3}$)	Initial $[H^+]$ ($mol\,dm^{-3}$)	Relative initial rate $mol\,dm^{-3}\,s^{-1}$
1	0.56	0.56	0.56	5.6×10^{-3}
2	0.28	0.56	0.28	1.4×10^{-3}
3	0.56	0.28	0.56	5.6×10^{-3}
4	0.56	0.56	0.28	2.8×10^{-3}

Which row gives the correct order of reaction for each reactant?

	CH_3COCH_3	I_2	H^+
A.	1	0	1
B.	1	1	0
C.	0	0	2
D.	0	1	1

31. The acid-catalysed reaction between iodine, I_2, and propanone, CH_3COCH_3, was carried out at various temperatures to find the activation energy. The following graph was obtained from the processed data, and the slope was calculated to be –6400.



Which expression gives the activation energy for this reaction?

$$\ln k = \frac{-E_a}{RT} + \ln A$$

A. $\frac{-6400 \times 1000}{R}$ kJ mol^{-1}

B. $\frac{6400 \times R}{1000}$ kJ mol^{-1}

C. $\frac{-6400 \times R}{1000}$ kJ mol^{-1}

D. $\frac{6400 \times 1000}{R}$ kJ mol^{-1}

24. Which are units for rate of reaction?

A. mol s

B. $\text{dm}^{-3}\,\text{h}^{-1}$

C. $\text{mol dm}^{-3}\,\text{h}^{-1}$

D. $\text{mol dm}^{-3}\,\text{s}$

25. Which changes increase the rate of the reaction?

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

I. Introducing a catalyst

II. Increasing concentration of $H_2O_2(aq)$

III. Increasing pressure

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

26. Which species is an intermediate in the following reaction mechanism?

$$(CH_3)_3CBr \rightarrow (CH_3)_3C^+ + Br^-$$

$$(CH_3)_3C^+ + H_2O \rightarrow H^+ + (CH_3)_3COH$$

A. $(CH_3)_3C^+$

B. Br^-

C. H_2O

D. H^+

27. What is the overall reaction order?

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

[NO] / mol dm^{-3}	[Cl_2] / mol dm^{-3}	Rate
0.10	0.10	2.5×10^{-6}
0.10	0.20	5.0×10^{-6}
0.20	0.10	10.0×10^{-6}

A. Zero order

B. First order

C. Second order

D. Third order

Turn over

28. What is true of rate constants of elementary reactions?

A. Always increase with temperature

B. Only increase with temperature for endothermic reactions

C. Never vary with temperature

D. Only decrease with temperature for endothermic reactions

26. Which apparatus can be used to monitor the progress of this reaction?

$$NaHCO_3(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l) + CO_2(g)$$

I. A pH meter

II. A gas syringe

III. A colorimeter

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

27. Compounds **P** and **Q** were mixed together at various concentrations and the initial rate of each reaction was measured.

Experiment	[P] mol dm^{-3}	[Q] mol dm^{-3}	Initial rate of reaction (mol dm^{-3} s^{-1})
1	0.20	0.15	0.50
2	0.10	0.15	0.25
3	0.20	0.30	1.00

What are the orders of reaction with respect to **P** and **Q**?

	Order with respect to P	Order with respect to Q
A.	1	1
B.	1	2
C.	2	1
D.	1	0

28. What are the units for the rate constant, k, in the following expression?

$\text{Rate} = k[\text{X}]^2[\text{Y}]^0$

A. $\text{mol}^2\,\text{dm}^{-6}\,\text{s}^{-1}$

B. $\text{mol}\,\text{dm}^{-3}\,\text{s}^{-1}$

C. $\text{mol}^{-1}\,\text{dm}^3\,\text{s}^{-1}$

D. $\text{mol}^{-2}\,\text{dm}^6\,\text{s}^{-1}$

8. The mechanism of an exothermic reaction between A and B consists of two steps.

$$A + B \rightleftharpoons C + D \text{ Fast step}$$

$$D + B \rightarrow E \text{ Slow step}$$

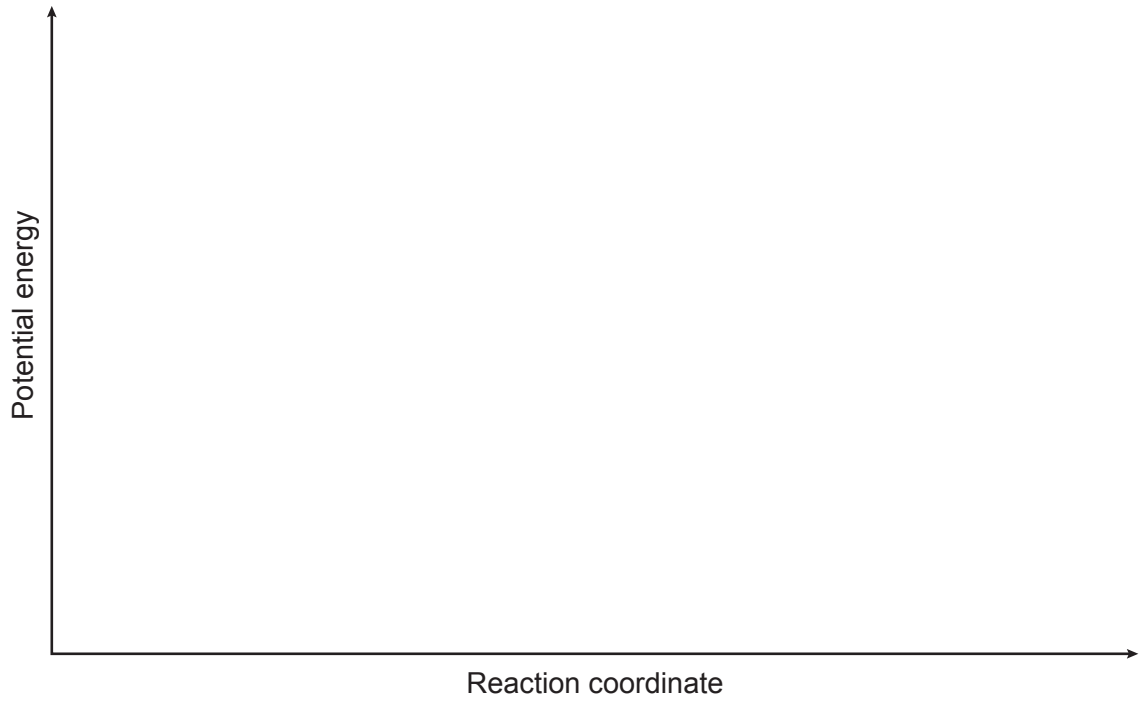
(a) (i) State the products of the reaction. [1]

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(ii) Sketch the energy profile for this reaction. Include labels for reactants, products, transition state(s) and intermediate(s). [3]



(iii) Deduce the rate equation of the reaction. [2]

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(Question 8 continued)

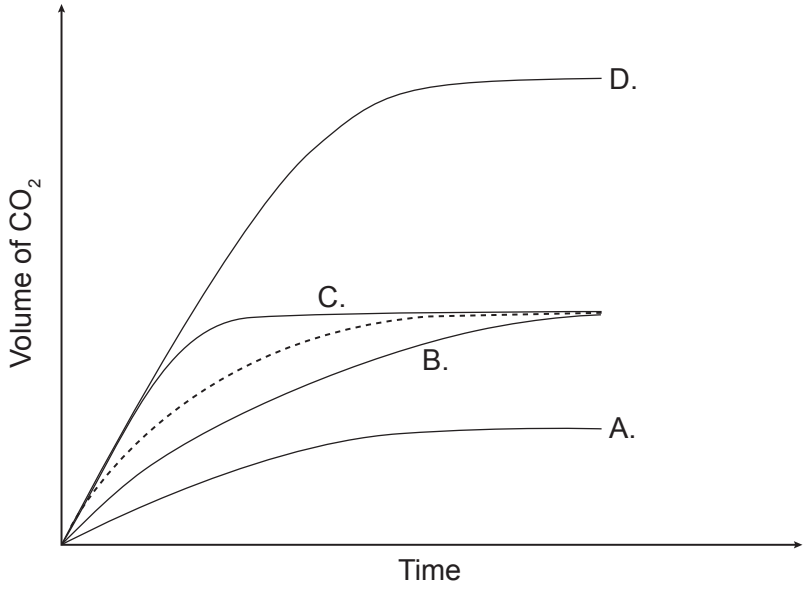
(b) Explain, using collision theory, how an increase in temperature increases the reaction rate. [3]

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Question 8 - working space

27. The dotted line represents the volume of carbon dioxide evolved when excess calcium carbonate is added into 100 cm^3 of 1.0 $mol\,dm^{-3}$ of hydrochloric acid.

Which graph represents the production of carbon dioxide when excess calcium carbonate is added to the 200 cm^3 of 0.25 $mol\,dm^{-3}$ of hydrochloric acid?



28. Which reaction has the lowest activation energy?

A. $Cl_2(g) \rightarrow 2Cl(g)$

B. $HCl(g) \rightarrow H(g) + Cl(g)$

C. $HCl(g) \rightarrow H^+(g) + Cl^-(g)$

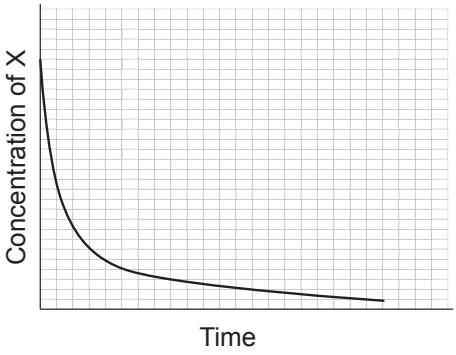
D. $2H(g) \rightarrow H_2(g)$

29. Consider the following equation:

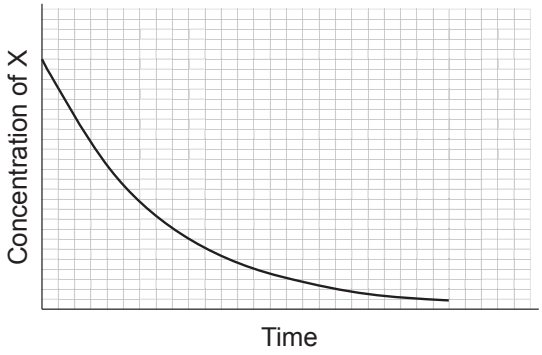
$$2X \rightarrow Y + Z$$

Which graph shows that the reaction is first order with respect to X?

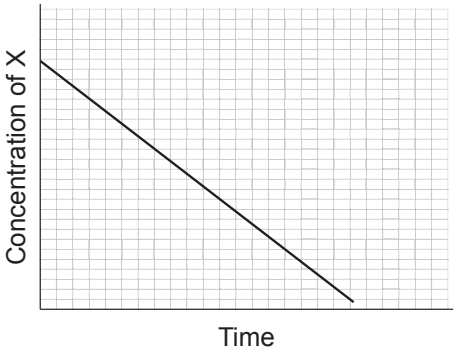
A.



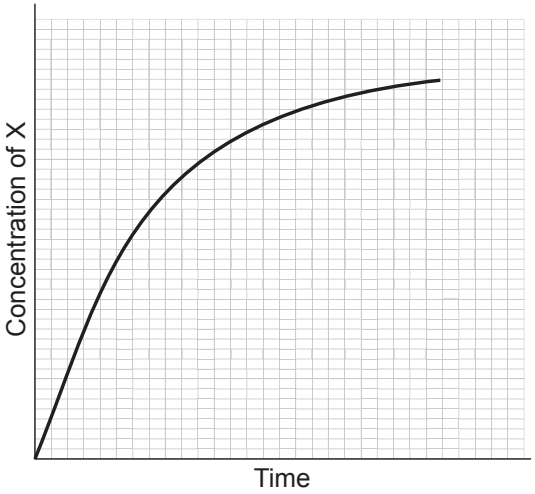
B.



C.



D.

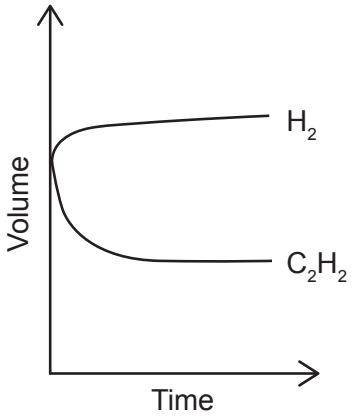


25. The volume of ethyne as it reacts with hydrogen is shown in the graphs.

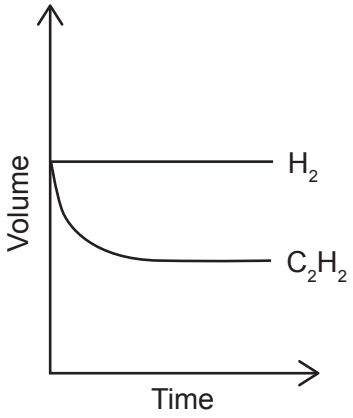
$$C_2H_2(g) + 2H_2(g) \rightarrow C_2H_6(g)$$

Which graph shows how the volume of hydrogen changes with time?

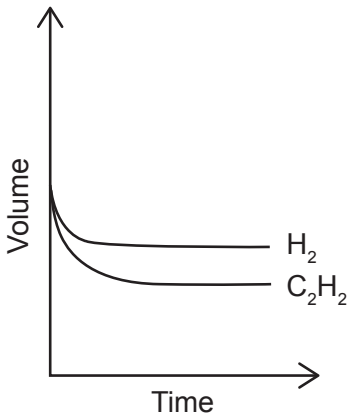
A.



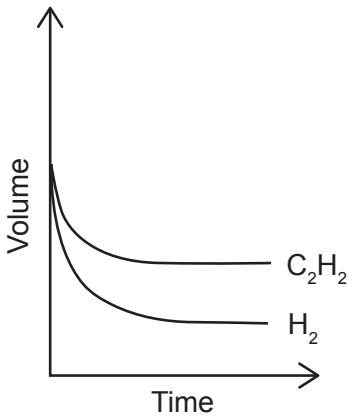
B.



C.



D.



26. The reaction between bromine and nitrogen(II) oxide follows a two-step mechanism.

$$Br_2(g) + NO(g) \rightleftharpoons NOBr_2(g) \quad \text{fast}$$

$$NOBr_2(g) + NO(g) \rightarrow 2NOBr(g) \quad \text{slow}$$

What is the rate equation?

A. $\text{Rate} = k[Br_2][NO]$

B. $\text{Rate} = k[Br_2][NO]^2$

C. $\text{Rate} = k[Br_2][NO]^2[NOBr_2]$

D. $\text{Rate} = k[NOBr]^2$

27. Which statement about catalysts is correct?

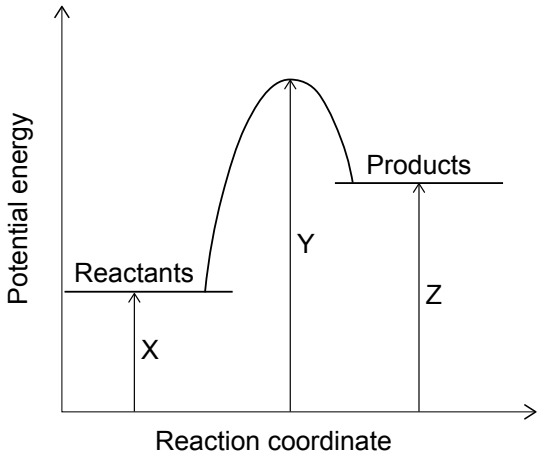
A. Catalysts increase the kinetic energy of reacting particles.

B. Catalysts affect endothermic reactions more than exothermic reactions.

C. Catalysts increase reaction rate and are used up in a reaction.

D. Catalysts alter the mechanism of a reaction.

26. The diagram shows the energy profile of a reaction.



Which combination is correct?

	Activation energy of forward reaction	Activation energy of reverse reaction
A.	X	Z
B.	Y – X	Y – Z
C.	Y	Y
D.	Y – X	Z – X

Turn over

27. What is the main reason for an increase in rate of reaction when the temperature is raised?

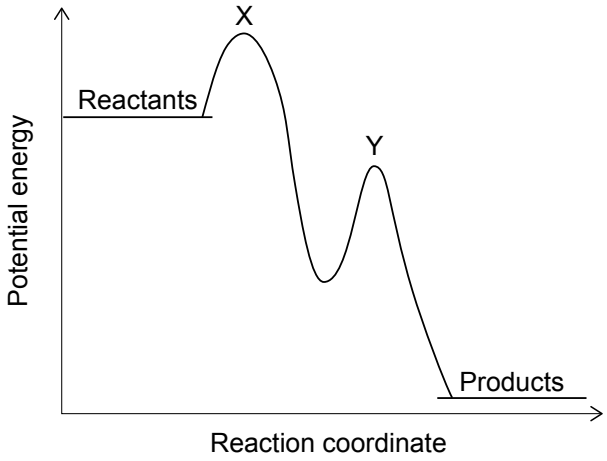
A. A greater proportion of collisions are successful.

B. Particles collide more frequently.

C. The bonds in the reactants are weakened.

D. The activation energy of the reaction decreases.

29. Which statement is correct about points X and Y on the energy profile diagram?



A. X is a transition state and Y is an intermediate.

B. X is an intermediate and Y is a transition state.

C. X and Y are transition states.

D. X and Y are intermediates.

31. Which reaction would be expected to have the largest Arrhenius (pre-exponential) factor, *A,* at constant temperature?

A. $H(g) + I(g) \rightarrow HI(g)$

B. $H_2(g) + I_2(g) \rightarrow 2HI(g)$

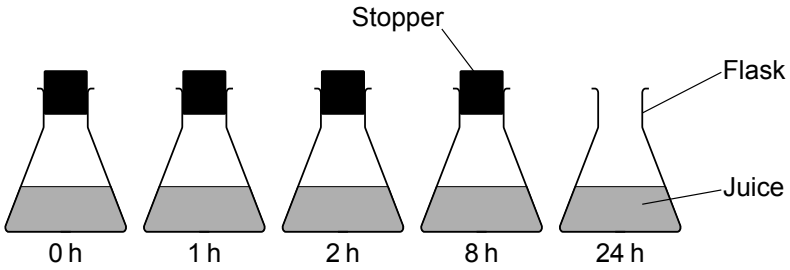
C. $2HCl(g) \rightarrow H_2(g) + Cl_2(g)$

D. $H_2 + C_2H_4 \rightarrow C_2H_6$

Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

2. A student investigates the effect of exposure to the air on the ascorbic acid (vitamin C) concentration in a specific orange juice. Equal volumes of orange juice are sealed into identical flasks and placed in a refrigerator for two weeks. The samples in the refrigerator are exposed to the air by removing the stopper for a different number of hours each day as shown.



(a) Identify **two** variables that are controlled. [1]

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(b) The concentration of ascorbic acid is determined by titration with a standard iodine solution. Every few days, 10.00 cm^3 of orange juice is removed from each sample, diluted to 100.0 cm^3, and titrated.

(i) Suggest why the juice is diluted before titration. [1]

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(ii) Identify a possible systematic error with this method regarding the sample that is exposed for zero hours. [1]

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(iii) Suggest how an additional flask could be set up to verify whether the systematic error in (ii) has occurred. [1]

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(Question 2 continued)

(c) The following data are collected during a titration.

Final burette reading = $16.10 \pm 0.05\,cm^3$

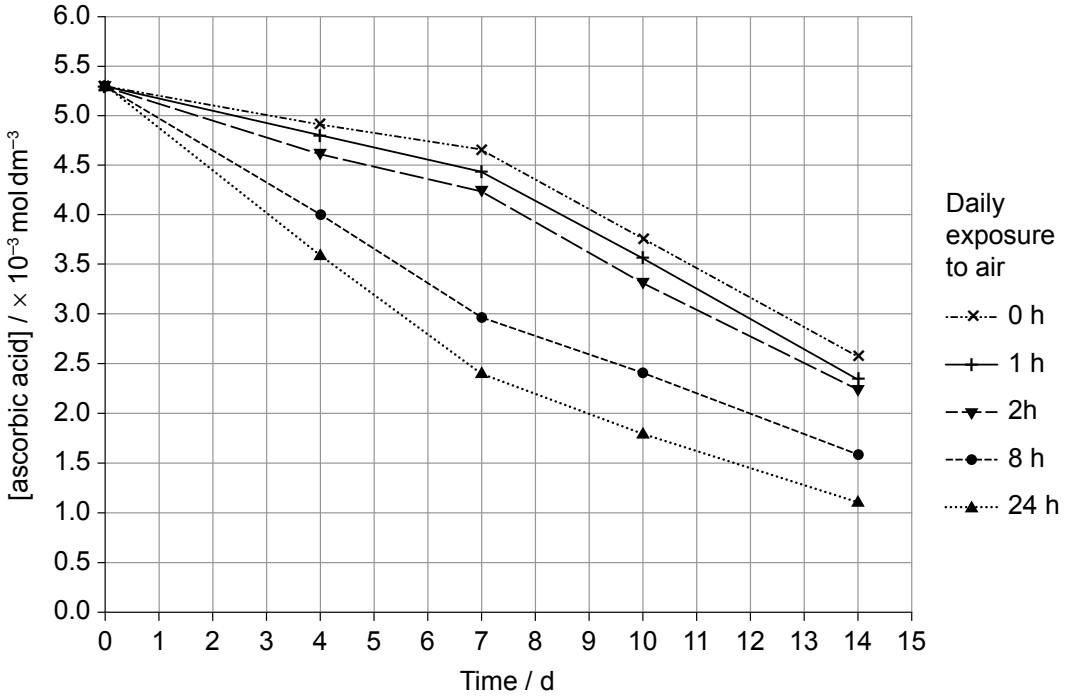
Initial burette reading = $1.10 \pm 0.05\,cm^3$

Calculate the percentage uncertainty of the titre. [1]

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(d) The following graph shows the student's results.



(i) Calculate the average rate of decrease in ascorbic acid concentration for the 24 h sample over the period of 14 days, including units. [2]

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12EP08

(Question 2 continued)

(ii) The student's hypothesis is: "A lower ascorbic acid concentration will be found in juice exposed to the air for longer, due to oxidation of ascorbic acid by oxygen."

Discuss whether or not the data support the hypothesis. [2]

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(iii) State the implications of the results of the experiment for avoiding loss of vitamin C in the storage of orange juice. [1]

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(e) Suggest an extension to the investigation that would generate further recommendations for the storage of orange juice. [1]

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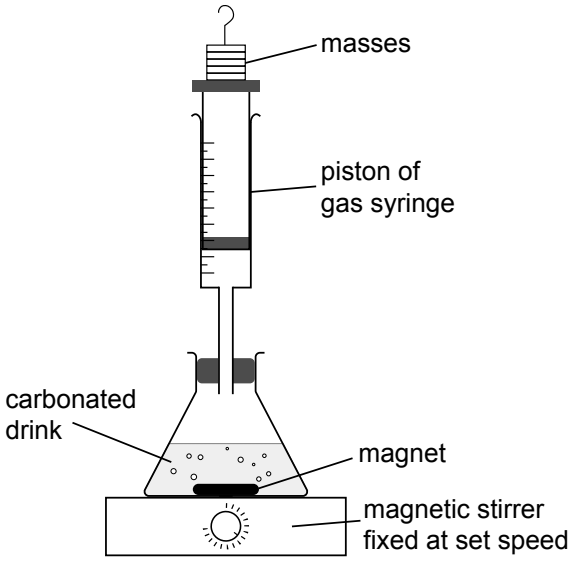
Question 2 - working space

Section B

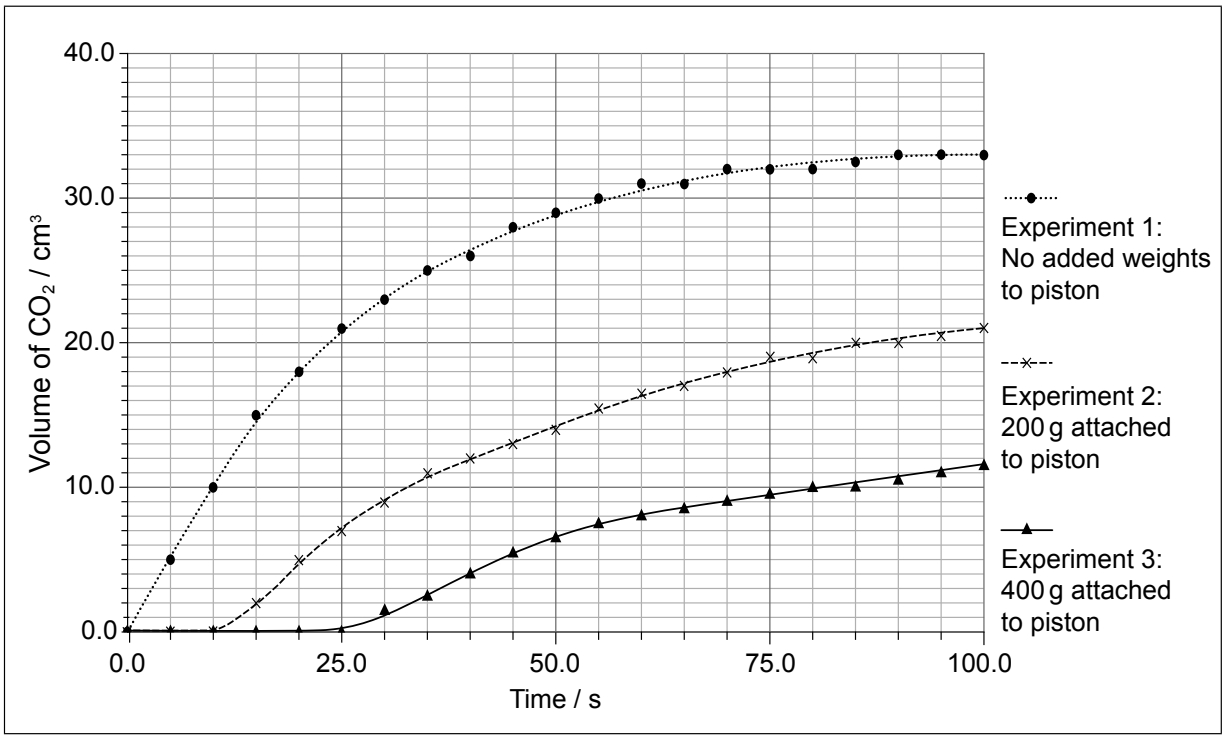
Answer **all** questions. Answers must be written within the answer boxes provided.

3. A student investigates the effect of pressure on the volume of carbon dioxide gas released from a carbonated drink poured into a flask.

To alter the pressure on the carbonated drink, masses are placed on top of the piston of the gas syringe as shown.



The graph shows some of the data collected.



(a) Determine, by annotating the graph, the initial rate of release of CO_2 in Experiment 1 in $cm^3 s^{-1}$. [2]

(This question continues on the following page)

(Question 3 continued)

(b) Estimate the time at which the piston would begin to move if a 600 g mass is used. [1]

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(c) Suggest **two** reasons why the volume of CO_2 collected in the gas syringe is smaller when more masses are placed on top of the piston. [2]

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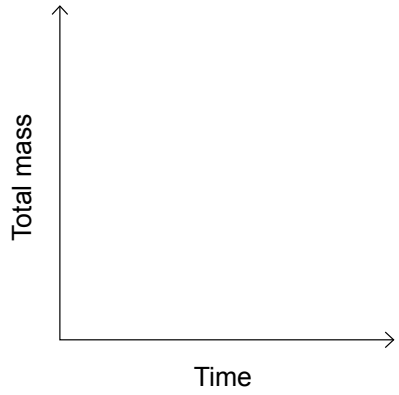
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(d) Calculate the percentage decrease in the final volume of CO_2 per 100 g mass placed on the piston, using the results of Experiment 1 and Experiment 3 at 100 s. [1]

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(e) Sketch and give a reason for a graph of the total mass of the apparatus in Experiment 1 against time. [2]



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References:

1(c) National Center for Biotechnology Information, 2020. *PubChem Compound Summary for CID 24526, Chlorine* [online] Available at: <https://pubchem.ncbi.nlm.nih.gov/compound/Chlorine> [Accessed 23 September 2020].

1(e) Norlex, 2020. *Chlorine for water disinfection.* [online] Available at: <https://norlexpoolspa.com/guidance/about-the-right-water-balance/safe> [Accessed 23 September 2020].

1(f)(ii) ResearchGate, 2015. *Distributions of chloramines as a function of pH.* [image online] Available at: <https://www.researchgate.net/figure/Distribution-of-chloramines-as-a-function-of-pH_fig8_273449675> [Accessed 23 September 2020].

Question 3 - working space

APOLLO

How far? The extent of chemical change

14 questions

29. Consider the following system at equilibrium:

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H_r^{\ominus} = -46\,\text{kJ mol}^{-1}$$

Which row correctly describes the initial effect of a change in pressure on the equilibrium position and the relationship between Q and K?

	Change in pressure	Equilibrium shift	Relationship between Q and K
A.	decrease	to the left	$Q < K$
B.	increase	to the left	$Q > K$
C.	decrease	to the right	$Q > K$
D.	increase	to the right	$Q < K$

29. The following system is at equilibrium.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad K = 4.3$$

What is the value of the equilibrium constant, *K*, for the reverse reaction?

A. $\sqrt{\frac{1}{4.3}}$

B. 4.3

C. $\frac{1}{4.3}$

D. $\sqrt{4.3}$

30. What is the effect of doubling the pressure on the equilibrium? All other conditions remain unchanged.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

	Effect on equilibrium position	Effect on equilibrium constant, *K*
A.	shifts right	no change
B.	shifts left	no change
C.	shifts right	increases
D.	shifts left	decreases

29. Which statement about this equilibrium reaction is correct?

$$CH_3CH_2OH\,(aq) + HCOOH\,(aq) \rightleftharpoons CH_3CH_2OOCH\,(aq) + H_2O\,(l)$$

A. Removing water from the reaction mixture has no effect on the position of equilibrium.

B. Adding ethanol to the reaction mixture moves the position of equilibrium to the left.

C. Removing ethanol from the reaction mixture moves the position of equilibrium to the left.

D. Adding water to the reaction mixture moves the position of equilibrium to the right.

2. Cobalt ions form coloured compounds.

(a) Deduce the electron configuration of the Co^{2+} ion. [1]

. . . . . .

(b) An equilibrium is established when hydrated cobalt ions are mixed with concentrated hydrochloric acid.

$$[Co(H_2O)_6]^{2+}(aq) + 4Cl^-(aq) \rightleftharpoons [CoCl_4]^{2-}(aq) + 6H_2O(l)$$

Pink Blue

(i) Predict the effect on the value of *K* and the equilibrium position when solid sodium chloride, NaCl(s), is added to the mixture at constant temperature. [1]

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(ii) Heating an equilibrium mixture that is initially pink changes the colour to purplish-blue. Deduce, giving a reason, whether the formation of $[CoCl_4]^{2-}(aq)$ is an exothermic or endothermic process. [1]

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Question 2 - working space

3. Ammonia is produced industrially using the reversible reaction.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(a) (i) Calculate the equilibrium constant, *K*, when 30.0 mol N_2, 40.0 mol H_2 and 6.17 mol NH_3 are at equilibrium in a 55.0 dm^3 reaction container at a temperature of 450 °C. [3]

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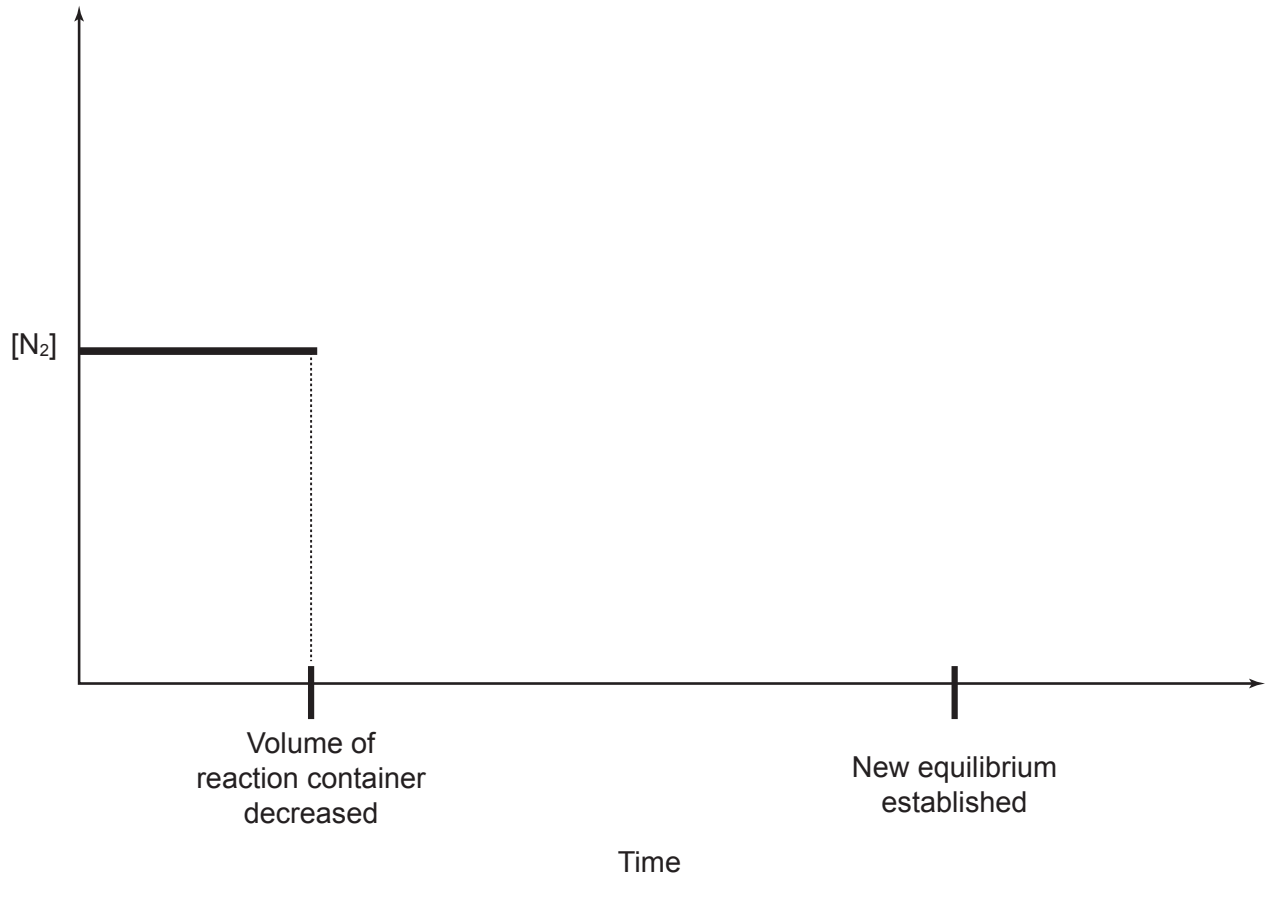
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(ii) The volume of the reaction container of the mixture at equilibrium is suddenly decreased.

Sketch the graph of the concentration of nitrogen versus time on the axes below until after the new equilibrium is established at a constant temperature. [3]



(This question continues on the following page)

(Question 3 continued)

(iii) Calculate the standard change in Gibbs energy, $\Delta G^{\ominus}$, for this reaction at 450 °C, stating its units. Use your answer to part (a)(i) and section 1 of the data booklet. [2]

If you did not obtain an answer to part (a)(i) then use the value 0.200, although this is not the correct answer.

(b) (i) Outline how ammonia acts as a Lewis base when it forms the complex ion $[Cu(NH_3)_4(H_2O)_2]^{2+}(aq)$. [1]

(ii) Determine the pH of a 0.350 mol dm^{-3} solution of ammonia. Use section 1 of the data booklet. [3]

$pK_b(NH_3) = 4.75$

Question 3 - working space

30. Which statement regarding the chemical equilibrium explains why it is described as dynamic?

A. There is a continuous shift in the equilibrium position.

B. The reactants and products continue to react.

C. The concentrations of reactants and products continue to change.

D. The rates of forward and reverse reactions continue to change.

31. SO_2 reacts with O_2 to produce SO_3.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$$

A mixture of 1.10 mol of $SO_2(g)$ and 1.95 mol of $O_2(g)$ was placed into a 1 dm^3 container at a certain temperature. When the equilibrium was reached, the mixture contained 0.18 mol of $SO_2(g)$.

What is the value of the equilibrium constant, *K*, for this reaction?

A. $\frac{0.92^2}{0.92^2 \times 0.46}$

B. $\frac{0.46}{0.18 \times 1.03}$

C. $\frac{0.92}{0.18 \times 1.49}$

D. $\frac{0.92^2}{0.18^2 \times 1.49}$

23. A crystal of copper(II) sulfate is in equilibrium with a copper(II) sulfate solution in a stoppered flask at constant temperature.

Which observation is possible?

A. The colour of the solution becomes darker.

B. The volume of the liquid decreases.

C. The shape of the crystal changes slowly over time.

D. The size of the crystal decreases.

29. 2 mol of NO (g) and 1 mol of Cl_2 (g) were mixed together, and the system was allowed to reach equilibrium at 35 °C:

$$2NO(g) + Cl_2(g) \rightleftharpoons 2NOCl(g) \qquad K = 6.5 \times 10^4 \text{ at } 35\,°C$$

Which relationship is correct for this equilibrium at 35 °C?

A. [NOCl] = [NO]

B. [NOCl] = 2[Cl_2]

C. [NOCl] >> [NO]

D. [NOCl] << [NO]

30. Consider the equilibrium reaction:

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

Under certain conditions, $K = 2.5$.

At the same temperature and pressure, a mixture has the following concentrations, in $mol\,dm^{-3}$

$$[CO] = 0.2 \qquad [H_2] = 0.4 \qquad [CH_3OH] = 0.32$$

Which statement is correct?

A. Mixture is at equilibrium and no reactions are occurring.

B. Forward and reverse reactions are occurring at the same rate.

C. Forward reaction rate is favoured to establish equilibrium.

D. Reverse reaction rate is favoured to establish equilibrium.

28. What is the equilibrium constant expression for the following reaction?

$$2SO_3(g) \rightleftharpoons 2SO_2(g) + O_2(g)$$

A. $\frac{[SO_2]^2[O_2]}{[SO_3]^2}$

B. $\frac{[SO_2]^2 + [O_2]}{[SO_3]^2}$

C. $\frac{[SO_3]^2}{[SO_2]^2[O_2]}$

D. $\frac{2[SO_2][O_2]}{2[SO_3]}$

30. The equation for the reaction between two gases, A and B, is:

$$A(g) + 2B(g) \rightleftharpoons 2C(g)$$

When the reaction is at equilibrium at 600 K, the concentrations of A, B, and C are 2, 1, and 2 mol dm^{-3} respectively. What is the value of the equilibrium constant at 600 K?

A. 0.25

B. 1

C. 2

D. 4

Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

1. Hypochlorous acid, HOCl, is a sterilizing agent used in swimming pools and is produced when chlorine reacts with water.

$$Cl_2(aq) + H_2O(l) \rightleftharpoons HOCl(aq) + HCl(aq)$$

(a) Deduce the oxidation states of chlorine in the reactants and products. [2]

Reactant: Cl_2:

. . . . . .

Products: HOCl:

. . . . . .

HCl:

. . . . . .

(b) Explain why more chlorine reacts with water when NaOH(aq) is added. [1]

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(c) Researchers studying the solubility of chlorine in pure water at different temperatures compile the following data from different sources.

Source	Temperature / °C	Solubility of chlorine
A	0	1.46 g per 100 cm^3
B	10	310 cm^3 per 100 cm^3
C	20	0.70 g per 100 cm^3
D	25	6300 mg per 1000 cm^3
E	30	177 cm^3 per 100 cm^3
F	30	0.57 g per 100 cm^3

(This question continues on the following page)

(Question 1 continued)

(i) Identify a problem in comparing the data from different sources. [1]

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(ii) The units of solubility are converted to mol dm^{-3}.

Source	Temperature / °C	Solubility of chlorine	Solubility of chlorine / mol dm^{-3}
A	0	1.46 g per 100 cm^3	0.206
B	10	310 cm^3 per 100 cm^3	0.13
C	20	0.70 g per 100 cm^3	0.099
D	25	6300 mg per 1000 cm^3	0.089
E	30	177 cm^3 per 100 cm^3	
F	30	0.57 g per 100 cm^3	0.080

Complete the table by calculating the value for source E.

Assume the density of chlorine is 2.86 g dm^{-3} at 30 °C. [2]

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(iii) Suggest an explanation for the effect of temperature on solubility. [1]

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(d) Suggest why chlorine is not often added to swimming pools directly. [1]

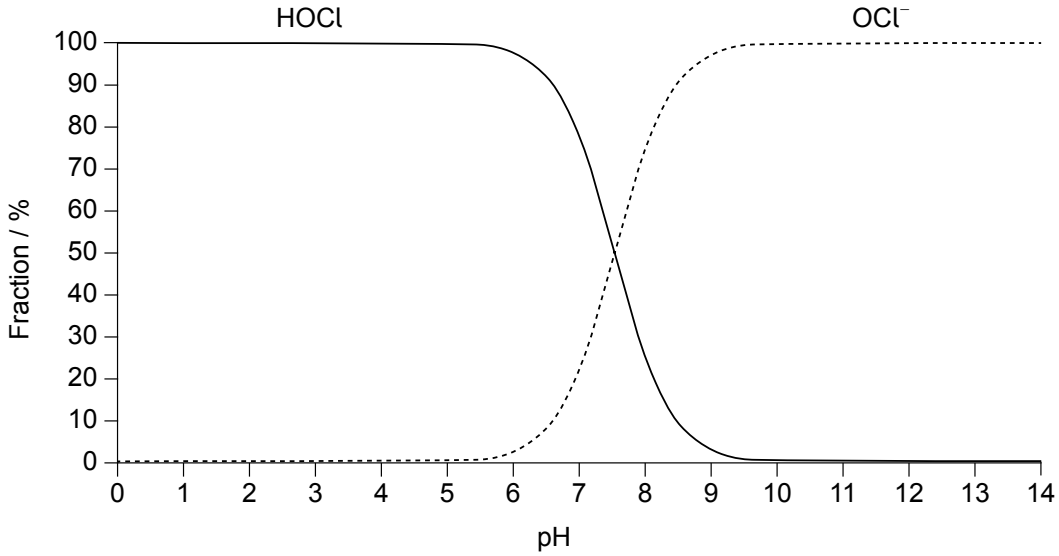
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(This question continues on the following page)

(Question 1 continued)

(e) HOCl ionizes to form the hypochlorite ion, OCl^-, which is a less effective disinfectant than the undissociated acid.

The graph shows the concentrations of HOCl(aq) and OCl^-(aq) at different pH values at 25°C.



(i) Deduce the pH range where the water is most effectively sterilized. [1]

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(ii) Determine, with reference to the graph in (e), the pK_a of HOCl. [2]

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(Question 1 continued)

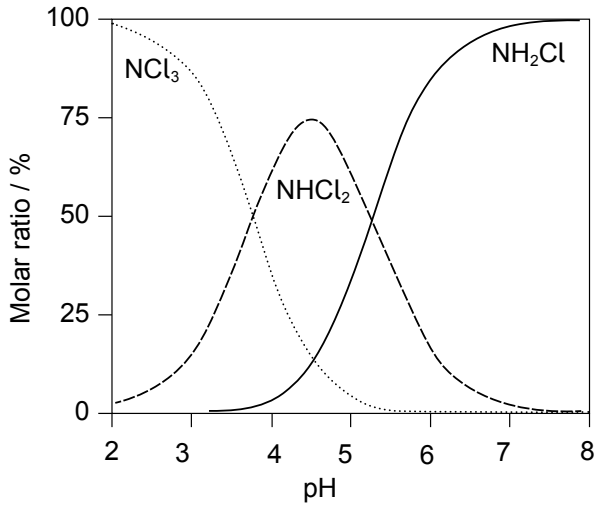
(f) Ammonia released from sweat and urine reacts with HOCl to form a range of compounds including chloramines.

(i) Deduce an equation for the formation of dichloramine, $NHCl_2(aq)$, from ammonia and $HOCl(aq)$. [1]

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(ii) The graph shows the molar ratio of chloramines formed at different pH values at 25 °C. Trichloramine, NCl_3, causes pool water to smell bad.



State **two** conditions needed to prevent the bad smell. [2]

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(g) Suggest **two** reasons why operating a swimming pool at a lower temperature is favourable for the environment. [2]

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Question 1 - working space

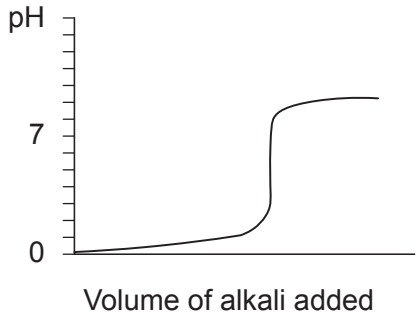
APOLLO

Proton transfer reactions

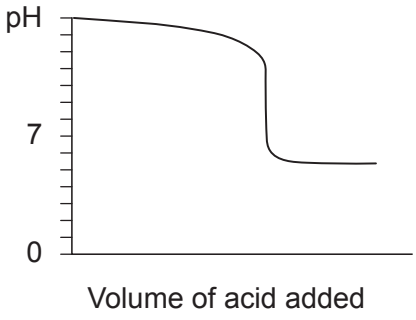
20 questions

3. Which chart shows the neutralization curve of a strong base with a strong acid?

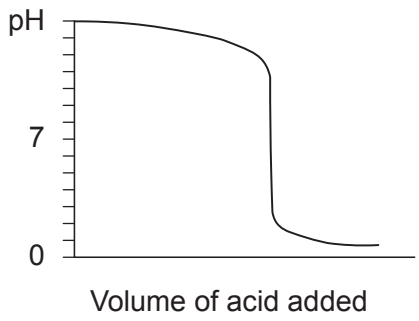
A.



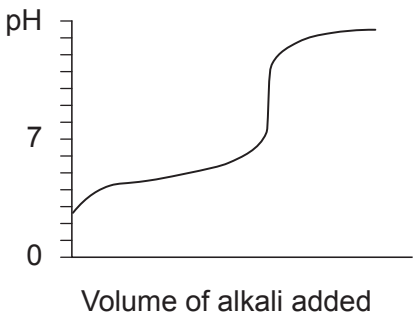
B.



C.



D.



32. Which two species can be both BrØnsted-Lowry acids and BrØnsted-Lowry bases?

A. H_3PO_4 and PO_4^{3-}.

B. HPO_4^{2-} and $H_2PO_4^{-}$.

C. HPO_4^{2-} and PO_4^{3-}.

D. PO_4^{3-} and $H_2PO_4^{-}$.

33. A solution has a pH of 3.0. What is the hydroxide ion concentration, $[OH^-]$, in the solution?

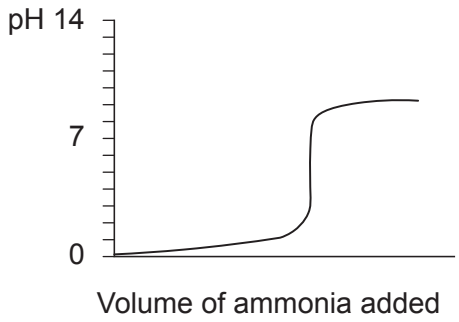
A. 11

B. 10^{-3}

C. 10

D. 10^{-11}

39. When an excess of ammonia was added to hydrochloric acid, the following neutralization curve was obtained.



Which would be the best indicator for this titration?

	Indicator	pk_a
A.	Phenol red	7.9
B.	Bromothymol blue	7.0
C.	Phenolphthalein	9.6
D.	Bromocresol green	4.7

31. What is required to convert a base into its conjugate acid?

A. A negative charge

B. A hydrogen atom

C. An electron pair

D. A proton

32. Which solution has a pH of 9.0?

A. $10^{-9}\,\text{mol}\,\text{dm}^{-3}\ \text{NH}_3\,(\text{aq})$

B. $10^{-9}\,\text{mol}\,\text{dm}^{-3}\ \text{NaOH}\,(\text{aq})$

C. $10^{-5}\,\text{mol}\,\text{dm}^{-3}\ \text{NH}_3\,(\text{aq})$

D. $10^{-5}\,\text{mol}\,\text{dm}^{-3}\ \text{NaOH}\,(\text{aq})$

33. What is the main reason why sulfuric acid has a lower pH than methanoic acid of the same concentration?

A. Sulfuric acid is diprotic, whereas methanoic acid is monoprotic.

B. Sulfuric acid ionizes more than methanoic acid.

C. Sulfuric acid has a stronger conjugate base than methanoic acid.

D. Sulfuric acid is more soluble in water than methanoic acid.

34. Which salt is basic?

A. HCOONa

B. $HCOONH_4$

C. $NaNO_3$

D. NH_4Cl

35. What is the best indicator to use in the titration of phenylamine with nitric acid?

A. Bromophenol blue, $pK_a = 4.2$

B. Bromothymol blue, $pK_a = 7.0$

C. Phenol red, $pK_a = 7.9$

D. Phenolphthalein, $pK_a = 9.6$

31. What is the pH of $0.0010\,\text{mol}\,\text{dm}^{-3}\,\text{HCl}\,(\text{aq})$?

A. 2.0

B. 2.5

C. 3.0

D. 3.5

32. Which solution is acidic at 25 °C?

A. $[H^+] = 1.0 \times 10^{-9} \text{mol dm}^{-3}$

B. $[OH^-] = 1.0 \times 10^{-13} \text{mol dm}^{-3}$

C. $[OH^-] = 1.0 \times 10^{-6} \text{mol dm}^{-3}$

D. $[H_3O^+] = 1.0 \times 10^{-13} \text{mol dm}^{-3}$

34. Which of these bases has the strongest conjugate acid?

Bases	K_b	pK_b
NH_3	1.8×10^{-5}	
CH_3NH_2		3.35
$(CH_3)_2NH$	5.9×10^{-4}	
CH_3CONH_2		14.5

A. NH_3

B. CH_3NH_2

C. $(CH_3)_2NH$

D. CH_3CONH_2

35. What is the pH of a buffer solution which contains $0.500\,\text{mol}\,\text{dm}^{-3}$ of methanoic acid and $0.250\,\text{mol}\,\text{dm}^{-3}$ of sodium methanoate?

pK_a (methanoic acid) = 3.75

A. 3.25

B. 3.45

C. 3.75

D. 4.05

32. In which of the following reactions does ammonia behave as a Brønsted–Lowry base?

A. $4NH_3 + 5O_2 \rightarrow 4NO + 6H_2O$

B. $NH_3 + H_2O + CO_2 \rightarrow (NH_4)HCO_3$

C. $NH_3 + CH_3CH_2Cl \rightarrow CH_3CH_2NH_2 + HCl$

D. $2NH_3 + 2K \rightarrow 2KNH_2 + H_2$

33. Which aqueous solution has the lowest pH?

A. $0.01\,\text{mol}\,\text{dm}^{-3}\,NH_4Cl$

B. $0.01\,\text{mol}\,\text{dm}^{-3}\,NaCl$

C. $0.01\,\text{mol}\,\text{dm}^{-3}\,NH_4HCO_3$

D. $0.01\,\text{mol}\,\text{dm}^{-3}\,NaHCO_3$

31. What is the concentration of $OH^-(aq)$, in $mol\,dm^{-3}$, in a solution at 298.15 K with a pH of 4.50?

$pH = -\log_{10}[H^+]$ $[H^+] = 10^{-pH}$ $pOH = -\log_{10}[OH^-]$ $[OH^-] = 10^{-pOH}$ $K_w = [H^+][OH^-]$

A. 3.16×10^{-10}

B. 3.16×10^{-9}

C. 3.16×10^{-5}

D. 3.16×10^{-4}

32. Which aqueous solution has the lowest pH?

A. $1.0\,\text{mol}\,\text{dm}^{-3}\ HNO_3$

B. $2.0\,\text{mol}\,\text{dm}^{-3}\ HCl$

C. $1.0\,\text{mol}\,\text{dm}^{-3}\ CH_3COOH$

D. $2.0\,\text{mol}\,\text{dm}^{-3}\ NaOH$

32. Which reactions involve the transfer of a proton?

I. $2HCl\,(aq) + Mg\,(s) \rightarrow MgCl_2\,(aq) + H_2\,(g)$

II. $2HCl\,(aq) + MgO\,(s) \rightarrow MgCl_2\,(aq) + H_2O\,(l)$

III. $2HCl\,(aq) + MgCO_3\,(s) \rightarrow MgCl_2\,(aq) + H_2O\,(l) + CO_2\,(g)$

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

Turn over

33. The indicator, HInd, is used in an acid–base titration.

$$\underset{\text{colour A}}{HInd\,(aq)} \rightleftharpoons \underset{\text{colour B}}{H^+(aq) + Ind^-(aq)}$$

Which statements are correct?

I. In a strongly alkaline solution, colour B is observed.

II. Colour A is observed when [HInd] < [Ind^-].

III. [Ind^-] approximately equals [HInd] at the end point.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

37. Which term cannot characterize ammonia, NH_3?

A. Lewis acid

B. Brønsted–Lowry acid

C. ligand

D. nucleophile

APOLLO

Electron transfer reactions

25 questions

34. Ammonia, NH_3 and nitrous acid, HNO_2, are compounds of nitrogen.
What are the oxidation states of nitrogen in these compounds?

	NH_3	**HNO_2**
A.	+3	+3
B.	–3	–3
C.	+3	–3
D.	–3	+3

Turn over

35. Below is a reactivity series of selected elements, arranged from highest activity to lowest.

Zn
Fe
Cd
Co
Ni
Sn
Pb
Cu

Which reaction is spontaneous?

A. $Cd^{2+}(aq) + Pb(s) \rightarrow Pb^{2+}(aq) + Cd(s)$

B. $Fe^{2+}(aq) + Sn(s) \rightarrow Sn^{2+}(aq) + Fe(s)$

C. $Zn^{2+}(aq) + Cu(s) \rightarrow Cu^{2+}(aq) + Zn(s)$

D. $Ni^{2+}(aq) + Co(s) \rightarrow Co^{2+}(aq) + Ni(s)$

14. What is the oxidation state of nitrogen in N_2O_4?

A. −4

B. −2

C. +2

D. +4

36. In which compound does sulfur have an oxidation state of +4?

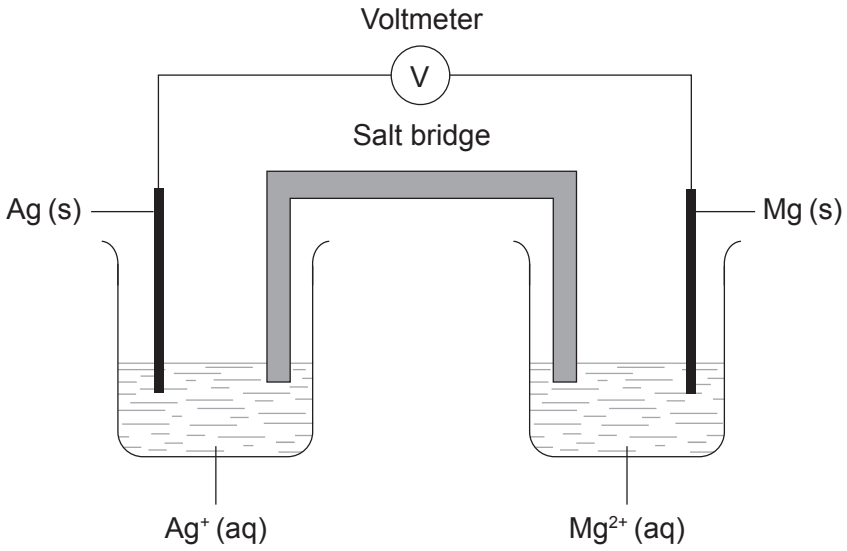
A. H_2S

B. SO_3

C. H_2SO_3

D. H_2SO_4

37. What is the standard cell potential, $E^{\ominus}_{cell}$, of the following cell?



$Ag^{+}(aq) + e^{-} \rightleftharpoons Ag(s)$ $\quad E^{\ominus} = +0.80\,V$

$Mg^{2+}(aq) + 2e^{-} \rightleftharpoons Mg(s)$ $\quad E^{\ominus} = -2.37\,V$

A. $-3.17\,V$

B. $-1.57\,V$

C. $+1.57\,V$

D. $+3.17\,V$

38. Which change represents oxidation of the functional group?

A. $CH_3COOH \rightarrow CH_3CHO$

B. $H_2CO \rightarrow HCOOH$

C. $HCCH \rightarrow H_2CCH_2$

D. $H_2CO \rightarrow CH_3OH$

39. What are the products of the electrolysis of dilute aqueous copper(II) sulfate when using inert electrodes?

	Product at anode	Product at cathode
A.	oxygen gas	hydrogen gas
B.	oxygen gas	copper metal
C.	copper metal	oxygen gas
D.	hydrogen gas	copper metal

15. Which compounds contain an atom in a +3 oxidation state?

I. NO_2^-

II. $FeCl_3$

III. BrF_3

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

36. The following occurs when tin is added to separate solutions of lead(II) nitrate, $Pb(NO_3)_2$, and manganese(II) nitrate, $Mn(NO_3)_2$.

$$Sn(s) + Pb(NO_3)_2(aq) \rightarrow Sn(NO_3)_2(aq) + Pb(s)$$

$$Sn(s) + Mn(NO_3)_2(aq) \rightarrow \text{no reaction}$$

What is the order of decreasing reactivity of the metals?

A. $Sn > Pb > Mn$

B. $Sn > Mn > Pb$

C. $Mn > Sn > Pb$

D. $Pb > Sn > Mn$

37. What are the products of the electrolysis of molten aluminium oxide, $Al_2O_3(l)$?

	Product at anode	Product at cathode
A.	O_2	Al
B.	O_3	Al
C.	Al	O_2
D.	Al	O_3

39. Consider the following standard electrode potentials:

	$E^{\ominus}$ (V)
$Zn^{2+}(aq) + 2e^- \rightleftharpoons Zn(s)$	−0.76
$Fe^{2+}(aq) + 2e^- \rightleftharpoons Fe(s)$	−0.45
$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s)$	−0.26

Which species will react with each other spontaneously under standard conditions?

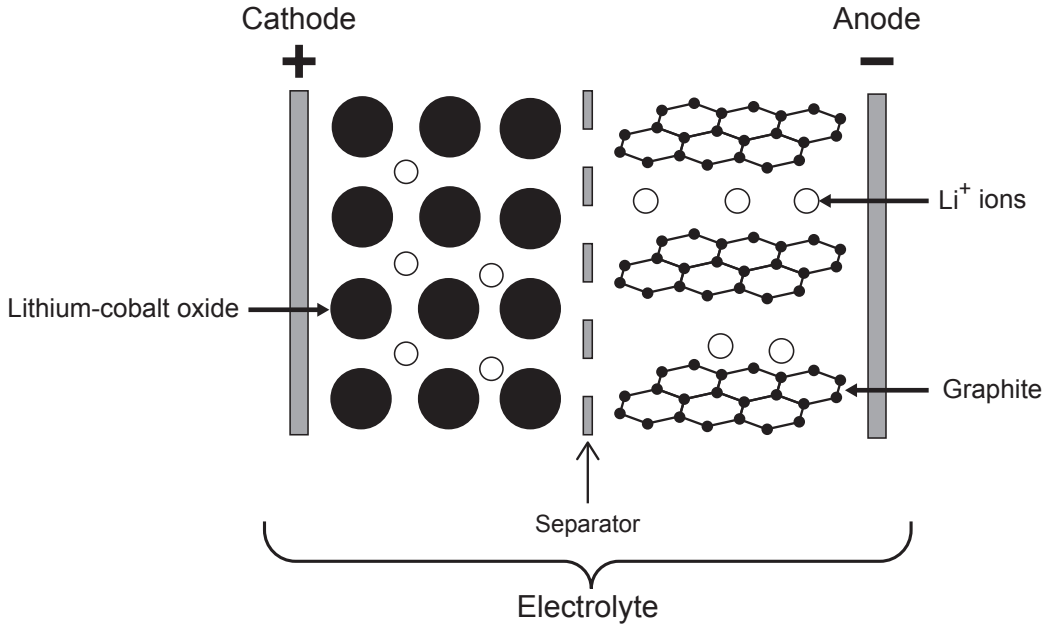
A. Zn and Fe^{2+}

B. Fe and Zn^{2+}

C. Ni and Zn^{2+}

D. Ni and Fe^{2+}

6. A lithium-ion battery consists of lithium ions on lithium-graphite (LiC_6) and lithium-cobalt oxide ($LiCoO_2$) in an electrolyte.



Lithium-ion battery

(a) The lithium ions are produced at the anode from the lithium atoms embedded in graphite.

(i) State a half-equation for the reaction occurring at the anode during discharge. [1]

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(ii) Comment on the sign and value of the standard reduction potential of lithium that make it suitable to use in the battery. Use section 19 of the data booklet. [2]

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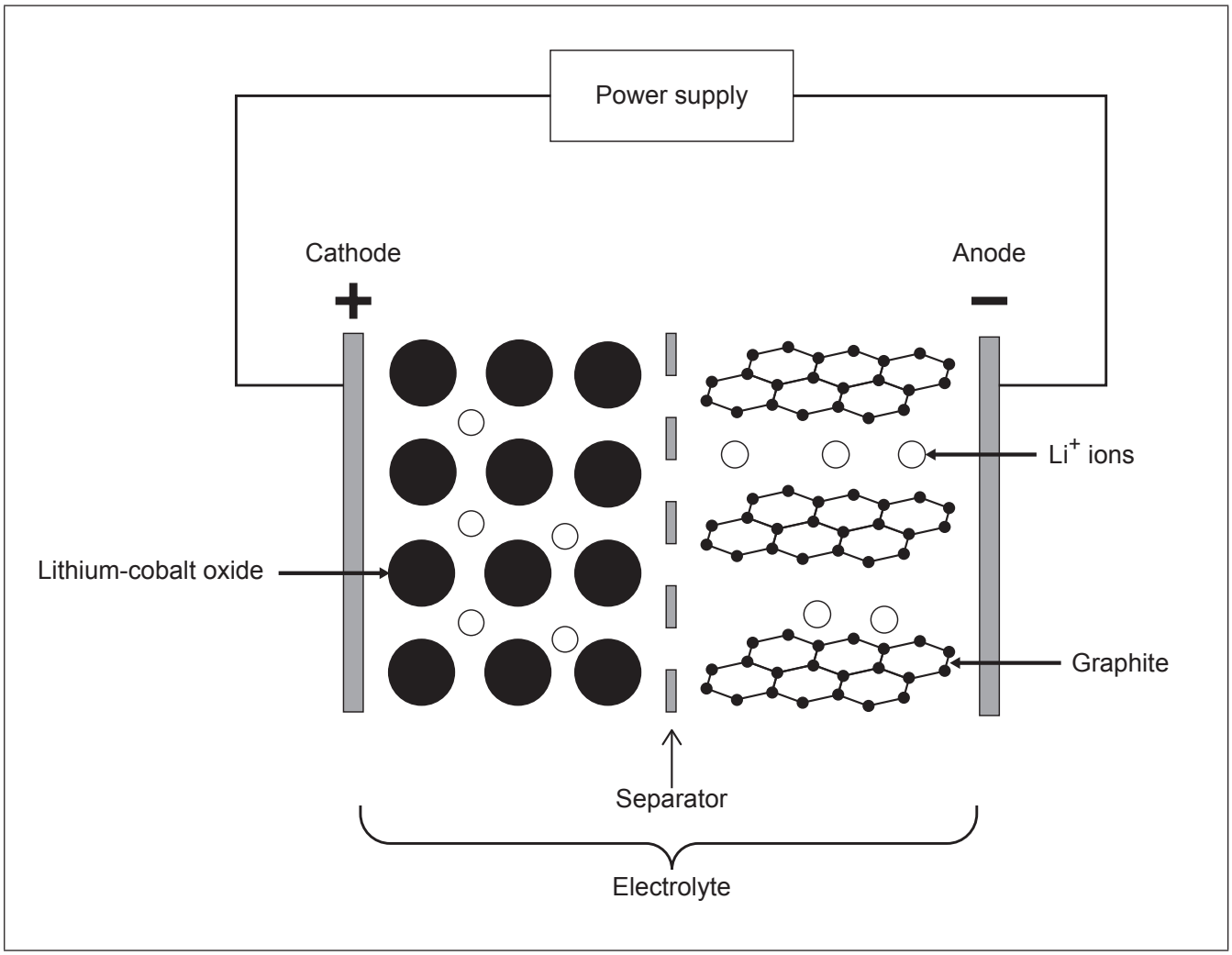
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(This question continues on the following page)

(Question 6 continued)

(b) The lithium-ion battery is rechargeable. Annotate the diagram below to show the direction of the flow of electrons in the wire while the battery is recharging. [1]



(c) Suggest why solar panels are often connected in parallel with lithium-ion batteries. [1]

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(This question continues on page 15)

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(Question 6 continued)

(d) A charge of 1000.0 C passes through a lithium-ion battery during discharge. Determine the number of lithium ions released at the anode. Use section 2 of the data booklet. [2]

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Question 6 - working space

14. What are the oxidation states of the elements in Na_2CrO_4?

	Sodium	Chromium	Oxygen
A.	+1	+6	−1
B.	+2	+3	−1
C.	+1	+6	−2
D.	+2	+3	−2

34. What is the half equation for the reduction of nitric acid to nitrogen(II) oxide in acidic medium?

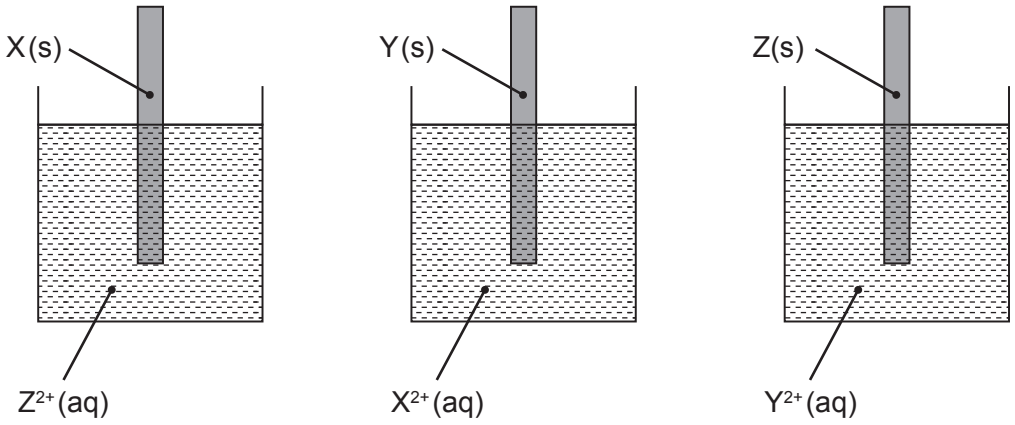
A. $HNO_3 + 3H^+ + 3e^- \rightarrow NO + 2H_2O$

B. $HNO_3 + 4H^+ + 4e^- \rightarrow NO + 2H_2O$

C. $HNO_3 + 2H_2O \rightarrow NO + 4H^+ + 4e^-$

D. $HNO_3 + 2H_2O \rightarrow NO + 3H^+ + 3e^-$

36. A student performed displacement reactions using metals X, Y, Z and solutions of their ions, X^{2+}, Y^{2+}, Z^{2+} . The results are shown.



Results:	No reaction	No reaction	Reaction occurs

What is the increasing order of the reactivity of X, Y and Z metals?

A. X, Y, Z

B. Y, X, Z

C. Z, X, Y

D. Y, Z, X

Turn over

33. What are the oxidizing and reducing agents in this reaction?

$$ClO^-(aq) + SO_2(g) + H_2O(l) \rightarrow Cl^-(aq) + SO_4^{2-}(aq) + 2H^+(aq)$$

	Oxidizing agent	Reducing agent
A.	ClO^-	H_2O
B.	SO_2	SO_4^{2-}
C.	SO_2	ClO^-
D.	ClO^-	SO_2

34. Which statement about electrochemical cells is correct?

A. Primary (voltaic) cells use electrical energy to produce a redox reaction.

B. Electrolytic cells are rechargeable.

C. Secondary cells can use electrical energy to produce a redox reaction.

D. Primary (voltaic) cells are rechargeable.

35. Consider two half-cells: $Al(s)/Al^{3+}(aq)$ and $Ni(s)/Ni^{2+}(aq)$.

What will be the cell potential, in V, when the two half-cells are connected?

$$Al^{3+}(aq) + 3e^- \rightleftharpoons Al(s) \qquad E^{\ominus} = -1.66\,V$$

$$Ni^{2+}(aq) + 2e^- \rightleftharpoons Ni(s) \qquad E^{\ominus} = -0.26\,V$$

A. -2.54

B. -1.40

C. $+1.40$

D. $+2.54$

36. Which statement about the standard hydrogen electrode, SHE, is correct?

A. The SHE must be the anode when measuring $E^{\ominus}$ values of another half-cell.

B. SHE has a standard reduction potential of 0 V at any temperature.

C. Cell potential is unaffected by the pressure of the hydrogen gas.

D. Any acid with a concentration of 1.0 mol dm^{-3} would give the same cell potential.

37. What are the main products when concentrated $NaCl(aq)$ is electrolysed using inert electrodes?

	Anode	Cathode
A.	$Cl_2(g)$	$H_2(g)$
B.	$O_2(g)$	$H_2(g)$
C.	$H_2(g)$	$Cl_2(g)$
D.	$H_2(g)$	$O_2(g)$

39. What is the oxidation state of Pt in $[Pt(NH_3)_5Cl]Cl_3$?

A. +1

B. +2

C. +3

D. +4

Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

4. Half-cells such as

$$Fe^{3+}(aq) + e^- \rightleftharpoons Fe^{2+}(aq)$$

can be connected to other half-cells to form a voltaic cell.

(a) Describe how you would connect the $Fe^{3+}|Fe^{2+}$ half-cell to another half-cell to compare their potentials. [2]

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(b) The reduction potential, ***E***, of the $Fe^{3+}|Fe^{2+}$ electrode varies with the concentration of the ions according to the equation:

$$E = 0.77 + \frac{RT}{F} \ln \frac{\left[Fe^{3+}\right]}{\left[Fe^{2+}\right]}$$

Determine the reduction potential at 25 °C, if $[Fe^{2+}] = 1.37 \times 10^{-2}\,mol\,dm^{-3}$ and $[Fe^{3+}] = 3.25 \times 10^{-4}\,mol\,dm^{-3}$.

Use section 2 of the data booklet. [3]

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Question 4 - working space

5. Transition elements are known for having multiple oxidation states, forming coloured compounds and acting as catalysts. The existence of variable oxidation states means many are used in rechargeable batteries, also known as secondary cells.

(a) (i) A common rechargeable battery is the nickel-cadmium, NiCd, battery where the two reactions during discharge are as follows.

$$Cd(s) + 2OH^-(aq) \rightleftharpoons Cd(OH)_2(s) + 2e^-$$

$$2NiO(OH)(s) + 2H_2O(l) + 2e^- \rightleftharpoons 2Ni(OH)_2(s) + 2OH^-(aq)$$

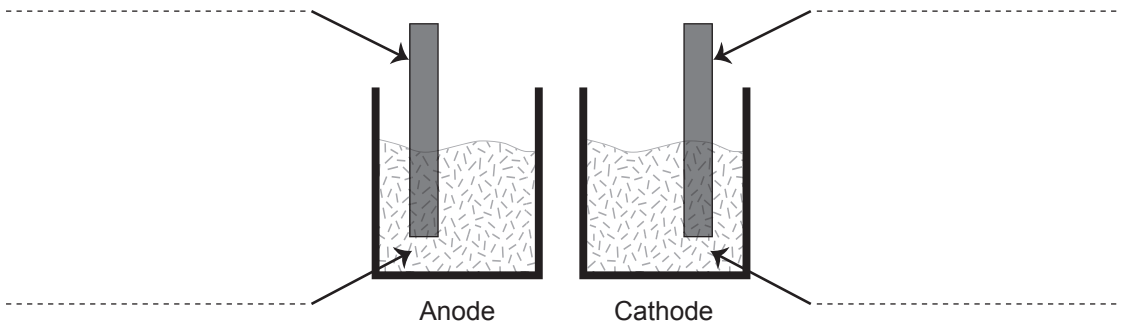
Deduce the overall cell equation. [1]

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(ii) Simple cells rely on differences in standard electrode potential values between different elements and their ions. The following is an incomplete diagram for measuring a cell potential between $Mn^{2+}(aq)/Mn$ and $Ni^{2+}(aq)/Ni$ half-cells.

Draw the missing components and fully label the diagram to show how the cell potential can be measured. [3]



(iii) Calculate the standard cell potential, E^{θ}_{cell}, for this cell. Use section 19 of the data booklet. [1]

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(This question continues on the following page)

(Question 5 continued)

(b) A different combination of half-cells produced a calculated value of Gibbs energy change, ΔG^{θ}, of $-570.3\,kJ\,mol^{-1}$. The cell involved the transfer of one electron between the electrodes.

Deduce the half-cells involved in this battery. Use sections 1, 2 and 19 of the data booklet. [3]

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(c) Chromium, Cr, is a transition metal that produces a shiny surface and is used in the automobile industry. The chromium is deposited onto a base metal in an electrolytic cell.

Annotate the table, with ticks, ✓, to show the direction and place of movement of the species shown. [2]

	Direction of movement		**Place of movement**	
Species	Towards cathode	Towards anode	In the wires	Through the electrolyte
Electrons				
Cr^{3+} ions				

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Question 5 - working space

34. The overall reaction occurring at the electrodes of a rechargeable metal hydride battery can be summarized as:

$$MH + NiO(OH) \rightleftharpoons M + Ni(OH)_2$$

Which statement is correct?

A. The oxidation state of Ni does not change.

B. M is oxidized by loss of hydrogen.

C. The oxidation state of one H atom changes from -1 to $+1$.

D. The oxidation state of one O atom changes from -1 to -2.

35. In a redox titration, manganate(VII) ions are reduced to manganese(II) ions and iron(II) ions are oxidized to iron(III) ions.

$$MnO_4^-(aq) \text{ reduced to } Mn^{2+}(aq)$$
$$Fe^{2+}(aq) \text{ oxidized to } Fe^{3+}(aq)$$

What volume, in cm^3, of $0.1\,mol\,dm^{-3}$ $MnO_4^-(aq)$ is required to reach the equivalence point in the titration of $20.00\,cm^3$ of $0.1\,mol\,dm^{-3}$ $Fe^{2+}(aq)$?

A. 2.00

B. 4.00

C. 20.00

D. 100.00

APOLLO

Electron sharing reactions

3 questions

40. Which equation represents propagation in a radical substitution mechanism?

A. $CH_4 + Cl\bullet \rightarrow \bullet CH_3 + HCl$

B. $\bullet CH_3 + Cl\bullet \rightarrow CH_3Cl$

C. $Cl_2 \rightarrow 2Cl\bullet$

D. $CH_3Cl + Cl\bullet \rightarrow CH_2Cl_2 + H\bullet$

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37. Which radical is most likely to form during the breakdown of one covalent bond of dichlorofluoromethane, $CHCl_2F$, in the upper atmosphere?

A. • $CHClF$

B. • CCl_2F

C. • $CHCl_2$

D. • $CHCl_2F$

36. Which statements explain the following reactions occurring in the upper atmosphere?

	Chlorofluorocarbon (CFC) compounds break down to produce chlorine radicals but usually not fluorine radicals.	**A single chlorine radical breaks down many ozone, O_3, molecules.**
A.	C–Cl bond is stronger than C–F bond	chain propagation steps produce more radicals
B.	C–F bond is stronger than C–Cl bond	chain termination steps cause chlorine radicals to reform chlorine molecules
C.	C–Cl bond is stronger than C–F bond	chain termination steps cause chlorine radicals to reform chlorine molecules
D.	C–F bond is stronger than C–Cl bond	chain propagation steps produce more radicals

APOLLO

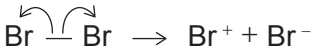
Electron-pair sharing reactions

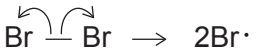
16 questions

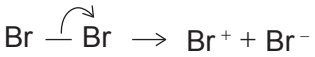
36. Which alcohol and conditions would produce the highest yield of methylpropanoic acid?

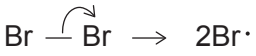
	Alcohol	Conditions
A.	2-methylpropan-2-ol	Reflux
B.	2-methylpropan-1-ol	Reflux
C.	2-methylpropan-2-ol	Distillation
D.	2-methylpropan-1-ol	Distillation

37. Which correctly shows heterolytic bond fission?

A. 

B. 

C. 

D. 

38. What is the role of the CN^- ion in the reaction of 1-chloropropane with excess KCN in ethanol?

$$C_3H_7Cl + KCN \rightarrow C_3H_7CN + KCl$$

A. Electrophile and Lewis base

B. Nucleophile and Lewis acid

C. Electrophile and Lewis acid

D. Nucleophile and Lewis base

40. Which species would take part in a substitution reaction with benzene?

A. Cl_2

B. Cl•

C. Cl^+

D. Cl^-

Turn over

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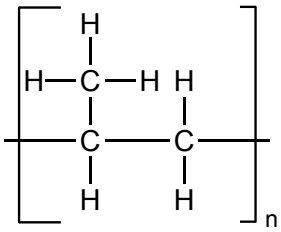
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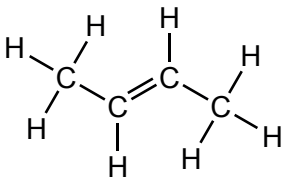
10. 영원파란, 2017. N2O 루이스 구조 그리기. [online] Available at: http://ywpop.tistory.com/7363 [Accessed 7 May 2024]. Source adapted.

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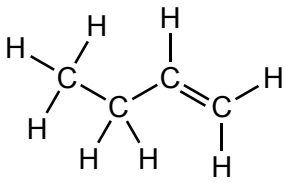
11. Which monomer produces this addition polymer?



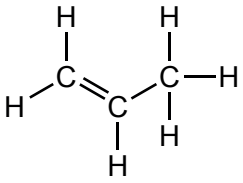
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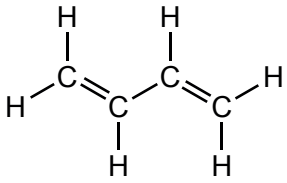
B.



C.



D.



38. Which compound can be reduced to produce butanal?

A. Butanoic acid

B. Butan-1-ol

C. Butanone

D. Butan-2-ol

40. Which of these ions would be a suitable species to react with benzene in a substitution reaction?

A. NO_2^-

B. NH_4^+

C. NO_2^+

D. Br^-

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35. Which compound undergoes oxidation when heated with acidified potassium dichromate?

I. $CH_3CH_2CH_2CH_2OH$

II. $CH_3C(CH_3)_2OH$

III. $CH_3CH(OH)CH_2CH_3$

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

38. But-2-ene undergoes a variety of addition reactions.

Which of the following is correct?

	Reagent added	Product
A.	H_2	But-1-ene
B.	H_2O	Butan-1-ol
C.	HBr	2-bromobutane
D.	Br_2	2,2-dibromobutane

40. Which statement is correct about an S_N2 mechanism?

A. Two molecules are involved in the rate-determining step of the mechanism.

B. Two steps are involved in the mechanism.

C. A nucleophile is substituted by an electrophile.

D. The mechanism involves formation of an intermediate carbocation.

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38. Which product may be obtained by the reduction of CH_3CH_2COOH?

A. $CH_3CH(OH)CH_3$

B. $CH_3CH_2CH_2OH$

C. $CH_3CH_2OCH_3$

D. CH_3COOCH_3

40. What is the main product of the reaction between but-1-ene, $CH_2CHCH_2CH_3$, and hydrogen bromide, HBr?

A. $CH_3CHBrCH_2CH_3$

B. $CH_2BrCH_2CH_2CH_3$

C. $CH_2BrCHBrCH_2CH_3$

D. $CH_2BrCH(CH_3)_2$

4. Bromoethane, C_2H_5Br, is produced by reacting ethene, C_2H_4, with hydrogen bromide, HBr.

$$C_2H_4(g) + HBr(g) \rightarrow C_2H_5Br(l)$$

(a) (i) State the type of reaction and the role of HBr. [1]

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(ii) Outline why ethene is susceptible to attack by molecules such as HBr. [1]

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(b) (i) Determine the standard enthalpy change of the reaction, in $kJ\,mol^{-1}$. Use section 12 of the data booklet. [2]

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(ii) State **two** reasons why the result using bond enthalpies is less accurate than one calculated from enthalpies of formation. [2]

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(Question 4 continued)

(iii) Outline why the entropy change of the reaction is negative. [1]

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(iv) Predict, showing your working, if the reaction is spontaneous at 298 K.
Use section 13 of the data booklet and your answer for part (b)(i). If you did not get an answer in part (b)(i), use $-58\,kJ\,mol^{-1}$. [2]

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(Question 4 continued)

(c) Bromoethane can react with aqueous hydroxide ions to produce ethanol.

$$H_3CCH_2Br(l) + OH^-(aq) \rightarrow H_3CCH_2OH(aq) + Br^-(aq)$$

(i) State the type of reaction. [1]

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(ii) Sketch the mechanism of the reaction, using curly arrows to represent the movement of electron pairs. [3]

(iii) Outline why the reaction takes place by this mechanism. [1]

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(iv) State the order of reaction. [1]

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(Question 4 continued)

(v) Predict, with a reason, a halogenoethane that would react more quickly than bromoethane. [1]

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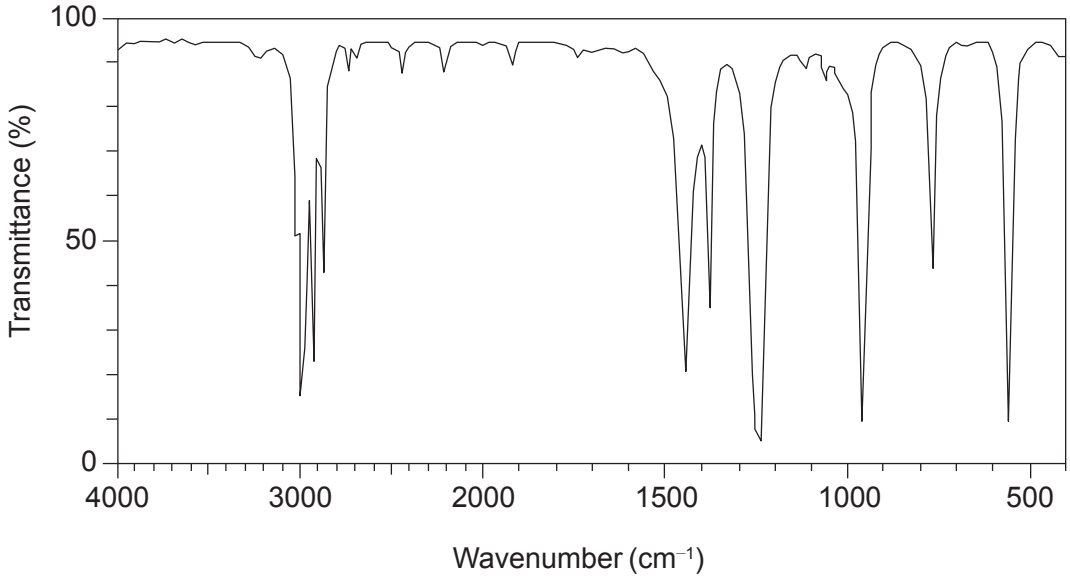
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(vi) Bromoethane shows a signal in the 3.5–4.4 ppm region of its ^{1}H NMR spectrum. Deduce the splitting pattern of this signal. Use section 21 of the data booklet. [1]

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(vii) Deduce whether this infrared spectrum is produced by bromoethane or ethanol. Give evidence from section 20 of the data booklet. [1]



[Source: SDBS. National Institute of Advanced Industrial Science and Technology.]

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Question 4 - working space

38. Which ion is a better leaving group in nucleophilic substitutions?

A. bromide ion

B. chloride ion

C. fluoride ion

D. iodide ion

39. Which statement is correct when 2-chloro-2-methylpentane reacts with water to form 2-methylpentan-2-ol?

A. Water acts as a nucleophile and attacks the chlorine atom.

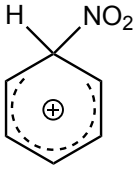
B. The reaction occurs in a single step.

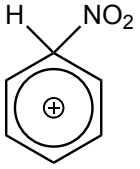
C. A carbocation intermediate is formed.

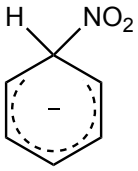
D. Homolytic bond fission occurs.

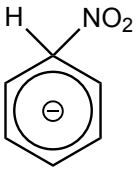
Turn over

40. Which illustrates the correct intermediate formed in the nitration of benzene by NO_2^+?

A. 

C. 

B. 

D. 

APOLLO

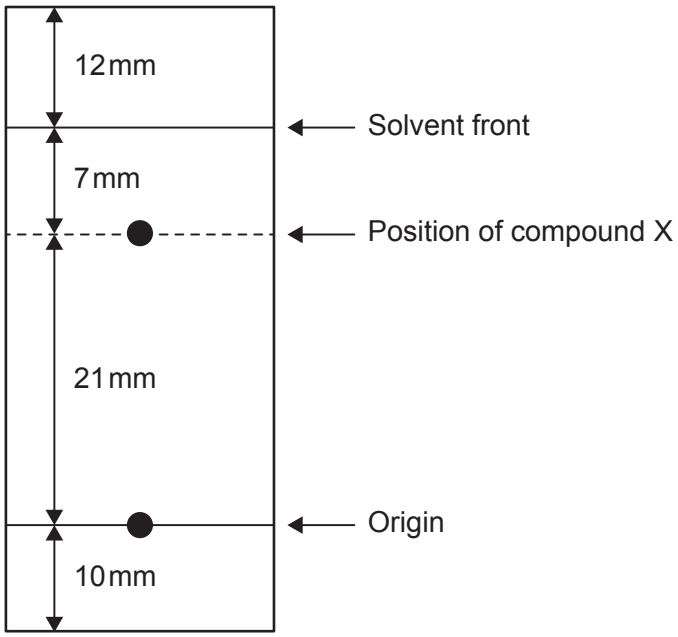
Introduction to the particulate nature of matter

4 questions

1. A test tube contains a mixture of liquid hydrocarbons. What is the type of mixture and the best method of separation?

	Type of mixture	Method of separation
A.	homogeneous	distillation
B.	homogeneous	filtration
C.	heterogeneous	distillation
D.	heterogeneous	filtration

8. What is the retardation factor, R_F, of compound X according to this paper chromatogram?



A. 0.55

B. 0.75

C. 0.82

D. 1.33

1. Which methods for separating the given mixtures into their components are correct?

	Mixture	**Method**
I.	A mixture of solid in a liquid in which solubility of the solid varies with temperature	Crystallization
II.	A mixture of a solid in a liquid in which the solid is not dissolved	Filtration
III.	A mixture of two miscible liquids with different boiling points	Distillation

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

1. What is the name of this change of state?

$$CO_2(g) \rightarrow CO_2(s)$$

A. Condensation

B. Deposition

C. Sublimation

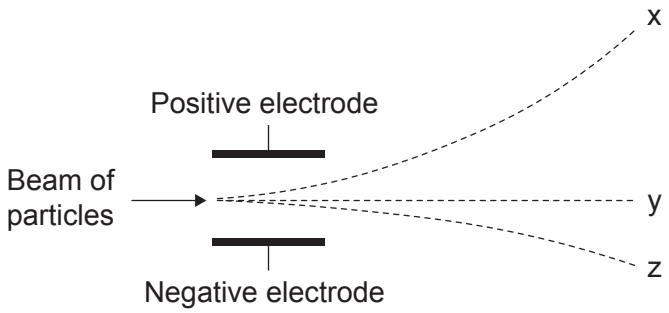
D. Freezing

APOLLO

The nuclear atom

5 questions

1. The diagram below shows the behaviour of protons, neutrons and electrons in an electric field.



What is the correct identity of each particle?

	Protons	Electrons	Neutrons
A.	y	z	x
B.	x	y	z
C.	z	x	y
D.	x	z	y

2. Which property is the same for water containing tritium (^{3}H) and water containing hydrogen (^{1}H)?

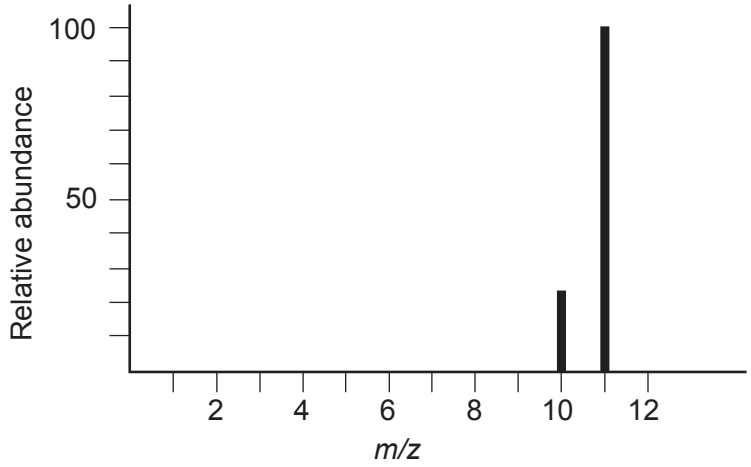
A. Density

B. Dipole moment of a molecule

C. Boiling point

D. Relative molecular mass

4. What is the relative atomic mass of an element with the following mass spectrum?



A. 10.2

B. 10.5

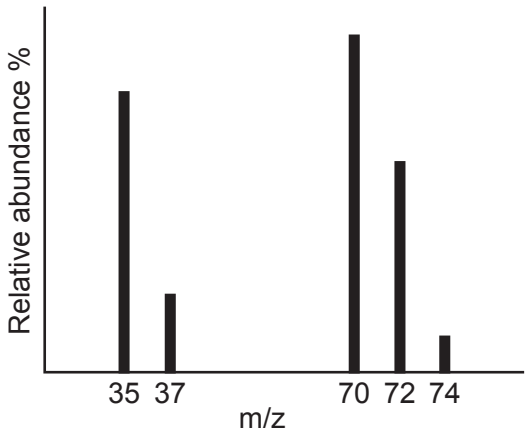
C. 10.8

D. 11.0

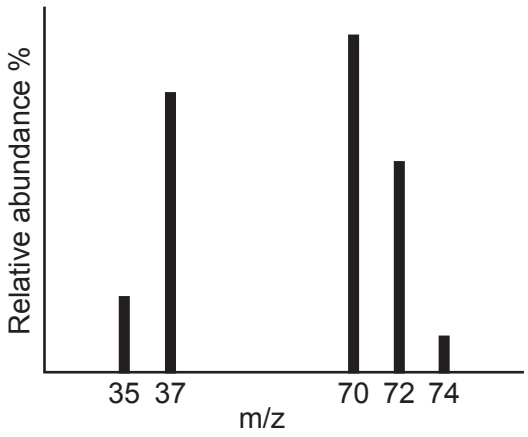
2. Chlorine is a diatomic molecule that contains 75% of ^{35}Cl and 25% of ^{37}Cl.

Which graph shows the full mass spectrum of chlorine?

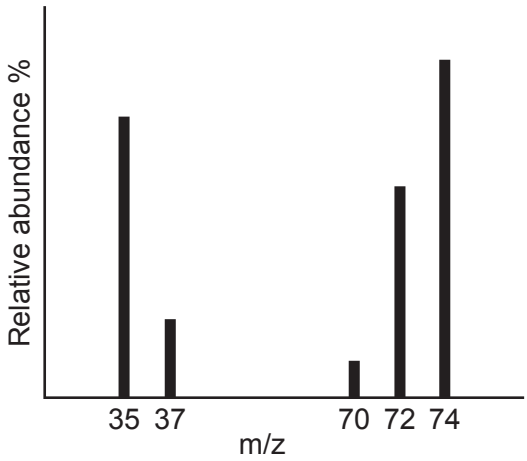
A.



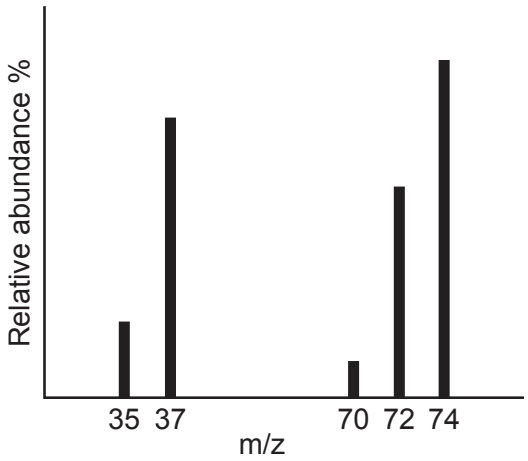
B.



C.



D.



2. Ice containing only the isotope ^{2}H sinks and does not melt when dropped into ordinary distilled water maintained at 3 °C.

Which statement is correct?

A. The isotope ^{2}H has a high natural abundance.

B. $^{2}H_2O(s)$ has a higher melting point than normal ice.

C. $^{2}H_2O(s)$ has a lower density than normal ice-cold water.

D. $^{2}H_2O$ has different chemical properties from normal water.

APOLLO

Electron configurations

14 questions

2. Which of the following species have the same number of outer electrons?
The letters **do not** represent symbols of elements.

$^{24}_{12}W^{2+}$ $^{31}_{16}X^{-}$ $^{45}_{21}Y^{2+}$ $^{19}_{9}Z^{-}$

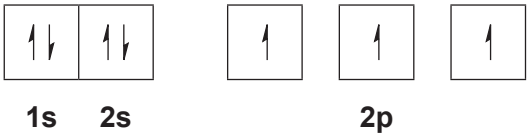
A. X and Y

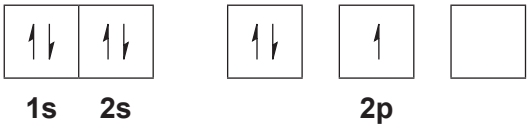
B. X and W

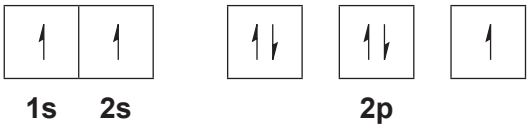
C. Z and Y

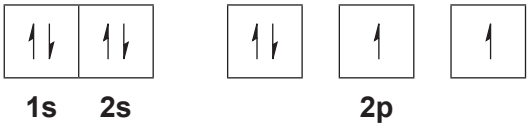
D. Z and W

4. Which diagram shows the correct electron configuration of a nitrogen atom in the ground state?

A. 

B. 

C. 

D. 

6. Which of the following correctly shows the shape of s and p orbitals?

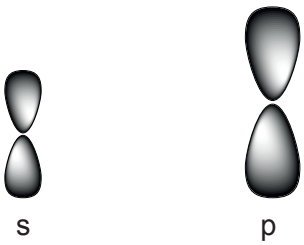
A.



B.



C.



D.



3. What is the maximum number of electrons that can occupy the n = 3 main energy level?

A. 3

B. 8

C. 18

D. 28

6. What is the charge of the monatomic ion usually formed by the element with the following electron configuration?

$$[He]\,2s^2 2p^3$$

A. $3-$

B. $2+$

C. $3+$

D. $5+$

16. What is the electron configuration of the Cr^{2+} ion?

A. $[Ar]\,4s^2 3d^2$

B. $[Ar]\,4s^1 3d^5$

C. $[Ar]\,3d^4$

D. $[Ar]\,3d^5$

5. What is the maximum number of electrons that can occupy the fourth main energy level of an atom?

A. 8

B. 18

C. 32

D. 64

13. What is the electron configuration of an atom of Cu?

A. $[Ar]3d^9$

B. $[Ar]4s^2 3d^9$

C. $[Ar]4s^2 4d^9$

D. $[Ar]4s^1 3d^{10}$

16. Which statement correctly explains the violet colour of the complex ion $[Cu(NH_3)_4(H_2O)_2]^{2+}$, formed when copper(II) sulfate reacts with an excess of ammonia?

A. Violet light is released as electrons move from higher to lower energy levels.

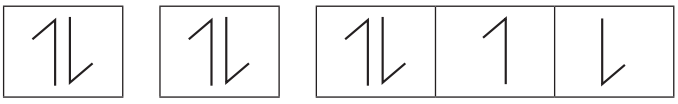
B. Violet light is absorbed as electrons move from lower to higher energy levels.

C. Yellow light is released as electrons move from higher to lower energy levels.

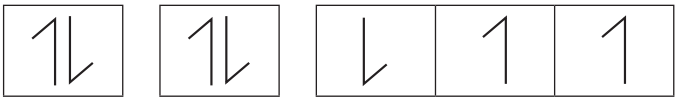
D. Yellow light is absorbed as electrons move from lower to higher energy levels.

3. Which orbital diagram represents a correct ground state electron configuration based on the Pauli exclusion principle and Hund's rule?

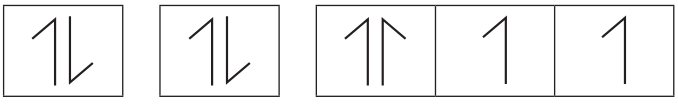
A.



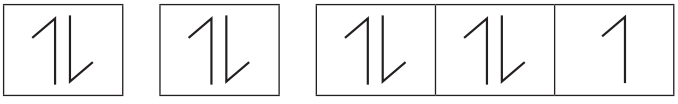
B.



C.



D.



16. Which aqueous solution of an ion is likely to be coloured based on the electron configuration of that ion?

A. Ni^{2+}

B. Sc^{3+}

C. Cu^{+}

D. Zn^{2+}

2. What is the best evidence that energy levels are closer together as distance from the nucleus increases?

A. Hydrogen has a line emission spectrum in each of the UV, visible and IR regions.

B. First ionization energies decrease down a group.

C. Lines in an emission spectrum converge at higher energy.

D. First ionization energy generally increases across a period.

15. Which statements best explain why copper(II) ions, $Cu^{2+}(aq)$, are blue in aqueous solution?

I. Copper(II) ions absorb orange light.

II. Blue light is emitted as electrons move to lower orbitals.

III. Electrons are promoted between d-orbitals.

A. I and II only

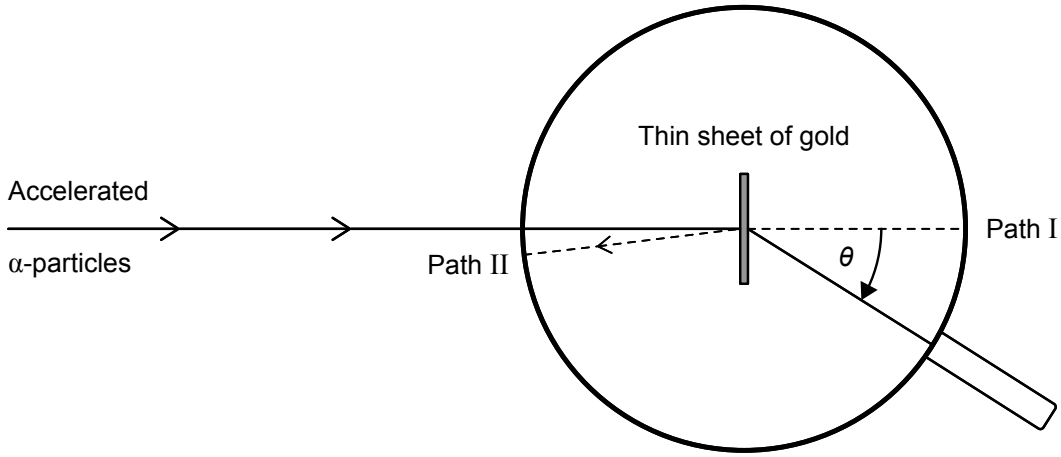
B. I and III only

C. II and III only

D. I, II and III

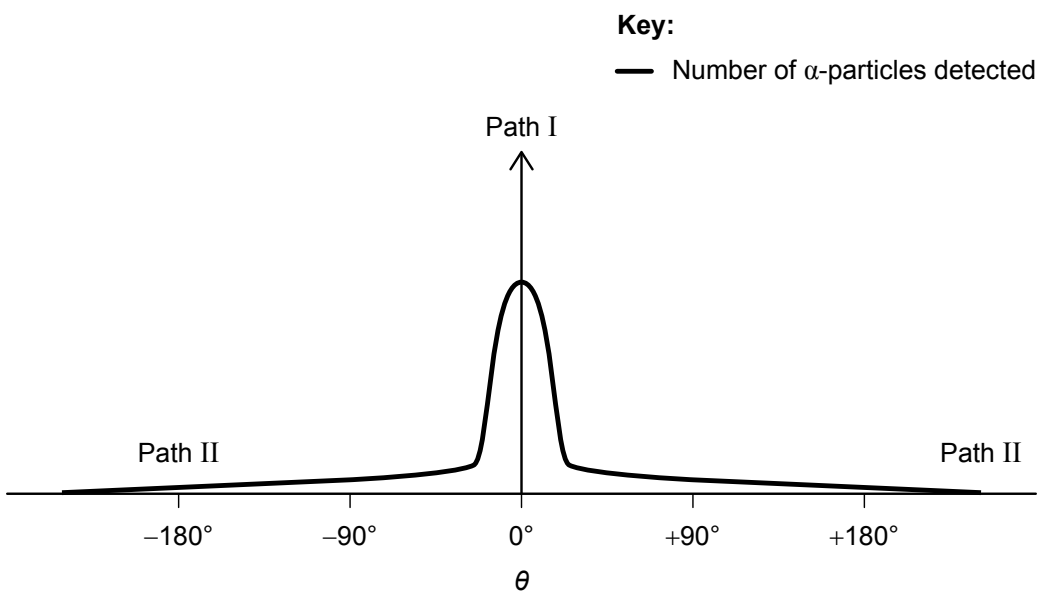
2. Scientific models are used to explain the structure of matter.

(a) An α-particle is a helium-4 nucleus. In an experiment, α-particles are accelerated towards a thin sheet of gold and their resulting paths are detected, giving evidence of the positive charge of the nucleus.



Angle of detection θ increase from 0° to 180°

The number of α-particles detected at different angles of deflection θ are shown.



(This question continues on the following page)

(Question 2 continued)

(i) Explain why some α-particles follow path II, rebounding from the gold sheet. [1]

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(ii) Most of the α-particles follow path I and pass straight through undeflected ($\theta = 0°$). Suggest a conclusion that can be made about the structure of the atom based on this evidence. [1]

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(This question continues on the following page)

(Question 2 continued)

(b) Helium was first identified by analysing spectra of solar radiation.

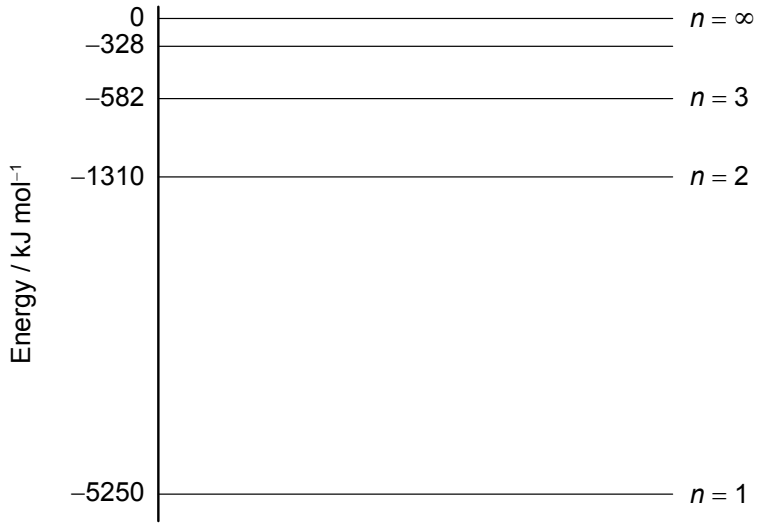
(i) Outline the appearance of the emission spectrum of helium. [1]

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Emission spectra of one-electron systems can be explained using a model with the electron attracted to the nucleus by an electrostatic force.

This model predicts that the electron occupies discrete energy levels. Some energy levels for the He^+ ion are shown.



(ii) Explain how the frequencies observed in emission spectra support the idea of the electron occupying discrete energy levels. [2]

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(This question continues on the following page)

(Question 2 continued)

(iii) Deduce the ionization energy of the He^+ ion from the energy levels shown. [1]

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(iv) Suggest **two** reasons why the ionization energy of the hydrogen atom is significantly smaller than the ionization energy of the He^+ ion. [2]

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(v) Suggest why the model outlined in (b)(ii) can predict the emission spectrum of He^+ but not He. [1]

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(c) Outline why models of the atom have evolved over time. [1]

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Question 2 - working space

APOLLO

Counting particles by mass: The mole

11 questions

5. What is the empirical formula of a compound with the following composition by mass?

C = 37.5 % H = 12.5 % O = 50.0 %

A. $C_4H_{12}O_5$

B. $C_3H_{12}O_3$

C. C_3HO_4

D. CH_4O

1. How many oxygen atoms are present in 0.0200 mol $CuSO_4 \cdot 5H_2O$?

A. 1.20×10^{22}

B. 1.08×10^{22}

C. 6.02×10^{23}

D. 1.08×10^{23}

2. What is a possible empirical formula for a substance with $M_r = 58$?

I. C_2H_5

II. C_4H_{10}

III. C_3H_6O

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

3. Which volume of butane gas, in cm^3, will produce 40 cm^3 of carbon dioxide gas when it is completely combusted in oxygen?

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 8CO_2(g) + 10H_2O(g)$$

A. 5

B. 10

C. 20

D. 40

7. An unknown organic compound contains only carbon, hydrogen and oxygen.

(a) 4.32 g of the compound was combusted completely in oxygen and produced 9.49 g of CO_2 and 5.18 g of H_2O.
Determine the empirical formula of the compound, using sections 1 and 7 of the data booklet. [3]

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(b) The same organic compound was vaporized completely at a controlled temperature and pressure.

(i) 0.108 g of the vaporized compound was found to have a volume of 55.7 cm^3 at 100 °C and a pressure of 1.00×10^5 Pa.
Calculate the amount, in moles, of the compound. Use sections 1, 2 and 4 of the data booklet. [2]

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(ii) Determine the molar mass of the organic compound, using section 1 of the data booklet.
If you did not get an answer to (i), use $n = 0.00220$ mol, although this is not the correct answer. [1]

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Question 7 - working space

4. 5.72 g of $Na_2CO_3 \cdot 10H_2O$ ($M_r = 286\ g\ mol^{-1}$) is dissolved in water to prepare 0.4 dm^3 of aqueous solution.

What is the concentration of sodium ions, in mol dm^{-3}, in the resulting solution?

A. 0.02

B. 0.04

C. 0.05

D. 0.10

25. Equal volumes of X_2 and Y_2 gases are allowed to react in a sealed container to form XY_3 gas. After completion of the reaction, the volume of XY_3 is measured to be $40\,cm^3$.

What was the volume, in cm^3, of X_2 gas at the beginning?

$$X_2(g) + 3Y_2(g) \rightarrow 2XY_3(g)$$

A. 20

B. 40

C. 60

D. 120

26. What is the volume of nitrogen dioxide, in cm^3, produced at STP when 1.28 g of copper reacts with excess nitric acid?

$$Cu(s) + 4HNO_3(aq) \rightarrow Cu(NO_3)_2(aq) + 2NO_2(g) + 2H_2O(l)$$

Molar volume of an ideal gas at STP is $22.7\,dm^3\,mol^{-1}$

A. 227

B. 456

C. 684

D. 914

3. How many ions are present in 0.20 mol of $(NH_4)_2SO_4$?

A. $0.20 \times 1 \times 6 \times 10^{23}$

B. $0.20 \times 2 \times 6 \times 10^{23}$

C. $0.20 \times 3 \times 6 \times 10^{23}$

D. $0.20 \times 7 \times 6 \times 10^{23}$

4. A container holds 30 g of argon and 60 g of neon.

What is the ratio of number of atoms of argon to number of atoms of neon in the container?

A. 0.25

B. 0.50

C. 2.0

D. 4.0

25. The complete combustion of 20.0 cm^3 of a gaseous hydrocarbon, C_xH_y, produces 80.0 cm^3 of gaseous products. This volume reduces to 40.0 cm^3 when the water vapour present condenses. All volumes are measured at the same temperature and pressure.

What is the molecular formula of the hydrocarbon?

A. CH_4

B. C_2H_2

C. C_2H_4

D. C_3H_6

APOLLO

Ideal gases

6 questions

5. Which row shows a gas that would deviate the least from ideal gas behaviour?

	Gas	Pressure	Temperature
A.	Phosphine, PH_3	Low	High
B.	Ammonia, NH_3	Low	High
C.	Phosphine, PH_3	High	Low
D.	Ammonia, NH_3	High	Low

17. The volume of a container filled with a fixed amount of gas is increased by 100 % at constant temperature. How does this affect the pressure in a container? $pV = nRT$

A. Pressure increases by 100 %

B. Pressure decreases by 100 %

C. Pressure increases by 50 %

D. Pressure decreases by 50 %

5. In which of the following sets of conditions does the gas exhibit behaviour closest to an ideal gas ?

	Gas	Pressure / kPa	Temperature / K
A.	H_2	100	273
B.	NH_3	50	473
C.	H_2	50	473
D.	NH_3	100	273

5. A fixed volume of an ideal gas, initially at 30 °C and with a pressure of **P** Pa, was heated to 60 °C. What is the resulting pressure in Pa?

A. Half of **P**

B. A little less than **P**

C. A little more than **P**

D. Two times **P**

1. Nitrogen monoxide, NO(g), is produced in internal combustion and jet engines.

(a) Outline a reason why NO is a pollutant. [1]

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. . . . . .

(b) Calculate the amount, in moles, of NO in $1.0 \times 10^{-3}\,m^3$ of engine exhaust gas which contains 0.10 % NO by volume at 200 °C and 1.0×10^5 Pa.

Use sections 1 and 2 of the data booklet. [3]

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(c) Outline why NO deviates more than nitrogen, N_2, from the ideal gas model. [2]

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(This question continues on the following page)

(Question 1 continued)

(d) In an exhaust pipe catalytic converter, NO reacts with carbon monoxide, CO, to form N_2.

(i) State the initial and final oxidation states of nitrogen. [1]

Initial: . . . . . Final: . . . . . .

(ii) Deduce the second product and the balanced equation for the reaction. [1]

. . . . . .

. . . . . .

Question 1 - working space

5. A gas storage tank of fixed volume V contains N molecules of an ideal gas at 300 K with a pressure of 40 kPa. $\frac{N}{4}$ molecules are removed, and the temperature is changed to 450 K.

What is the new pressure of the gas in kPa?

A. 15

B. 30

C. 45

D. 60

APOLLO

The ionic model

6 questions

7. Which row shows the correct formula and electron configuration of the species in calcium nitride?

	Formula	Electron configuration of the Ca species	Electron configuration of the N species
A.	Ca_2N_3	[Ar]	[Ne]
B.	Ca_2N_3	[Ar] $4s^2$	[He] $2s^2$ $2p^3$
C.	Ca_3N_2	[Ar] $4s^2$	[He] $2s^2$ $2p^3$
D.	Ca_3N_2	[Ar]	[Ne]

6. What is the formula of the compound formed by aluminium ions and sulfate(VI) ions?

A. $AlSO_3$

B. $Al_2(SO_3)_3$

C. $AlSO_4$

D. $Al_2(SO_4)_3$

7. A substance has the following properties:

Melting point (°C)	Electrical conductivity	
	When solid	**When molten**
714	poor	good

What is the most probable structure of this substance?

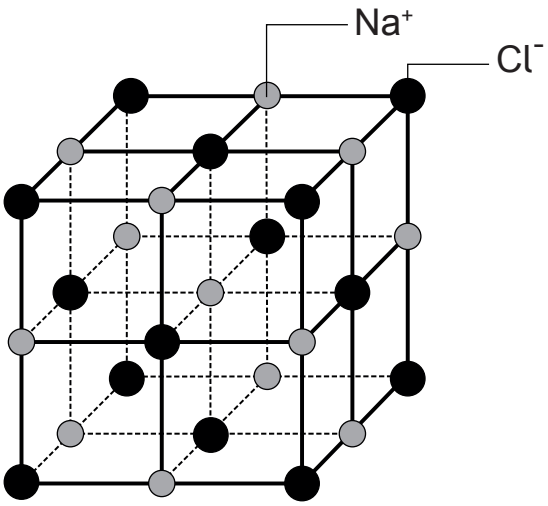
A. Simple molecular

B. Ionic lattice

C. Covalent network

D. Metallic lattice

6. An expanded view of the NaCl lattice is given in the figure.



Which statement is correct for the lattice structure of NaCl?

A. The ions are held together in the lattice by covalent bonds.

B. The forces of attraction in the lattice are very weak.

C. Each sodium ion is surrounded by four chloride ions.

D. The structure breaks apart when dissolved in water.

13. Which two elements form a compound with the strongest ionic attraction?

A. Li and O

B. Li and Se

C. K and O

D. K and Se

6. What is the formula of the compound formed between magnesium ions and hydrogencarbonate ions?

A. $MgHCO_3$

B. $Mg(HCO_3)_2$

C. $Mg(HCO_3)_3$

D. $Mg_3(HCO_3)_2$

APOLLO

The covalent model

28 questions

9. In which of the following molecules do all atoms obey the octet rule?

I. NF_3
II. BF_3
III. PCl_3

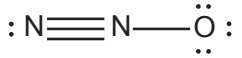
A. I and II only

B. I and III only

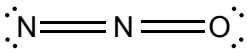
C. II and III only

D. I, II and III

10. Nitrogen(I) oxide, N_2O, can be represented by two Lewis formulas.



Structure X



Structure Y

Which row correctly identifies the formal charges and the more stable structure?

	Structure X : N≡N—Ö :			**Structure Y** :N≡N=O:			**More stable**
A.	0	+1	−1	−1	+1	0	X
B.	−1	+1	0	+1	0	−1	X
C.	0	+1	−1	−1	0	+1	Y
D.	−1	0	+1	0	+1	−1	Y

11. Which row puts these molecules in order of decreasing bond angle?

A. NH_3, H_2O, C_2H_4, CH_4

B. H_2O, C_2H_4, CH_4, NH_3

C. C_2H_4, CH_4, NH_3, H_2O

D. CH_4, NH_3, H_2O, C_2H_4

13. Kekulé suggested a structure of benzene with alternating single and double bonds. Which piece of evidence disproves this structure?

A. Benzene has the formula C_6H_6.

B. Benzene is an unsaturated molecule.

C. All C–C bonds have the same length.

D. Benzene can be hydrogenated.

7. Which molecule is polar?

A. CH_4

B. C_6H_6

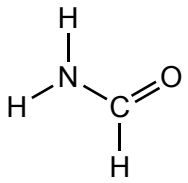
C. SO_2

D. CO_2

9. What are the electron domain and molecular geometries of $XeCl_4$?

	Electron domain geometry	Molecular geometry
A.	octahedral	tetrahedral
B.	octahedral	square planar
C.	tetrahedral	tetrahedral
D.	tetrahedral	square planar

10. What are the hybridizations of the N, C and O atoms in this molecule?



	N	C	O
A.	sp^3	sp^3	sp^2
B.	sp^3	sp^2	sp^2
C.	sp^2	sp^2	sp
D.	sp^2	sp^3	sp

8. Which forces of attraction cause the boiling point of ammonia, NH_3, to be significantly higher than that of phosphine, PH_3?

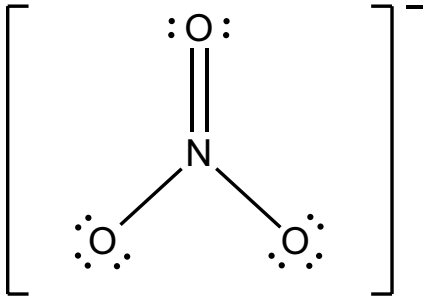
A. Covalent bonds

B. Dipole–dipole forces

C. London (dispersion) forces

D. Hydrogen bonds

9. What is the formal charge of the nitrogen atom in NO_3^-?



A. −3

B. −1

C. +1

D. +3

10. What is the hybridization of carbon and oxygen in CO_3^{2-}?

	C	O
A.	sp^2	sp^3
B.	sp^2	sp^2
C.	sp^3	sp^2
D.	sp^3	sp

1. Iron(II) sulfide can be produced by heating powdered iron and sulfur together.

(a) Describe the difference between an element and a compound. [2]

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(b) Outline why solid iron(II) sulfide is a polar covalent compound. Use sections 9 and 17 of the data booklet. [1]

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(c) Contrast **one** physical property of iron and iron(II) sulfide. [1]

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(d) Calculate the wavelength, in m, for the limit of convergence observed in the line spectrum of iron. Use sections 1, 2 and 9 of the data booklet. [3]

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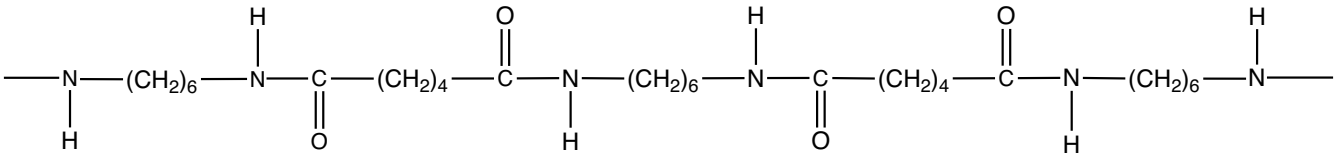
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Question 1 - working space

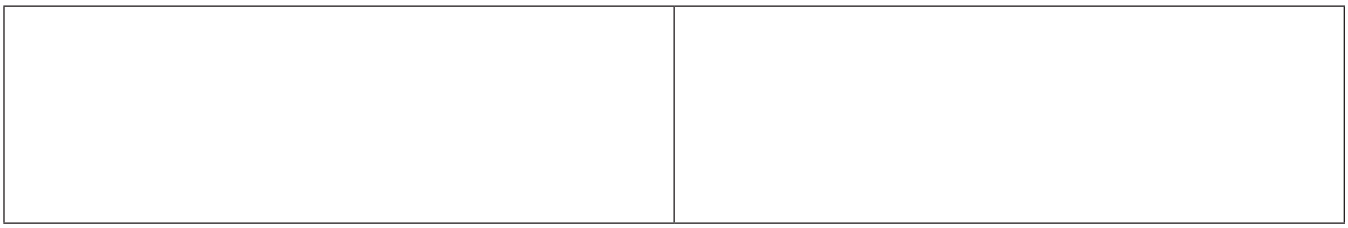
7. Nylon 6,6 is a polyamide used in many things, such as fishing lines.

A section of the polymer chain of nylon 6,6



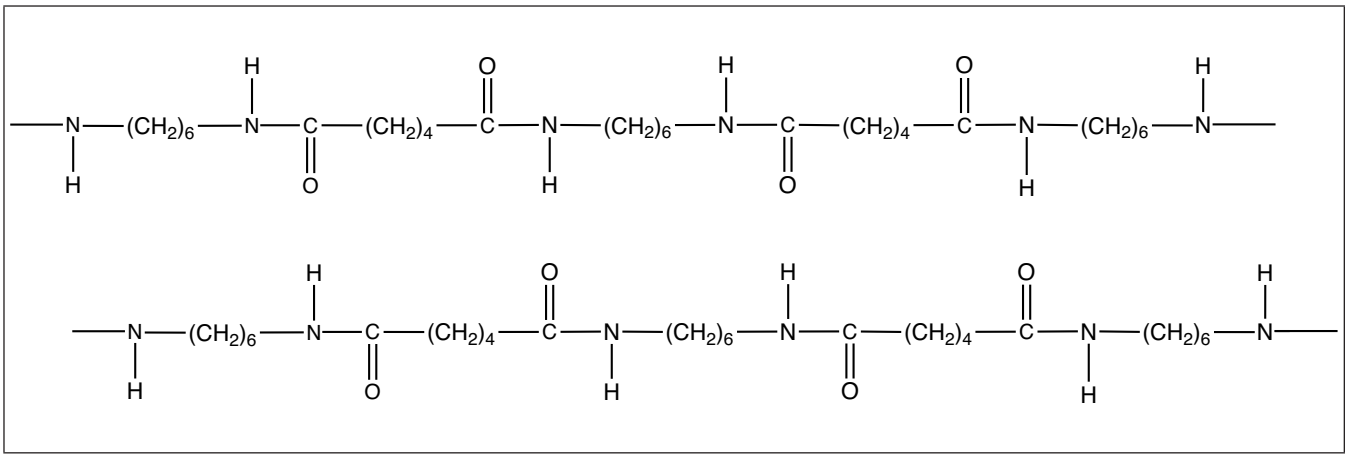
(a) Nylon 6,6 is formed by condensation polymerisation.

Deduce the structures of the two monomers that form the polyamide nylon 6,6. [2]



(b) (i) The strength of nylon 6,6 is due to the hydrogen bonding between the polymer chains.

Annotate the diagram to show a hydrogen bond between the sections of the polymer chains. Use a dotted line to represent the hydrogen bond. [1]



(ii) Outline how a hydrogen bond is formed. [2]

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(This question continues on the following page)

(Question 7 continued)

(c) Discuss the following data in terms of the bonding **and/or** intermolecular forces in each substance. [3]

Substance	Melting point / K
Silicon	1683
Poly(ethene)	393

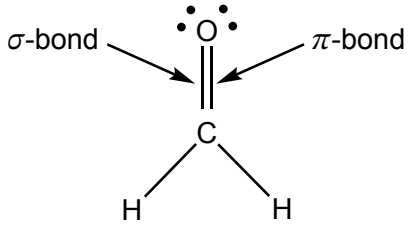
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Question 7 - working space

7. What are the electron domain and molecular geometries of IF_4^+ ion?

	Electron domain geometry	Molecular geometry
A.	Trigonal bipyramidal	Seesaw
B.	Tetrahedral	Tetrahedral
C.	Tetrahedral	Seesaw
D.	Trigonal bipyramidal	Tetrahedral

8. Which orbitals overlap to form σ-bond and π-bond between carbon and oxygen in methanal?



	σ-bond	**π-bond**
A.	sp^2 and sp^3	p and p
B.	sp^2 and sp^2	p and sp^2
C.	sp^2 and sp^2	p and p
D.	sp^2 and sp^3	p and sp^2

9. Which species contain a coordination bond?

I. O_3

II. CO_2

III. NO_3^-

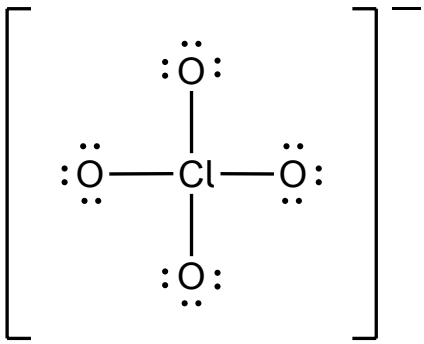
A. I and II only

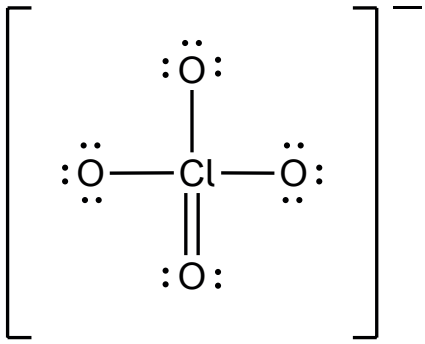
B. I and III only

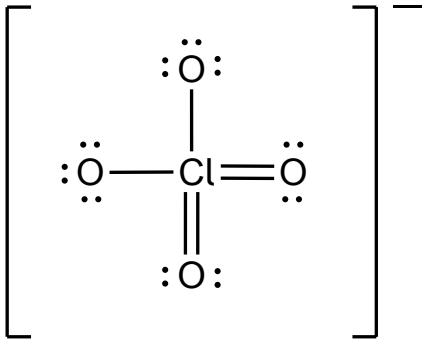
C. II and III only

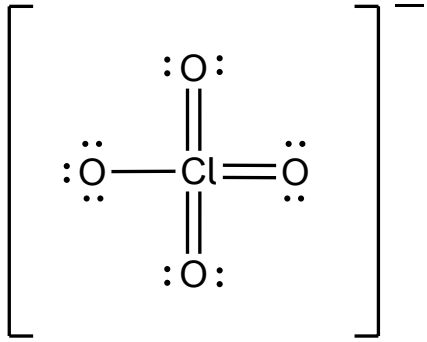
D. I, II and III

10. What is the preferred Lewis formula for chlorate(VII), ClO_4^-, ion based on formal charges?

A. 

B. 

C. 

D. 

12. Which material is a good electrical conductor?

A. Diamond

B. Graphite

C. Fullerene

D. Silicon

39. Which statements are correct for the complex ion $[FeCl_4]^{2-}$?

I. Chloride ions are behaving as ligands.

II. The oxidation state of iron is +3.

III. Iron ion forms coordination bonds with chloride ions.

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

6. What are the electron domain and molecular geometries of thionyl chloride, $SOCl_2$?

	Electron domain geometry	Molecular geometry
A.	Tetrahedral	Tetrahedral
B.	Tetrahedral	Trigonal pyramidal
C.	Trigonal planar	Trigonal planar
D.	Trigonal planar	Bent

7. Which molecule is most polar?

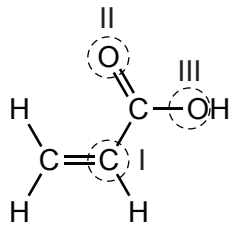
A. CF_4

B. CO_2

C. NBr_3

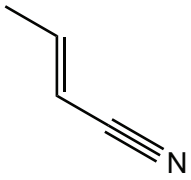
D. NH_3

9. What is the hybridization of each circled atom I, II and III?



	I	II	III
A.	sp^3	sp	sp^2
B.	sp^3	sp	sp^3
C.	sp^2	sp^2	sp^2
D.	sp^2	sp^2	sp^3

11. How many π (pi) and σ (sigma) bonds are there in but-2-enenitrile, $CH_3CHCHCN$?



	π, pi	**σ, sigma**
A.	5	2
B.	5	7
C.	3	4
D.	3	9

16. Which compound has the highest boiling point?

A. $CH_3CH_2CH_2CH_3$

B. $CH_3CH_2CH_2CH_2CH_2CH_3$

C. $(CH_3)_3CCH_2CH_3$

D. $CH_3CH_2CH(CH_3)CH_2CH_3$

7. In which group of ions and molecules are electrons delocalized in all species?

A. CH_3COOH, O_3, C_{60}

B. CH_3COO^-, NO_2^-, C(graphite)

C. C_2H_2, $(COOH)_2$, C(diamond)

D. C_2H_4, NO_2^+, SiO_2

Turn over

8. What is the molecular geometry of the central atom in SF_4Cl_2?

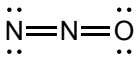
A. linear

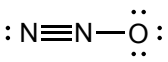
B. tetrahedral

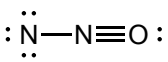
C. hexagonal

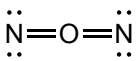
D. octahedral

9. Which is the preferred Lewis formula of nitrous oxide, N_2O, as deduced by formal charges?

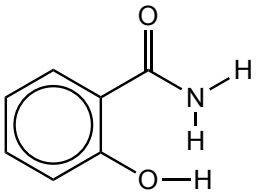
A. 

B. 

C. 

D. 

10. Which pair of statements about electrons in this molecule is correct?



	Number of non-bonding pairs of electrons	Number of electrons in π bonds
A.	3	6
B.	3	8
C.	5	6
D.	5	8

17. What do all greenhouse gases have in common?

A. They are emitted by the burning of fossil fuels.

B. They absorb ultraviolet radiation.

C. They are symmetrical molecules with no polar bonds.

D. They absorb infrared radiation.

APOLLO

The metallic model

4 questions

11. Which answer shows the correct order of metallic bond strength from strongest to weakest?

A. Al > Mg > Na > K

B. Al > Mg > K > Na

C. Na > K > Mg > Al

D. K > Na > Mg > Al

11. Which statement best explains the malleability of magnesium metal?

A. The metal lattice is held together by the attraction between magnesium ions.

B. The outer shell electrons of magnesium are free to move.

C. The layers of magnesium ions can slide relative to each other.

D. There are strong attractions between the magnesium ions and the free moving electrons.

10. Which type of material is a good conductor of heat and electricity in solid and liquid states, is insoluble in water, and typically has a high melting point?

A. Covalent molecular

B. Covalent network

C. Ionic

D. Metallic

11. What is the explanation for the malleability of metals?

A. The bonds are strong.

B. The bonds are weak.

C. The bonds involve free electrons.

D. The bonds do not have a specific direction.

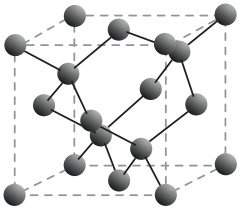
APOLLO

From models to materials

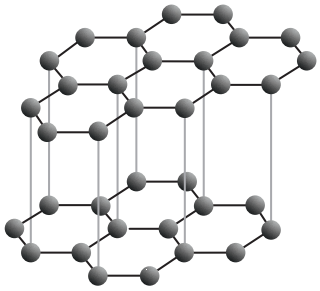
2 questions

8. Diagrams of four stable allotropes of carbon are shown.
Which row correctly identifies each structure?

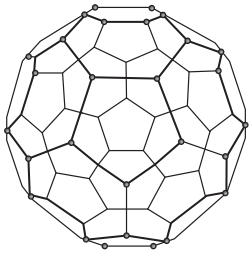
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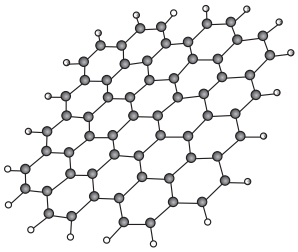
X



Y



Z



	Graphene	Fullerene	Graphite	Diamond
A.	Z	Y	X	W
B.	W	Z	Y	X
C.	X	W	Z	Y
D.	Y	X	W	Z

8. Which allotropes of carbon are electrical conductors?

I. Graphite
II. Diamond
III. Graphene

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

APOLLO

The periodic table: Classification of elements

18 questions

14. Germanium has several stable oxidation states. Which row shows these species in order of increasing radius?

A. Ge^{4+}, Ge^{2+}, Ge, Ge^{4-}.

B. Ge^{4-}, Ge^{4+}, Ge^{2+}, Ge.

C. Ge, Ge^{4-}, Ge^{4+}, Ge^{2+}.

D. Ge^{2+}, Ge, Ge^{4-}, Ge^{4+}.

15. Which statement explains the trend in first ionisation energy from sodium, Na, to chlorine,Cl?

A. Nuclear charge increases.

B. Electronegativity decreases.

C. Atomic radius increases.

D. Shielding decreases.

16. Which elements would react with each other most vigorously?

A. K(s) and $Br_2(g)$.

B. K(s) and $Cl_2(g)$.

C. Na(s) and $Br_2(g)$.

D. Na(s) and $Cl_2(g)$.

18. Which statement explains why transition elements have variable oxidation states?

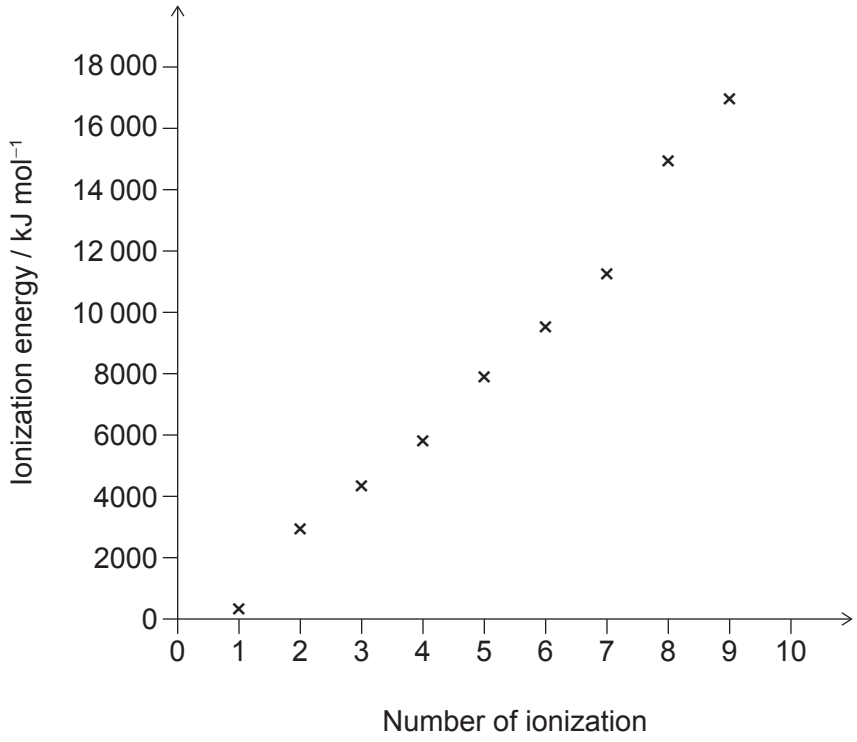
A. d-Electrons are delocalized.

B. All have a +2 oxidation state.

C. They can accept electron pairs from ligands.

D. Successive ionization energies are close in value.

4. What is the group number of the element whose successive ionization energies are shown?



A. 1

B. 2

C. 13

D. 14

12. Why do group 17 elements have higher first ionization energies than group 1 elements in the same period?

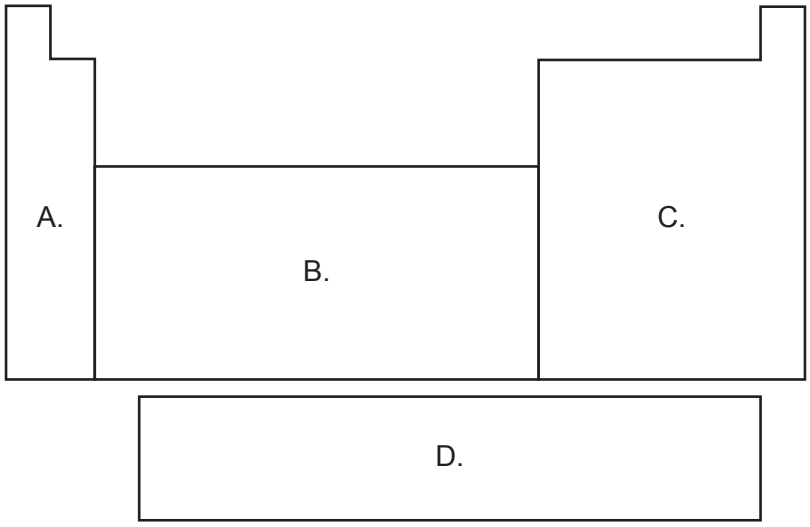
A. Group 17 elements have more electrons in the valence shell.

B. Group 17 elements have more filled energy levels.

C. Group 17 elements have more paired electrons.

D. Group 17 elements have more protons in the nucleus.

13. Which part of the periodic table contains elements which are likely to form acidic oxides only?



15. Which properties are typical of transition elements?

I. Low melting points
II. Formation of coloured compounds
III. Variable oxidation states

A. I and II only

B. I and III only

C. II and III only

D. I, II and III

12. Which of these elements is in the f-block of the periodic table?

A. Ra

B. Lu

C. Rf

D. Nh

14. Which pair of elements would react with each other the least vigorously?

A. Lithium and fluorine

B. Lithium and iodine

C. Caesium and fluorine

D. Caesium and iodine

15. Which statement is correct for the group 17 elements from fluorine to iodine?

A. The elements become more volatile.

B. The hydrides of the elements become more acidic.

C. The elements become more reactive.

D. The bond between the halogen atoms becomes less polar.

12. Which element is a p-block metal?

A. Sn

B. Te

C. Cd

D. At

14. Which oxide is the most basic?

A. MgO

B. Al_2O_3

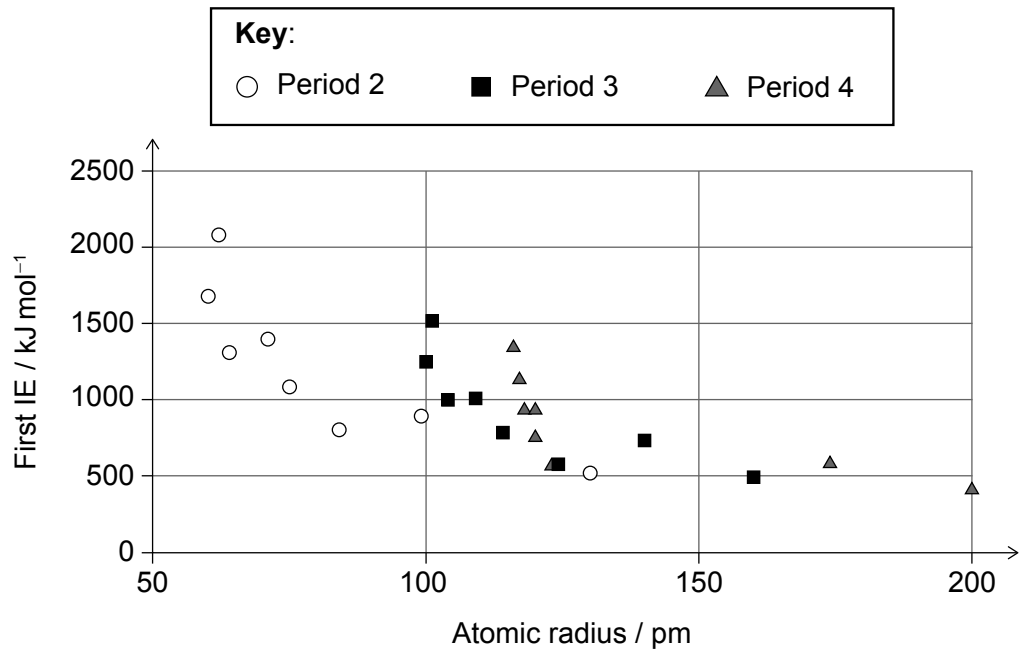
C. SiO_2

D. SO_3

Section B

Answer **all** questions. Answers must be written within the answer boxes provided.

1. The graph shows the variation of the first ionization energy with atomic radius for periods 2, 3 and 4 of the periodic table, with the d-block elements omitted.



(a) Annotate the graph with an additional data point, marked with a cross (X), for scandium. Use sections 9 and 10 of the data booklet. [1]

(b) Suggest why there might be a link between the two variables in the graph. [1]

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(This question continues on the following page)

(Question 1 continued)

(c) The graph shows a relationship between first ionization energy and atomic radius.

(i) State the type of relationship between the variables. [1]

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(ii) Compare and contrast the trends shown by the different periods. [2]

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Question 1 - working space

3. The table lists successive ionization energies of an element **Z**.

Ionization number	**1st**	**2nd**	**3rd**	**4th**	**5th**	**6th**
Ionization energy / kJ mol^{-1}	577.54	1816.68	2744.78	11577.5	14841.9	18379.0

Which is the formula of the stable oxide of the element **Z**?

A. Z_2O

B. ZO

C. Z_2O_3

D. ZO_2

13. Why is copper(II) sulfate blue?

A. Red light is absorbed when electrons are promoted between the orbitals in the split d-sublevels.

B. Blue light is emitted when electrons fall between the orbitals in the split d-sublevels.

C. Red light is absorbed when electrons fall between the orbitals in the split d-sublevels.

D. Blue light is emitted when electrons are promoted between the orbitals in the split d-sublevels.

15. The block structure of the periodic table groups elements according to which characteristic?

A. atomic number

B. atomic mass

C. electron configuration

D. reactivity

Turn over

16. Which d block element has the highest number of different oxidation states?

A. Ti

B. Mn

C. Cu

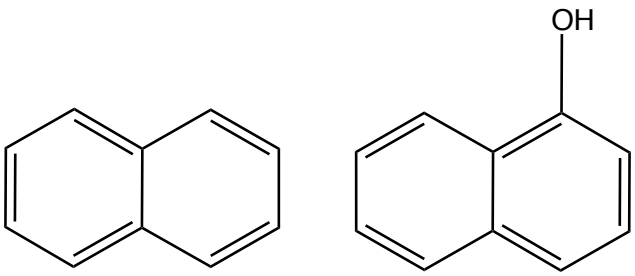
D. Zn

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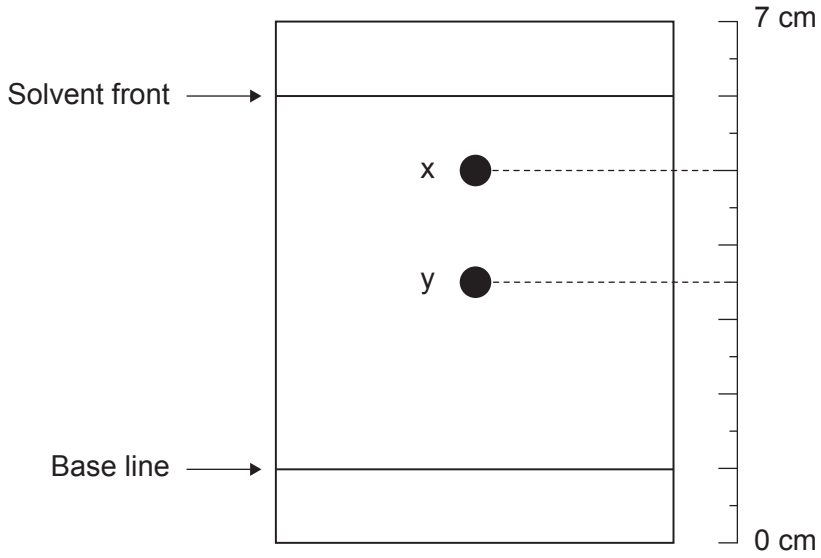
Functional groups: Classification of organic compounds

20 questions

12. The following thin-layer chromatogram was obtained from a mixture of naphthalene, $C_{10}H_8$, and naphthol, $C_{10}H_8O$. A polar silica was used as the stationary phase, and a non-polar hexane as the mobile phase.



Naphthalene Naphthol



What are the position and retardation factor (R_F) of naphthalene?

A. y and 0.50

B. y and 0.58

C. x and 0.80

D. x and 0.83

Turn over

19. Which oxygen-containing molecule has this low-resolution ^{1}H NMR spectrum?

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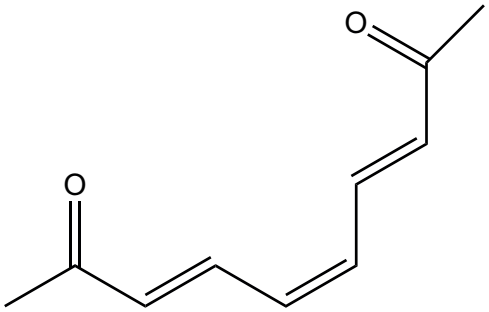
A. Butanoic acid

B. Ethyl ethanoate

C. Methyl propanoate

D. Butanone

20. Consider this molecule, deca-3,5,7-triene-2,9-dione.



How many stereoisomers are possible for deca-3,5,7-triene-2,9-dione?

A. 3

B. 6

C. 8

D. 9

21. What is a disadvantage of using infrared (IR) spectroscopy as a technique?

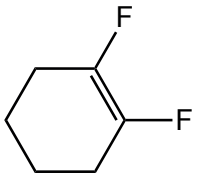
A. It cannot detect small atoms like H.

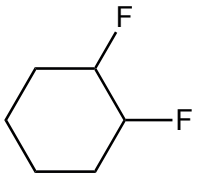
B. It can only detect molar mass.

C. It alters the chemical structure of the sample.

D. It can only identify bonds, not their position.

17. Which compound shows *cis-trans* isomerism?

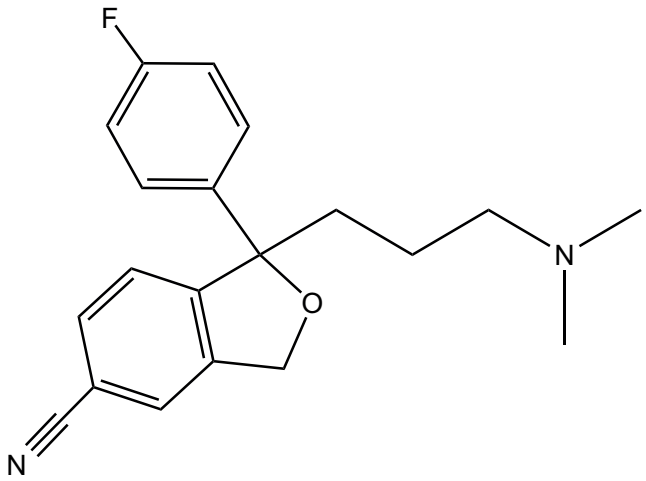
A. 

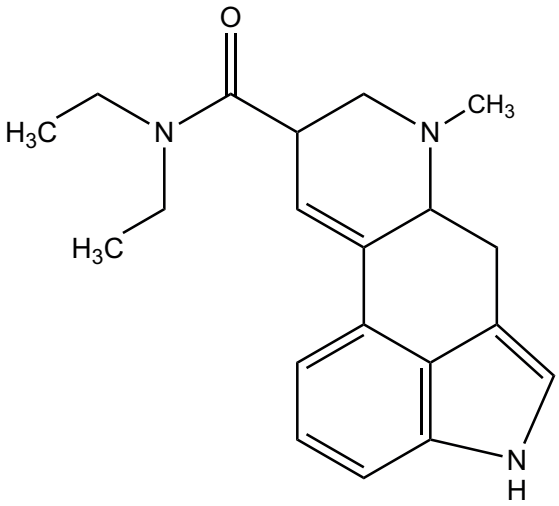
B. 

C. $H_2C{=}CF_2$

D. $HFC{=}CF_2$

17. Which functional groups are present in both of these molecules?





A. Amino and amido

B. Amino and alkoxy

C. Amino and carbonyl

D. Amino and a benzene ring

18. What is the identity of the alcohol with the molecular formula C_4H_9OH, with four peaks in the ratio 6:2:1:1 in its ^1H NMR spectrum?

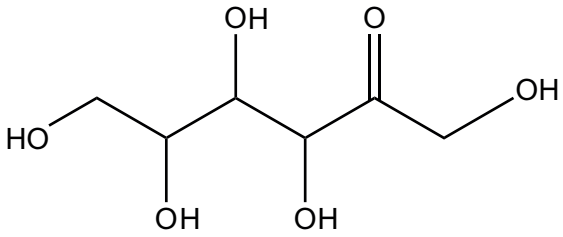
A. Butan-1-ol

B. Butan-2-ol

C. 2-methylpropan-1-ol

D. 2-methylpropan-2-ol

19. How many chiral centres are there in the following molecule?



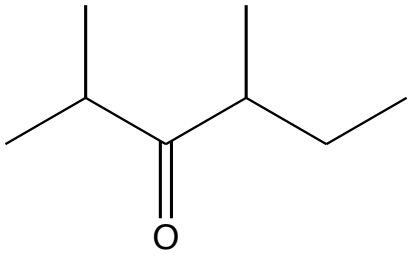
A. 2

B. 3

C. 4

D. 5

13. What is the IUPAC name of the molecule below?



A. 2-ethyl-4-methylpentan-3-one

B. 4-ethyl-2-methylpentan-3-one

C. 2,4-dimethylhexan-3-one

D. 3,5-dimethylhexan-4-one

17. Which molecule contains a chiral centre?

A. $CH_3CH(CH_3)CHO$

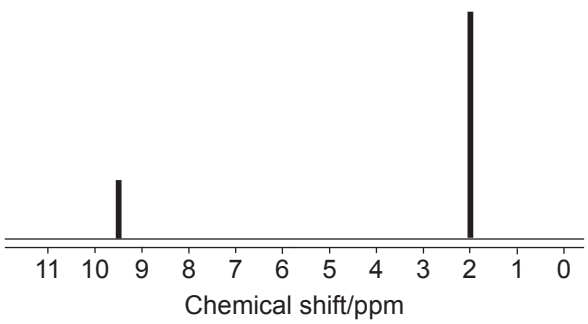
B. $CH_3CHClCH_2CH_3$

C. $CH_3C(CH_3)_2OH$

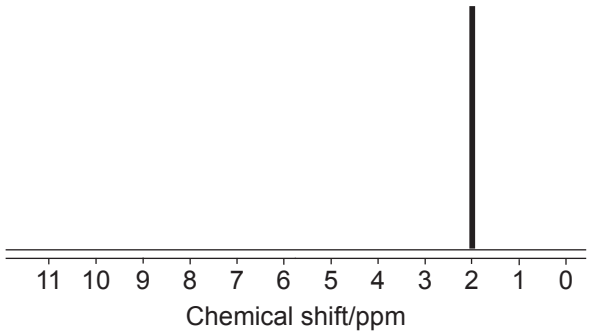
D. $ClCH_2CH_2COOH$

18. What is the low-resolution ^{1}H NMR spectrum of ethanal?

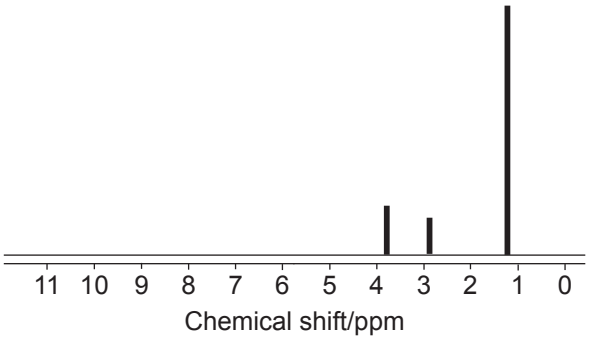
A.



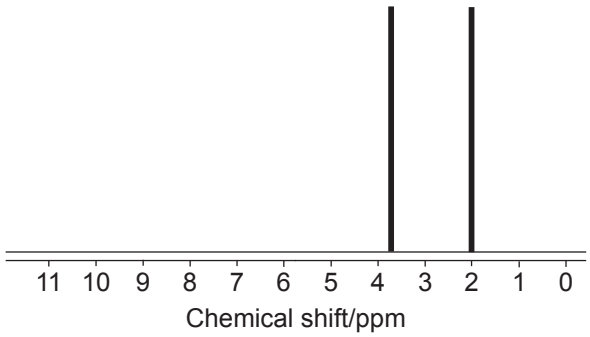
B.



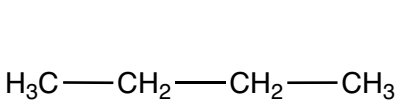
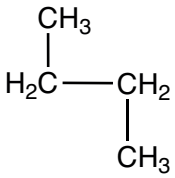
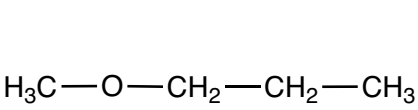
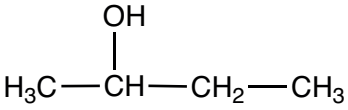
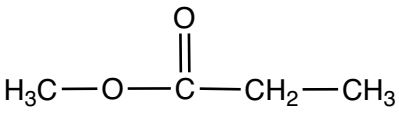
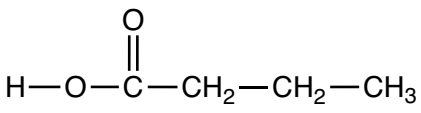
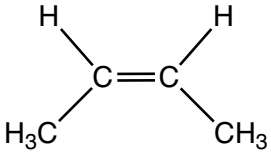
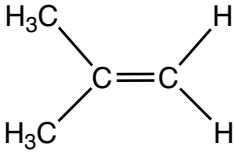
C.



D.



19. Which pair of compounds represents the correct type of isomerism?

	Type of isomerism	Pair of compounds
A.	Chain	 and 
B.	Functional group	 and 
C.	Positional	 and 
D.	*Cis-trans*	 and 

17. Which compounds could exist as stereoisomers?

I. CH_2CClBr

II. CHBrICl

III. CHBrCClBr

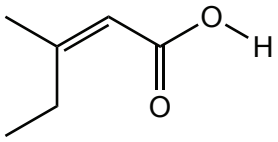
A. I and II only

B. I and III only

C. II and III only

D. I, II and III

18. What is the IUPAC name of this compound?



A. 3-methylpent-2-enoic acid

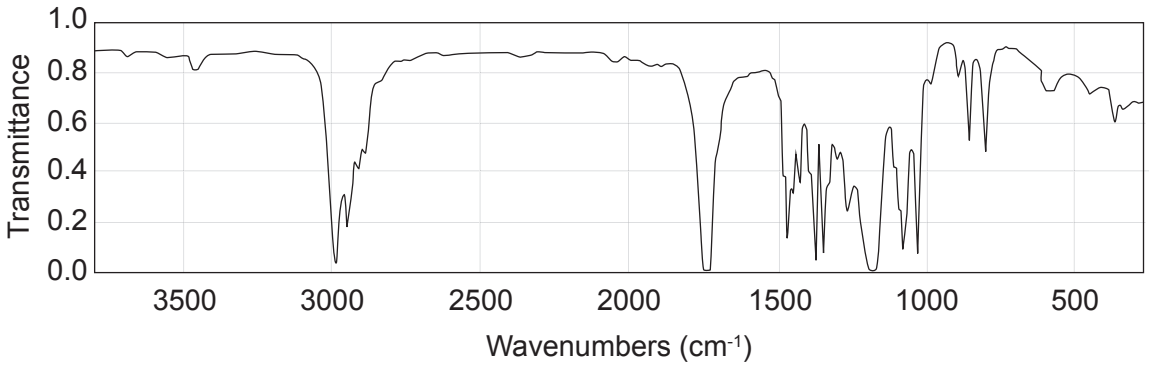
B. 3-ethylbut-2-enoic acid

C. 2-ethylbut-2-en-4-oic acid

D. 2-methylpent-3-en-5-oic acid

4. Another ester was made following a similar reaction sequence.

(a) The infrared spectrum of the final product is shown below.



[Source: Used with permission. © United States of America as represented by the Secretary of Commerce.]

(i) Deduce the identity of two peaks that confirm the product is an ester. Use section 20 of the data booklet. [2]

Peak 1 wavenumber: . . . . . bond: . . . . . .

Peak 2 wavenumber: . . . . . bond: . . . . . .

(ii) Deduce the absorption ranges and the bond(s) responsible for these absorptions that would be present in the IR spectra of alcohols and the carboxylic acids but not in the IR spectrum in part (a). Use section 20 of the data booklet. [1]

. . . . . .

. . . . . .

(b) The mass spectrum shows a molecular ion peak with m/z 102.

(i) Deduce the molecular formula of this ester if it contains no multiple C–C bonds or rings. Use section 7 of the data booklet. [2]

. . . . . .

. . . . . .

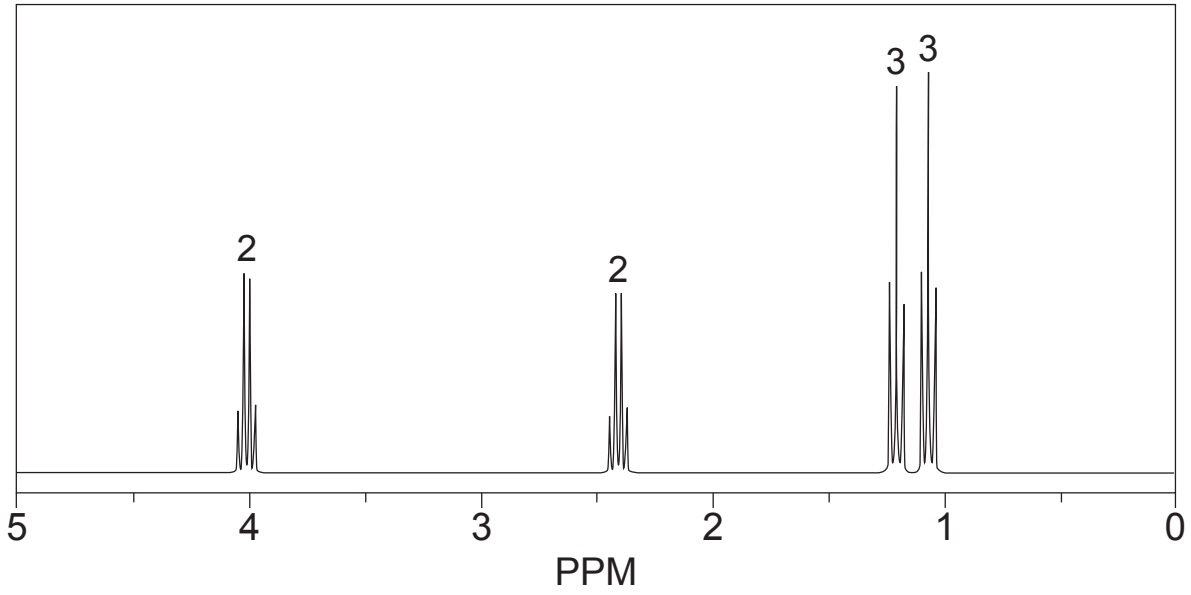
. . . . . .

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(This question continues on the following page)

(Question 4 continued)

The high-resolution ^{1}H NMR spectrum of the ester is shown. The integration is indicated above the signals on the trace.



(ii) Deduce the identity of the ester. Use section 21 on the data booklet. [1]

. . . . . .

. . . . . .

Question 4 - working space

1. What is thin-layer chromatography best used for separating?

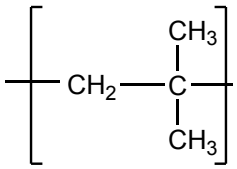
A. molecules of varying polarity

B. molecules of similar polarity

C. metals in an alloy

D. water of crystallization from hydrated salts

12. The structure shows the repeating unit of a polymer found in some plastics.



Which monomer is used to form this plastic?

A. $H_2C{=}C(CH_3)_2$

B. $CH_3CH(CH_3)_2$

C. $(H_3C)_2C{=}C(CH_3)_2$

D. $(H_3C)_2C{=}CHCH(CH_3)_2$

14. Which molecule has a carbonyl functional group?

A. CH_3OCH_3

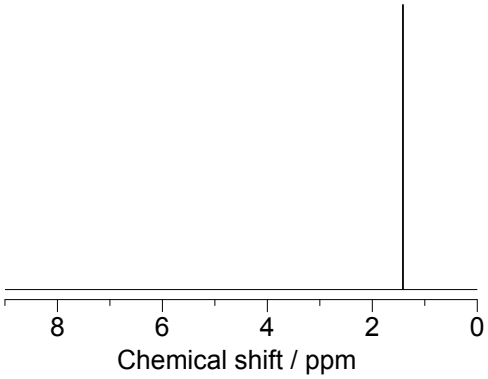
B. CH_3COCH_3

C. CH_3CH_2OH

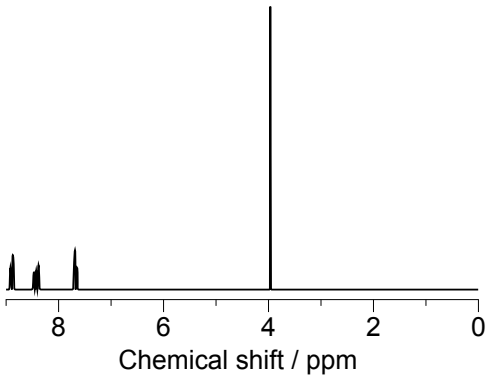
D. $CH_3CH_2NH_2$

18. Which is the ^{1}H NMR spectrum of cyclohexane?

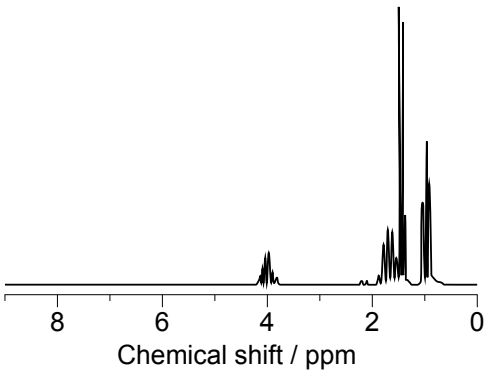
A.



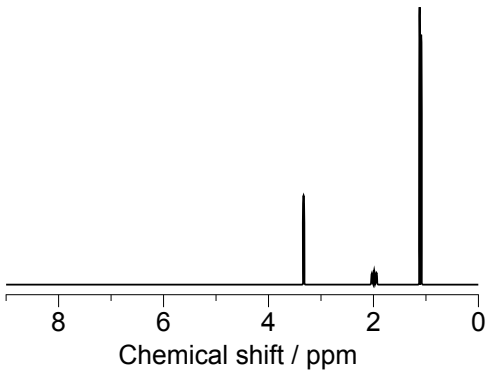
C.



B.

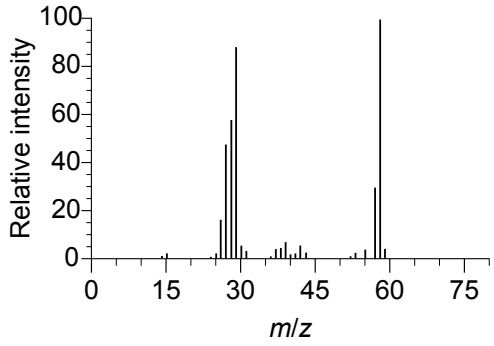


D.

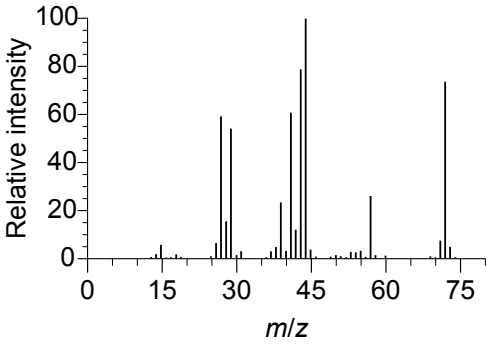


19. Which is the mass spectrum of butanal?

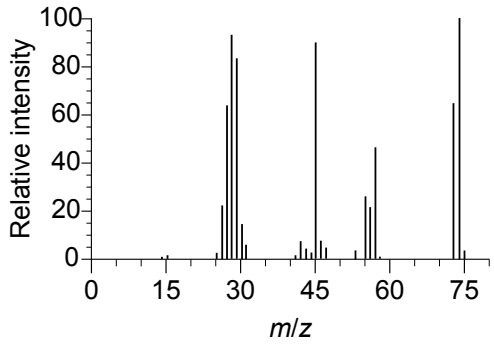
A.



C.



B.



D.

