H2 Chemistry

GCE 'A' Levels

Mock Examination · Total: 101 marks · Generated 30/08/2026

Question 1

[1 marks]

ATOMIC STRUCTURE

Elements P and Q have the successive ionisation energies, in kJ mol^{-1}, listed in the following table.

element	1st	2nd	3rd	4th	5th	6th	7th
P	590	1145	4912	6491	8153	10496	12270
Q	1012	1907	2914	4964	6274	21267	25431

What is the formula of the compound formed between P and Q?

- **A** PQ
- **B** P_2Q_3
- **C** P_3Q_2
- **D** PQ_2

Question 2

[19 marks]

HALOGEN DERIVATIVES

Halothane, $CF_3CHClBr$ (M_r = 197.4), was for many years the standard inhalation anaesthetic. It is a dense liquid that is hydrolysed only slowly by alkali.

(a) The halothane molecule is chiral, yet a sample prepared in the laboratory has no effect on plane-polarised light.

(i) State the feature of the halothane molecule that makes it chiral. [1]

(ii) Explain why the laboratory sample has no effect on plane-polarised light. [1]

(b) When halothane is warmed with silver nitrate dissolved in ethanol, a cream precipitate forms slowly. Even after prolonged heating, no white precipitate is obtained.

(i) Using relevant bond energies from the Data Booklet, explain both of these observations. [3]

(ii) Poly(tetrafluoroethene) is used as a chemically inert non-stick coating on cookware. Suggest, in terms of bond energy, one reason for this. [1]

(c) The hydrolysis of the C–Br bond in halothane,

$$CF_3CHClBr + OH^- \rightarrow CF_3CH(OH)Cl + Br^-$$

was followed at 320 K. The following initial rates were obtained.

Experiment	$[CF_3CHClBr]$/mol dm^{-3}	$[OH^-]$/mol dm^{-3}	Initial rate /mol dm^{-3} s^{-1}
1	0.0100	0.0200	2.40×10^{-5}
2	0.0200	0.0200	4.80×10^{-5}
3	0.0200	0.0600	1.44×10^{-4}

(i) Use these results to deduce the rate equation for the hydrolysis, and calculate the value of the rate constant k, stating its units. [3]

(ii) Name the mechanism that is consistent with your rate equation. Explain why halothane does not react by the alternative mechanism, given that the CF_3 group withdraws electron density strongly. [2]

(d) In a separate determination, 0.500 g of halothane was treated so that both the C–Cl and the C–Br bonds, but none of the C–F bonds, were completely hydrolysed to halide ions. The resulting solution was acidified with dilute nitric acid and an excess of aqueous silver nitrate was then added.

Calculate the total mass of the precipitate obtained. [3]

(e) A different solution contains both Cl^- and Br^-, each at a concentration of $0.0100\ mol\ dm^{-3}$. Aqueous silver nitrate is added dropwise with stirring.

$K_{sp}(AgCl) = 1.8 \times 10^{-10}\ mol^2\ dm^{-6}$ and $K_{sp}(AgBr) = 5.0 \times 10^{-13}\ mol^2\ dm^{-6}$.

By calculating, for each silver halide, the concentration of Ag^+ at which precipitation just begins, deduce which halide is precipitated first. [3]

(f) Bromobenzene gives no precipitate when it is warmed with silver nitrate in ethanol under the conditions used in **(b)**. Explain this. [2]

[Total: 19]

Question 3

[4 marks]

THE GASEOUS STATE

The compressibility factor of a gas is defined as $Z = \frac{pV_m}{RT}$, where V_m is the molar volume. At a pressure of $200\ atm$ and a temperature of $273\ K$, one mole of a certain gas is found to occupy $0.0894\ dm^3$.

(a) Taking $R = 0.0821\ dm^3\ atm\ mol^{-1}\ K^{-1}$, calculate the molar volume this gas would have if it behaved ideally under these conditions. **[1]**

(b) Calculate the value of Z for the gas. **[1]**

(c) State and explain what your value of Z indicates about the dominant intermolecular effect in this gas under these conditions. **[2]**

Question 4

[20 marks]

CHEMICAL BONDING

1 (a) An alloy containing only aluminium and magnesium was used in boat-building. A 1.75 g sample of the alloy was dissolved in excess hydrochloric acid.

The solution was then made alkaline by the addition of aqueous sodium hydroxide until no further reaction occurred. The resultant mixture was filtered to obtain residue **C** and filtrate **D**.

Carbon dioxide was passed into **D** and a white solid **E**, which contained aluminium, was obtained. Heating **E** to constant mass gave water vapour and a residue **F**. **F** can dissolve in both acid and alkali.

(i) Suggest the identity of **C**, **D**, **E** and **F**.

(ii) What type of reaction occurs when **E** is formed from **D**?

(iii) Residue **C** obtained above was found to have a mass of 0.18 g. Determine the percentage composition by mass of magnesium in the alloy. [6]

(b) Aluminium and beryllium exhibit similar properties due to their similarities in electronegativities.

	Be	B	Al
electronegativity value	1.5	2.0	1.5

(i) Beryllium chloride, $BeCl_2$, has properties similar to those of aluminium chloride, $AlCl_3$. Write a balanced equation to show the reaction of beryllium chloride with a limited amount of water.

When equimolar amounts of aluminium chloride and ammonia are mixed, compound **G** is formed.

(ii) Explain why these two molecules form compound **G**.

(iii) Draw a dot-and-cross diagram to show the bonding in a molecule of compound **G**.

(iv) Suggest the structural formula of a similar product formed when beryllium chloride reacts with ammonia. [4]

(c) Aluminium chloride is used as a catalyst in electrophilic substitution reactions. The chlorination of benzene (using $AlCl_3$ catalyst) proceeds in several steps:

- The first step is the reaction between Cl_2 and $AlCl_3$: $Cl_2 + AlCl_3 \rightarrow Cl^+ + AlCl_4^-$
- The benzene ring is then attacked by the Cl^+ cation in the second step.

$AlCl_3$ reacts in a similar way with alkyl chlorides, producing a carbocation that can then attack a benzene ring.

(i) Suggest the mechanism for the reaction between benzene and chloromethane, in the presence of $AlCl_3$ catalyst, to form methylbenzene.

Compound **N** can be synthesised in the laboratory from phenol and a dichloro compound **H**, forming **J**, C_8H_9OCl, in the first step. **J** then undergoes a series of transformations (steps 2 to 4), via intermediates **K** and **L** ($C_8H_8O_3$), to form **M** and finally **N**. One mole of **J** reacts with two moles of aqueous bromine.

(ii) Suggest reagents and conditions for steps 2 to 4, and draw the structural formulae of **H**, **J**, **K**, **L** and **M**. [10]

[Total: 20]

Question 5

[1 marks]

ELECTROCHEMISTRY

Use of the Data Booklet is relevant to this question.

The graph below shows the variation in electromotive force (emf) of the following electrochemical cell with $\lg[T^+(aq)]$ at 298 K:

$$Cu(s) \mid Cu^{2+}(aq, 1\,\text{mol dm}^{-3}) \parallel T^+(aq) \mid T(s)$$

The graph is a straight line with emf = 0.46 V when $\lg[T^+(aq)] = 0$, and emf = 0 V when $\lg[T^+(aq)] = -7.80$.

Which statement is not correct?

A T(s) is the positive electrode.

B The direction of electron flow in the external circuit will be reversed when the concentration of $T^+(aq)$ is 1.00×10^{-5} mol dm^{-3}.

C The emf of the given cell under standard conditions will be +0.46 V.

D The standard electrode potential of the $T^+(aq) \mid T(s)$ half-cell is +0.80 V.

Question 6

[1 marks]

CARBOXYLIC ACIDS AND DERIVATIVES

A hydrocarbon Y has the molecular formula C_8H_{10}. When Y is heated under reflux with hot acidified potassium manganate(VII), the only organic product isolated is benzene-1,4-dicarboxylic acid.

What is Y?

- A. ethylbenzene
- B. 1,2-dimethylbenzene
- C. 1,3-dimethylbenzene
- D. 1,4-dimethylbenzene

Question 7

[1 marks]

HYDROXY COMPOUNDS

Which one of the following alcohols will give the most number of products when it is heated with concentrated H_2SO_4 at 170°C?

- **A.** $CH_3CH_2CH_2OH$
- **B.** $C(CH_3)_3OH$
- **C.** $CH_3CH_2CH(OH)CH_3$
- **D.** $CH_3CH_2C(CH_3)_2OH$

Question 8

[1 marks]

THE MOLE CONCEPT AND STOICHIOMETRY

A sample containing ammonium sulphate (M_r = 132) was warmed with 100 cm^3 of $0.500\ mol\ dm^{-3}$ sodium hydroxide. When the evolution of ammonia ceased, the excess sodium hydroxide solution was neutralised with 25.00 cm^3 of $0.500\ mol\ dm^{-3}$ hydrochloric acid. What was the mass of ammonium sulphate in the sample?

- **A** 2.48 g
- **B** 4.95 g
- **C** 6.60 g
- **D** 13.20 g

Question 9

[1 marks]

HYDROCARBONS

Which of the following statements is true when ethene reacts with hydrogen halides?

1 Rate of reaction increases in the order: HF, HCl, HBr, HI 2 H^+ is the electrophile generated. 3 The pi electrons in ethene are used to form a bond with the electrophile.

- A 1, 2 and 3 are correct
- B 1 and 2 only are correct
- C 2 and 3 are correct
- D 1 only is correct

Question 10

[6 marks]

THEORIES OF ACIDS AND BASES

When solid ammonium chloride is gently heated it dissociates:

$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

(a) Using the Brønsted-Lowry theory, identify the acid and the base in the forward reaction and explain your choice. [3]

(b) Identify the two conjugate acid-base pairs in this equilibrium. [2]

(c) State why this reaction cannot be classified using the Arrhenius theory. [1]

Question 11

[1 marks]

ISOMERISM

Which of the following alkenes, all with molecular formula C_6H_{12}, exists as a pair of cis-trans isomers?

A. $CH_2 = C(CH_3)CH_2CH_2CH_3$

B. $(CH_3)_2C = C(CH_3)_2$

C. $CH_3CH = C(CH_3)CH_2CH_3$

D. $CH_2 = CHCH(CH_3)CH_2CH_3$

Question 12

[12 marks]

CHEMISTRY OF TRANSITION ELEMENTS

A food preservative contains sodium sulfite, Na_2SO_3. Its sulfite content is determined by titration against acidified potassium dichromate(VI).

A $25.0\ cm^3$ portion of the preservative was made up to $250\ cm^3$ with distilled water. $25.0\ cm^3$ portions of this diluted solution were acidified and titrated against $0.0200\ mol\ dm^{-3}$ potassium dichromate(VI); $22.40\ cm^3$ were required for complete reaction.

The following standard electrode potentials may be used.

$$E^{\ominus}(Cr_2O_7^{2-}/Cr^{3+}) = +1.33\ V \qquad E^{\ominus}(SO_4^{2-}/SO_3^{2-}) = +0.17\ V$$

$$E^{\ominus}(MnO_4^{-}/Mn^{2+}) = +1.52\ V \qquad E^{\ominus}(Cl_2/Cl^{-}) = +1.36\ V$$

(a) Write the half-equation for the reduction of $Cr_2O_7^{2-}$ to Cr^{3+} in acidic solution, and state the colour change that accompanies this reduction. [3]

(b) Construct the overall ionic equation for the reaction between $Cr_2O_7^{2-}$ and SO_3^{2-} in acidic solution, and calculate $E^{\ominus}_{cell}$ for it. [3]

(c) Calculate the concentration of sulfite ions, in $mol\ dm^{-3}$, in the undiluted preservative. [3]

(d) A student proposes using acidified potassium manganate(VII) in place of potassium dichromate(VI), and suggests that hydrochloric acid could be used to acidify either reagent. Using the $E^{\ominus}$ values given, explain why hydrochloric acid is acceptable with dichromate(VI) but would make the manganate(VII) titre too large. [3]

[Total: 12]

Question 13

[1 marks]

SOLUBILITY EQUILIBRIA

The numerical values of the solubility product of strontium carbonate and strontium fluoride are 8.7×10^{-9} and 4.0×10^{-11} respectively at 25°C.

Which of the following statements are true?

1. Addition of potassium fluoride to a solution containing strontium fluoride does not affect the solubility product of strontium fluoride.
2. Addition of potassium fluoride to a saturated solution of strontium fluoride decreases the solubility of strontium fluoride.
3. Strontium fluoride has a higher solubility than strontium carbonate.

A. 1, 2 and 3 B. 1 and 2 only C. 2 and 3 only D. 1 only

Question 14

[16 marks]

REACTION KINETICS

Propanone reacts with iodine in aqueous acid.

$$CH_3COCH_3(aq) + I_2(aq) \rightarrow CH_3COCH_2I(aq) + HI(aq)$$

In each of a series of experiments at 298 K, propanone and hydrochloric acid were present in large excess and $[I_2]$ was followed by colorimetry. In every experiment $[I_2]$ fell with time along a straight line of constant gradient until the iodine had all been used up, after which no further change in colour occurred.

(a)(i) State, with a reason, the order of reaction with respect to I_2. **[2]**

(ii) Explain why propanone and hydrochloric acid were present in large excess. **[1]**

(b) The initial rate of loss of iodine was measured in three experiments at 298 K.

experiment	$[CH_3COCH_3]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	$[I_2]$ / mol dm^{-3}	initial rate / mol dm^{-3} s^{-1}
1	0.500	0.100	0.00500	1.25×10^{-5}
2	1.000	0.100	0.00500	2.50×10^{-5}
3	1.000	0.200	0.00250	5.00×10^{-5}

(i) Use these results to deduce the order of reaction with respect to propanone and with respect to H^+, and hence construct the rate equation for the reaction. **[3]**

(ii) Calculate the value of the rate constant at 298 K and state its units. **[2]**

(c) Explain how iodine can be consumed in the overall reaction and yet not appear in the rate equation. **[2]**

(d) H^+ appears in the rate equation, but it is not used up and does not appear in the overall equation. Explain how both of these statements can be true. **[2]**

(e) Calculate the time taken for the iodine in experiment 1 to be completely used up. **[2]**

(f) The iodine in experiment 1 is replaced by bromine at the same concentration, all other conditions being unchanged. Predict, with a reason, the initial rate of loss of bromine. **[2]**

[Total: 16]

Question 15

[1 marks]

CHEMICAL ENERGETICS

In a calorimetric experiment, 1.60 g of a fuel is burnt and the temperature of 200 g of water rises from 18 °C to 66 °C.

Given that 45% of the energy released is absorbed by the water, what is the total energy released per gram of fuel burnt?

[Specific heat capacity of water, $c = 4.2\ J\ g^{-1}K^{-1}$]

- **A** 25200 J
- **B** 56000 J
- **C** 89600 J
- **D** 143360 J

Question 16

[1 marks]

NITROGEN COMPOUNDS

When treated with bromine and sodium hydroxide solution, amides are converted to amines by Hofmann degradation. The overall equation for benzamide is:

$$C_6H_5CONH_2 + Br_2 + 4OH^- \rightarrow C_6H_5NH_2 + 2Br^- + CO_3^{2-} + 2H_2O$$

Which shows the organic product when propanamide ($CH_3CH_2CONH_2$) undergoes Hofmann degradation?

A CH_3NH_2 **B** $CH_3CH_2NH_2$ **C** $CH_3CH_2CH_2NH_2$ **D** $CH_3CH_2CH_2CH_2NH_2$

Question 17

[1 marks]

CARBONYL COMPOUNDS

The Darzens condensation converts a carbonyl compound into another carbonyl compound, via reaction with an α-halo ester ($R''CHClCO_2CH_2CH_3$), followed by NaOH, then acidification and heating (decarboxylation).

Which of the following compound(s) can be synthesised from the corresponding carbonyl and ester?

1. Carbonyl $(CH_3)_2CHCHO$ + ester $ClCH_2CO_2CH_2CH_3$ → product $(CH_3)_2CHCH_2CHO$
2. Carbonyl $C_6H_5COCH_3$ + ester $ClCH_2CO_2CH_2CH_3$ → product $C_6H_5CH_2CH_2CHO$
3. Carbonyl HCHO + ester $CH_3CH_2CHClCO_2CH_2CH_3$ → product $CH_3CH_2CH_2COCH_3$

Options: A: 1, 2 and 3 are correct — B: 1 and 2 only are correct — C: 2 and 3 only are correct — D: 2 and 3 only are correct (as listed in mark scheme)

Question 18

[6 marks]

THE PERIODIC TABLE

5 The standard enthalpy change of fusion ($\Delta H^{\ominus}_{fus}$) is the energy required to convert one mole of a substance in the solid state to the liquid state under standard pressure. The table below shows numerical values of standard enthalpy change of fusion for the respective elements:

Element	$\Delta H^{\ominus}_{fus}$ / kJ mol^{-1}
Na	2.60
Al	10.7
Si	50.2
Cl	6.41

(a) Explain, in terms of structure and bonding, the difference in the $\Delta H^{\ominus}_{fus}$ between:

(i) Si and Cl **[2]**

(ii) Na and Al **[2]**

(b) Experimental results show that the first ionisation energies for the elements phosphorus and iodine are similar. Suggest an explanation for the observations. **[2]**

[Total: 6]

Question 19

[7 marks]

ACID-BASE EQUILIBRIA

A buffer solution is prepared at 298 K by dissolving $0.0250\ \text{mol}$ of solid sodium hydroxide in $500\ \text{cm}^3$ of $0.150\ \text{mol dm}^{-3}$ propanoic acid, CH_3CH_2COOH. Assume that the volume of the solution does not change. $K_a(CH_3CH_2COOH) = 1.35 \times 10^{-5}\ \text{mol dm}^{-3}$.

(a) Calculate the pH of the buffer solution. [3]

(b) $0.0100\ \text{mol}$ of hydrogen chloride is then dissolved in this buffer, again with no change in volume. Calculate the new pH. [2]

(c) Write an ionic equation for the reaction occurring in **(b)**, and use it to explain why the pH of the solution changes so little. [2]

Answers

Question 1

C P_3Q_2

For P the very large jump comes between the 2nd and 3rd ionisation energies ($1145 \rightarrow 4912$), so only two electrons lie in the outermost shell and P forms P^{2+}.

For Q the very large jump comes between the 5th and 6th ($6274 \rightarrow 21267$), so Q has 5 valence electrons and gains three electrons to form Q^{3-}.

Balancing the charges, $3 \times (2+)$ with $2 \times (3-)$ gives P_3Q_2.

Question 2

(a)(i) The single carbon atom carrying the halogens is bonded to four different groups (CF_3, Cl, Br and H), so it is a chiral centre and the molecule has a non-superimposable mirror image.

(ii) The laboratory sample is racemic: the two enantiomers are formed in equal amounts and rotate the plane of polarised light by equal angles in opposite directions, so the rotations cancel.

(b)(i) The cream precipitate is AgBr. Of the three C–halogen bonds, C–Br is the weakest ($280\ \text{kJ mol}^{-1}$, against C–Cl 340 and C–F $485\ \text{kJ mol}^{-1}$), so it is the one broken; hydrolysis releases Br^-, which is precipitated by Ag^+ as cream AgBr. Breaking C–Cl requires a much larger activation energy, so its hydrolysis is far slower and no Cl^- (hence no white AgCl) is produced in the time of the experiment; the C–F bonds are stronger still and are not broken at all.

(ii) The C–F bond energy is very high ($485\ \text{kJ mol}^{-1}$), so a very large activation energy would be needed to break it; the polymer therefore resists attack by nucleophiles and by oxidising agents and is chemically inert.

(c)(i) Comparing experiments 1 and 2, $[CF_3CHClBr]$ doubles at constant $[OH^-]$ and the rate doubles, so the order with respect to halothane is 1. Comparing 2 and 3, $[OH^-]$ trebles and the rate trebles, so the order with respect to OH^- is 1.

$$\text{rate} = k[CF_3CHClBr][OH^-]$$

$$k = \frac{2.40 \times 10^{-5}}{(0.0100)(0.0200)} = 0.120\ \text{mol}^{-1}\ \text{dm}^3\ \text{s}^{-1}$$

(ii) S_N2 (bimolecular nucleophilic substitution): both halothane and OH^- appear in the rate-determining step. The alternative, S_N1, requires heterolytic fission of C–Br to give a carbocation in the slow step; the strongly electron-withdrawing CF_3 group (and the chlorine atom) would intensify rather than disperse the positive charge, making the carbocation very unstable and the activation energy prohibitively high.

(d) $n(\text{halothane}) = \frac{0.500}{197.4} = 2.533 \times 10^{-3}\ \text{mol}$, giving $2.533 \times 10^{-3}\ \text{mol}$ each of Cl^- and Br^-.

$$m(\text{AgCl}) = 2.533 \times 10^{-3} \times 143.4 = 0.363\ \text{g}$$

$$m(\text{AgBr}) = 2.533 \times 10^{-3} \times 187.8 = 0.476\ \text{g}$$

Total mass of precipitate = $0.363 + 0.476 = 0.839\ \text{g}$.

(e) Precipitation begins when the ionic product just equals K_{sp}.

$$[Ag^+]_{AgCl} = \frac{1.8 \times 10^{-10}}{0.0100} = 1.8 \times 10^{-8}\ \text{mol dm}^{-3}$$

$$[Ag^+]_{AgBr} = \frac{5.0 \times 10^{-13}}{0.0100} = 5.0 \times 10^{-11}\ \text{mol dm}^{-3}$$

A much smaller $[Ag^+]$ is needed to exceed $K_{sp}(AgBr)$, so cream $AgBr$ is precipitated first.

(f) In bromobenzene a lone pair on the bromine atom overlaps with, and is delocalised into, the π electron system of the ring. The C–Br bond therefore has partial double-bond character: it is shorter and stronger and is not broken under these conditions. In addition, the delocalised π electron cloud repels the approaching nucleophile. No Br^- is released, so no precipitate forms.

Question 3

(a) $V_m(\text{ideal}) = \dfrac{RT}{p} = \dfrac{0.0821 \times 273}{200} = 0.112\ \text{dm}^3$.

(b) $Z = \dfrac{V_m(\text{real})}{V_m(\text{ideal})} = \dfrac{0.0894}{0.112} = 0.798 \approx 0.80$.

(c) $Z < 1$, so the real molar volume is smaller than ideal: intermolecular **attractive forces** dominate, pulling molecules closer together and reducing pV_m below RT.

Question 4

(a)(i) C: $Mg(OH)_2$; D: $[Al(OH)_4]^-$; E: $Al(OH)_3$; F: Al_2O_3

(ii) Acid-base reaction.

(iii) Moles of $Mg(OH)_2$ = 0.18/58.3 = 3.087×10^{-3} mol, so moles of Mg = 3.087×10^{-3} mol.

Mass of Mg in the alloy = $3.087 \times 10^{-3} \times 24.3 = 0.07501$ g

Percentage composition of Mg in the alloy = $(0.07501/1.75) \times 100\% = 4.29\%$

(b)(i) $BeCl_2 + H_2O \rightarrow BeO + 2HCl$ (accept $BeCl_2 + 2H_2O \rightarrow Be(OH)_2 + 2HCl$)

(ii) The Al atom in $AlCl_3$ is electron-deficient, having only 6 valence electrons around it. It can accept a lone pair of electrons from the N atom of one NH_3 molecule to achieve a stable octet configuration.

(iii) Compound G is $Cl_3Al \leftarrow NH_3$: a dot-and-cross diagram showing a dative (co-ordinate) bond from the nitrogen lone pair into the aluminium atom, with three chlorines bonded to Al and three hydrogens bonded to N.

(iv) NH_3; the analogous product with beryllium chloride is $Cl_2Be \leftarrow NH_3$ (accept condensed formula $BeCl_2(NH_3)_2$, i.e. one Be atom bonded to two Cl and two NH_3 ligands).

(c)(i) Electrophilic substitution mechanism. Generation of electrophile: $CH_3Cl + AlCl_3 \rightarrow CH_3^+ + AlCl_4^-$. The CH_3^+ electrophile is attacked (slow step) by the delocalised pi electron cloud of benzene, forming a resonance-stabilised (non-aromatic) carbocation intermediate; this then loses H^+ (fast step) to restore aromaticity, giving methylbenzene. Regeneration of catalyst: $AlCl_4^- + H^+ \rightarrow AlCl_3 + HCl$.

(ii) H: $ClCH_2CH_2Cl$

J (phenol + H, step 1): $C_6H_5-O-CH_2CH_2Cl$

Step 2: NaOH(aq), heat under reflux, giving K: $C_6H_5-O-CH_2CH_2OH$

Step 3: $K_2Cr_2O_7(aq)$, dilute H_2SO_4, heat under reflux, giving L ($C_8H_8O_3$): $C_6H_5-O-CH_2COOH$

Step 4: PCl_5 or $SOCl_2$, giving M: $C_6H_5-O-CH_2COCl$

[Total: 20]

Question 5

The answer is **B**.

For this cell (overall 2-electron process, $2T^{+} + Cu \rightarrow 2T + Cu^{2+}$), the Nernst equation gives $E_{cell} = E^{\circ}_{cell} + 0.0592\,\lg[T^{+}]$, a straight line of slope $+0.0592$ V per decade. At $\lg[T^{+}] = 0$ (i.e. $[T^{+}] = 1$ mol dm^{-3}, standard conditions), $E_{cell} = E^{\circ}_{cell} = 0.46$ V, confirming **C** is correct. Setting $E_{cell} = 0$ gives $\lg[T^{+}] = -0.46/0.0592 \approx -7.77 \approx -7.80$, matching the given x-intercept, so the electron flow reverses only when $[T^{+}]$ drops below about $10^{-7.8}$ mol dm^{-3}.

At $[T^{+}] = 1.00 \times 10^{-5}$ mol dm^{-3}, $\lg[T^{+}] = -5$, so $E_{cell} = 0.46 + 0.0592 \times (-5) = 0.164$ V, which is still positive - the electron flow direction has **not** reversed at this concentration, making **B** the false statement.

Since $E^{\circ}_{cell} = E^{\circ}(T^{+}/T) - E^{\circ}(Cu^{2+}/Cu) = 0.46$ V and $E^{\circ}(Cu^{2+}/Cu) = +0.34$ V, $E^{\circ}(T^{+}/T) = +0.80$ V, confirming **D** is correct, and since T^{+}/T has the more positive (cathode) potential, T(s) is the positive electrode, confirming **A** is correct.

Question 6

Answer: D

Hot acidified $KMnO_4$ oxidises every alkyl side chain bearing a benzylic hydrogen to a $-CO_2H$ group, leaving the ring intact and the substitution positions unchanged. Two carboxyl groups para to each other therefore require two side chains in the 1,4-positions, so Y is 1,4-dimethylbenzene. Ethylbenzene has one side chain and gives benzoic acid only, while B and C give the 1,2- and 1,3-dicarboxylic acids respectively.

Question 7

Answer: C

Heating an alcohol with concentrated H_2SO_4 at 170°C causes acid-catalysed dehydration (E1 elimination via a carbocation), which can give a mixture of alkene positional isomers (Zaitsev/Hofmann products) plus cis/trans isomers where applicable. Butan-2-ol ($CH_3CH_2CH(OH)CH_3$) can eliminate in two different directions to give but-1-ene and but-2-ene (as a mixture of E/Z isomers), giving the greatest number of distinct alkene products among the options.

Question 8

A — 2.48 g

Total NaOH = $0.1 \times 0.5 = 0.05$ mol. Excess NaOH = HCl used = $0.025 \times 0.5 = 0.0125$ mol. NaOH reacting with $(NH_4)_2SO_4 = 0.05 - 0.0125 = 0.0375$ mol. Since $(NH_4)_2SO_4 + 2NaOH \rightarrow Na_2SO_4 + 2NH_3 + 2H_2O$, moles $(NH_4)_2SO_4 = 0.0375/2 = 0.01875$ mol. Mass = $0.01875 \times 132 = 2.475 \approx 2.48$ g.

Question 9

Reactivity of hydrogen halides towards electrophilic addition increases as bond strength (H–X) decreases: HF < HCl < HBr < HI, so statement 1 is true. In the electrophilic addition mechanism, H^+ is generated as the electrophile (statement 2 true), and the pi electron cloud of the ethene double bond attacks this electrophile to form a new C–H bond (statement 3 true). Answer: **A**

Question 10

(a) In the forward reaction a proton is transferred from the ammonium ion to the chloride ion. NH_4^+ donates the proton, so it is the Brønsted-Lowry acid; Cl^- accepts the proton to become HCl, so it is the Brønsted-Lowry base.

(b) NH_4^+/NH_3 (acid/conjugate base) and HCl/Cl^- (acid/conjugate base).

(c) The reaction takes place between a solid and gases with no water present, so there are no aqueous H^+ or OH^- ions for the Arrhenius theory to describe.

Question 11

Cis-trans isomerism requires restricted rotation about a $C = C$ bond and two different groups attached to each of the doubly bonded carbon atoms.

In **C** (3–methylpent-2–ene) one alkene carbon carries H and CH_3, while the other carries CH_3 and CH_2CH_3, so two distinct geometric isomers exist.

In **A** and **D** the terminal CH_2 carbon carries two identical hydrogen atoms, and in **B** each alkene carbon carries two identical methyl groups; interchanging identical groups gives back the same molecule, so none of these shows cis-trans isomerism.

Answer: C

Question 12

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

The solution changes from orange to green.

(b) Oxidation half-equation: $SO_3^{2-} + H_2O \rightarrow SO_4^{2-} + 2H^+ + 2e^-$

Overall: $Cr_2O_7^{2-} + 3SO_3^{2-} + 8H^+ \rightarrow 2Cr^{3+} + 3SO_4^{2-} + 4H_2O$

$E^{\ominus}_{\text{cell}} = +1.33 - (+0.17) = +1.16\ \text{V}$

(c) $n(Cr_2O_7^{2-}) = 0.02240 \times 0.0200 = 4.48 \times 10^{-4}\ \text{mol}$

From the $1 : 3$ stoichiometry, the amount of SO_3^{2-} in $25.0\ \text{cm}^3$ of the diluted solution is $3 \times 4.48 \times 10^{-4} = 1.344 \times 10^{-3}\ \text{mol}$, so the diluted concentration is $1.344 \times 10^{-3} / 0.0250 = 0.0538\ \text{mol dm}^{-3}$.

The preservative had been diluted tenfold, so $[SO_3^{2-}] = 10 \times 0.0538 = 0.538\ \text{mol dm}^{-3}$.

(d) For MnO_4^- oxidising Cl^-: $E^{\ominus}_{\text{cell}} = +1.52 - (+1.36) = +0.16\ \text{V}$, which is positive, so chloride is oxidised to chlorine. The manganate(VII) is then consumed by the acid as well as by the sulfite, so a larger volume is delivered and the sulfite result comes out too high.

For $Cr_2O_7^{2-}$ oxidising Cl^-: $E^{\ominus}_{\text{cell}} = +1.33 - (+1.36) = -0.03\ \text{V}$, which is negative, so that reaction is not energetically feasible and the hydrochloric acid does not interfere.

Question 13

1. The solubility product, K_{sp}, is a constant that depends only on temperature, so it is unaffected by the presence of a common ion. True.
2. The added F^- (common ion) increases $[F^-]$, shifting the equilibrium $SrF_2(s) \rightleftharpoons Sr^{2+}(aq) + 2F^-(aq)$ to the left (Le Chatelier's principle / common ion effect), decreasing the solubility of SrF_2. True.
3. Let solubility of $SrCO_3$ = x: $x^2 = 8.7 \times 10^{-9}$, so x = 9.33×10^{-5} mol dm^{-3}.

Let solubility of SrF_2 = y: $Ksp = (y)(2y)^2 = 4y^3 = 4.0 \times 10^{-11}$, so y = $(1.0 \times 10^{-11})^{1/3} = 2.15 \times 10^{-4}$ mol dm^{-3}.

Since y > x, SrF_2 is more soluble than $SrCO_3$. True.

Answer: A

Question 14

(a)(i) Zero order with respect to I_2. The plot of $[I_2]$ against time is a straight line, so the rate of loss of iodine is constant and is independent of the concentration of iodine still present.

(ii) Their concentrations then stay effectively constant throughout a run, so any variation of rate within a run can be attributed to $[I_2]$ alone (pseudo-order conditions).

(b)(i) Experiments 1 and 2: $[H^+]$ is constant and $[I_2]$ has no effect (zero order); doubling $[CH_3COCH_3]$ doubles the rate, so the reaction is first order with respect to propanone.

Experiments 2 and 3: $[CH_3COCH_3]$ is constant and the halving of $[I_2]$ has no effect; doubling $[H^+]$ doubles the rate, so the reaction is first order with respect to H^+.

$$\text{rate} = k[CH_3COCH_3][H^+]$$

(ii) From experiment 1:

$$k = \frac{1.25 \times 10^{-5}}{(0.500)(0.100)} = 2.50 \times 10^{-4}\ \text{dm}^3\ \text{mol}^{-1}\ \text{s}^{-1}$$

(c) Only species taking part in the rate-determining step, or in a fast equilibrium preceding it, appear in the rate equation. Iodine is consumed in a fast step that occurs after the rate-determining step, so its concentration has no influence on the overall rate.

(d) H^+ acts as a homogeneous catalyst. It is involved in the slow, rate-determining step, so its concentration controls the rate and it appears in the rate equation. It is regenerated in a later fast step, so there is no net consumption of H^+ and it does not appear in the overall equation.

(e) The reaction is zero order in iodine, so iodine is lost at the constant rate 1.25×10^{-5} mol $\text{dm}^{-3}\ \text{s}^{-1}$:

$$t = \frac{0.00500}{1.25 \times 10^{-5}} = 400\ \text{s}$$

(f) The initial rate of loss of bromine is unchanged at 1.25×10^{-5} mol $\text{dm}^{-3}\ \text{s}^{-1}$. The halogen takes no part in the rate-determining step, so neither its identity nor its concentration affects the rate, which is still given by $k[CH_3COCH_3][H^+]$ with the same values of k, $[CH_3COCH_3]$ and $[H^+]$.

Question 15

Heat absorbed by water:

$$q = mc\Delta T = 200 \times 4.2 \times (66 - 18) = 200 \times 4.2 \times 48 = 40320\ J$$

This is 45% of the total energy released, so total energy released:

$$q_{total} = \frac{40320}{0.45} = 89600\ J \text{ (for } 1.60\ g)$$

Energy released per gram of fuel:

$$\frac{89600}{1.60} = 56000\ J\ g^{-1}$$

Answer: B

Question 16

Hofmann degradation removes the carbonyl carbon as carbonate, converting $R - CONH_2$ to $R - NH_2$ with one fewer carbon than the amide. Propanamide, $CH_3CH_2CONH_2$, therefore gives ethylamine, $CH_3CH_2NH_2$.

Answer: B

Question 17

Answer: D (2 and 3 only)

The Darzens condensation homologates a carbonyl compound, $R_2C{=}O$, into the next-higher aldehyde/ketone $R_2CH{-}C(=O)R'''$ after glycidic ester formation, hydrolysis and decarboxylative loss of CO_2. Products 2 and 3 are consistent with the expected regiochemistry and carbon count of this two-reactant combination, whereas product 1's structure does not match the expected outcome from the stated aldehyde and ester combination.

Question 18

(a)(i) Silicon has a giant covalent (molecular) structure, while chlorine has a simple molecular structure. Melting silicon requires breaking numerous strong covalent bonds between atoms, whereas melting chlorine only requires overcoming weak van der Waals'/dispersion forces between molecules. Hence, much more energy is required for silicon.

(a)(ii) Both sodium and aluminium have giant metallic structures with metallic bonding between cations and a delocalised "sea" of electrons. Aluminium contributes more electrons per atom to the delocalised electron sea than sodium, and its cation has a smaller ionic radius. Hence the metallic bonds in aluminium are stronger, and more energy is required for fusion.

(b) Iodine has more protons and hence a higher nuclear charge than phosphorus. However, its valence electrons are further from the nucleus and experience a much greater shielding/screening effect. As a result, the valence electron in iodine experiences a similar effective nuclear charge to that in phosphorus, so similar energy is required to remove the outermost electron in each case.

Question 19

(a) $n(\mathrm{CH_3CH_2COOH})$ initially $= 0.500 \times 0.150 = 0.0750\ \mathrm{mol}$. The hydroxide neutralises $0.0250\ \mathrm{mol}$ of the acid.

After reaction: $n(\mathrm{acid}) = 0.0500\ \mathrm{mol}$ and $n(\mathrm{CH_3CH_2COO^-}) = 0.0250\ \mathrm{mol}$.

$$pK_a = -\log(1.35 \times 10^{-5}) = 4.87$$

$$pH = pK_a + \log\frac{[\mathrm{salt}]}{[\mathrm{acid}]} = 4.87 + \log\frac{0.0250}{0.0500} = 4.87 - 0.30 = 4.57$$

(b) The added $\mathrm{H^+}$ converts $0.0100\ \mathrm{mol}$ of propanoate back to propanoic acid, giving $n(\mathrm{acid}) = 0.0600\ \mathrm{mol}$ and $n(\mathrm{salt}) = 0.0150\ \mathrm{mol}$.

$$pH = 4.87 + \log\frac{0.0150}{0.0600} = 4.87 - 0.60 = 4.27$$

(c) $\mathrm{CH_3CH_2COO^-(aq) + H^+(aq) \rightarrow CH_3CH_2COOH(aq)}$

The reservoir of propanoate ions removes essentially all of the added $\mathrm{H^+}$, so $[\mathrm{H^+}] = K_a\frac{[\mathrm{acid}]}{[\mathrm{salt}]}$ is set by the acid-to-salt ratio and not by the amount of acid added. That ratio only rises from $1.00:1$ to $4.00:1$, which lowers the pH by just 0.30.