
A-Level Chemistry - Exam Style Questions

| | | | |
|-------------------|---------------------------|-----------|-------------------------|
| Section A: | Multiple Choice Questions | 1 mark, | 2 minutes per question |
| Section B: | Physical Chemistry | 25 marks, | 30 minutes per question |
| Section C: | Organic Chemistry | 25 marks, | 30 minutes per question |
| Section D: | Inorganic Chemistry | 25 marks, | 30 minutes per question |

A1. Listed are the electronic configurations for the atoms of different elements. Which one represents the most reactive non-metal?

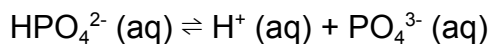
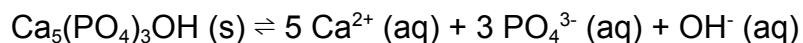
- ① [He] 2s¹
- ② [He] 2s² 2p⁵
- ③ [Ne] 3s² 3p²
- ④ [Ne] 3s² 3p⁵

A2. It is estimated that there are 8.1×10^{-4} nanograms of globular protein molecules within the cytoplasm of a particular human skin cell. The volume of the cytoplasm is $3.4 \mu\text{m}^3$. The average molecular mass of the proteins is 51.9 kg mol^{-1} . Proteins make up 15% by mass of the cytoplasm, with the remainder made up of water, ions and other small molecules.

Based on these quantities, which calculation can be correctly deduced?

- ① There are approximately one million protein molecules in the cytoplasm.
- ② The concentration of proteins within the cytoplasm is 4.6 mol dm^{-3} .
- ③ The density of the cytoplasm is within 15% that of water.
- ④ The average volume of a single protein molecule is $1.4 \times 10^{-26} \text{ m}^3$.

A3. Hydroxyapatite, $\text{Ca}_5(\text{PO}_4)_3\text{OH}$, is the main constituent of tooth enamel. In the presence of saliva, the following equilibria exist:



Which of the following statements help to explain why tooth enamel is dissolved more readily when the saliva is acidic?

- A** The hydroxide ions are neutralised by the acid.
- B** The phosphate ion $\text{PO}_4^{3-} \text{ (aq)}$ accepts $\text{H}^+ \text{ (aq)}$.
- C** Calcium ions react with acids.

- ① **A** and **B** only
- ② **A** and **C** only
- ③ **B** and **C** only
- ④ **A**, **B** and **C**

- A4.** A sample of strontium has a relative atomic mass of 87.7 and consists of three isotopes, ^{86}Sr , ^{87}Sr and ^{88}Sr . The isotopes ^{86}Sr : ^{87}Sr are equally abundant.

What is the percentage abundance of the ^{88}Sr isotope in this sample?

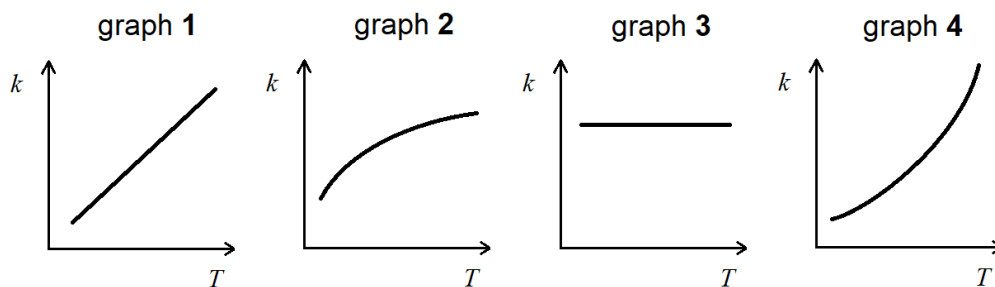
- ① 10%
- ② 20%
- ③ 30%
- ④ 40%

- A5.** The acylium ion is an organic cation generated by the reaction of ethanoyl chloride with AlCl_3 .

The geometry around the carbocation in an acylium ion is

- ① linear
- ② bent
- ③ trigonal planar
- ④ trigonal pyramidal

- A6.** Which graph correctly shows the variation of rate constant k with temperature T ?



- ① graph 1
- ② graph 2
- ③ graph 3
- ④ graph 4

A7. The following tests were carried out on separate samples of two monoprotic acids, HX and HY, with $[HX] = [HY] = 1.00 \text{ mol dm}^{-3}$.

- A** Measure the time taken for a 1 cm strip of magnesium to react completely when added to 25 cm^3 of each acid.
- B** Measure the volume of 1.00 mol dm^{-3} sodium hydroxide solution needed to completely neutralise 20 cm^3 of each acid.
- C** Measure the electrical conductance of each acid.

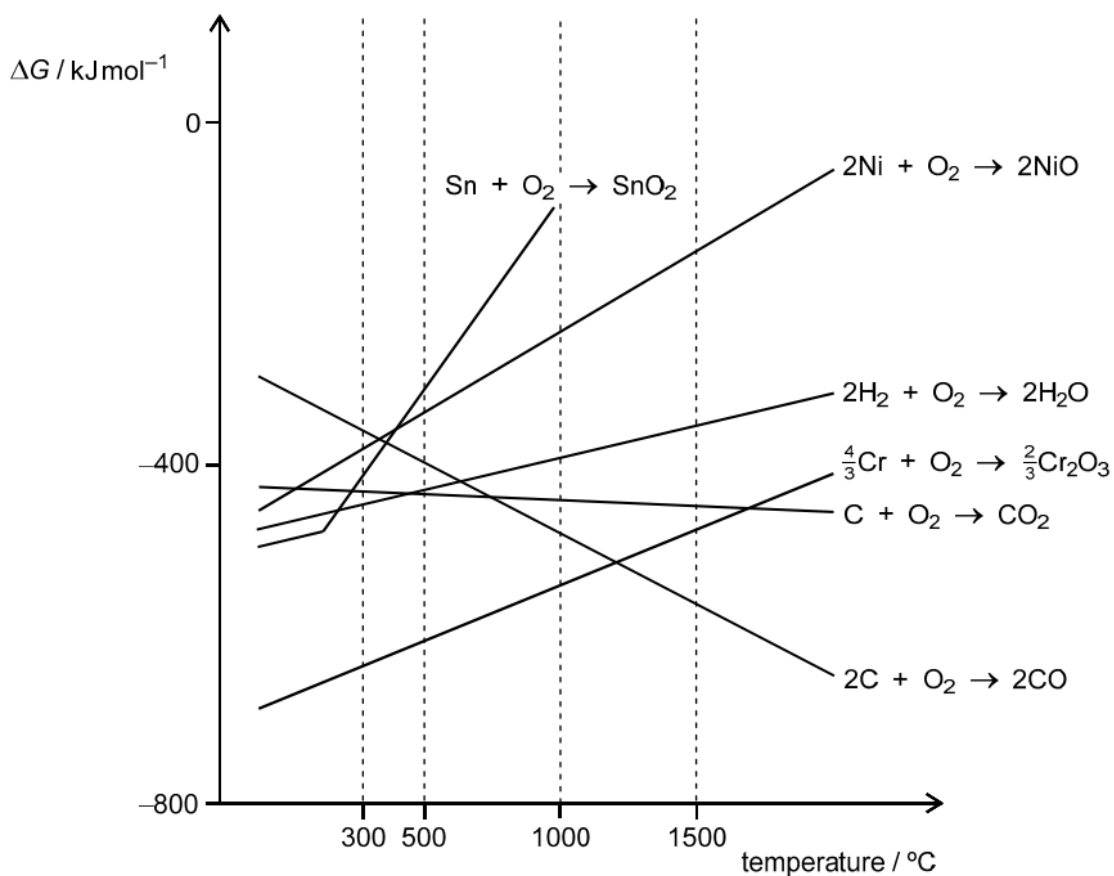
Each test was carried out under the same conditions. Which of the tests, considered independently, would show that HX was a stronger acid than HY?

- ① tests **A** and **B** only
- ② tests **A** and **C** only
- ③ tests **B** and **C** only
- ④ tests **A**, **B** and **C**

A8. Chloroethanoic acid is a stronger acid than ethanoic acid. It follows that

- ① The charge distribution of the COO^- ion is more spread out in CH_3COOH than in CH_2ClCOOH
- ② The O-H bond in CH_2ClCOOH is stronger than in CH_3COOH
- ③ The O-H bond in CH_2ClCOOH is more polarised than in CH_3COOH
- ④ A buffer solution of CH_3COOH and CH_3COONa has a lower pH than that of CH_2ClCOOH and $\text{CH}_2\text{ClCOONa}$ with each acid and salt solution at the same concentrations.

- A9. Ellingham diagrams show how the quantity ΔG for a reaction varies over a range of temperatures. The ΔG values for different reactions can be combined using Hess's law.



Using the Ellingham diagram shown, which one of the following statements is correct?

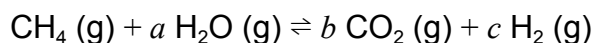
- ① Nickel can reduce tin(IV) oxide at 300 °C
- ② Carbon can reduce chromium(III) oxide at 1500 °C forming carbon dioxide and chromium
- ③ Chromium(III) oxide and nickel oxide will decompose to their elements at all the temperatures shown
- ④ Chromium will react with steam at all the temperatures shown

- *A10.** Steam-methane reforming (SMR) is the main industrial process used to generate hydrogen gas from natural gas. In the first step, methane reacts with water vapour to form hydrogen and carbon monoxide. In the second step, the carbon monoxide generated is reacted further with more water vapour to form carbon dioxide and more hydrogen.

Data for each reaction step, carried out on average at 400 °C, is given below.

| Reaction | Equilibrium constant K_p at 400 °C | Standard molar enthalpy change ΔH° |
|--|---|--|
| $\text{CH}_4 + \text{H}_2\text{O} \rightleftharpoons \text{CO} + 3 \text{H}_2$ | $5.80 \times 10^{-5} \text{ Pa}^2$ | +206 kJ mol ⁻¹ |
| $\text{CO} + \text{H}_2\text{O} \rightleftharpoons \text{CO}_2 + \text{H}_2$ | 12.0 | -41 kJ mol ⁻¹ |

The overall reaction for SMR is therefore of the form



where a , b and c are stoichiometric coefficients per mole of methane.

You are given that for a homogeneous system at equilibrium, the standard Gibbs free energy change is related to the equilibrium constant K_p through the equation

$$K_p = \exp\left(-\frac{\Delta G^\circ}{RT}\right)$$

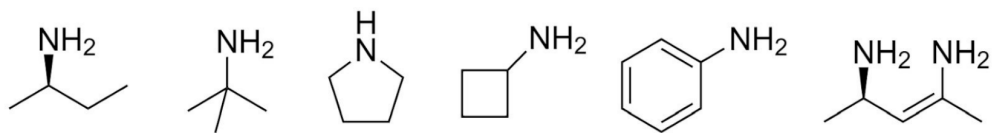
where $R = 8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ is the gas constant and T is temperature in Kelvins.

Assuming that the same conditions are used in each case, which statement(s) about the **overall** reaction is/are true?

- A** $a = 0$, $b = 1$ and $c = 4$
B $K_p = 6.96 \times 10^{-4} \text{ Pa}^2$
C $\Delta S^\circ = +305 \text{ J mol}^{-1} \text{ K}^{-1}$

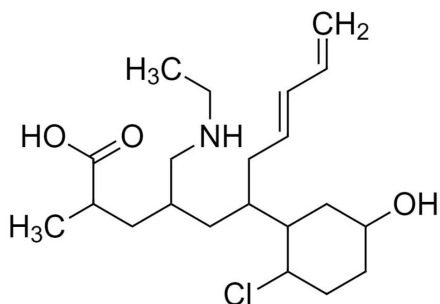
- ① **A** and **C** only
② **B** only
③ **C** only
④ **B** and **C** only

A11. How many of the six amines below can be formed by the reduction of a **nitrile**?



- ① 0
- ② 1
- ③ 2
- ④ 3

A12.



The IUPAC name of this molecule ends in what suffix?

- ① -amine
- ② -amide
- ③ -anoic acid
- ④ -enoic acid

- A13.** Propene was reacted with steam in the presence of H_3PO_4 at high temperature and pressure forming **X** and **Y** as the major and minor products respectively.

When **Y** was warmed with $\text{K}_2\text{Cr}_2\text{O}_7$ and sulfuric acid, followed by addition of alkaline CuSO_4 to the distillate collected, a red precipitate **R** is formed.

What are **Y** and **R** ?

- ① **Y** is propanone; **R** is copper(II) hydroxide
- ② **Y** is propanone; **R** is copper(II) oxide
- ③ **Y** is propanal; **R** is copper(I) dichromate
- ④ **Y** is propanal; **R** is copper(I) oxide

- A14.** Which pair of statements about intermolecular forces in amines is true?

- A** Primary and secondary amines form hydrogen bonds both in the pure state and in aqueous solution
- B** Tertiary amines form hydrogen bonds in aqueous solution but not in the pure state
- C** Quaternary (4°) ammonium salts form ion-dipole attractions in the pure state but only weak Van der Waals dispersion forces in aqueous solution
- D** The forces between molecules of amino acids are stronger than those of 4° ammonium salts when both are in neutral aqueous solution

- ① **A** and **B** only
- ② **B** and **C** only
- ③ **A** and **D** only
- ④ **C** and **D** only

- A15.** The structural formula of the possible dipeptides formed between alanine and cysteine in their aqueous states are

(Neglect differences due to stereoisomerism.)

- A** $\text{CH}_3\text{CH}(\text{NH}_3^+)\text{CONHCH}(\text{CH}_2\text{SH})\text{COO}^-$
B $\text{CH}_3\text{CH}(\text{NH}_3^+)\text{COOCH}(\text{CH}_2\text{SH})\text{COO}^-$
C $\text{HSCH}_2\text{CH}(\text{NH}_3^+)\text{CONHCH}(\text{CH}_3)\text{COO}^-$
D $^-\text{OOCCH}(\text{NH}_3^+)\text{CH}_2\text{SSCH}_2\text{CH}(\text{NH}_3^+)\text{COO}^-$

- ① **A and C**
② **B and D**
③ **A and B**
④ **C and D**

- A16.** A sample of a dipeptide is to be analysed by time of flight (TOF) mass spectrometry in order to determine its relative molecular mass.

Which of the following solvents, if any, is most suitable for carrying out the electrospray ionisation process?

(Assume the ionisation process takes place under standard conditions.)

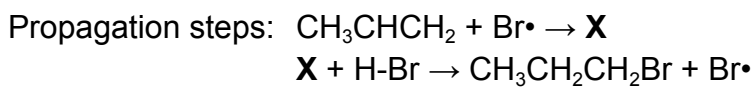
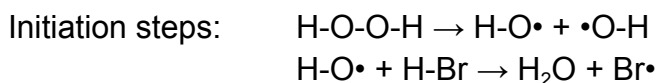
- ① water
② tetramethylsilane
③ pentane-hexane mixture
④ none of these

- A17.** How many different alkenes are formed when 2-bromo-2-methylbutane reacts with ethanolic potassium hydroxide?

- ① 0
② 1
③ 2
④ 3

- A18.** When aqueous hydrogen bromide reacts with propene in the presence of hydrogen peroxide, the major product is 1-bromopropane, instead of the usual 2-bromopropane which forms when peroxide is not present.

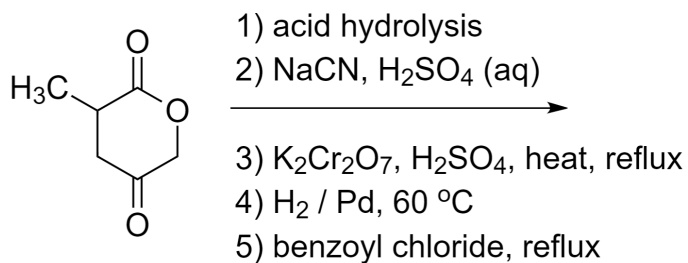
This is due to a different reaction pathway in which free radicals form:



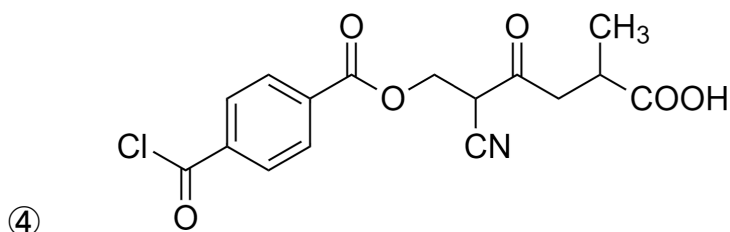
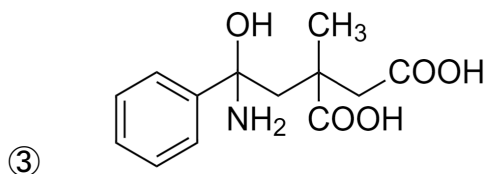
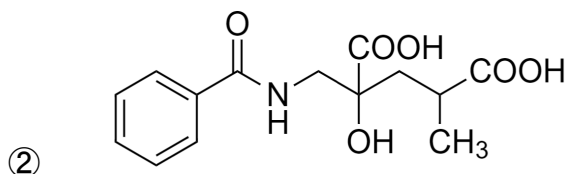
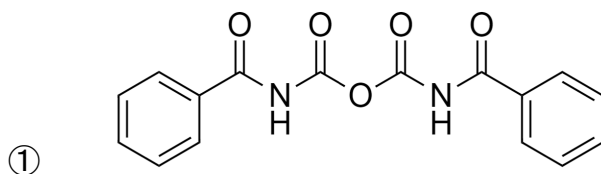
Which of these is true?

- ① In the intermediate species **X**, the unpaired electron lies predominantly on the 2° carbon
- ② 1,3-dibromo-2,3-dimethylbutane could be formed from a termination step
- ③ In the initiation step, the O-O peroxide bond is polarised by the propene
- ④ Hydrogen peroxide disproportionates in the initiation step

- A19.** The compound shown undergoes a series of 5 reactions, as shown in the sequence below. The organic product(s) of each step is/are isolated and used as the reactant(s) in the next step.

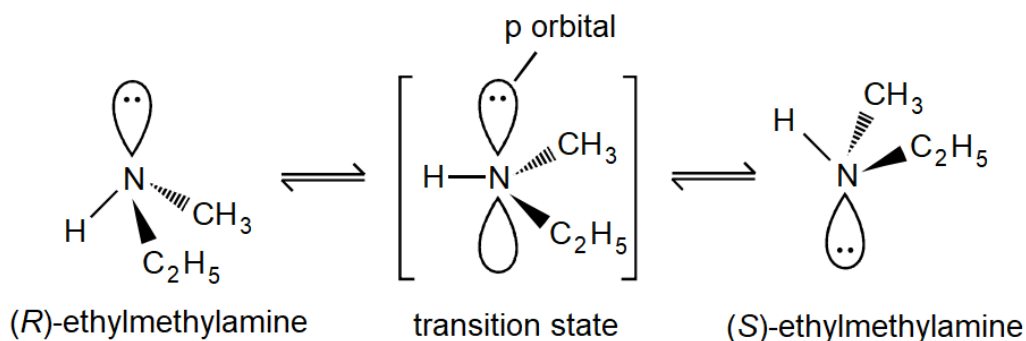


What is the structure of the final major organic product?



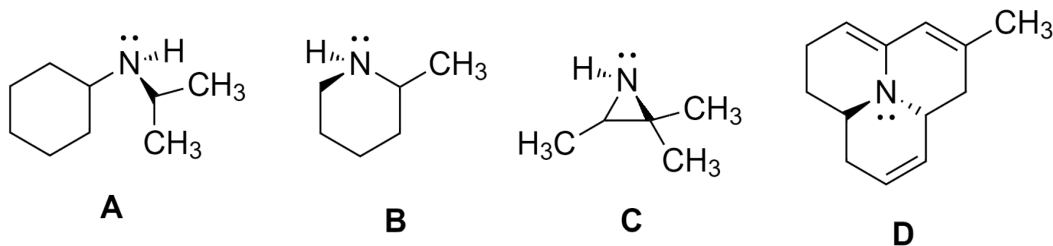
***A20.** Di- and tri-substituted amines where the carbon chains are different are chiral at the nitrogen atom, due to presence of four unique 'substituents'; one of which is the lone electron pair.

In the case of ethylmethanamine, these enantiomers, denoted with the letters *R* and *S*, interconvert extremely rapidly to form racemic mixtures at room temperature via inversion of the pyramidal geometry through a trigonal planar intermediate state:



The rate of interconversion is slowed significantly when the activation energy required to reach the transition state is higher. The enthalpy change between the (*R*) and (*S*) forms in any relevant amine is always zero.

If enantiomerically pure aqueous samples of the following four amines:



were isolated at equal concentrations and temperatures, predict which solutions would remain optically active for the longest period of time (in decreasing order).

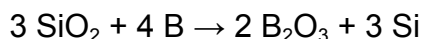
- ① **A > B > C > D**
- ② **A > C > B > D**
- ③ **D > B > C > A**
- ④ **D > C > B > A**

A21. Chlorine reacts with cold, dilute aqueous sodium hydroxide.

Which is a complete list of the products?

- ① sodium chloride, sodium chlorate(I) and water
- ② sodium chlorate(I) and water
- ③ sodium chloride, sodium chlorate(V) and water
- ④ sodium chloride and sodium chlorate(I)

A22. The reducing agent in the reaction



is

- ① silicon dioxide
- ② oxygen
- ③ boron
- ④ boron trioxide

A23. Using your knowledge of physical properties, the **incorrect** statement is

- ① Bi_2O_5 is a more basic oxide than N_2O_5
- ② NF_3 is more covalent than BiF_3
- ③ PH_3 boils at a lower temperature than NH_3
- ④ The N-N σ -bond in N_2H_4 is stronger than the P-P σ -bond in P_2H_4

A24. The oxidation states of the transition metal in the compounds CrO_2F_2 , $\text{K}_2\text{Mn}_2\text{O}_7$ and BaTiO_3 respectively, are

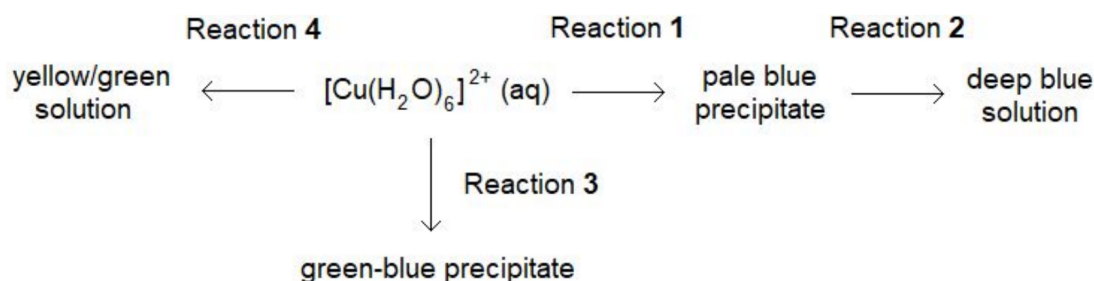
- ① +6, +6, +4
- ② +2, +7, +3
- ③ +4, +5, +4
- ④ +6, +4, +3

- A25.** The percentage of iron in a sample of impure iron(II) sulphate crystals can be determined by titrating solutions, made from separate weighed samples acidified with dilute sulphuric acid, against a standard solution of potassium manganate(VII).

Which one of the following statements explains why dilute hydrochloric acid is unsuitable for use in this titration?

- ① HCl will oxidise Fe^{2+} to Fe^{3+}
- ② Cl^- will reduce Fe^{3+} to Fe^{2+}
- ③ Cl^- will reduce MnO_4^-
- ④ Iron(II) sulfate forms an insoluble complex with Cl^-

- A26.** Consider the following reaction scheme, which starts from $[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ ions.



Which of these statements is true?

- ① The complexes formed from reactions **1**, **2**, **3** and **4** are, respectively: $[\text{Cu}(\text{H}_2\text{O})_4(\text{OH})_2]$, $[\text{Cu}(\text{H}_2\text{O})_2(\text{NH}_3)_4]^{2+}$, CuCO_3 , $[\text{Cu}(\text{H}_2\text{O})_2\text{Cl}_4]^{2-}$.
- ② Reactions **1**, **3** and **4** are carried out with, respectively: excess alkaline NH_3 (aq), Na_2CO_3 , conc. HCl .
- ③ The complexes formed in reactions **2** and **4**, respectively, have octahedral and square planar geometries.
- ④ The complex ion responsible for the deep blue solution in reaction **2** displays cis-trans isomerism.

Section A. Multiple Choice Questions

Inorganic Chemistry

A27. An aqueous solution of the tetrachloridocuprate(II) anion, $[\text{CuCl}_4]^{2-}$, is a different colour to that of only aqueous copper(II) cations. Two possible explanations of this observation are provided.

- A** the d -orbital of Cu^{2+} is split into two sets of orbitals by the Cl^- ligands, allowing electron transitions between the two energy levels, changing the frequencies at which visible photons are absorbed
- B** the energy of the Cu-Cl dative bond is different to that of the Cu- OH_2 dative bond, and the energy difference corresponds to that of the absorbed visible photons

Which row in the table gives these colours, and the correct explanation?

| | colour of Cu^{2+} (aq) | colour of $[\text{CuCl}_4]^{2-}$ (aq) | reason for difference |
|---|---------------------------------|---------------------------------------|-----------------------|
| ① | blue | yellow-green | explanation A |
| ② | blue | yellow-green | explanation B |
| ③ | colourless | deep blue | explanation A |
| ④ | colourless | deep blue | explanation B |

A28. The second ionisation energy of calcium is lower than the second ionisation energy of potassium because

- ① The Ca^{2+} ion has a higher nuclear charge than the K^+ ion
- ② The Ca^+ ion has its valence electron in a higher energy orbital than those of the K^+ ion
- ③ The atomic radius of K^+ is larger than that of Ca^+
- ④ There is mutual electron repulsion in the $3p$ sub-orbitals of the K^+ ion but no such repulsion in the $4s$ orbital of the Ca^+ ion

- A29.** Both oxygen and carbon monoxide bind reversibly to haemoglobin. Assume that only one molecule of either oxygen or carbon monoxide can bind to haemoglobin at any one time. Within the human body, carbon monoxide is 200 times more effective than oxygen in binding to haemoglobin available in human blood. The binding efficiency is the equilibrium constant for this process and you may assume that the system is at equilibrium.

The effects of carboxy-haemoglobin in humans can typically be observed when it reaches 5% of the concentration of oxy-haemoglobin in their blood. Assume that oxygen and carbon monoxide have the same molar solubility in blood.

What is the minimum proportion of carbon monoxide molecules in dry air, expressed as parts per million (ppm), that will result in a 5% ratio of carboxy-haemoglobin molecules to oxy-haemoglobin molecules in blood?

- ① 10 ppm
- ② 52.5 ppm
- ③ 210 ppm
- ④ 1000 ppm

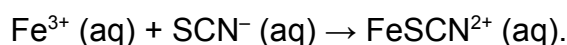
- A30.** In the Haber process, platinum acts as a heterogeneous catalyst for the reaction between ammonia and oxygen. It provides an alternative reaction route with a lower activation energy.

Which of these is **not** a stage in this alternative route?

- ① diffusion of NH_3 and O_2 molecules to the platinum surface
- ② absorption of NH_3 and O_2 molecules into the platinum metal
- ③ weak bond formation between reactants and platinum atoms
- ④ desorption of the products from the platinum surface

B1.

- a. Draw **two** alternative 'dot and cross' diagrams to describe the bonding in the linear thiocyanate anion SCN^- . In one diagram, place the negative charge on the sulfur, and in the other place the negative charge on the nitrogen. [5 marks]
- b. Breakfast cereals frequently have elemental iron added to them as a dietary supplement. A method for making a quantitative measurement of the amount of iron is to use the reaction between $\text{Fe}^{3+}(\text{aq})$ and thiocyanate, $\text{SCN}^-(\text{aq})$, which gives the deep red complex $\text{FeSCN}^{2+}(\text{aq})$:



The depth of the colour can be measured using a spectrophotometer which gives a value for the absorbance proportional to the concentration of the complex:

$$\text{absorbance} = \text{constant} \times [\text{FeSCN}^{2+}]. \quad \text{[Equation 1]}$$

The constant can be found by measuring the absorbance of a solution of known concentration.

- i) The absorbance of a solution of the complex with concentration 2.5×10^{-1} millimoles per litre was measured to be 1.85. Determine the value of the constant in **Equation 1**. [2 marks]

100 g of breakfast cereal was mixed with sufficient dilute acid to dissolve all of the iron. The solution was carefully filtered and mixed with sufficient oxidising agent to convert all of the iron to Fe^{3+} . The solution was made up to a total volume of 250 cm^3 . 10.0 cm^3 of this solution was mixed with 10.0 cm^3 of a solution of thiocyanate; you may assume that all of the iron is converted to the complex. The absorbance of the resulting solution was measured as 0.519.

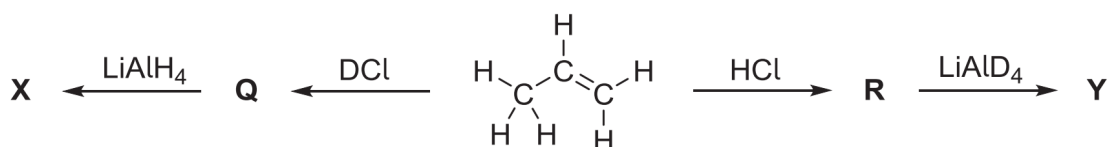
- ii) Using the value of the constant found in (i), calculate the concentration of Fe^{3+} in the solution for which the absorbance was measured. [2 marks]
- iii) Calculate the concentration of Fe^{3+} in the solution prepared from the cereal. [2 marks]
- iv) Hence calculate the mass of iron present in the 100 g of breakfast cereal. [4 marks]

- c. Hydrogen peroxide, H_2O_2 , is used as the oxidising agent to convert Fe^{2+} to Fe^{3+} in the assay described in part b.ii).
- i) Determine the oxidation state of oxygen in H_2O_2 . [2 marks]
- ii) When H_2O_2 acts as an oxidising agent in acidic solution, what is the oxygen-containing species that is produced and what is the oxidation state of oxygen in this species? [4 marks]
- iii) Write a balanced chemical equation describing the oxidation of Fe^{2+} (aq) to Fe^{3+} (aq) by H_2O_2 in acidic solution. [4 marks]

- B2.** When lithium metal and hydrogen gas are heated together, a single substance, **A**, is formed as colourless crystals with a melting point of 688 °C. Molten **A** conducts electricity, and electrolysis of the molten substance re-forms the elements.
- a. i) Give an equation for the formation of **A**. [1 mark]
- ii) Classify the structure of **A** as either molecular covalent, giant covalent, or ionic. Briefly justify your answer. [2 marks]
- b. Substance **A** reacts with aluminium chloride to form lithium aluminium hydride (LiAlH_4) and one other by-product.
- i) Give a balanced chemical equation for the formation of lithium aluminium hydride from **A** and aluminium chloride. [2 marks]
- ii) Give a common use of **A** in synthetic chemistry. [1 mark]
- c. When 3.8 g of lithium aluminium hydride is heated to 125 °C, it decomposes to give three substances: 1.8 g of aluminium metal, 2.4 dm³ of a flammable gas (measured at room temperature and pressure), and substance **B**.
- i) Determine the formula for substance **B**. [5 marks]
- ii) Calculate the density of the flammable gas. [2 marks]

- d. Lithium aluminium deuteride can be prepared if deuterium gas is used in place of normal hydrogen. Deuterium, often given the symbol D, is the non-radioactive isotope of hydrogen, i.e. $D = {}^2\text{H}$. The formula for lithium aluminium deuteride can be written LiAlD_4 . Both LiAlH_4 and LiAlD_4 are common reducing agents and the latter is useful for preparing deuterium-containing compounds.

Isomers of mono-deuterated propane, **X** and **Y**, may be prepared from propene according to the following scheme which also uses hydrogen chloride, HCl , and deuterium chloride, DCl . In the scheme, only the carbon-containing compounds are shown; other by-products are not.



Give the structures of

- the intermediates **Q** and **R** formed during the syntheses [2 marks]
 - the products **X** and **Y**. [2 marks]
- e. 2,2-dideuterated propane may be prepared easily in two steps, from a mono-deuterated propene, **Z**. The formula for **Z** is $\text{C}_3\text{H}_5\text{D}$.
- Draw the structures of all the alkenes with formula $\text{C}_3\text{H}_5\text{D}$. [2 marks]
 - Give a synthesis of 2,2-dideuterated propane starting from **Z** showing reagents and intermediates in each step, making sure to give the displayed formula for **Z**. [3 marks]

B3. Free radicals are highly reactive species, relevant in several types of chemical reaction. They are typically formed when external energy sources are present in a reaction.

a. Identify the energy source and the free radical species formed in each of the following processes:

- i) the thermal cracking of long-chained aliphatic hydrocarbons; [2 marks]
- ii) the action of CFCs on ozone in the upper atmosphere; [2 marks]

b. The extent to which concentration affects its rate is indicated by the order of reaction. For most reactions, the order is a whole number such as 0, 1 or 2. Some reactions can have fractional (non-integer) orders. A fractional order often indicates a chain reaction mechanism such as those involving free radicals.

Consider the thermal decomposition of ethanal at 500 °C in an inert atmosphere into methane and carbon monoxide.

- i) Write down the symbol equation for this reaction. [1 mark]
- ii) Write down the form of the rate equation for this reaction. [1 mark]

The initiation step for the decomposition is the homolytic fission of the C-C bond in ethanal, symbolised as: $\text{CH}_3\text{CHO} \rightarrow \cdot\text{CH}_3 + \cdot\text{CHO}$.

- iii) Draw dot-and-cross structures for the two free radicals formed from the initiation step. [4 marks]
- iv) The first propagation step involves the methyl radical and generates methane as a stable gaseous product.

Write down the equation for this step, and draw the dot-and-cross structure for the other product, showing any unpaired electrons. [3 marks]

- v) Suggest an equation for the second propagation step. [2 marks]

- c. The kinetics of the thermal decomposition described in part b) can be analysed by making the following assumptions:

- (1) the rates of formation and destruction of methyl radicals are equal
- (2) any reaction of the $\bullet\text{CHO}$ radical is ignored
- (3) the only major termination step forms ethene: $2 \bullet\text{CH}_3 \rightarrow \text{C}_2\text{H}_6$

It is also assumed that, for each step of the reaction, the reaction occurs in a single step, with no further intermediates. This allows us to assume that the order of reaction with respect to a particular species is **equal** to its stoichiometric coefficient.

- i) Using assumption (1), show that

$$k_i [\text{CH}_3\text{CHO}] - k_t [\bullet\text{CH}_3]^2 = 0,$$

where k_i and k_t are the rate constants for the initiation and termination steps respectively.

[4 marks]

- ii) Show that this implies that $[\bullet\text{CH}_3]$ is proportional to $[\text{CH}_3\text{CHO}]^{1/2}$.

[2 marks]

- iii) By considering the rate of formation of methane, show that the overall order of the reaction is $\frac{3}{2}$.

[4 marks]

Section B. Physical Chemistry

B4. Aqueous solutions of carboxylate salts can undergo electrolysis. In an experiment, small pieces of freshly-cut sodium metal were placed into a flask of aqueous pentanoic acid, and the excess acid was neutralised to give an aqueous solution of sodium pentanoate. Inert graphite electrodes were inserted into the solution and a voltage source was connected between them.

a. When the voltage source was turned on, the following observations were made:

- Effervescence at steady rates was seen from both electrodes. When the gas from the anode was bubbled through a saturated calcium hydroxide solution, a white precipitate formed, while the gas from the cathode gave no visible change. When the gas from the cathode was collected and exposed to a lighted splint, a squeaky pop was heard.
- A layer of immiscible, colourless liquid emerged from the anode, which then floated to the top of the solution. This layer had a gasoline-like smell, and when collected, burned easily when touched with a lit splint.
- The pH of the solution was measured to increase as the reaction continued.

i) Identify all products formed during the reaction, giving half-equations for each electrode, and the overall balanced equation. [7 marks]

ii) Suggest and outline how free radicals are involved in the mechanism of the anode reaction. [4 marks]

b. The initial mass of sodium added was 250 mg, and the 50 ml of pentanoic acid used had a concentration of 2.5 mol dm^{-3} , with a dissociation constant $K_a = 1.51 \times 10^{-5} \text{ mol dm}^{-3}$.

i) Calculate the concentration of the sodium pentanoate. [4 marks]

A steady electric current of 1.2 A was registered on an ammeter connected in series between the electrodes. The charge of a single electron is $1.61 \times 10^{-19} \text{ C}$.

ii) Calculate the rate of formation of the immiscible liquid layer at the anode, given that its density is 703 kg m^{-3} .

Give your answer in millilitres per second. [5 marks]

Section C. Organic Chemistry

C1. There are six isomers with the formula C_5H_{10} that are alkenes. The alkenes all have different enthalpies of formation, all of which are negative.

a. Using skeletal formulae, draw the structures of the six alkenes. [6 marks]

b. Samples of the six alkenes, in a random order, are labelled **P**, **Q**, **R**, **S**, **T**, and **U**.

Alkenes **P**, **Q**, and **R** react with hydrogen gas and a metal catalyst to give the same alkane **A**; alkenes **S**, **T**, and **U** react under the same conditions to give a different alkane **B**. Both alkanes **A** and **B** react with chlorine gas under UV light to form chloroalkanes with the formula $C_5H_{11}Cl$. Under such conditions, alkane **A** forms four different structural isomers, whereas **B** gives three.

i) Draw the skeletal structures of alkanes **A** and **B**. [2 marks]

ii) Draw the skeletal structures of the four isomers arising from the chlorination of **A**, and the three isomers arising from the chlorination of **B**. [4 marks]

c. The alkenes react with HBr to form bromoalkanes with the formula $C_5H_{11}Br$; the reaction proceeds via a carbocation intermediate. Alkenes **S** and **T** give a mix of two structural isomers, whereas alkene **U** gives only one.

Give the displayed formula of alkene **U**. [4 marks]

*d. Out of **P**, **Q** and **R**, **R** has the most negative (most exothermic) enthalpy of formation.

i) Give the displayed formula of **R**. [1 mark]

ii) Some standard enthalpy change data are given as follows.

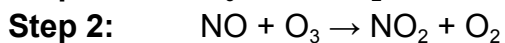
Hydrogenation of **P** = -113 kJ mol^{-1} ; Hydrogenation of **Q** = -119 kJ mol^{-1} ;
Combustion of **A** = $-3528 \text{ kJ mol}^{-1}$; Formation of $H_2O(l)$ = -286 kJ mol^{-1} .

Use the data to deduce the structures of alkenes **P** and **Q**. [4 marks]

iii) Calculate the standard enthalpy change of combustion of alkene **P**. [4 marks]

- C2.** Tetrachloromethane (CCl_4) is an effective fire extinguisher but it is no longer used because of its toxicity and its role in the depletion of the ozone layer. In the upper atmosphere, a bond in CCl_4 breaks and reactive species are formed.
- a. Identify the condition that causes a bond in CCl_4 to break in the upper atmosphere and deduce an equation for the formation of the reactive species.
[2 marks]
- b. One of the reactive species formed from CCl_4 acts as a catalyst in the decomposition of ozone.
- i) Write two equations to show how this species acts as a catalyst.
[2 marks]
- ii) Write down the overall equation for the decomposition of ozone.
[1 mark]
- c. A small amount of the freon CF_3Cl with a mass of 1.78×10^{-4} kg escaped from a refrigerator, into a room of volume 100 m^3 . Assuming that the freon is evenly distributed throughout the air in the room, calculate the number of freon molecules in a volume of 500 cm^3 .
[4 marks]
- d. The refrigerant R410A, used in air conditioners, is a mixture of two fluoroalkanes, pentafluoroethane and difluoromethane. The mechanism for the reaction of fluorine with either an alkane or a fluoroalkane is similar to that for the reaction of chlorine with methane.
- i) Name the type of mechanism for the reaction of chlorine with methane.
[1 mark]
- ii) Write equations for the initiation, propagation and termination steps in the mechanism for the reaction of fluorine with fluoromethane to form difluoromethane. In the termination step, form 1,2-difluoroethane.
[4 marks]
- iii) Write an overall equation for the reaction of fluorine with ethane to form pentafluoroethane by this mechanism.
[1 mark]

- e. Nitrogen monoxide (NO) also catalyses the decomposition of ozone into oxygen. The sequence of reactions that occur when nitrogen monoxide catalyses the decomposition of ozone is shown.



Step 3:

Complete **Step 3** in the above mechanism.

[1 mark]

- f. Bromine atoms have a similar role to chlorine atoms in the decomposition of ozone. Suggest and explain which of CClF_3 or CBrF_3 , if released into the upper atmosphere, would form free halogen atoms more readily.

[2 marks]

Section C. Organic Chemistry

C3.

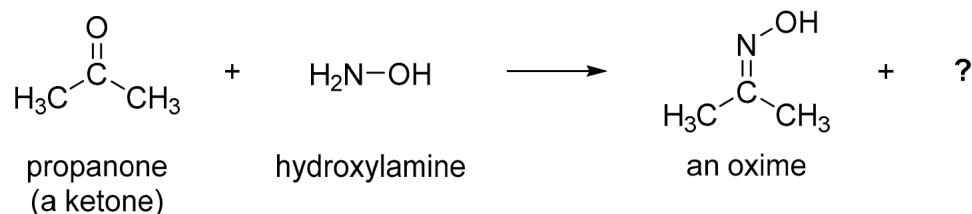
C4. Some alkenes can undergo dimerisation reactions at room temperature.

- a. State what is meant by the term *dimerisation*. [2 marks]
- b. 2-methylpropene dimerises in the presence of concentrated sulfuric acid catalyst to form two products, one of which is **X**, named 2,4,4-trimethylpent-1-ene.
- i) Name the mechanism for the reaction of 2-methylpropene with concentrated sulfuric acid. [1 mark]
- ii) Suggest and outline a mechanism for this dimerisation to form this particular product **X**.
- In each step, explain your reasoning to justify why each step might occur. [8 marks]
- iii) Name the other dimer **Y** that could form as a product of this reaction. [1 mark]
- iv) State the type of isomerism exhibited by **X** and **Y**. [1 mark]
- v) When **X** and **Y** are hydrogenated in the presence of a nickel catalyst at 150 °C, the same product **Z** is formed in each case.

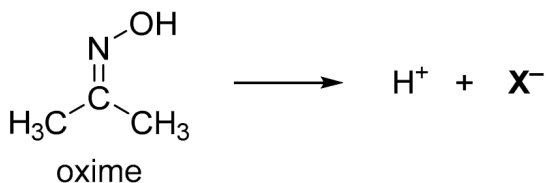
Draw the skeletal formula of **Z** and give a common use of this compound. [2 marks]

Section C. Organic Chemistry

C3. Ketones react with hydroxylamine, NH_2OH , to give oximes. An example of such a reaction involving the ketone propanone is shown below:

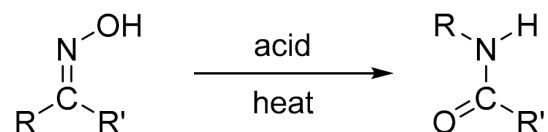


- a.
- i) In addition to the oxime, this reaction produces a second product. Suggest what this molecule might be. [1 mark]
 - ii) Draw the structure of the oxime that you would expect to be formed from the reaction of cyclohexanone with hydroxylamine. [2 marks]
 - iii) Oximes are weakly acidic. For the oxime below, explain which hydrogen atom will be the most acidic and draw the structure of the resulting anion X^- .



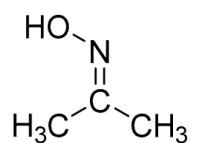
[3 marks]

- b. Under acidic conditions, oximes undergo the following rearrangement reaction (note carefully that there are two different groups R and R').



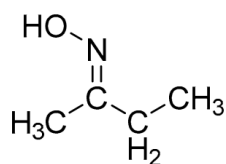
Give the analogous structures into which each of the following oximes rearrange under the same conditions.

i)



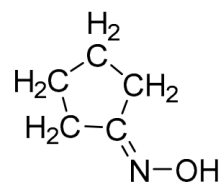
[1 mark]

ii)



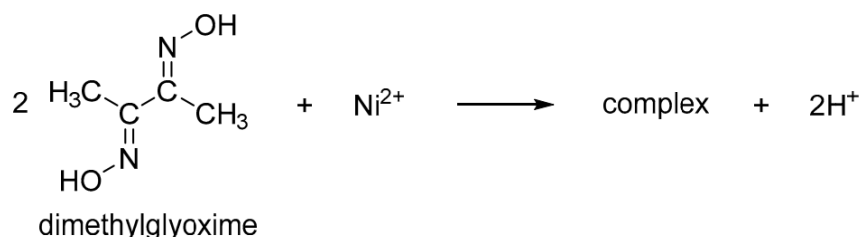
[1 mark]

iii)



[2 marks]

- c. Dimethylglyoxime reacts with Ni^{2+} ions in aqueous solution under mildly basic conditions to give a complex which is an insoluble red precipitate. The reaction involves two molecules of dimethylglyoxime and also results in the production of two H^+ ions, as shown in the balanced equation below.



Determine the **molecular formula** of the complex and state its relative molecular mass.

[4 marks]

- d. The reaction between dimethylglyoxime and Ni^{2+} ions can be used to determine the nickel content of alloys by weighing the amount of the red precipitate produced from a known mass of a sample of an alloy.

A sample of mass 1.50 g of an alloy was dissolved in dilute acid and an excess of dimethylglyoxime was then added to the resulting solution. The pH was then adjusted to make the solution mildly alkaline, and this resulted in the formation of a red precipitate. The precipitate was carefully filtered off, dried and then weighed. The mass of the dry precipitate was 0.368 g.

Determine the nickel content of the alloy, expressed as a percentage by mass.

[4 marks]

- e. Other metal ions, such as Pd^{2+} or Pt^{2+} , also react with dimethylglyoxime to give insoluble precipitates.

What effect would the presence of palladium in the alloy have on the value of the nickel content determined using the method in part d)?

[2 marks]

Section D. Inorganic Chemistry

D1. This question concerns the chemistry of tellurium, an element in Group 6 of the Periodic Table.

- a.
- i) Predict the maximum and minimum oxidation states of tellurium. Briefly explain your answer. [3 marks]
 - ii) How do the electronegativities of the elements vary on descending Group 6? [1 mark]
 - iii) Which hydride, H_2O or H_2Te , has the higher boiling point? Briefly explain your answer. [2 marks]
- b. Tellurium reacts directly with fluorine gas to form a dense gas, **A**, in which each molecule contains a single tellurium atom bonded to several fluorine atoms. In an experiment, 50 cm^3 of gas **A** is formed from 150 cm^3 of fluorine and a certain mass of tellurium, measured at room temperature and pressure (rtp).
- i) Calculate the formula of the gas **A**. [2 marks]
 - ii) Predict the value(s) of the F–Te–F bond angles in **A**. [1 mark]
 - iii) Calculate the minimum mass of tellurium needed to produce 50 cm^3 of **A**. [2 marks]
 - iv) Calculate the density of gas **A** in g cm^{-3} at rtp. [2 marks]
 - v) Calculate how many times denser gas **A** is than oxygen gas at rtp. [1 mark]

Section D. Inorganic Chemistry

- c. In another experiment, 5.0 g of tellurium is oxidised and dissolved in water to form 9.0 g of an acid with general formula H_mTeO_n . On neutralisation with aqueous KOH, 18 g of a salt is formed with general formula K_mTeO_n .
- i) Give an expression, in terms of m and n , for the oxidation state of the tellurium in the acid H_mTeO_n . [1 mark]
 - ii) Calculate the relative molecular mass of the acid H_mTeO_n . [1 mark]
 - iii) Calculate the values of m and n , and hence the formulae of the acid H_mTeO_n and the salt formed on neutralisation. [2 marks]
 - iv) Calculate the volume of a 2.0 mol dm^{-3} aqueous solution of KOH that would be needed to neutralise the 9.0 g of acid formed from 5.0 g of tellurium. [2 marks]