

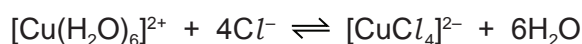
Answer **all** the questions in the spaces provided.

1 Copper is a transition element and has atomic number 29.

(a) Complete the electronic configuration for the copper atom and the copper ion in the +2 oxidation state.

- copper atom [Ar]
- copper ion in the +2 oxidation state [Ar] [2]

(b) The following equilibrium exists between two complex ions of copper in the +2 oxidation state.



(i) Name the *type of reaction* occurring here.

..... [1]

(ii) State the colours of these two complex ions.

$[\text{Cu}(\text{H}_2\text{O})_6]^{2+}$ $[\text{CuCl}_4]^{2-}$ [1]

(iii) State the shape of the $[\text{CuCl}_4]^{2-}$ ion.

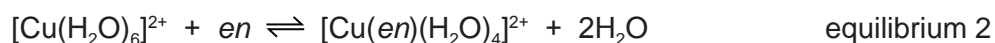
..... [1]

(iv) Write the expression for the stability constant, K_{stab} , for this equilibrium.

$$K_{\text{stab}} =$$

[1]

(c) Copper also forms the complex ions $[\text{Cu}(\text{NH}_3)_2(\text{H}_2\text{O})_4]^{2+}$ and $[\text{Cu}(\text{en})(\text{H}_2\text{O})_4]^{2+}$ where *en* is the bidentate ligand ethane-1,2-diamine, $\text{H}_2\text{NCH}_2\text{CH}_2\text{NH}_2$.



(i) What is meant by the term *bidentate ligand*?

.....
 [2]

3

- (ii) The table lists the values of stability constants for these two complexes.

	stability constant, K_{stab}
$[\text{Cu}(\text{NH}_3)_2(\text{H}_2\text{O})_4]^{2+}$	7.94×10^7
$[\text{Cu}(\text{en})(\text{H}_2\text{O})_4]^{2+}$	3.98×10^{10}

What do these K_{stab} values tell us about the relative positions of equilibria 1 and 2?

.....
 [1]

- (d) Nickel forms the complex ion $[\text{Ni}(\text{en})_3]^{2+}$ in which it is surrounded octahedrally by six nitrogen atoms.

- (i) Name the type of stereoisomerism displayed by $[\text{Ni}(\text{en})_3]^{2+}$.

..... [1]

- (ii) Draw three-dimensional diagrams to show the **two** stereoisomers of $[\text{Ni}(\text{en})_3]^{2+}$.

[3]

- (e) Ethane-1,2-diamine is a useful reagent in organic chemistry.

- (i) Explain how the amino groups in ethane-1,2-diamine allow the molecule to act as a Brønsted-Lowry base.

.....
 [2]

- (ii) Write an equation for the reaction of ethane-1,2-diamine with an excess of hydrochloric acid.

..... [1]

4

- (f) (i) Under certain conditions, ethane-1,2-diamine reacts with ethanedioic acid, $\text{HO}_2\text{CCO}_2\text{H}$, to form the polymer **Z**.

Draw the structure of this polymer, **Z**, showing **two** repeat units.

[2]

- (ii) Name the *type of reaction* occurring during this polymerisation.

..... [1]

- (iii) Polymer **Z** is an example of a biodegradable polymer.

Name a polymer that is non-biodegradable.

..... [1]

[Total: 20]

- 2 (a) When copper(II) carbonate is heated strongly, it decomposes in a similar way to Group 2 carbonates.

Predict what would be observed when anhydrous copper(II) carbonate is heated.

.....
 [1]

- (b) Describe and explain how the thermal stability of the Group 2 carbonates varies down the group.

.....

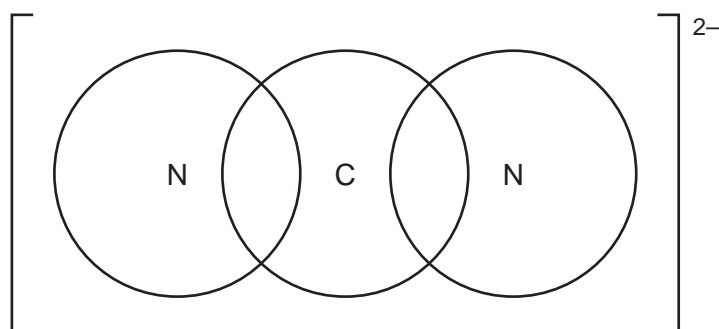
 [3]

- (c) Calcium cyanamide, CaCN_2 , can be used as a fertiliser.

- (i) Complete the 'dot-and-cross' diagram for the cyanamide ion, CN_2^{2-} .

Use the following key for the electrons.

- electrons from carbon
- × electrons from nitrogen
- added electron(s) responsible for the overall negative charge



[2]

- (ii) CaCN_2 decomposes readily on contact with water forming an insoluble white solid and ammonia only.

Suggest an equation for this reaction.

..... [2]

[Total: 8]

- 3 The spontaneity (feasibility) of a chemical reaction depends on the standard Gibbs free energy change, ΔG° . This is related to the standard enthalpy and entropy changes by the equation shown.

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

- (a) State and explain whether the following processes will lead to an increase or decrease in entropy.

- (i) the reaction of magnesium with hydrochloric acid

entropy change

explanation

[1]

- (ii) solid potassium chloride dissolving in water

entropy change

explanation

[1]

- (iii) steam condensing to water

entropy change

explanation

[1]

- (b) Magnesium carbonate can be decomposed.



Standard entropies are shown in the table.

substance	MgCO ₃ (s)	MgO(s)	CO ₂ (g)
S°/J mol ⁻¹ K ⁻¹	+65.7	+26.9	+214

- (i) Calculate ΔG° for this reaction at 298 K.
Include a relevant sign and give your answer to **three** significant figures.

$\Delta G^\circ = \dots\dots\dots \text{ kJ mol}^{-1}$ [3]

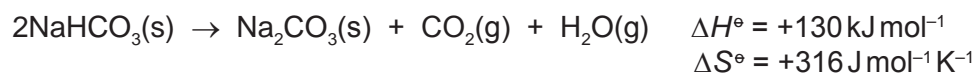
- (ii) Explain, with reference to ΔG° , why this reaction becomes more feasible at higher temperatures.

.....

..... [1]

7

(c) On heating, sodium hydrogencarbonate decomposes into sodium carbonate as shown.



Calculate the **minimum** temperature at which this reaction becomes spontaneous (feasible).
Show your working.

temperature = K [2]

(d) The solubility of Group 2 sulfates decreases down the Group.

Explain this trend.

.....

 [2]

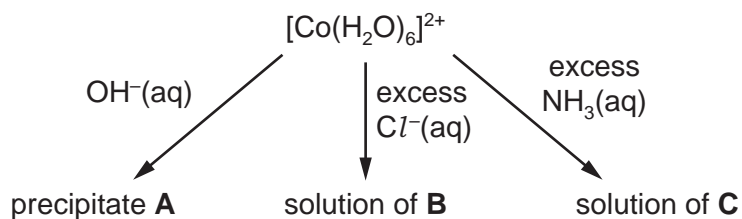
[Total: 11]

- 4 (a) Cobalt is a transition element that forms complex ions with oxidation states +2 and +3.

Explain what is meant by the term *transition element*.

.....
 [1]

- (b) The following scheme shows some reactions of $[\text{Co}(\text{H}_2\text{O})_6]^{2+}$.



- (i) State the formula of each of the following.

A

B

C

[2]

- (ii) State the colour of the following solutions.

$[\text{Co}(\text{H}_2\text{O})_6]^{2+}$

solution of **B**

solution of **C**

[2]

- (c) Define the term *standard electrode potential*.

.....

 [2]

- (d) An electrochemical cell was set up to measure the standard electrode potential, $E_{\text{cell}}^{\ominus}$, of a cell made of a Co^{2+}/Co half-cell and a $\text{Fe}^{3+}/\text{Fe}^{2+}$ half-cell.
- (i) Complete the table with the substance used to make the electrode in each of these half-cells.

half-cell	electrode
Co^{2+}/Co	
$\text{Fe}^{3+}/\text{Fe}^{2+}$	

[1]

- (ii) Write the equation for the overall cell reaction.

..... [1]

- (iii) Use the *Data Booklet* to calculate the $E_{\text{cell}}^{\ominus}$.

$$E_{\text{cell}}^{\ominus} = \dots\dots\dots \text{V} \quad [1]$$

- (e) The electrochemical cell in (d) was set up again but this time the concentration of $\text{Co}^{2+}(\text{aq})$ was $0.050 \text{ mol dm}^{-3}$.

The Nernst equation can be used to calculate the value of an electrode potential at different concentrations.

$$E = E^{\ominus} + (0.059/z) \log [\text{Co}^{2+}(\text{aq})] \quad \text{Nernst equation}$$

- (i) Use the *Data Booklet* and the Nernst equation to calculate the value of E for the Co^{2+}/Co half-cell in this experiment.

$$E \text{ for } \text{Co}^{2+}/\text{Co} = \dots\dots\dots \text{V} \quad [1]$$

- (ii) Suggest how this change will affect the overall cell potential, E_{cell} , compared to $E_{\text{cell}}^{\ominus}$ in (d)(iii).

Circle your answer.

less positive no change more positive

[1]

- (f) Iron(III) ions can oxidise vanadium metal.

Construct an equation for the reaction of an excess of iron(III) ions with vanadium metal. Use of the *Data Booklet* will be helpful.

..... [2]

[Total: 14]

- 5 Compound **F** contains the elements carbon, hydrogen and oxygen only. All carbon-carbon bonds in **F** are single bonds. The structure of **F** was analysed by mass spectrometry and infra-red and NMR spectroscopy.

- (a) The mass spectrum shows that the m/e value for the M peak is 90.

The ratio of the heights of the M and M+1 peaks is 22.1 : 0.7.

- (i) Use the ratio of the heights of the M and M+1 peaks to calculate the number of carbon atoms in a molecule of **F**.

number of carbon atoms = [2]

- (ii) Suggest the molecular formula of **F**.

molecular formula = C H O [1]

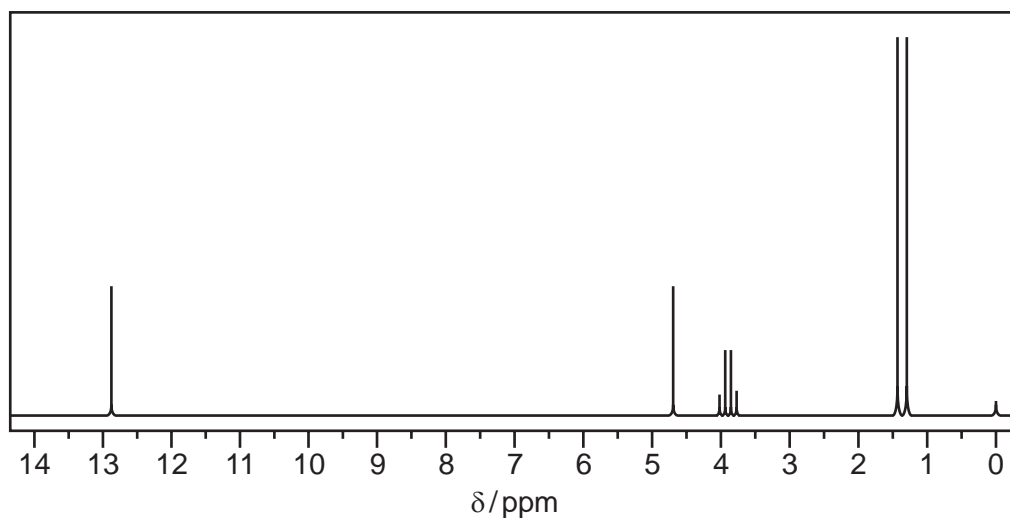
- (b) The infra-red spectrum of **F** was obtained.

Use the *Data Booklet* and your knowledge of infra-red spectroscopy to identify the type of bond and the functional group responsible for these **three** absorptions.

absorption/cm ⁻¹	appearance of the peak	type of bond	functional group
3350	broad and strong		
2680	very broad and strong		
1725	strong		

[2]

- (c) **F** was dissolved in deuterated trichloromethane, CDCl_3 , and the proton NMR spectrum of this solution obtained.



- (i) Use the *Data Booklet* and your answer to (a)(ii) to complete Table 1 for the proton NMR spectrum of **F**.
The actual chemical shifts for the four absorptions in **F** have been added for you.

Table 1

δ/ppm	type of proton	relative peak area
1.4		
3.9		
4.7		
12.9		

[4]

- (ii) Describe and explain the splitting pattern for the absorption at $\delta = 1.4$.

.....
 [1]

- (iii) **F** was dissolved in D_2O and the proton NMR spectrum of this new solution obtained. Two of the absorptions in Table 1 were not present in this spectrum.

Which absorptions were **not** present?

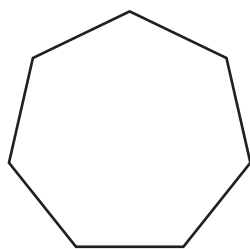
..... and [1]

- (iv) Suggest the structure of **F**.

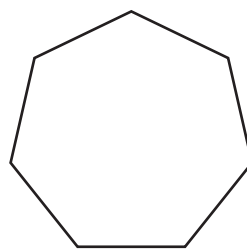
[1]

(d) Molecules of cycloheptadiene, C_7H_{10} , consist of a seven-membered ring with two carbon-carbon double bonds.

(i) Complete the skeletal formulae of two isomers of cycloheptadiene.



P



Q

[1]

The isomers **P** and **Q** were analysed using carbon-13 NMR spectroscopy.

(ii) Predict the number of peaks that will be seen in the carbon-13 NMR spectra of **P** and **Q**.

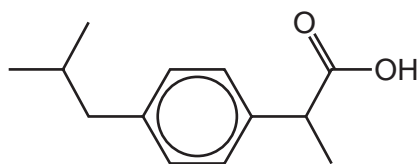
isomer	number of peaks
P	
Q	

[2]

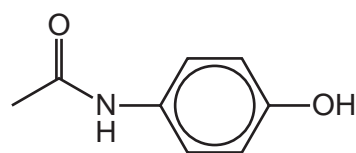
[Total: 15]

Question 6 starts on the next page.

6 Ibuprofen and paracetamol are pain-relief drugs.



ibuprofen



paracetamol

(a) Ibuprofen and paracetamol both contain the aryl (benzene) functional group.

Name the **other** functional groups present in each molecule.

ibuprofen

paracetamol

[2]

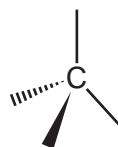
(b) Ibuprofen contains a chiral centre and shows stereoisomerism.

(i) State what is meant by the term *chiral centre*.

.....

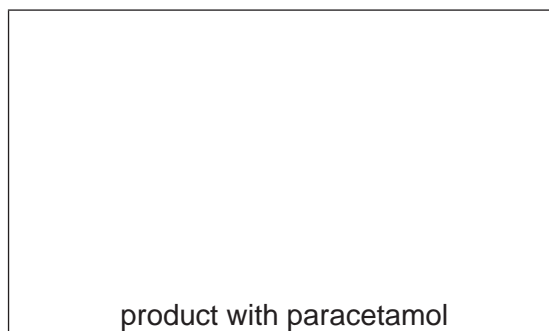
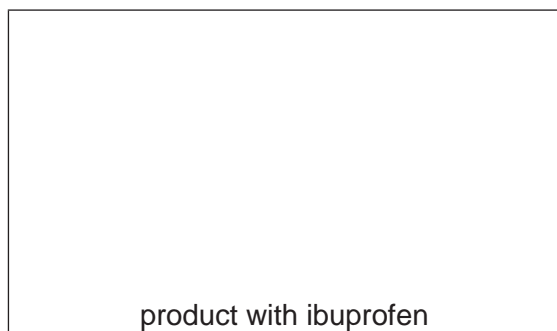
..... [1]

(ii) Draw the two stereoisomers of ibuprofen.



[2]

- (c) Draw the structures of the organic products when ibuprofen and paracetamol react separately with LiAlH_4 .



[2]

- (d) A student carried out some reactions with solutions of ibuprofen and paracetamol using reagents **D** and **E** and the following results were obtained. (\checkmark means a reaction took place.)

reagent	ibuprofen	paracetamol
D	\checkmark	\times
E	\times	\checkmark

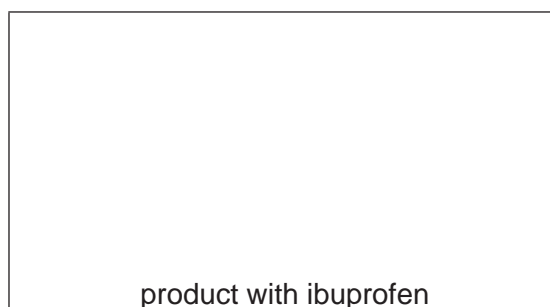
- (i) Suggest a possible identity for each reagent **D** and **E**.

D

E

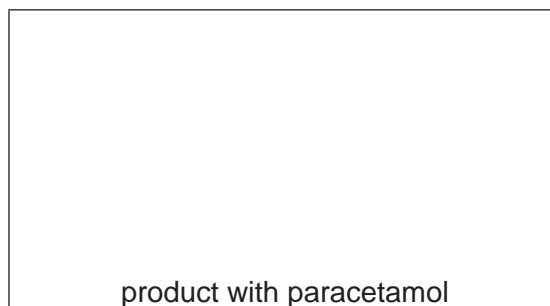
[2]

- (ii) Give the structure of the organic product formed when reagent **D** reacted with ibuprofen.



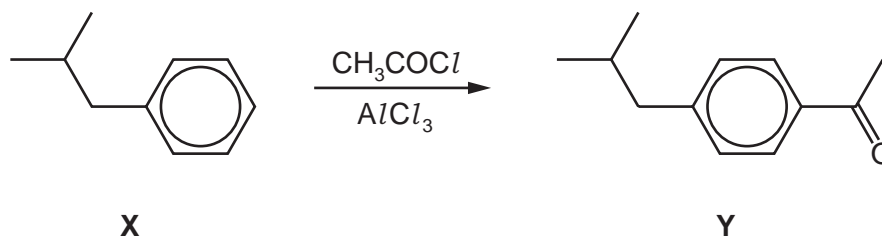
[1]

- (iii) Give the structure of the organic product formed when reagent **E** reacted with paracetamol.



[1]

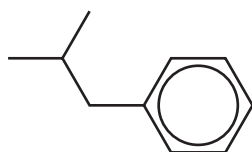
(e) One of the steps in the manufacture of ibuprofen is shown.



(i) Write an equation for the reaction between CH_3COCl and AlCl_3 .

..... [1]

(ii) Complete the mechanism for the conversion of **X** into **Y**. Include all necessary curly arrows, any relevant dipoles and charges.



X

[3]

(iii) Name the mechanism in (ii).

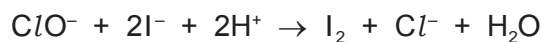
..... [1]

[Total: 16]

Question 7 starts on the next page.

- 7 (a) Sodium chlorate(I), NaClO , is the active ingredient in commercial bleach. The concentration of chlorate(I) ions was determined by titration.
- 10.0 cm³ of a bleach solution was diluted to 250 cm³ in a volumetric flask using distilled water.
 - Dilute sulfuric acid and an excess of potassium iodide solution were added to a 25.0 cm³ portion of this solution to liberate iodine.
 - The resulting solution required 20.80 cm³ of 0.100 mol dm⁻³ aqueous sodium thiosulfate solution to react with the iodine produced.

The titration reactions are shown.



Calculate the concentration, in mol dm⁻³, of ClO^- ions in the bleach solution.

concentration of ClO^- = mol dm⁻³ [3]

(b) An indicator was used in the thiosulfate-iodine titration.

(i) Name a suitable indicator for this titration.

..... [1]

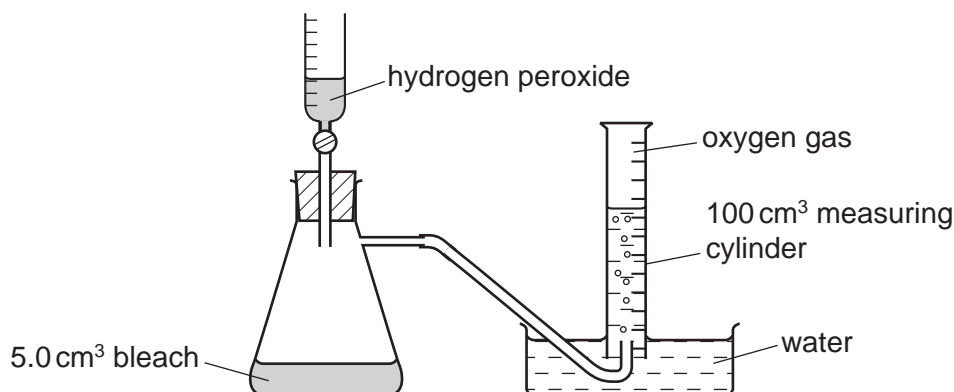
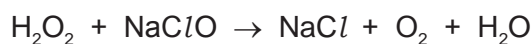
(ii) State the expected colour change you would observe at the end-point in this titration.

from to [1]

(iii) State when in the procedure you would add the indicator.

.....
 [1]

- (c) The concentration of chlorate(I) ions can also be determined by adding an excess of hydrogen peroxide to the sample of bleach and measuring the volume of oxygen gas produced.

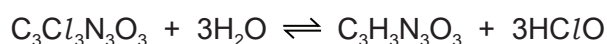


When an excess of aqueous hydrogen peroxide was added to 5.0 cm³ of a different bleach solution, 82 cm³ of oxygen was produced at room temperature and pressure.

Calculate the concentration of ClO^- ions in this bleach solution.

concentration of ClO^- = mol dm⁻³ [2]

- (d) Trichlorocyanuric acid, $\text{C}_3\text{Cl}_3\text{N}_3\text{O}_3$, acts as a chlorine buffer and disinfectant for swimming pools. It reacts with water to give chloric(I) acid, HClO .



- (i) Write the expression for K_c for this equilibrium.

$K_c =$

[1]

- (ii) In outdoor swimming pools, the HClO is decomposed by sunlight. The decomposition of HClO is a redox reaction which forms a gas that relights a glowing splint.

Describe and explain the effect of the decomposition of HClO on the equilibrium in (d). State the effect on K_c .

.....

effect on K_c

[2]

- (iii) The decomposition of HClO is a redox reaction.

Suggest an equation for this reaction.

..... [1]

- (e) The buffer solution in blood is a mixture of carbonic acid, H_2CO_3 , and hydrogencarbonate ions, HCO_3^- . Healthy blood has a pH of 7.40.



- (i) Explain how this buffer system acts to control the blood pH. Include equations in your answer.

.....

 [2]

- (ii) A patient's blood has a $[\text{HCO}_3^-]:[\text{H}_2\text{CO}_3]$ ratio of 9.5:1.

Calculate the pH of the patient's blood.

pH = [2]

[Total: 16]

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