1 Sulfuric acid is made from sulfur, oxygen and water in a three-stage process.
This can be represented by the following overall equation.

$$2S(s) + 3O_2(g) + 2H_2O(l) \rightarrow 2H_2SO_4(l)$$

(a) Explain why the overall process to make sulfuric acid has an atom economy of 100%.

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..... **[1]**

(b) A factory uses 51.4 tonnes of sulfur to manufacture 147 tonnes of H_2SO_4.

What is the percentage yield of H_2SO_4?

Give your answer to **two** significant figures. (1 tonne = 1×10^6 g)

percentage yield = ... % **[3]**

(c) One of the reactions involved in making sulfuric acid converts sulfur dioxide, SO_2, into sulfur trioxide, SO_3.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -197 \text{ kJ mol}^{-1}$$

This reaction can be carried out at 450 °C and 3 atmospheres pressure in the presence of a V_2O_5 catalyst.

Under these conditions the position of equilibrium is almost completely on the right-hand side.

(i) A research chemist investigates this reaction.
He uses a temperature of 450 °C and 3 atmospheres pressure.
The research chemist does **not** use the catalyst.

Predict the changes, if any, on each of the following.

position of equilibrium .....

rate of backward reaction ..... **[2]**

(ii) The temperature of the reaction mixture is **increased** to 600 °C.

State and explain what will happen to the position of equilibrium.

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..... **[1]**

(iii) The pressure of the reaction mixture is **decreased** to 2 atmospheres.

State and explain what will happen to the position of equilibrium.

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..... **[1]**

(d) Concentrated H_2SO_4 is used as an acid catalyst in the elimination of water from alcohols.

There are several alcohols that are structural isomers with the formula $C_5H_{11}OH$. When these alcohols are heated with H_2SO_4 they form alkenes.

$$C_5H_{11}OH \rightarrow C_5H_{10} + H_2O$$

(i) Pentan-1-ol is a structural isomer of $C_5H_{11}OH$ that is a primary alcohol.

Draw the structure of another structural isomer of $C_5H_{11}OH$ that is a primary alcohol.

[1]

(ii) Pentan-2-ol is a structural isomer of $C_5H_{11}OH$ that is a secondary alcohol.
Pentan-2-ol is heated with H_2SO_4.

Three alkenes are formed, **L**, **M** and **N**.

- **L** and **M** are stereoisomers.
- **N** is a structural isomer of the stereoisomers **L** and **M**.

Draw the structures for alkenes **L**, **M** and **N**.

alkene **L**

alkene **M**

alkene **N**

[3]

(iii) One structural isomer of $C_5H_{11}OH$ is an alcohol that **cannot** be oxidised by heating with acidified potassium dichromate(VI).

Draw the structure of this alcohol.

[1]

[Total: 13]

2 Catalysts speed up the rate of a reaction without being consumed by the overall reaction.

(a) Chlorine radicals in the stratosphere act as a catalyst for ozone depletion.

(i) Research chemists have proposed possible reaction mechanisms for ozone depletion. The equations below represent part of such a mechanism.

Complete the equations.

$Cl + O_3 \longrightarrow$ …… + ……

ClO + …… $\longrightarrow$ …… + O_2 **[2]**

(ii) Write an equation for the overall reaction in **(i)**.

..... **[1]**

(b) One of the catalysed reactions that takes place in a catalytic converter is shown below.

$$2CO(g) + 2NO(g) \longrightarrow N_2(g) + 2CO_2(g)$$

The catalyst used is platinum/rhodium attached to a ceramic surface.

Outline the stages that take place in a catalytic converter to allow CO to react with NO.

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..... **[4]**

(c) Explain, using an enthalpy profile diagram and a Boltzmann distribution, how the presence of a catalyst increases the rate of reaction.

In your answer you should organise your answer and use the correct technical terms.

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.... **[7]**

(d) Explain why many industrial manufacturing processes use catalysts.

Include in your answer ideas about sustainability, economics and pollution control.

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..... **[4]**

[Total: 18]

3 Dilute aqueous hydrogen peroxide, $H_2O_2(aq)$, is used to sterilise contact lenses.

(a) Dilute $H_2O_2(aq)$ slowly decomposes at room temperature to produce oxygen and water.

The decomposition of $H_2O_2(aq)$ can be made faster by:

- increasing the concentration of the $H_2O_2(aq)$,
- adding a small amount of manganese(IV) oxide catalyst,
- heating the solution to 60 °C.

(i) Construct the equation for the decomposition of H_2O_2.

..... **[1]**

(ii) Explain why increasing the concentration of $H_2O_2(aq)$ increases the rate of decomposition.

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..... **[2]**

(iii) Explain how the catalyst can increase the rate of decomposition of $H_2O_2(aq)$.

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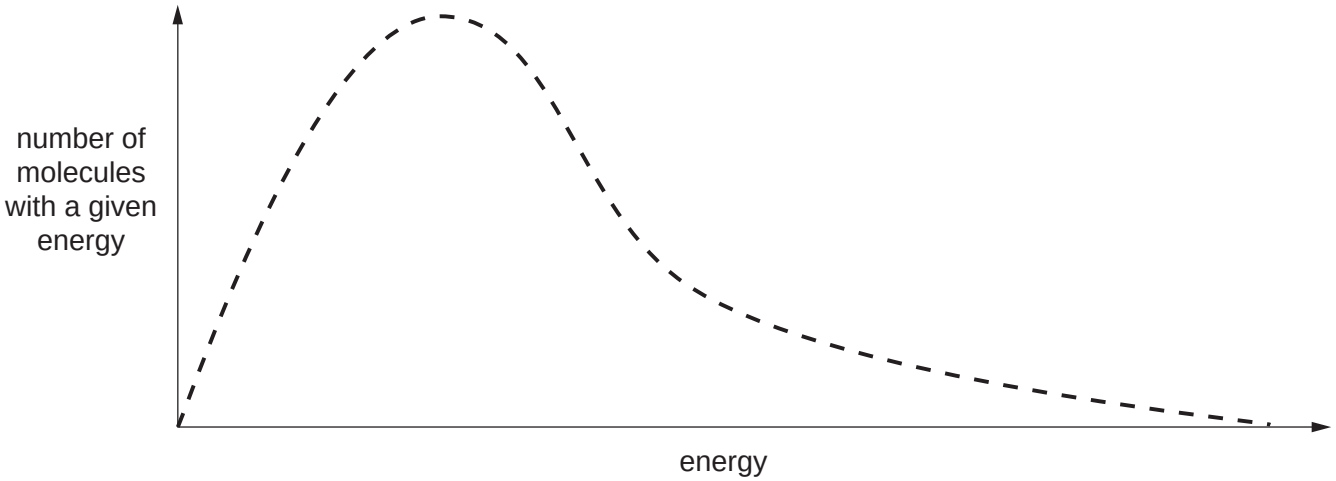
..... **[2]**

(iv) Explain why increasing the temperature of $H_2O_2(aq)$ increases the rate of decomposition.

As part of your answer, you should add a second curve and any necessary labels to the Boltzmann distribution of molecular kinetic energies shown below.



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..... **[3]**

(b) (i) In the past, hydrogen peroxide was manufactured by reacting barium peroxide, BaO_2, with ice-cold dilute sulfuric acid.

$$BaO_2(s) + H_2SO_4(aq) \rightarrow BaSO_4(s) + H_2O_2(aq)$$

This method required the disposal of poisonous barium compounds.

Calculate the atom economy for this manufacture of hydrogen peroxide from BaO_2.
Use the table of relative formula masses given below.

compound	**relative formula mass**
BaO_2	169.3
H_2SO_4	98.1
$BaSO_4$	233.4
H_2O_2	34.0

atom economy = ... % **[2]**

(ii) Nowadays, hydrogen peroxide is manufactured using hydrogen gas, oxygen from the air and a substance called anthraquinone.

stage 1 H_2 + anthraquinone $\rightarrow$ anthraquinol

stage 2 O_2 + anthraquinol $\rightarrow$ H_2O_2 + anthraquinone

Compare the manufacture of H_2O_2 from hydrogen and oxygen with the manufacture from barium peroxide described in **b(i)**.

Explain the advantages of the manufacture of H_2O_2 from hydrogen and oxygen.

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..... **[3]**

(c) Some reactions of H_2O_2 are exothermic.

Use ideas about the enthalpy changes that take place during bond breaking and bond making to explain why some reactions are exothermic.

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..... **[2]**

[Total: 15]

4 Alkenes are a very useful series of hydrocarbons used widely in synthesis. Alkenes are more reactive than alkanes.

(a) What is the name of the process used to convert long chain alkanes into more useful shorter chain alkenes?

..... **[1]**

(b) Ethene and steam can be converted into ethanol.
The equilibrium is shown below.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \qquad \Delta H = -46 \text{ kJ mol}^{-1}$$

le Chatelier's principle can be used to predict the effect of changing conditions on the position of equilibrium.

(i) Name the catalyst used in this reaction.

..... **[1]**

(ii) State le Chatelier's principle.

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..... **[1]**

(iii) Using le Chatelier's principle, predict and explain the conditions that would give the maximum equilibrium yield of ethanol from ethene and steam.

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..... **[3]**

(iv) The actual conditions used are 60 atmospheres pressure at 300 °C in the presence of a catalyst. Compare these conditions with your answer to **(iii)** and comment on why these conditions are used.

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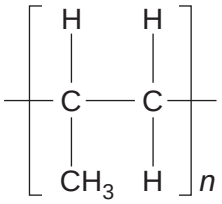
..... **[3]**

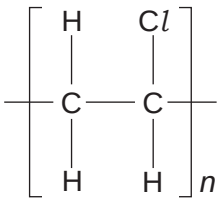
(c) Alkenes are used to make addition polymers.
The repeat unit for an addition polymer is shown below.



What is the name of the monomer used to make this polymer?

..... **[1]**

(d) Poly(chloroethene) has the repeat unit below.



This repeat unit can be written as —CH_2CHCl— .

One way to dispose of poly(chloroethene) is to react it with oxygen at high temperature. This is called incineration.

(i) Complete the following equation that shows the reaction taking place during incineration.

—CH_2CHCl— + ... O_2 → ..... CO_2 + ... H_2O + ... HCl **[1]**

(ii) Research chemists have reduced the environmental impact of incineration by removing the HCl formed from the waste gases.

Suggest a type of reactant that could be used to remove the HCl.

..... **[1]**

(e) The disposal of polymers causes environmental damage.
Research chemists are developing polymers that will reduce this environmental damage and increase sustainability.

Describe **two** ways in which chemists can reduce this environmental damage.

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..... **[2]**

[Total: 14]

5 Kerosene is used as a fuel for aeroplane engines.

(a) Kerosene is obtained from crude oil.

Name the process used to obtain kerosene from crude oil **and** explain why the process works.

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..... **[2]**

(b) Some of the hydrocarbons in kerosene have the formula $C_{10}H_{22}$.

(i) What is the name of the straight chain hydrocarbon with the formula $C_{10}H_{22}$?

..... **[1]**

(ii) Draw the skeletal formula of one branched chain isomer with the formula $C_{10}H_{22}$.

[1]

(iii) Explain why the straight chain isomer of $C_{10}H_{22}$ has a higher boiling point than any of its branched chain structural isomers.

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..... **[2]**

(iv) Explain why the straight chain isomer of $C_{10}H_{22}$ is converted by the petroleum industry into its branched chain isomers.

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..... **[1]**

(c) When kerosene burns in an aeroplane engine very little carbon monoxide, CO, is formed but a significant amount of nitrogen monoxide, NO, is formed.

(i) Construct the equation to show the **complete** combustion of $C_{10}H_{22}$.

..... **[2]**

(ii) Suggest, with the aid of an equation, how NO is formed within an aeroplane engine.

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..... **[1]**

(d) NO is a radical and contributes towards ozone depletion in the stratosphere.

(i) What is a *radical*?

.....

..... **[1]**

(ii) One of the processes leading to the breakdown of ozone in the stratosphere can be represented by the following two equations.

$$NO(g) + O_3(g) \rightarrow NO_2(g) + O_2(g)$$

$$NO_2(g) + O(g) \rightarrow NO(g) + O_2(g)$$

What is the role of the NO in this process?

..... **[1]**

(iii) Ozone in the stratosphere is broken down to make O_2 and O.

Describe and explain how the concentration of ozone in the stratosphere is maintained.

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..... **[2]**

(iv) Why is it important to life on the Earth's surface that the concentration of ozone in the stratosphere is maintained?

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..... **[1]**

[Total: 15]