1 The uses of catalysts have great economic and environmental importance. For example, catalysts are used in ammonia production and in catalytic converters.

(a) Nitrogen and hydrogen react together in the production of ammonia, NH_3.

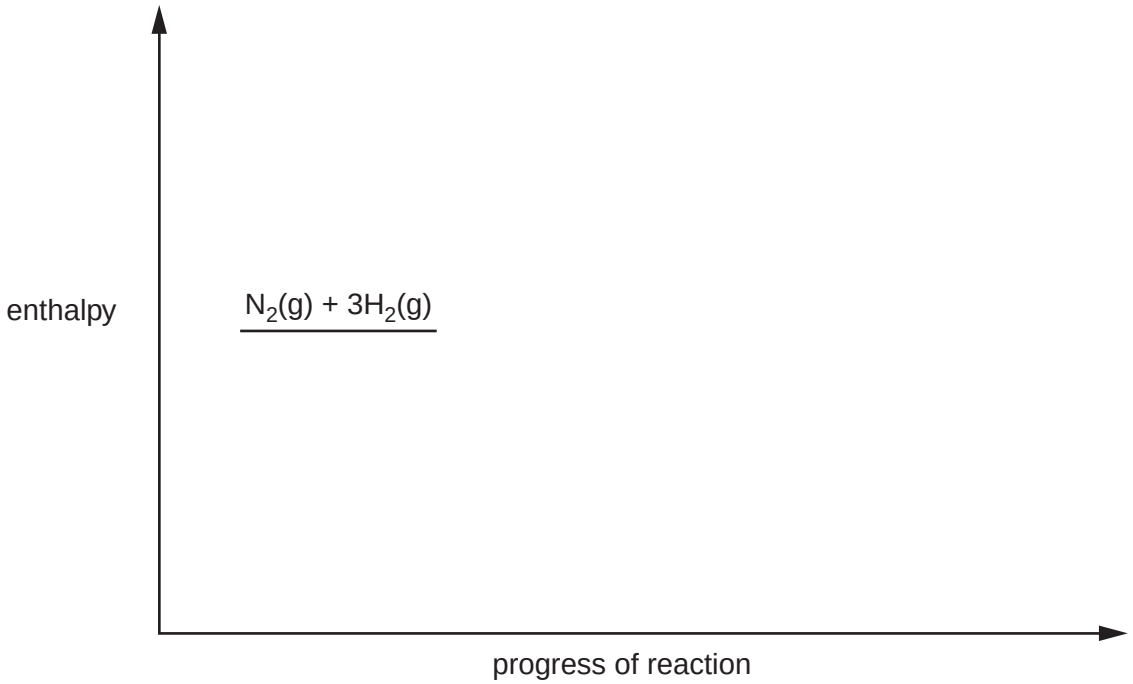
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

The activation energy for the forward reaction, E_a, is $+250\,kJ\,mol^{-1}$.

(i) Complete the enthalpy profile diagram for this reaction between nitrogen and hydrogen.

Include the

- products
- enthalpy change of reaction, ΔH
- activation energy for the forward reaction, E_a.



[3]

(ii) What is the value of the enthalpy change of formation of ammonia?

answer = ... $kJ\,mol^{-1}$ **[1]**

(iii) The reaction between nitrogen and hydrogen can be catalysed.

Suggest a possible value for the activation energy of the **catalysed** forward reaction.

answer = ... $kJ\,mol^{-1}$ **[1]**

(iv) What is the value of the activation energy for the uncatalysed **reverse** reaction (the decomposition of ammonia into nitrogen and hydrogen)?

mol_{-1} **[1]**

answer = ... kJ

(b) In a catalytic converter, nitrogen monoxide reacts with carbon monoxide.

(i) Write the equation for this reaction.

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

(ii) Outline the stages that allow nitrogen monoxide and carbon monoxide to react in a catalytic converter.

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

(c) Scientists monitor pollutant gases in the atmosphere.

(i) State **two** modern analytical techniques that scientists can use to monitor environmental pollution.

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

(ii) Explain why it is important to establish **international** cooperation to reduce pollution levels.

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

(d) In the stratosphere, nitrogen monoxide, NO, is linked with ozone depletion.

Complete the equations below that describe how NO contributes to ozone depletion.

step 1 $NO + O_3 \longrightarrow$ ..... + ...

step 2 NO_2 + ... $\longrightarrow NO +$ .....

overall ..... + ... $\longrightarrow 2O_2$

[3]

(e) Hess' law can be used to calculate enthalpy changes of reaction.

The equation for the reaction that gives the enthalpy change of formation, ΔH_f, of $N_2O(g)$ is as follows.

$$N_2(g) + \tfrac{1}{2}O_2(g) \longrightarrow N_2O(g)$$

(i) It is not possible to measure the enthalpy change of formation of $N_2O(g)$ directly.

Suggest why it is **not** possible.

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

(ii) The data below can be used to calculate the enthalpy change of formation, ΔH_f, of $N_2O(g)$.

reaction	**enthalpy change of reaction / kJ mol^{-1}**
$C(s) + N_2O(g) \longrightarrow CO(g) + N_2(g)$	–193
$C(s) + \tfrac{1}{2}O_2(g) \longrightarrow CO(g)$	–111

Calculate ΔH_f for $N_2O(g)$.

$\Delta H_f =$ ..... kJ mol^{-1} **[2]**

[Total: 19]

2 Methane and ethane are important fuels.

(a) Methane could be manufactured by the reaction between carbon dioxide and hydrogen.

$$CO_2(g) + 4H_2(g) \rightarrow CH_4(g) + 2H_2O(g)$$

Using the table of bond enthalpies, calculate the enthalpy change of reaction for this manufacture of methane.

bond	**average bond enthalpy / kJ mol^{-1}**
C–H	+415
H–H	+436
C=O	+805
O–H	+464

enthalpy change of reaction = ... kJ mol^{-1} **[3]**

(b) Methane is a greenhouse gas. Scientists are concerned that the concentration of methane in the atmosphere is slowly increasing.

(i) Explain how atmospheric methane molecules can contribute to global warming.

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

(ii) One way that scientists hope to minimise global warming is by developing Carbon Capture and Storage, CCS, techniques.

Describe **two** of these CCS techniques.

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

(c) Ethane reacts with bromine in the presence of ultraviolet radiation to form many organic products.

(i) Two of these products are bromoethane and hydrogen bromide.

Describe the mechanism of the reaction between ethane and bromine that forms bromoethane and hydrogen bromide.

Include in your answer

- the type of bond fission that occurs
- equations for each step of the reaction
- the name of each step of the reaction.

Your answer needs to be clear and well organised using the correct terminology.

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..... **[7]**

(ii) Give **two** reasons why there are many organic products of the reaction between bromine and ethane.

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

[Total: 16]

3 Nitrogen monoxide is an atmospheric pollutant, formed inside car engines by the reaction between nitrogen and oxygen.

$$N_2(g) + O_2(g) \rightarrow 2NO(g) \qquad \Delta H = +66\,kJ\,mol^{-1}$$

This reaction is endothermic.

(a) (i) Explain the meaning of the term *endothermic*.

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

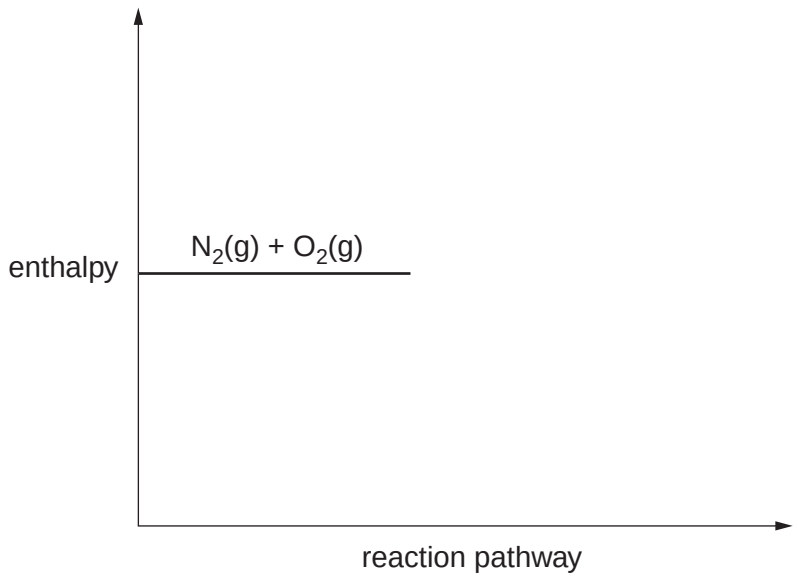
(ii) What is the value for the enthalpy change of formation of nitrogen monoxide?

answer = ... kJ mol^{-1} **[1]**

(b) (i) Complete the enthalpy profile diagram for the reaction between nitrogen and oxygen.

On your diagram

- add the product
- label the activation energy as E_a
- label the enthalpy change as ΔH.



[3]

(ii) Explain the meaning of the term *activation energy*.

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

(c) A research chemist investigates the reaction between nitrogen and oxygen.
She mixes nitrogen and oxygen gases in a sealed container.
She then heats the container at a constant temperature for one day until the gases reach a dynamic equilibrium.

(i) Explain, in terms of the rate of the forward reaction and the rate of the backward reaction, how the mixture of $N_2(g)$ and $O_2(g)$ reaches a dynamic equilibrium containing $N_2(g)$, $O_2(g)$ **and** NO(g).

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

(ii) The research chemist repeats the experiment at the same temperature using the same initial amounts of $N_2(g)$ and $O_2(g)$. This time she carries out the experiment at a much **higher pressure**.

Suggest why

- much less time is needed to reach dynamic equilibrium
- the composition of the equilibrium mixture is the same as in the first experiment.

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..... **[5]**

(iii) The reaction between nitrogen and oxygen in a car engine does not reach a dynamic equilibrium.

Suggest why not.

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

(d) Nitrogen monoxide is a radical.

What does this tell you about a molecule of nitrogen monoxide?

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

(e) Oxides of nitrogen, NO_x, are atmospheric pollutants.

(i) Nitrogen monoxide reacts with oxygen to form NO_2.

Write an equation for the formation of NO_2 from nitrogen monoxide and oxygen.

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

(ii) Aeroplane engines produce nitrogen monoxide.

Describe, with the aid of equations, how nitrogen monoxide catalyses ozone depletion in the stratosphere.

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

(iii) Outline the use of infrared spectroscopy in identifying air pollutants such as NO_x.

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

[Total: 21]

4 Petrol and diesel are both complex mixtures of hydrocarbons used as fuels in transport.

(a) Petrol contains some branched chain alkanes.
The number of carbon atoms per molecule varies between five and nine.

Name one branched chain alkane with between five and nine carbon atoms.

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

(b) When petrol burns in an internal combustion engine the exhaust gases contain CO_2, CO, NO, N_2, O_2, H_2O and unburnt hydrocarbons.

(i) What effect does the absorption of infrared radiation have on the bonds in CO_2 molecules in the atmosphere?

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

(ii) Why is CO present in the exhaust gases?

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

(iii) Both NO and CO are atmospheric pollutants.

For each pollutant, describe one environmental problem.

NO.....

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CO.....

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

(c) Most cars are fitted with a catalytic converter which catalyses the exothermic reaction between NO and CO to form two less harmful gases.

(i) Name the two gases formed and write an equation for this reaction.

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

(ii) NO and CO react very slowly without a catalyst.
The catalyst in a catalytic converter increases the rate of reaction.

Explain, using an enthalpy profile diagram and the Boltzmann distribution model, how the use of a catalyst increases the rate of reaction.

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[7]

(d) Many lorries and some cars use diesel powered engines.
Biodiesel is being developed as a substitute for diesel from crude oil.

Biodiesel is a methyl ester of a long chain carboxylic acid.
The flow chart shows how it is produced.

plants $\longrightarrow$ plant oil $\longrightarrow$ long chain carboxylic acids $\longrightarrow$ biodiesel

Describe the benefits and disadvantages of changing from diesel to biodiesel.

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

[Total: 17]