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.

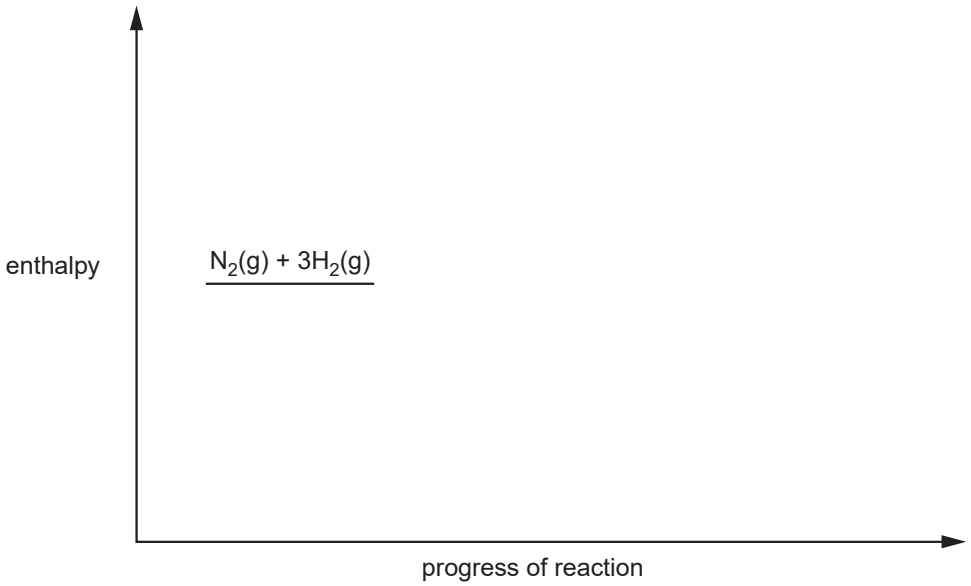
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

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)?

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

(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.

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

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 Many organisms use the aerobic respiration of glucose, $C_6H_{12}O_6$, to release useful energy.

(a) The overall equation for aerobic respiration is the same as for the complete combustion of $C_6H_{12}O_6$.

(i) Write the equation for the aerobic respiration of $C_6H_{12}O_6$.

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

(ii) Explain, in terms of bond breaking and bond forming, why this reaction is exothermic.

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

(b) The table shows some enthalpy changes of combustion, ΔH_c.

substance	ΔH_c **/ kJ mol^{-1}**
C(s)	–394
$H_2(g)$	–286
$C_6H_{12}O_6(s)$	–2801

(i) What is meant by the term *enthalpy change of combustion*, ΔH_c?

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

(ii) The enthalpy change of formation, ΔH_f, of glucose, $C_6H_{12}O_6$, cannot be determined directly. The equation for this enthalpy change is shown below.

$$6C(s) + 6H_2(g) + 3O_2(g) \longrightarrow C_6H_{12}O_6(s)$$

Suggest why the enthalpy change of formation of $C_6H_{12}O_6$ **cannot** be determined directly.

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

(iii) Use the ΔH_c values in the table to calculate the enthalpy change of formation of $C_6H_{12}O_6$.

ΔH_f = ... kJ mol^{-1} **[3]**

[Total: 9]

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

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

This reaction is endothermic.

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

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

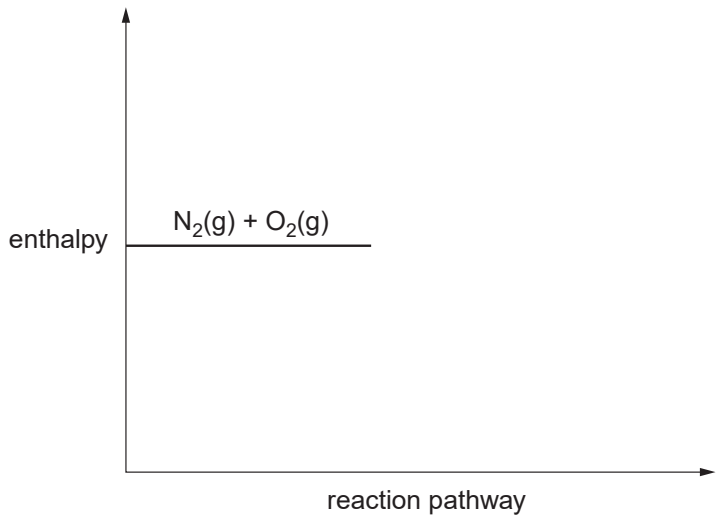
(ii) What is the value for the enthalpy change of formation of nitrogen monoxide?

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

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

[Total: 21]

5 An important reaction in the manufacture of nitric acid is the catalytic oxidation of ammonia.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H = -909 \text{ kJ mol}^{-1}$$

(a) Low pressures and low temperatures would give the maximum equilibrium yield of NO.

Explain why.

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

(b) The actual conditions used in the catalytic oxidation of ammonia include 900 °C and an increase in pressure.

Suggest why these conditions are a compromise.

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

(c) A factory makes 2.50×10^5 mol of NO a day.

(i) How much energy is released every day?

energy released = ... kJ **[1]**

(ii) Suggest how this energy can be used to reduce the cost of making NO.

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

[Total: 7]