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 $C_6H_{12}O_6$.

$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ ✓ ..... **[1]**

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

Bond breaking absorbs energy **AND** bond forming releases energy ✓

More energy released than absorbed ✓

.....

.....

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

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.

Would make carbon dioxide and water instead .....
OR activation energy (too) high .....
OR rate is (too) slow .....
OR do not react together ✓ ..... **[1]**

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.

Low pressure because more (gas) molecules on right hand side of equation **OR** low pressure because ΔV = positive ✓

Low temperature because the (forward) reaction is exothermic ✓

[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.

Increased pressure speeds up reaction / ora ✓

900 °C increases the rate **OR** increased temperature speeds up reaction / ora ✓

Idea that high enough temperature without compromising yield **OR** idea that high enough pressure without compromising yield ✓

[3]

8

In the chemical industry methanol, CH_3OH, is synthesised by reacting together carbon monoxide and hydrogen in the presence of copper, zinc oxide and alumina which act as a catalyst. This is a reversible reaction.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g) \quad \Delta H = -91\,kJ\,mol^{-1}$$

(a) High pressures and low temperatures would give the maximum equilibrium yield of methanol. Explain why.

high pressure as fewer moles (of gas) on right-hand side OR .....
high pressure as volume of products less than that of reactants ✓ .....

low temperature as (forward) reaction is exothermic ✓ .....

.....

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

(b) Explain why the actual conditions used in the chemical industry might be different from those in **(a)** above.

Too expensive to use a high pressure ✓ .....

.....

Too slow to use a low temperature ✓ .....

.....

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

(ii) Using the axes below, sketch an enthalpy profile diagram for an exothermic reaction to show how a catalyst provides an alternative reaction route with a lower activation energy. Include on your diagram labels for:

- enthalpy change, ΔH;
- activation energy for the catalysed route, E_c;
- activation energy for the uncatalysed route, E_a.

ΔH shown **and** products below reactants ✓

E_a shown ✓

E_c shown < E_a ✓