1 Ammonia is made by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The forward reaction is exothermic.

Typical reaction conditions are:

- finely divided iron catalyst,
- temperature 450 °C,
- pressure 200 atmospheres.

(a) Explain why the catalyst is used as a very fine powder and larger pieces of iron are not used.

.....

.....

..... [2]

(b) Using the above conditions, the equilibrium mixture contains about 15% ammonia.

State two changes to the reaction conditions which would increase the percentage of ammonia at equilibrium.

.....

.....

..... [2]

(c) Suggest why the changes you have described in **(b)** are **not** used in practice.

.....

.....

..... [2]

[Total: 6]

2 Plant growth is improved by the availability of essential elements, such as nitrogen, and by the soil having a suitable pH.

(a) Nitrogen-based fertilisers are made from ammonia. Ammonia is manufactured by the Haber process.

(i) Describe the Haber process giving reaction conditions and a balanced equation.
(Do not discuss reaction rate and yield.)

.....

.....

.....

.....

..... [5]

(ii) Fertilisers contain nitrogen.
Name the other **two** elements essential for plant growth commonly found in fertilisers.

..... [2]

(b) Crops do not grow well if the soil is too acidic.

(i) One cause of acidity in soil is acid rain. Explain how acid rain is formed.

.....

.....

.....

..... [3]

(ii) Name **two** bases which are used to increase the pH of acidic soils.

..... [2]

[Total: 12]

3 The reactivity series shows the metals in order of reactivity.

(a) The reactivity series can be established using displacement reactions. A piece of zinc is added to aqueous lead nitrate. The zinc becomes coated with a black deposit of lead.

$$Zn + Pb^{2+} \rightarrow Zn^{2+} + Pb$$

Zinc is more reactive than lead.

The reactivity series can be written as a list of ionic equations.

.....	→	.....	+	.....	most reactive metal : the best reductant (reducing agent)
Zn	→	Zn^{2+}	+	$2e^-$	
Fe	→	Fe^{2+}	+	$2e^-$	
Pb	→	Pb^{2+}	+	$2e^-$	
Cu	→	Cu^{2+}	+	$2e^-$	
Ag	→	Ag^+	+	e^-	

(i) In the space at the top of the list, write an ionic equation for a metal which is more reactive than zinc. [1]

(ii) Write an ionic equation for the reaction between aqueous silver(I) nitrate and zinc.

..... [2]

(iii) Explain why the positive ions are likely to be oxidants (oxidising agents).

..... [1]

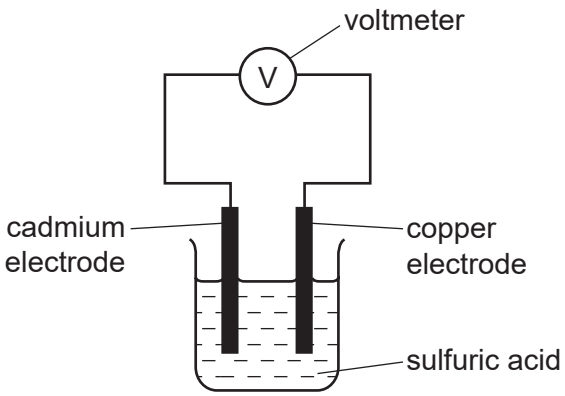
(iv) Deduce which ion is the best oxidant (oxidising agent).

..... [1]

(v) Which ion(s) in the list can oxidise lead metal?

..... [1]

(b) A reactivity series can also be established by measuring the voltage of simple cells. The diagram shows a simple cell.



Results from cells using the metals tin, cadmium, zinc and copper are given in the table below.

cell	electrode 1 positive electrode	electrode 2 negative electrode	voltage / volts
1	copper	cadmium	0.74
2	copper	tin	0.48
3	copper	zinc	1.10

Write the four metals in order of increasing reactivity and explain how you used the data in the table to determine this order.

.....

.....

..... [3]

[Total: 9]

4 Ammonia is manufactured by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

The forward reaction is exothermic.

(a) Describe how the reactants are obtained.

(i) Nitrogen

.....

..... [2]

(ii) Hydrogen

.....

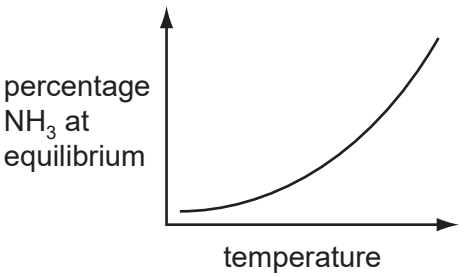
.....

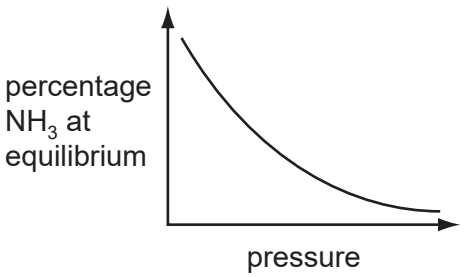
..... [3]

(b) The percentage of ammonia in the equilibrium mixture varies with temperature and pressure.

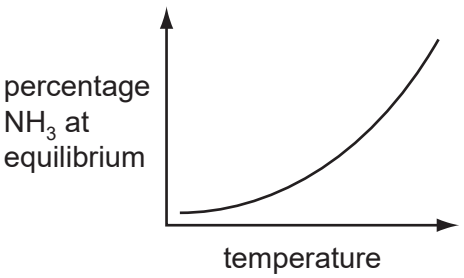
(i) Which pair of graphs, **A**, **B** or **C**, shows correctly how the percentage of ammonia at equilibrium varies with temperature and pressure?

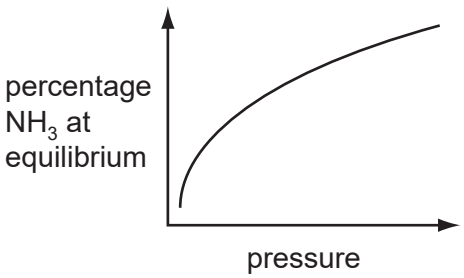
pair **A**



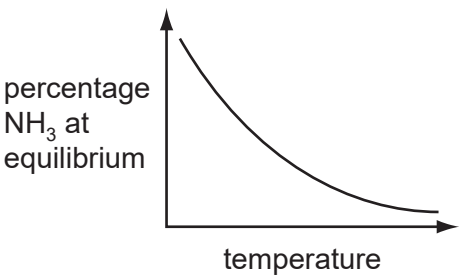


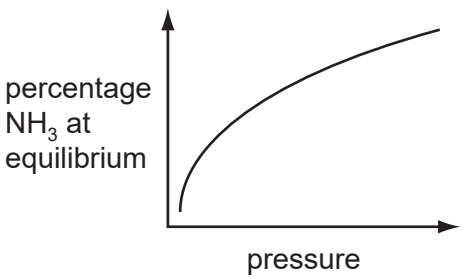
pair **B**





pair **C**





The pair with **both graphs correct** is ..... [1]

(ii) Give a full explanation of why the pair of graphs you have chosen in **(i)** is correct.

.....

.....

.....

.....

.....

.....

..... [6]

(iii) Catalysts do not alter the position of equilibrium. Explain why a catalyst is used in this process.

.....

.....

.....

..... [2]

[Total: 14]

5 **(a)** Nitric acid is now made by the oxidation of ammonia. It used to be made from air and water. This process used very large amounts of electricity.

Air was blown through an electric arc and heated to 3000 °C.

$$N_2(g) + O_2(g) \rightleftharpoons \underset{\text{nitric oxide}}{2NO(g)} \qquad \textbf{equilibrium 1}$$

The equilibrium mixture leaving the arc contained 5 % of nitric oxide. This mixture was cooled rapidly. At lower temperatures, nitric oxide will react with oxygen to form nitrogen dioxide.

$$2NO(g) + O_2(g) \rightleftharpoons 2NO_2 \qquad \textbf{equilibrium 2}$$

Nitrogen dioxide reacts with oxygen and water to form nitric acid.

(i) Suggest a reason why the yield of nitric oxide in **equilibrium 1** increases with temperature.

..... [1]

(ii) What effect, if any, would increasing the pressure have on the percentage of nitric oxide in **equilibrium 1**? Explain your answer.

.....

..... [2]

(iii) Deduce why **equilibrium 2** is only carried out at lower temperatures.

.....

..... [2]

(iv) Complete the equation for the reaction between nitrogen dioxide, water and oxygen to form nitric acid.

.....NO_2 + O_2 + ... $\rightarrow$ .....HNO_3 [2]

(v) Ammonia is more expensive than water and air. Suggest a reason why the ammonia-based process is preferred to the electric arc process.

..... [1]

(b) Nitric acid is used to make the fertiliser ammonium nitrate, NH_4NO_3.
What advantage has this fertiliser over another common fertiliser, ammonium sulfate, $(NH_4)_2SO_4$?

..... [1]

(ii) Plants need nitrogen to make chlorophyll. Explain why chlorophyll is essential for plant growth.

.....

.....

.....

.....

..... [4]

[Total: 13]

6 Ammonia is made by the Haber process.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$$

(a) State **one** major use of ammonia.

..... [1]

(b) Describe how hydrogen is obtained for the Haber process.

.....

.....

..... [3]

(c) This reaction is carried out at a high pressure, 200 atmospheres.
State, with an explanation for each, **two** advantages of using a high pressure.

.....

.....

.....

.....

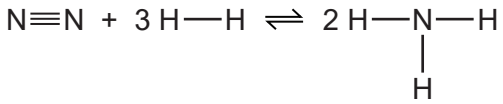
..... [5]

(d) What is the difference between an endothermic and an exothermic reaction?

.....

..... [1]

(ii) Bond breaking is an endothermic process. Bond energy is the amount of energy needed to break or form one mole of the bond. Complete the table and explain why the forward reaction is exothermic.



bond	bond energy kJ / mol	energy change kJ	exothermic or endothermic
N≡N	944	+944	endothermic
H—H	436	$3 \times 436 = +1308$	
N—H	388		

.....

..... [3]

[Total: 13]