Q1. Ammonia is manufactured by the Haber process in which the following equilibrium is established.

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

(a) Give **two** features of a reaction at equilibrium.

Feature 1 Concentrations remain constant

Feature 2 forward and backward rate are equal.

(2)

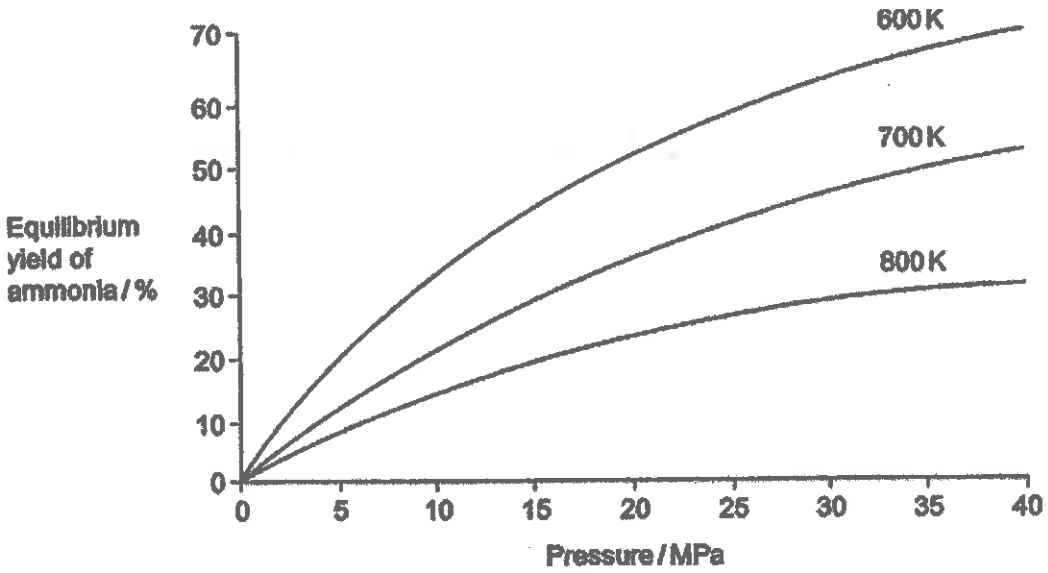
(b) Explain why a catalyst has no effect on the position of an equilibrium.

Catalyst speed up the rate of reaction in both the forward and backwards direction the same amount.

(Extra space)

(2)

(c) The diagram shows how the equilibrium yield of ammonia varies with changes in pressure and temperature.



(i) Use the diagram to state the effect of an **increase** in pressure at constant temperature on the yield of ammonia. Use Le Chatelier's principle to explain this effect.

Effect on yield ... Increases ...

Explanation ... More moles on the left hand side of the equation, therefore increasing pressure causes equilibrium position to shift to the side with less moles, the right, to oppose the change. ...

...

(3)

(ii) Use the diagram to state the effect of an **increase** in temperature at constant pressure on the yield of ammonia. Use Le Chatelier's principle to explain this effect.

Effect on yield ... decreases ...

Explanation ... forward reaction is exothermic so equilibrium position shifts to the left to oppose increase in temperature. ...

...

...

...

(3)

(d) At equilibrium, with a pressure of 35 MPa and a temperature of 600 K, the yield of ammonia is 65%.

(i) State why industry uses a temperature higher than 600 K.

to speed up the rate of reaction.

(1)

(ii) State why industry uses a pressure lower than 35 MPa.
Do **not** include references to safety.

uses less expensive equipment - so cheaper costs.

(1)
(Total 12 marks)

Q2. The following dynamic equilibrium was established at temperature T in a closed container.

$$P(g) + 2Q(g) \rightleftharpoons 2R(g) \qquad \Delta H^{\ominus} = -50 \text{ kJ mol}^{-1}$$

The value of K_c for the reaction was 68.0 $\text{mol}^{-1}\ \text{dm}^3$ when the equilibrium mixture contained 3.82 mol of **P** and 5.24 mol of **R**.

(a) Give the meaning of the term *dynamic equilibrium*.

forward and backwards reactions are at equal rates and concentrations remain constant.

(Extra space)

(2)

(b) Write an expression for K_c for this reaction.

$$K_c = \frac{[R]^2}{[P] \times [Q]^2}$$

(1)

(c) The volume of the container was 10.0 dm^3.

Calculate the concentration, in mol dm^{-3}, of Q in the equilibrium mixture.

$K_c = \frac{[R]^2}{[P][Q]^2}$ $\sqrt{\frac{[R]^2}{K_c \times [P]}} = Q$

$\sqrt{\frac{(5.24/10)^2}{68 \times (3.82/10)}} = [Q]$ $\sqrt{\frac{0.275}{25.976}} = 0.103$

(Extra space) .....

(4)

(d) State the effect, if any, on the equilibrium amount of P of increasing the temperature.
All other factors are unchanged.

Increases (exothermic in forward reaction so opposes change)

(1)

(e) State the effect, if any, on the equilibrium amount of P of using a container of larger volume. All other factors are unchanged.

Increases (more moles on left so decrease in pressure/increase in vol. shifts eq to left)

(1)

(f) State the effect, if any, on the value of K_c of increasing the temperature.
All other factors are unchanged.

decrease

(1)

(g) State the effect, if any, on the value of K_c of using a container of larger volume.
All other factors are unchanged.

No change

(1)

(h) Deduce the value of the equilibrium constant, at temperature *T*, for the reaction

$2R(g) \rightleftharpoons P(g) + 2Q(g)$

$K = \frac{[P][Q]^2}{[R]^2}$

$K_c = \frac{(3.62/10) \times (0.103)^2}{(5.24/10)^2}$

$K_c = 0.0148 \text{ mol dm}^{-3}$

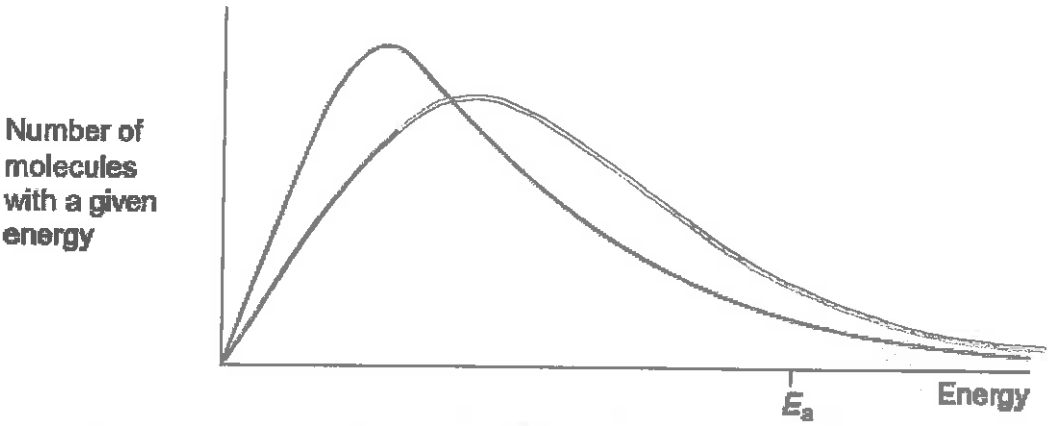
Be careful as you worked this out as concentration already!!

(1)

(Total 12 marks)

Q3. The diagram below shows a Maxwell–Boltzmann distribution for a sample of gas at a fixed temperature.

E_a is the activation energy for the decomposition of this gas.



(a) (i) On this diagram, sketch the distribution for the same sample of gas at a higher temperature.

(2)

(ii) With reference to the Maxwell–Boltzmann distribution, explain why an increase in temperature increases the rate of a chemical reaction.

Increase number of molecules with Ea - therefore more successful collisions

(2)

(b) Dinitrogen oxide (N_2O) is used as a rocket fuel. The data in the table below show how the activation energy for the decomposition of dinitrogen oxide differs with different catalysts.

$$2N_2O(g) \longrightarrow 2N_2(g) + O_2(g)$$

	Ea / kJ mol^{-1}
Without a catalyst	245
With a gold catalyst	121
With an iron catalyst	116
With a platinum catalyst	136

(i) Use the data in the table to deduce which is the most effective catalyst for this decomposition.

Iron

(1)

(ii) Explain how a catalyst increases the rate of a reaction.

By providing an alternate pathway by lowering activation energy

(2)

(Total 7 marks)

Q4. Hess's Law is used to calculate the enthalpy change in reactions for which it is difficult to determine a value experimentally.

(a) State the meaning of the term *enthalpy change*.

Heat change at a constant pressure

(1)

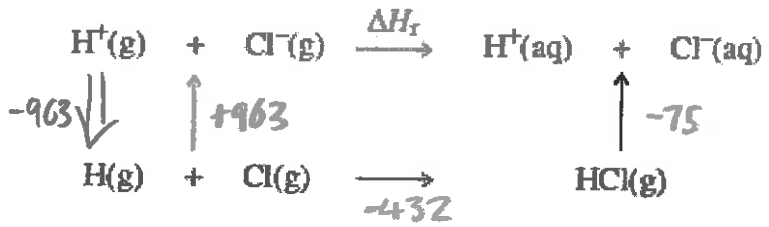
(b) State Hess's Law.

Enthalpy change in a reaction is independent of the route taken

(1)

(c) Consider the following table of data and the scheme of reactions.

Reaction	Enthalpy change / kJ mol^{-1}
$HCl(g) \rightarrow H^+(aq) + Cl^-(aq)$	–75
$H(g) + Cl(g) \rightarrow HCl(g)$	–432
$H(g) + Cl(g) \rightarrow H^+(g) + Cl^-(g)$	+963



Use the data in the table, the scheme of reactions and Hess's Law to calculate a value for ΔH_r

$-963 + (-432) + (-75) = -1470$ kJ mol^{-1}

(3)
(Total 5 marks)

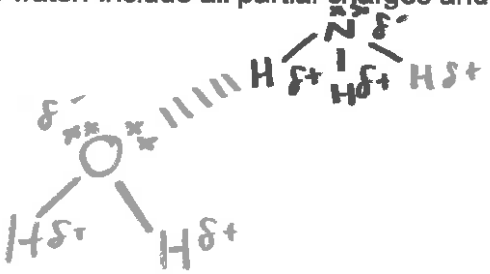
Q5. Fritz Haber, a German chemist, first manufactured ammonia in 1909.
Ammonia is very soluble in water.

(a) State the strongest type of intermolecular force between one molecule of ammonia and one molecule of water.

Hydrogen bonding

(1)

(b) Draw a diagram to show how one molecule of ammonia is attracted to one molecule of water. Include all partial charges and all lone pairs of electrons in your diagram.



(3)

(c) Phosphine (PH_3) has a structure similar to ammonia.

In terms of intermolecular forces, suggest the main reason why phosphine is almost insoluble in water.

Does not form hydrogen bonds.

(1)

(Total 5 marks)

Q6. Compound **A** is an oxide of sulphur. At 415 K, a gaseous sample of **A**, of mass 0.304 g, occupied a volume of 127 cm^3 at a pressure of 103 kPa.

State the ideal gas equation and use it to calculate the number of moles of **A** in the sample, and hence calculate the relative molecular mass of **A**.
(The gas constant R = 8.31 J K^{-1} mol^{-1})

Ideal gas equation $PV = nRT$

Calculation $n = \frac{PV}{RT}$ $n = \frac{103000 \times 1.27 \times 10^{-4}}{8.31 \times 415}$

$n = 3.79 \times 10^{-3}$ moles moles = $\frac{\text{mass}}{Mr}$ $\frac{\text{mass}}{\text{moles}} = Mr$

$\frac{0.304}{3.79 \times 10^{-3}} = 80.2$

(Total 5 marks)

Q7. Which change requires the largest amount of energy?

A $He^-(g) \longrightarrow He^{2+}(g) + e^-$ ☒

B $Li(g) \longrightarrow Li^+(g) + e^-$ ○

C $Mg^+(g) \longrightarrow Mg^{2+}(g) + e^-$ ○

D $N(g) \longrightarrow N^+(g) + e^-$ ○

smallest atom - close to nucleus

(Total 1 mark)

Q8. A saturated aqueous solution of magnesium hydroxide contains 1.17×10^{-3} g of $Mg(OH)_2$ in 100 cm^3 of solution. In this solution, the magnesium hydroxide is fully dissociated into ions.

What is the concentration of $Mg^{2+}(aq)$ ions in this solution?

A 2.82×10^{-2} mol dm^{-3} ☐

B 2.01×10^{-3} mol dm^{-3} ☐

C 2.82×10^{-3} mol dm^{-3} ☐

D 2.01×10^{-4} mol dm^{-3} ☒

$mol = \frac{mass}{Mr} \quad \frac{1.17 \times 10^{-3}}{58} = 2.017 \times 10^{-5}$ moles

$C = \frac{mol}{vol} \quad \frac{2.017 \times 10^{-5}}{(100/1000)} = 2.017 \times 10^{-4}$

(Total 1 mark)

Q9. The table below shows some information about three hydrochloric acid solutions used to clean bricks and concrete.

	Cleaner	Acid content by mass / %	Price per 25dm^3 / £
(1)	Plattern Concrete Acid	24.0	14.39
(2)	Dub-Lit Brick Cleaner	28.9	16.99
(3)	Conpat Brick Acid	35.9	24.99

Use the data in the table above to determine the cleaner that offers the best value for money, based on acid content. Show your working.

(1) $\frac{24}{14.39} = 1.667$ (3) $\frac{35.9}{24.99} = 1.44$

(2) $\frac{28.9}{16.99} = 1.701$

∴ Dub-Lit Brick Cleaner

(Total 1 mark)

Q10. Which of these pieces of apparatus has the lowest percentage uncertainty in the measurement shown?

(A) Volume of 25 cm^3 measured with a burette with an uncertainty of ±0.1 cm^3. ☒ $\frac{0.1}{25} \times 100 = 0.4\%$

B Volume of 25 cm^3 measured with a measuring cylinder with an uncertainty of ±0.5 cm^3. ○ $\frac{0.5}{25} \times 100 = 2\%$

C Mass of 0.150 g measured with a balance with an uncertainty of ±0.001 g. ○ $\frac{0.001}{0.150} \times 100 = 0.6\%$

D Temperature change of 23.2 °C measured with a thermometer with an uncertainty of ±0.1 °C. ○ $\frac{0.1}{23.2} \times 100 = 0.43\%$

(Total 1 mark)