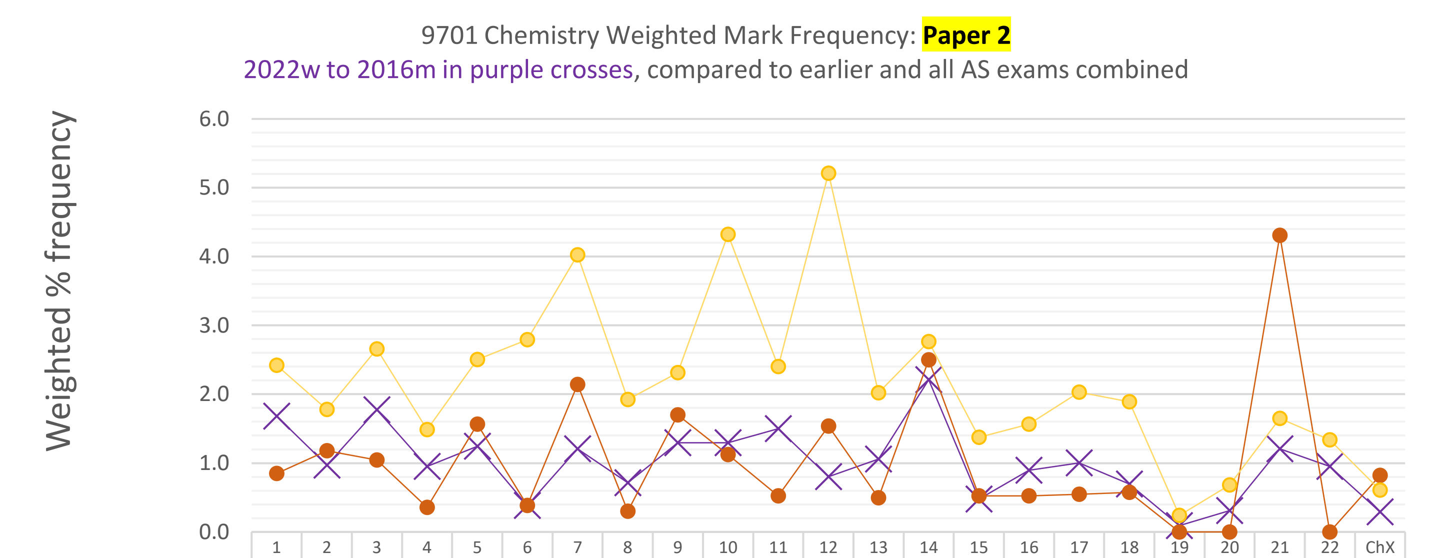
Name: Class: Date:

ALvl Chem 7 EQ P2 22w to 09s Paper 2 Equilibria 144marks

As you start and work through this worksheet you can tick off your progress to show yourself how much you have done, and what you need to do next. The first task is just to read the first question and should take you less than one minutes to complete.

Paper 2 Topic 7 **Checklist** Tick each task off as you go along	RANK:	P1 Noob	P1 Novice	P1 Bronze	P1 Silver	P1 Gold	P1[1] Winner	P1 Hero	P1 Legend
		1 Q started	1 Q done	10% of marks	25% of marks	40% of marks	50% of marks	75% of marks	100% of marks
Topic (marks)	144		6	14	36	58	72	108	144
Time @75s/mark (minutes)	180		7	18	45	72	90	135	180



	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	ChX
P2 16-22 WTD	1.7	1.0	1.8	0.9	1.2	0.4	1.2	0.7	1.3	1.3	1.5	0.8	1.1	2.2	0.5	0.9	1.0	0.7	0.1	0.3	1.2	0.9	0.3
P2 09-15 WTD	0.9	1.2	1.0	0.4	1.6	0.4	2.1	0.3	1.7	1.1	0.5	1.5	0.5	2.5	0.5	0.5	0.5	0.6	0.0	0.0	4.3	0.0	0.8
P1,2,3 16-22 WTD	2.4	1.8	2.7	1.5	2.5	2.8	4.0	1.9	2.3	4.3	2.4	5.2	2.0	2.8	1.4	1.6	2.0	1.9	0.2	0.7	1.6	1.3	0.6

What the most thoughtful students will get out of their extensive studying will be a capacity to do meaningful brain-based work even under stressful conditions, which is a part of the self-mastery skillset that will continue to deliver value for the whole of their lives. Outstanding grades will also happen, but the most important goal from skillful action in study is being better at any important task, even if circumstances do not feel ideal.

As you are moving through your studies you can learn more about yourself by trying out new ways to manage yourself, and analysing how effective those new techniques were. In this reflective process not only will you get better at working positively and productively to deliver ambitious and successful outcomes, but you will be working towards one aspect of life's highest pursuit, summarised and inscribed on the Temple of Apollo at Delphi: "know thyself".

1. To complete these questions, as important as your answer, is checking your answer against the mark scheme.
2. For each page or group of 10-20 marks, convert your mark score into a percentage. This will allow you to see (and feel) your progress as you get more experience and understanding with each topic.
3. Multiple choice questions, done carefully where you explain and show yourself your thinking using written notes as you move through each question, can be more useful than just Paper 2 for students aiming for a C or B grade. Paper 2 should be the larger focus for students aiming for A and A* grades, however.
4. If you find you get a higher percentage answering short answer questions than multiple choice questions that often means you are NOT using the marking scheme correctly; your correct answer might not be fully complete for all the marks you are awarding. The marks easiest to miss rely on providing the largest amount of detail.

[1] **DO NOT** work on these higher levels of completion in your AS year unless you have also achieved at least a "**Silver**" (25%) in the same topic in **Paper 1**, which tend also to be easier questions, as well as ""**Silver**" (25%) in the same topic, if it exists, in Paper 3.

7 Equilibria

7.1 Chemical equilibria: reversible reactions, dynamic equilibrium

Learning outcomes

Candidates should be able to:

1 (a) understand what is meant by a reversible reaction
  (b) understand what is meant by dynamic equilibrium in terms of the rate of forward and reverse reactions being equal and the concentration of reactants and products remaining constant
  (c) understand the need for a closed system in order to establish dynamic equilibrium

2 define Le Chatelier's principle as: if a change is made to a system at dynamic equilibrium, the position of equilibrium moves to minimise this change

3 use Le Chatelier's principle to deduce qualitatively (from appropriate information) the effects of changes in temperature, concentration, pressure or presence of a catalyst on a system at equilibrium

4 deduce expressions for equilibrium constants in terms of concentrations, K_c

5 use the terms mole fraction and partial pressure

6 deduce expressions for equilibrium constants in terms of partial pressures, K_p (use of the relationship between K_p and K_c is not required)

7 use the K_c and K_p expressions to carry out calculations (such calculations will not require the solving of quadratic equations)

8 calculate the quantities present at equilibrium, given appropriate data

9 state whether changes in temperature, concentration or pressure or the presence of a catalyst affect the value of the equilibrium constant for a reaction

10 describe and explain the conditions used in the Haber process and the Contact process, as examples of the importance of an understanding of dynamic equilibrium in the chemical industry and the application of Le Chatelier's principle

7.2 Brønsted–Lowry theory of acids and bases

Learning outcomes

Candidates should be able to:

1 state the names and formulae of the common acids, limited to hydrochloric acid, HCl, sulfuric acid, H_2SO_4, nitric acid, HNO_3, ethanoic acid, CH_3COOH

2 state the names and formulae of the common alkalis, limited to sodium hydroxide, NaOH, potassium hydroxide, KOH, ammonia, NH_3

7.2 Brønsted–Lowry theory of acids and bases (continued)

Learning outcomes

Candidates should be able to:

3 describe the Brønsted–Lowry theory of acids and bases

4 describe strong acids and strong bases as fully dissociated in aqueous solution and weak acids and weak bases as partially dissociated in aqueous solution

5 appreciate that water has pH of 7, acid solutions pH of below 7 and alkaline solutions pH of above 7

6 explain qualitatively the differences in behaviour between strong and weak acids including the reaction with a reactive metal and difference in pH values by use of a pH meter, universal indicator or conductivity

7 understand that neutralisation reactions occur when $H^+(aq)$ and $OH^-(aq)$ form $H_2O(l)$

8 understand that salts are formed in neutralisation reactions

9 sketch the pH titration curves of titrations using combinations of strong and weak acids with strong and weak alkalis

10 select suitable indicators for acid-alkali titrations, given appropriate data (pK_a values will not be used)

Q# 144/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Some of the common chlorides of Period 3 elements are shown in the list.

$NaCl$ $MgCl_2$ $AlCl_3$ $SiCl_4$ PCl_5

(d) Sulfur, S_8, reacts with chlorine to form several different chlorides. The most common are S_2Cl_2 and SCl_2. SCl_2 forms when sulfur reacts with an excess of chlorine.

reaction **1** $S_8(s) + 4Cl_2(g) \rightarrow 4S_2Cl_2(l)$ $\Delta H_r = -58.2\,kJ\,mol^{-1}$

reaction **2** $S_2Cl_2(l) + Cl_2(g) \rightleftharpoons 2SCl_2(l)$ $\Delta H_r = -40.6\,kJ\,mol^{-1}$

(iii) State the effect of a decrease in pressure on the position of equilibrium in reaction **2**. Explain your answer.

....

....

.... [1]

Q# 145/ ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Nitrogen molecules, $N_2(g)$, contain two atoms attracted to each other by a triple covalent bond.

(d) 25 cm^3 of 0.10 $mol\,dm^{-3}$ $HCl(aq)$ is added to a beaker and its pH is recorded.

50 cm^3 of 0.10 $mol\,dm^{-3}$ $NH_3(aq)$ is added to the $HCl(aq)$ in 5 cm^3 portions.

The pH of the mixture is monitored until all the $NH_3(aq)$ is added.

HCl is a strong Brønsted-Lowry acid.

(i) Describe what is meant by a strong Brønsted-Lowry acid.

....

.... [2]

(ii) NH_3 is a weak base.

Construct an equation that shows the behaviour of NH_3 as a weak Brønsted-Lowry base when dissolved in water.

.... [1]

(iii) On Fig. 2.1 sketch a graph to show the change in pH which occurs when HC*l*(aq) is titrated with NH_3(aq) as described in **(d)**.

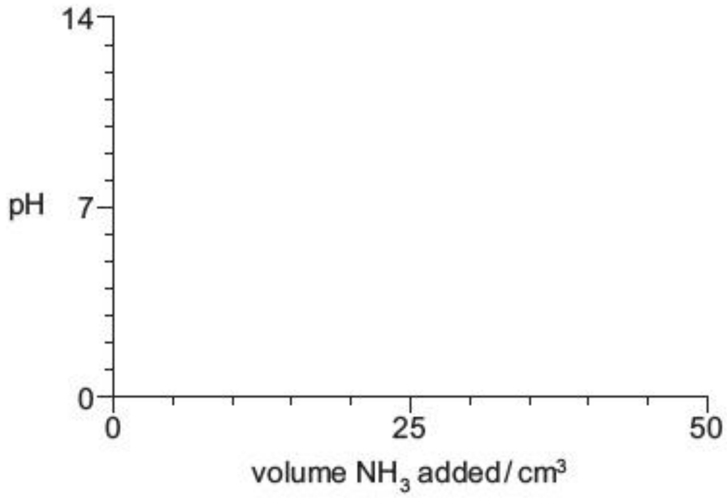


Fig. 2.1

[2]

Q# 146/ ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 The hydrogen halides HC*l*, HBr and HI are all colourless gases at room temperature.

(d) The hydrogen halides dissolve in water to form strong Brønsted–Lowry acids.

The concentration of a strong acid can be determined by titration.

(i) State what is meant by strong Brønsted–Lowry acid.

....

....

.... [2]

(ii) On Fig. 3.2, sketch the pH titration curves produced when:

- 0.1 mol dm^{-3} NaOH(aq) is added to 25 cm^3 of 0.1 mol dm^{-3} HBr(aq), to excess
- 0.1 mol dm^{-3} NH_3(aq) is added to 25 cm^3 of 0.1 mol dm^{-3} HBr(aq), to excess.

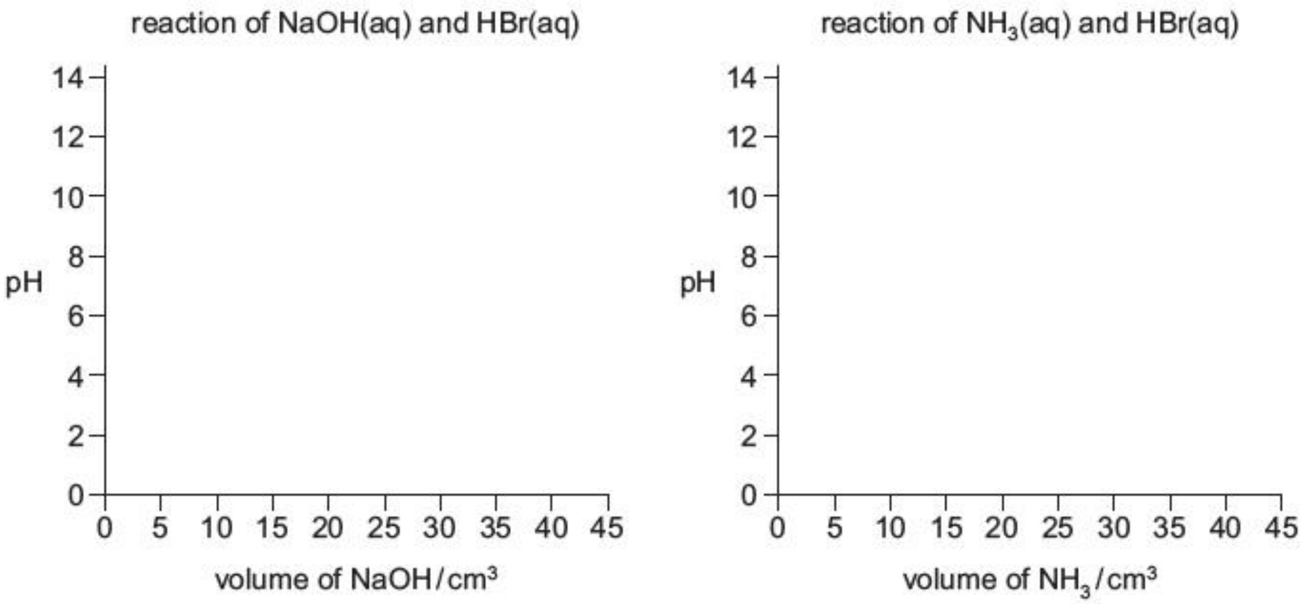


Fig. 3.2

[3]

Q# 147/ ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Some oxides of elements in Period 3 are shown.

Na_2O Al_2O_3 P_4O_6 P_4O_{10} SO_2 SO_3

(a) Na reacts with O_2 to form Na_2O. Na is the reducing agent in this reaction.

(iii) Fig. 2.2 shows how the temperature of the atmosphere varies with height from the ground.

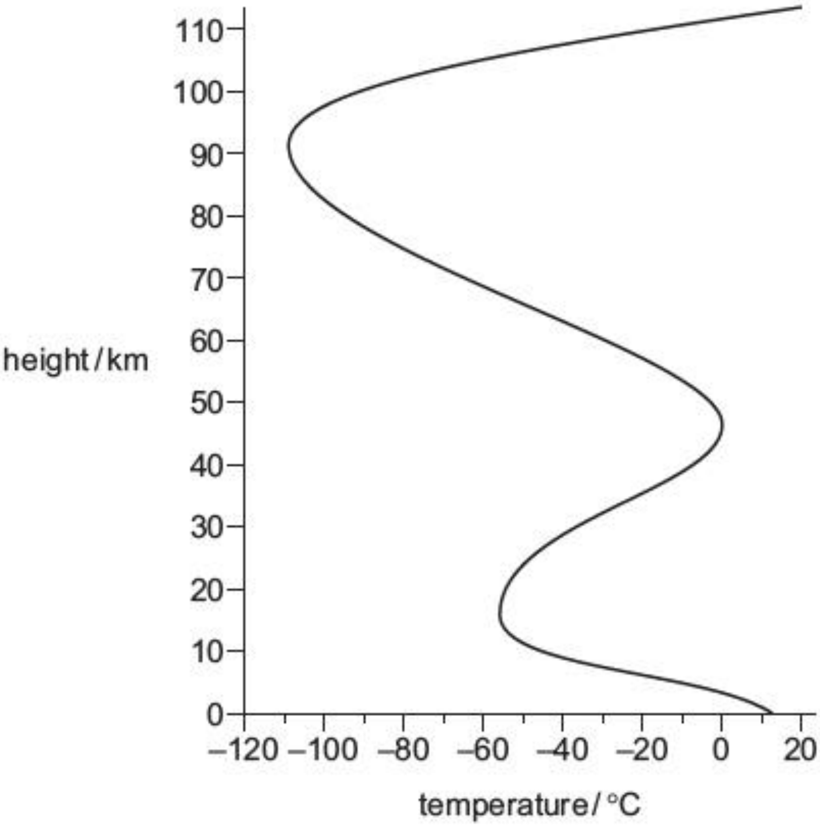


Fig. 2.2

The equilibrium reaction in equation 1 has $\Delta H_r = -168\,kJ\,mol^{-1}$.

Suggest how the position of this equilibrium differs at a height of 20 km compared with a height of 50 km from the ground.
Explain your answer.

....

....

.... [2]

Q# 148/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

(c) Hydrogen sulfide gas, $H_2S(g)$, is slightly soluble in water. It acts as a weak acid in aqueous solution.

(i) State the meaning of *weak acid*.

....

.... [1]

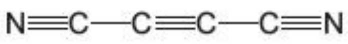
(ii) Give the formula of the conjugate base of H_2S.

.... [1]

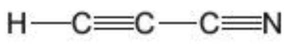
Q# 149/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Compounds **P**, **Q** and **R** have all been found in the atmosphere of one of Saturn's moons.

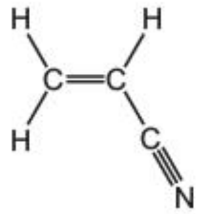
P



Q



R



(b) **Q** forms when HCN reacts with ethyne, H—C≡C—H.

(i) Ethyne, HCN and **Q** are all weak Brønsted–Lowry acids.

Explain what is meant by the term *weak Brønsted–Lowry acid*.

....

....

.... [2]

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(b) The two most common oxides of sulfur are SO_2 and SO_3.

When SO_2 dissolves in water, a small proportion of it reacts with water to form a weak Brønsted-Lowry acid.

(i) Explain the meaning of the term *weak Brønsted-Lowry acid*.

....

.... [2]

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(d) Chlorine forms several oxides, including Cl_2O, ClO_2 and Cl_2O_6.

(iii) $Cl_2O_6(g)$ is produced by the reaction of $ClO_2(g)$ with $O_3(g)$.

$$2ClO_2(g) + 2O_3(g) \rightleftharpoons Cl_2O_6(g) + 2O_2(g) \qquad \Delta H = -216\,kJ\,mol^{-1}$$

The reaction takes place at 500 K and 100 kPa.

State and explain the effect on the yield of $Cl_2O_6(g)$ when the experiment is carried out:

- at 1000 K and 100 kPa

....

....

....

....

- at 500 K and 500 kPa.

....

....

....

....
[4]

Q# 152/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 Calcium nitrate, $Ca(NO_3)_2$, reacts with ammonia, carbon dioxide and water to form a mixture of ammonium nitrate and calcium carbonate.

$$Ca(NO_3)_2 + 2NH_3 + CO_2 + H_2O \rightarrow 2NH_4NO_3 + CaCO_3$$

(a) Explain why ammonia is described as a Brønsted-Lowry base in this reaction.

.... [1]

Q# 153/ ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

(f) Magnesium oxide reacts reversibly with chlorine according to the following equation.

$$2MgO(s) + 2Cl_2(g) \rightleftharpoons 2MgCl_2(s) + O_2(g)$$

Under certain conditions, a dynamic equilibrium is established.

(i) State **two** features of a reaction that is in dynamic equilibrium.

1 ....

2 ....
[2]

(ii) The equilibrium constant, K_p, is given by the following expression.

$$K_p = \frac{p_{O_2}}{p_{Cl_2}^2}$$

At 1.00×10^5 Pa and 500 K, 70% of the initial amount of $Cl_2(g)$ has reacted.

Calculate K_p and state its units.

K_p = ...

units = ...
[3]

1 Sulfuric acid is manufactured by the Contact process.

One stage in this process is the conversion of sulfur dioxide into sulfur trioxide in the presence of a heterogeneous catalyst of vanadium(V) oxide, V_2O_5.

$$2O{=}S{=}O(g) + O{=}O(g) \rightleftharpoons 2O{=}\overset{\overset{\displaystyle O}{\|}}{S}{=}O(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

The equation for this stage of the Contact Process is shown.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad \Delta H = -196\,kJ\,mol^{-1}$$

(d) **(i)** State and explain the effect of increasing temperature on the rate of production of SO_3.

.... [3]

(ii) State and explain the effect of increasing temperature on the yield of SO_3.

.... [3]

(e) The SO_3 produced is converted to sulfuric acid in two stages. In the first stage the SO_3 is reacted with concentrated sulfuric acid to produce oleum, $H_2S_2O_7$.
The oleum is then reacted with water to form sulfuric acid.

Suggest an equation for the reaction of oleum, $H_2S_2O_7$, with water to form sulfuric acid.

.... [1]

(f) SO_2 reacts with water to form sulfurous acid.
Sulfurous acid is a weak Brønsted-Lowry acid, while sulfuric acid is a strong Brønsted-Lowry acid.

(ii) State the meaning of the term *strong Brønsted-Lowry acid*.

.... [2]

(iii) Write an equation to show the acid-base behaviour of sulfuric acid with water. Include state symbols.

.... [2]

1 Ammonia, NH_3, is manufactured from nitrogen and hydrogen by the Haber process.

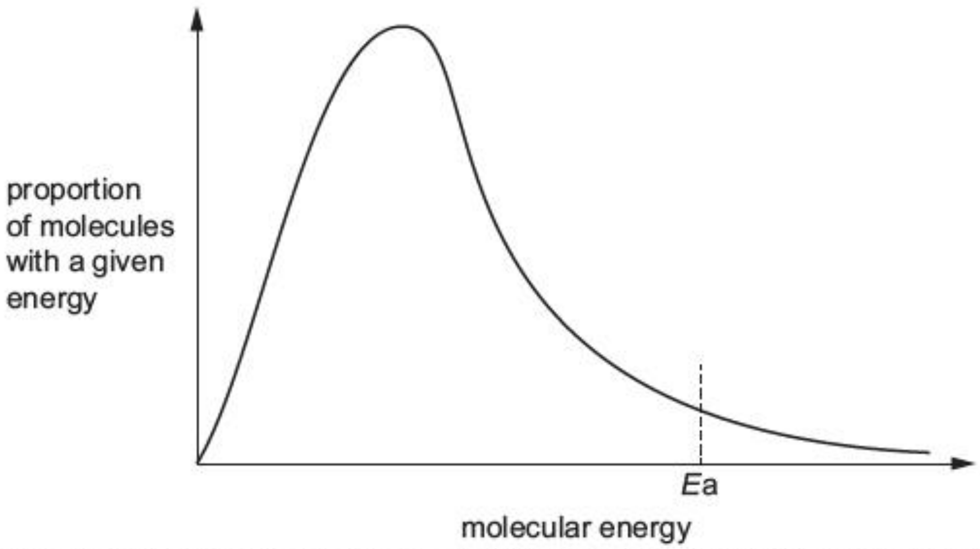
$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H = -92\,kJ\,mol^{-1}$$

(a) Some bond energies are given.

N≡N = 944 kJ mol^{-1}
H–H = 436 kJ mol^{-1}

(b) The Haber process is usually carried out at a temperature of approximately 400 °C in the presence of a catalyst. Changing the temperature affects both the rate of production of ammonia and the yield of ammonia.

The Boltzmann distribution for a mixture of nitrogen and hydrogen at 400 °C is shown.
*E*a represents the activation energy for the reaction.



(iii) State and explain the effect of increasing temperature on the yield of ammonia.
Use Le Chatelier's principle to explain your answer.

....

....

....

.... [3]

(c) At a pressure of 2.00 × 10^7 Pa, 1.00 mol of nitrogen, $N_2(g)$, was mixed with 3.00 mol of hydrogen, $H_2(g)$. The final equilibrium mixture formed contained 0.300 mol of ammonia, $NH_3(g)$.

(i) Calculate the amounts, in mol, of $N_2(g)$ and $H_2(g)$ in the equilibrium mixture.

$N_2(g)$ = ... mol

$H_2(g)$ = ... mol
[2]

(ii) Calculate the partial pressure of ammonia, pNH_3, in the equilibrium mixture.

Give your answer to **three** significant figures.

pNH_3 = ... Pa [3]

(d) In another equilibrium mixture the partial pressures are as shown.

substance	partial pressure / Pa
$N_2(g)$	2.20×10^6
$H_2(g)$	9.62×10^5
$NH_3(g)$	1.40×10^4

(i) Write the expression for the equilibrium constant, K_p, for the production of ammonia from nitrogen and hydrogen.

K_p =

[1]

(ii) Calculate the value of K_p for this reaction.

State the units.

K_p = ...

units = ...
[2]

(iii) This reaction is repeated with the same starting amounts of nitrogen and hydrogen. The same temperature is used but the container has a smaller volume.

State the effects, if any, of this change on the yield of ammonia and on the value of K_p.

effect on yield of ammonia ....

effect on value of K_p ....

[2]

[Total: 22]

Q# 156/ ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2 Hydrogen halides are compounds formed when halogens (Group 17 elements) react with hydrogen. The bond polarity of the hydrogen halides decreases from HF to HI.

Some relevant data are shown in the table.

hydrogen halide	HF	HC*l*	HBr	HI
boiling point / °C	19	–85	–67	–35
H–X bond energy / kJ mol^{-1}	562	431	366	299

(b) The equation for the preparation of hydrogen chloride using concentrated sulfuric acid is shown.

$$H_2SO_4 + NaCl \rightarrow NaHSO_4 + HCl$$

(i) Use the Brønsted-Lowry theory of acids and bases to identify the base and its conjugate acid in this reaction. Explain your answer.

Brønsted-Lowry base (base-I) = ...

conjugate acid (acid-II) = ...

....

....

....

[2]

(c) Hydrogen chloride undergoes a reversible reaction with oxygen.

$$4HCl(g) + O_2(g) \rightleftharpoons 2Cl_2(g) + 2H_2O(g)$$

The reaction is carried out at 400 °C in the presence of a copper(II) chloride catalyst.

(iii) The reaction exists in dynamic equilibrium.

The reaction was repeated at 1000 °C and the same pressure.

State and explain the effect on the composition of the equilibrium mixture of the change in temperature.

....

....

....

.... [2]

(iv) When 1.60 mol of HC*l* are mixed in a sealed container with 0.500 mol of O_2 at 400 °C, 0.600 mol of Cl_2 and 0.600 mol of H_2O are formed.

The total pressure inside the container is 1.50×10^5 Pa.

- Calculate the amounts, in mol, of HC*l* and O_2 in the equilibrium mixture.

HC*l* = ... mol

O_2 = ... mol

- Calculate the mole fraction of Cl_2 and hence the partial pressure of Cl_2 in the equilibrium mixture.

mole fraction of Cl_2 = ...

p_{Cl_2} = ... Pa
[3]

(v) In a separate experiment, an equilibrium reaction mixture was found to contain the four gases at the partial pressures shown in the table.

gas	HCl	O_2	Cl_2	H_2O
partial pressure / Pa	4.8×10^4	3.0×10^4	3.6×10^4	3.6×10^4

$$K_p = \frac{(p_{Cl_2})^2 \times (p_{H_2O})^2}{(p_{HCl})^4 \times p_{O_2}}$$

Use this information and the expression given for K_p to calculate a value for K_p. State the units of K_p.

K_p = ...

units = ...
[2]

(vi) The reaction is repeated without a catalyst.

State the effect of this on K_p.

.... [1]

[Total: 22]

Q# 157/ ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3 Over one million tonnes of hydrogen cyanide, HCN, are produced each year using the Andrussow process. The overall equation for the reaction is shown.

$$CH_4(g) + NH_3(g) + 1\tfrac{1}{2}O_2(g) \rightleftharpoons HCN(g) + 3H_2O(g)$$

(b) The reaction exists as a dynamic equilibrium.

(i) Explain what is meant by the term *dynamic equilibrium*.

....

.... [1]

(ii) State and explain how the amounts of the chemicals present in the equilibrium mixture will change when the pressure is increased.

....

....

.... [2]

Q# 158/ ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) Ammonia is manufactured by the Haber process.

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

(ii) State the essential operating conditions for the Haber process.

....

....

.... [3]

(iii) Explain the choices of temperature and pressure for the Haber process.

....

....

....

....

.... [4]

(c) One of the major uses of ammonia is in the manufacture of fertilisers such as diammonium hydrogen phosphate, $(NH_4)_2HPO_4$.

(i) Write an equation for the formation of diammonium hydrogen phosphate by the reaction between ammonia and phosphoric acid, H_3PO_4.

.... [1]

(ii) Explain this reaction in terms of the Brønsted-Lowry theory.

....

....

....

.... [2]

4 Compound **R** is a weak diprotic (dibasic) acid which is very soluble in water.

(a) A solution of **R** was prepared which contained 1.25 g of **R** in 250 cm^3 of solution. When 25.0 cm^3 of this solution was titrated with 0.100 $mol\,dm^{-3}$ NaOH, 21.6 cm^3 of the alkali were needed for complete reaction.

(i) Using the formula H_2X to represent **R**, construct a balanced equation for the reaction between H_2X and NaOH.

....

(ii) Use the data above to calculate the amount, in moles, of OH^- ions used in the titration.

(iii) Use your answers to **(i)** and **(ii)** to calculate the amount, in moles, of **R** present in 25.0 cm^3 of solution.

(iv) Calculate the amount, in moles, of **R** present in 250 cm^3 of solution.

(v) Calculate M_r of **R**.

[5]

(b) Three possible structures for **R** are shown below.

S	**T**	**U**
$HO_2CCH{=}CHCO_2H$	$HO_2CCH(OH)CH_2CO_2H$	$HO_2CCH(OH)CH(OH)CO_2H$

(i) Calculate the M_r of each of these acids.

M_r of **S** = ... M_r of **T** = ... M_r of **U** = ...

(ii) Deduce which of the structures, **S**, **T** or **U**, correctly represents the structure of the acid, **R**.

R is represented by ....

[2]

Q# 160/ ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Ammonium nitrate fertiliser is manufactured from ammonia. The first reaction in the manufacture of the fertiliser is the catalytic oxidation of ammonia to form nitrogen monoxide, NO. This is carried out at about 1×10^3 kPa (10 atmospheres) pressure and a temperature of 700 to 850 °C.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \qquad \Delta H^{\circ} = -906\,kJ\,mol^{-1}$$

(a) Write the expression for the equilibrium constant, K_p, stating the units.

K_p =

units .... [2]

(b) What will be the effect on the yield of NO of **each** of the following?
In each case, explain your answer.

(i) increasing the temperature

....

....

....

(ii) decreasing the applied pressure

....

....

....

[4]

Q# 161/ ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 A sample of a fertiliser was known to contain ammonium sulfate, $(NH_4)_2SO_4$, and sand only.

A 2.96 g sample of the solid fertiliser was heated with 40.0 cm^3 of NaOH(aq), an excess, and all of the ammonia produced was boiled away.

After cooling, the remaining NaOH(aq) was exactly neutralised by 29.5 cm^3 of 2.00 $mol\,dm^{-3}$ HCl.

In a separate experiment, 40.0 cm^3 of the original NaOH(aq) was exactly neutralised by 39.2 cm^3 of the 2.00 $mol\,dm^{-3}$ HCl.

(a) **(i)** Write balanced equations for the following reactions.

NaOH with HCl

....

$(NH_4)_2SO_4$ with NaOH

(ii) Calculate the amount, in moles, of NaOH present in the 40.0 cm^3 of the original NaOH(aq) that was neutralised by 39.2 cm^3 of 2.00 mol dm^{-3} HCl.

(iii) Calculate the amount, in moles, of NaOH present in the 40.0 cm^3 of NaOH(aq) that remained after boiling the $(NH_4)_2SO_4$.

(iv) Use your answers to **(ii)** and **(iii)** to calculate the amount, in moles, of NaOH that reacted with the $(NH_4)_2SO_4$.

(v) Use your answers to **(i)** and **(iv)** to calculate the amount, in moles, of $(NH_4)_2SO_4$ that reacted with the NaOH.

(vi) Hence calculate the mass of $(NH_4)_2SO_4$ that reacted.

(vii) Use your answer to **(vi)** to calculate the percentage, by mass, of $(NH_4)_2SO_4$ present in the fertiliser.
Write your answer to a suitable number of significant figures.

[9]

3 Ammonia is an important industrial chemical which is manufactured on a large scale by using the Haber process.

(a) **(i)** Write a balanced equation, with state symbols, for the reaction occurring in the Haber process.

....

(ii) Give **three** essential operating conditions that are used in the Haber process.

....

....

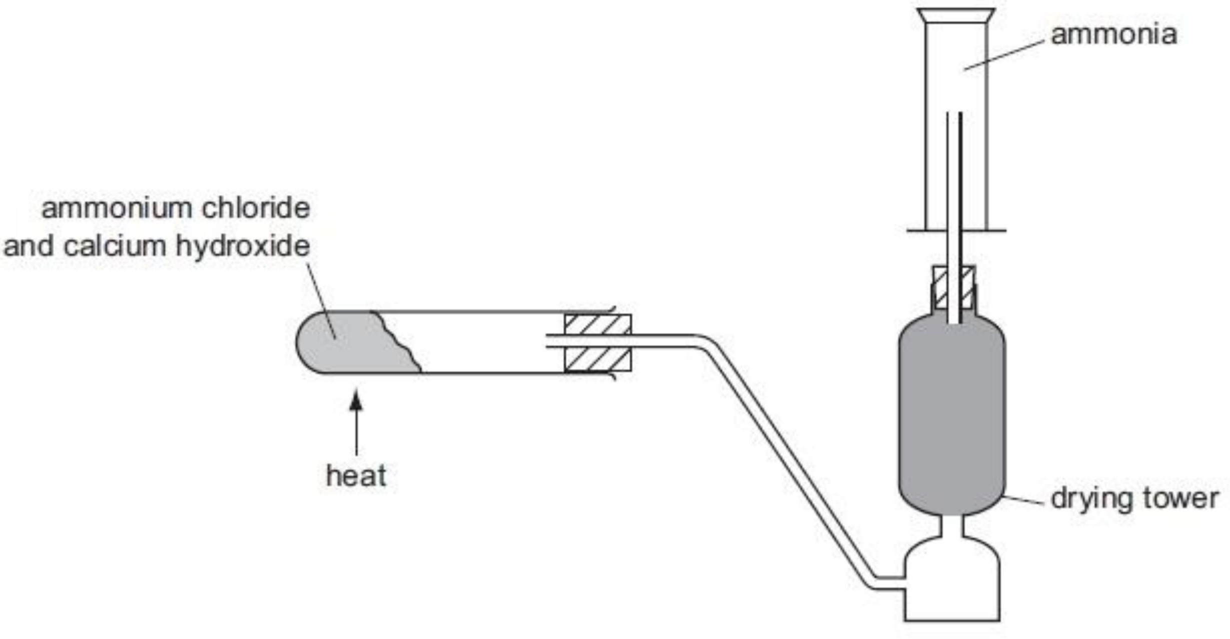
....

(iii) State **one** large scale use of ammonia.

....

[5]

(b) Ammonia may be prepared in a school or college laboratory by using the apparatus below.



The reaction involves the displacement of ammonia from one of its compounds.

(i) Give the formulae of the two reactants that are heated together to produce ammonia.

.... and ....

(ii) Construct a balanced equation for the reaction between your two reagents.

....

(iii) Common drying agents include calcium oxide, concentrated sulfuric acid and phosphorus(V) oxide.
Which **one** of these would be used in the drying tower in this experiment? Explain your answer.

....

....

[5]

Q# 163/ ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Each of the Group VII elements chlorine, bromine and iodine forms a hydride.

Hydrogen iodide can be made by heating together hydrogen gas and iodine vapour. The reaction is incomplete.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$$

(b) Write an expression for K_c and state the units.

K_c = ... units .... [2]

(c) For this equilibrium, the numerical value of the equilibrium constant K_c is 140 at 500 K and 59 at 650 K.

Use this information to state and explain the effect of the following changes on the equilibrium position.

(i) increasing the pressure applied to the equilibrium

....

....

(ii) decreasing the temperature of the equilibrium

....

....

[4]

(d) A mixture of 0.02 mol of hydrogen and 0.02 mol of iodine was placed in a 1 dm^3 flask and allowed to come to equilibrium at 650 K.

Calculate the amount, in moles, of each substance present in the equilibrium mixture at 650 K.

	$H_2(g)$	+	$I_2(g)$	$\rightleftharpoons$	$2HI(g)$
initial moles	0.02		0.02		0

[4]

Q# 164/ ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org
NOT with 2012/s/TZ 1/Paper 4/Q# 3(b)

3 Methanol, CH_3OH, is considered to be a possible alternative to fossil fuels, particularly for use in vehicles.

Methanol can be produced from fossil fuels and from agricultural waste. It can also be synthesised from carbon dioxide and hydrogen.

$$CO_2(g) + 3H_2(g) \rightleftharpoons CH_3OH(g) + H_2O(g) \quad \Delta H^{\circ}_{reaction} = -49\ kJ\ mol^{-1}$$

(c) The synthesis of methanol is carried out at about 500 K with a pressure of between 40 and 100 atmospheres (between 4×10^6 Pa and 10×10^7 Pa) and using a catalyst. The use of such conditions will affect both the rate of reaction and the equilibrium yield.

In the spaces below, explain the effects of higher temperature, higher pressure, and the use of a catalyst on the **equilibrium yield** of methanol.

higher temperature

effect ....

explanation ....

....

higher pressure

effect ....

explanation ....

....

use of catalyst

effect ....

explanation ....

....
[6]

[Total: 14]

Q# 165/ ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

Sulfur-containing compounds are removed from oil products at the refinery. The sulfur is recovered and converted into SO_2, which is then used in the Contact process.

(e) State the main operating details of the formation of SO_3 in the Contact process.

....

....

....

....

....[3]

[Total: 15]

Q# 166/ ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 Nitrogen makes up about 79% of the Earth's atmosphere. As a constituent element of proteins, it is present in living organisms.

Atmospheric nitrogen is used in the Haber process for the manufacture of ammonia.

(a) Write an equation for the formation of ammonia in the Haber process.

.... [1]

(b) The Haber process is usually carried out at a high pressure of between 60 and 200 atmospheres (between 60 □ 10^5 Pa and 200 □ 10^5 Pa).
State **two further** important operating conditions that are used in the Haber process.
For **each** of your conditions, explain why it is used.

condition 1 ....

reason ....

condition 2 ....

reason .... [4]

(c) State **one** large-scale use for ammonia, other than in the production of nitrogenous fertilisers.

.... [1]

Q# 167/ ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

The reaction between nitrogen and hydrogen to produce ammonia in the Haber process is an example of a large-scale gaseous reaction that is catalysed.

(c) **(i)** State the catalyst used and give the operating temperature and pressure of the Haber process.

catalyst ....

temperature ....

pressure .... [2]

Q# 168/ ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 Concern over the ever-increasing use of fossil fuels has led to many suggestions for alternative sources of energy. One of these, suggested by Professor George Olah, winner of a Nobel Prize in chemistry, is to use methanol, CH_3OH, which can be obtained in a number of different ways.

Methanol could be used instead of petrol in a conventional internal combustion engine or used to produce electricity in a fuel cell.

Methanol may be manufactured catalytically from *synthesis gas*, a mixture of CO, CO_2 and H_2. The CO is reacted with H_2 to form methanol, CH_3OH.

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

(c) From your understanding of Le Chatelier's principle, state **two** conditions that could be used in order to produce a high yield of methanol.

In **each** case, explain why the yield would increase.

condition 1 ....

explanation ....

....

condition 2 ....

explanation ....

.... [4]

Carbon monoxide, which can be used to make methanol, may be formed by reacting carbon dioxide with hydrogen.

$$CO_2(g) + H_2(g) \rightleftharpoons CO(g) + H_2O(g) \qquad K_c = 1.44 \text{ at } 1200\ K$$

(d)

(ii) A mixture containing 0.50 mol of CO_2, 0.50 mol of H_2, 0.20 mol of CO and 0.20 mol of H_2O was placed in a 1.0 dm^3 flask and allowed to come to equilibrium at 1200 K.

Calculate the amount, in moles, of each substance present in the equilibrium mixture at 1200 K.

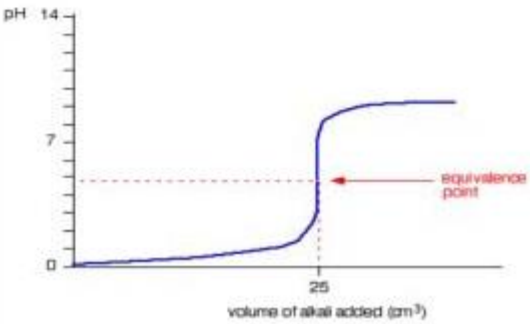
	CO_2	+	H_2	$\rightleftharpoons$	CO	+	H_2O
initial moles	0.50		0.50		0.20		0.20

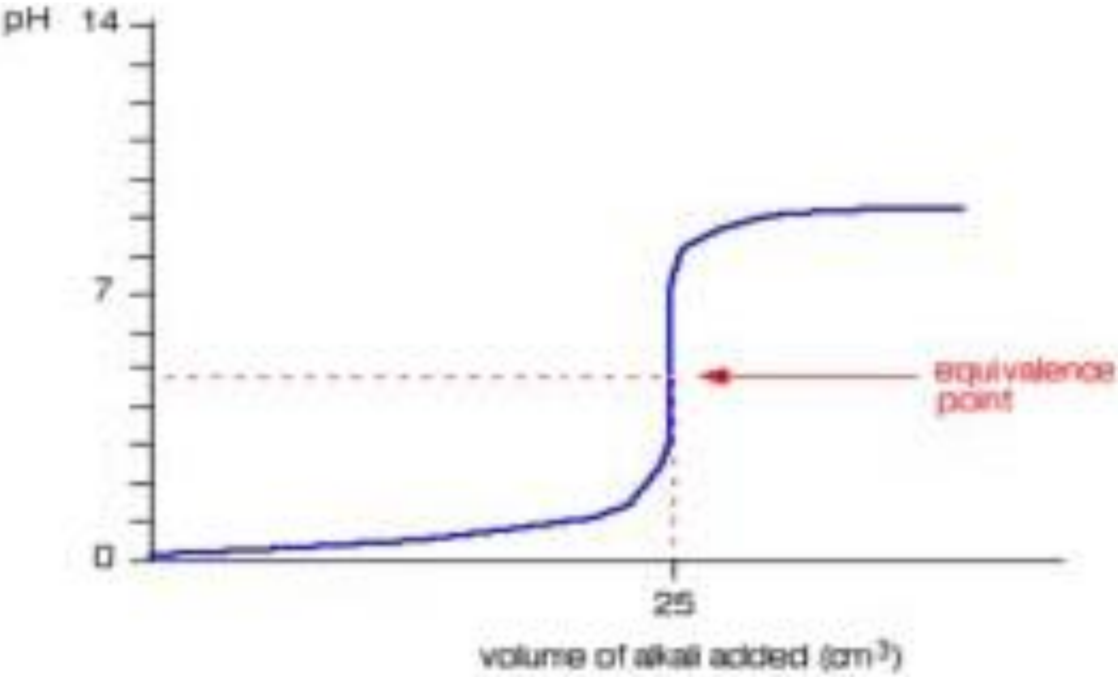
[5]

Q# 144/ ALvl Chemistry/2022/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

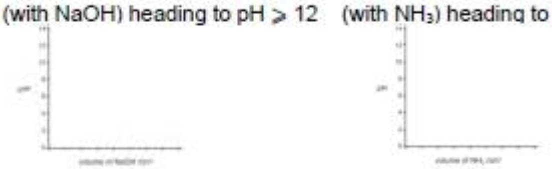
3(d)(iii)	equilibrium moves to left **AND** more moles / molecules of gas on LHS	1

Q# 145/ ALvl Chemistry/2022/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(c)	any Group 1 hydroxide or $Ca(OH)_2$ / $Sr(OH)_2$ / $Ba(OH)_2$	1
2(d)(i)	**M1** proton / H^+ donor **M2** fully dissociates (in aqueous solution / water / solvent)	2
2(d)(ii)	$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$	1
2(d)(iii)	**M1** correct basic shape extending to ~50 cm³ with vertical portion of curve at 25 cm³ **M2** initial pH at 0–2 (based on idea that HC*l* is a strong acid) **AND** final pH at between 8–12 (based on idea that NH_3 is a weak alkali) 	2



Q# 146/ ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(d)(i)	proton / H^+ donor [1] fully dissociates (in aqueous solution / water / solvent) [1]	2
3(d)(ii)	M1: correct sigmoid shape with vertical section at 25 cm³ for both M2: both curves show initial pH ≤ 2 M3: (with NaOH) heading to pH ≥ 12 (with NH_3) heading to pH 8–12 	3

Q# 147/ ALvl Chemistry/2022/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(d)(iii)	position of equilibrium moves / farther to right (at 20 km) [1] (forward) reaction is exothermic **AND** temperature colder at 20 km (*cf.* 50 km) [1]	2

Q# 148/ ALvl Chemistry/2021/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(c)(i)	*weak [acid]* partially dissociates/partially ionises (into H^+ ions/protons)	1
1(c)(ii)	HS^-	1

Q# 149/ ALvl Chemistry/2021/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

3(b)(i)	**M1:** proton / H^+ donor **M2:** partially dissociates / does not fully dissociate (in solution)	2

Q# 150/ ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	**M1:** proton / H^+ donor	2
	M2: partially dissociates (in solution)	

Q# 151/ ALvl Chemistry/2020/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2(d)(iii)	***(at 1000 K and 100 kPa)*** **M1:** (yield) **decreases**	4
	M2: reaction is exothermic **AND** equilibrium moves left	
	(at 500 K and 500 kPa) **M3:** (yield) **increases**	
	M4: fewer moles (of gas) on right-hand side **AND** equilibrium moves right	

Q# 152/ ALvl Chemistry/2020/s/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4(a)	Accepts a proton / H^+ (ion)	1

Q# 153/ ALvl Chemistry/2020/m/TZ 2/Paper 4/Q# 1/www.SmashingScience.org

1(f)(i)	**M1** equal rates of forward and backward reactions **M2** closed system OR macroscopic properties unchanging	2
1(f)(ii)	**M1** Cl_2 O_2 initial: x, 0 mol equilibrium: $0.3x$, $0.35x$ mol **mol fraction**: $\frac{6}{13}$, $\frac{7}{13}$ **M2** $K_p = \frac{100000 \times \frac{7}{13}}{(100000 \times \frac{6}{13})^2} = 2.53 \times 10^{-5}$ **M3** Pa^{-1}	3

Q# 154/ ALvl Chemistry/2018/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(d)(i)	Increases rate **AND** explanation re collisions	1
	By increasing number / proportion of / more molecules / particles / species with $E \geqslant E_a$	1
	(So) increases frequency of successful collisions / more successful collisions per unit time / higher chance of successful collisions per unit time / higher proportion of successful collisions per unit time	1
1(d)(ii)	(Increasing T) decreases yield (of SO_3)	1
	(Forward) reaction is exothermic (or reverse argument)	1
	So increasing T shifts (equilibrium) reaction to left / towards reactants / in endothermic direction (to oppose the change in T)	1
1(e)	$H_2S_2O_7 + H_2O \rightarrow 2H_2SO_4$	1

1(f)(ii)	fully ionises/dissociates	1
	(Brønsted-Lowry acid is a) proton / H^+ donor	1
1(f)(iii)	$H_2SO_4(l)/(aq) + H_2O(l) \rightarrow HSO_4^-(aq) + H_3O^+(aq)$	
	species and balancing	1
	correct state symbols on left hand side; all products aqueous	1

Q# 155/ ALvl Chemistry/2017/w/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1(b)(iii)	reduces yield (of ammonia).	1
	(increasing *T*) shifts equilibrium (reaction) to the left / in the reverse direction / towards N_2 and H_2 / towards reactants / in endothermic direction	1
	to oppose the change OR oppose the increase in temperature OR to absorb the (additional) heat / energy OR decrease the temperature	1
1(c)(i)	N_2 = 0.850 (mol)	1
	H_2 = 2.55 (mol)	1
1(c)(ii)	n_{TOTAL} = 3.7 mol	1
	mol fraction of NH_3 = 0.3 / 3.7	1
	$pNH_3 = 2 \times 10^7 \times (0.3 / 3.7) = 1.62 \times 10^6$	1
1(d)(i)	$K_p = \frac{pNH_3^{\,2}}{pN_2 \times pH_2^{\,3}}$	1
1(d)(ii)	$K_p = 1.(00) \times 10^{-16}$	1
	Pa^{-2}	1
1(d)(iii)	(yield of ammonia) increases	1
	(value of K_p) stays the same	1

Q# 156/ ALvl Chemistry/2017/m/TZ 2/Paper 4/Q# 2/www.SmashingScience.org

2(b)(i)	**M1** base is Cl^- **AND** conjugate acid is HCl **OR** base is HSO_4^- **AND** conjugate acid is H_2SO_4	1
	M2 Cl^- / HSO_4^- / base is a proton acceptor **OR** HCl / H_2SO_4 / (conjugate) acid has one more H^+	1

2(c)(iii)	reaction is exothermic	1
	(increased temperature) shifts equilibrium to the left **AND** decreases yield of products (Cl_2 and / or H_2O) / less product formed	1

2(c)(iv)	(see table below)		3

	HCl	O_2	Cl_2	H_2O
initial number of moles	1.60	0.500	0	0
M1 eqm number of moles	1.60 – 2 × 0.600 = 0.400	0.500 – ½ × 0.600 = 0.200	0.600	0.600
M2 mole fraction			$\frac{0.600}{1.80}$	
M3 partial pressure			$\frac{0.600}{1.80} \times p_{tot}$ = 5.00 × 10^4	

2(c)(v)	$K_p = \dfrac{(3.6\times10^4)^2 \times (3.6\times10^4)^2}{(4.8\times10^4)^4 \times 3.0\times10^4} = 1.05 \times 10^{-5}$	1
	units = Pa^{-1}	1
2(c)(vi)	K_p would not change	1

Q# 157/ ALvl Chemistry/2016/m/TZ 2/Paper 4/Q# 3/www.SmashingScience.org

(b) (i)	forward and backward reactions occurring at same rate OR the rate of forward and backward reactions are equal	[1]	[1]
(ii)	M1 = decreased yield of products / less products formed / ora M2 = left-hand side has fewer moles of gas OR equilibrium shifts to the left	[1] [1]	[2]

Q# 158/ ALvl Chemistry/2015/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(ii)	Fe catalyst 200 atm 400–500 (°)C	[1] [1] [1]	[3]
(iii)	High T increases rate AND Low T improves yield owtte Chosen temp is a compromise High P favours / increases (both rate and) yield owtte pressure chosen limited by cost (of compression and 'thick walls')	[1] [1] [1] [1]	[4]
(c) (i)	$2NH_3 + H_3PO_4 \rightarrow (NH_4)_2HPO_4$	[1]	[1]
(ii)	NH_3 identified as base AND H_3PO_4 identified as acid base accepts protons AND acid donates protons	[1] [1]	[2]

Q# 159/ ALvl Chemistry/2013/w/TZ 1/Paper 4/Q# 4/www.SmashingScience.org

4 (a) (i) $H_2X + 2NaOH \rightarrow Na_2X + 2H_2O$ (1)

(ii) $n(OH^-) = \dfrac{21.6\times0.100}{1000} = 2.16 \times 10^{-3}$ mol (1)

(iii) $n(R) = n(H_2X) = \dfrac{2.16\times10^{-3}}{2}$

$= 1.08 \times 10^{-3}$ mol in 25.0 cm^3 (1)

(iv) $n(R) = 1.08 \times 10^{-3} \times \dfrac{250}{25.0} = 0.0108$ mol in 250 cm^3 (1)

(v) 0.0108 mol of **R** = 1.25 g of **R**

1 mol of **R** = $\frac{1.25 \times 1}{0.0108}$ = 115.7 = 116 g (1) [5]

(b) (i) M_r of **S** = 116
M_r of **T** = 134
M_r of **U** = 150 **all three needed** (1)

(ii) **S** (1) [2]

Q# 160/ ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) $K_P = \frac{p(NO)^4 \, p(H_2O)^6}{p(NH_3)^4 \, p(O_2)^5}$ (1)

atmospheres **or** Pa **or** kPa (1)
allow ecf on incorrect powers [2]

(b) (i) **increasing temperature**
yield of NO is decreased **or** reaction moves to LHS (1)
forward reaction is exothermic (1)

(ii) **decreasing the pressure**
yield of NO is increased **or** reaction moves to RHS (1)
more moles/molecules of gas on RHS **or**
fewer moles/molecules of gas on LHS (1) [4]

Q# 161/ ALvl Chemistry/2013/s/TZ 1/Paper 4/Q# 1/www.SmashingScience.org

1 (a) (i) $NaOH + HCl \rightarrow NaCl + H_2O$ (1)

$(NH_4)_2SO_4 + 2NaOH \rightarrow 2NH_3 + Na_2SO_4 + 2H_2O$ (1)

allow ionic equations in each case

(ii) $n(NaOH) = n(HCl) = \frac{39.2 \times 2.00}{1000} = 0.0784$ (1)

(iii) $n(NaOH) = n(HCl) = \frac{29.5 \times 2.00}{1000} = 0.059$ (1)

(iv) $n(NaOH) = 0.0784 - 0.059 = 0.0194$ (1)

(v) $n[(NH_4)_2SO_4] = \frac{0.0194}{2} = 9.7 \times 10^{-3}$ (1)

(vi) mass of $(NH_4)_2SO_4 = 9.7 \times 10^{-3} \times 132.1 = 1.2814$ g (1)

(vii) % of $(NH_4)_2SO_4 = \frac{1.2814 \times 100}{2.96} = 43.30405405 = 43.3$
give one mark for the correct expression (1)
give one mark for answer given as 43.3 – i.e. to 3 sig. fig. (1)
allow ecf where appropriate [9]

Q# 162/ ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

3 (a) (i) $N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$ **or**
$N_2(g) + 3H_2(g) \rightarrow 2NH_3(g)$

state symbols required (1)

(ii) **pressure** between 60 and 250 atm **or**
between 60×10^5 Pa and 250×10^5 Pa (1)

temperature between 300 and 550 °C (1)

catalyst iron / iron oxide (1)

(iii) manufacture of HNO_3 / as a cleaning agent / refrigerant / fertiliser / manufacture of fertilisers / explosives / to remove SO_2 from combustion products of hydrocarbon fuels
(1) [5]

(b) (i) NH_4Cl **and** $Ca(OH)_2$
both formulae required (1)

(ii) $2NH_4Cl + Ca(OH)_2 \rightarrow CaCl_2 + 2NH_3 + 2H_2O$ **or**
$NH_4^+ + OH^- \rightarrow NH_3 + H_2O$

correct products (1)
correctly balanced equation (1)

(iii) CaO (1)
it is not an acid / it is basic / it does not react with NH_3 **or**
both P_2O_5 / P_4O_{10} **and** H_2SO_4 are acidic / react with NH_3 (1) [5]

Q# 163/ ALvl Chemistry/2012/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(b) $K_c = \dfrac{[HI]^2}{[H_2]\times[I_2]}$ (1)

no units – must be clearly stated (1) [2]

(c) (i) no change (1)
K_c has no units **or**
same no. of molecules / moles each side of equilibrium (1)

(ii) equilibrium moves to RHS (1)
K_c increases with decreasing temperature **or**
forward reaction is exothermic **or**
reverse reaction is endothermic (1) [4]

(d)

	$H_2(g)$	+	$I_2(g)$	$\rightleftharpoons$	$2HI(g)$	
initial moles	0.02		0.02		0	
equil. moles	(0.02 – y)		(0.02 – y)		2y	(1)
equil. conc/mol dm^{-3}	$\frac{(0.02 - y)}{1}$		$\frac{(0.02 - y)}{1}$		$\frac{2y}{1}$	

$K_c = \frac{HI^2}{[H_2]\times[I_2]} = \frac{(2y)^2}{(0.02-y)^2} = 59$ (1)

$\frac{2y}{(0.02-y)} = \sqrt{59} = 77$

$2y = (7.7 \times 0.02) - 7.7y$

$9.7y = 0.154$

gives $y = \frac{0.154}{9.7} = 0.0159 = 0.016$ (1)

at equilibrium

$n(HI) = 2 \times 0.016 = 0.032$ **and**
$n(H_2) = n(I_2) = (0.02 - 0.016) = 0.004$ (1)

allow ecf where possible [4]

Q# 164/ ALvl Chemistry/2012/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) In this part, in each case, the 'effect' must be correctly stated in order to gain the explanation mark.

higher temperature
yield is reduced/equilibrium goes to LHS (1)
because forward reaction is exothermic/reverse reaction is endothermic (1)

higher pressure
yield is increased **or** equilibrium goes to RHS (1)
fewer moles/molecules on RHS **or** more moles/molecules on LHS (1)

use of catalyst
yield does not change (1)
forward and backward rates speeded up by same amount (1) [6]

Q# 165/ ALvl Chemistry/2011/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(e) temperature of 450°C (1)
pressure of 1 – 2 atm (1)
V_2O_5/vanadium(V) oxide/vanadium pentoxide catalyst (1) [3]

Q# 166/ ALvl Chemistry/2010/w/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

2 (a) $N_2 + 3H_2 \rightleftharpoons 2NH_3$ (1) [1]

(b) temperature between 300 and 550°C (1)

correct explanation of effect of temperature on rate of formation of NH_3 **or** on position of equilibrium (1)

catalyst of iron **or** iron oxide (1)

to speed up reaction **or** to reduce E_a (1) [4]

(c) manufacture of HNO_3
or explosives
or nylon
or as a cleaning agent
or as a refrigerant (1) [1]

Q# 167/ ALvl Chemistry/2010/s/TZ 1/Paper 4/Q# 2/www.SmashingScience.org

(c) (i) iron **or** iron oxide (1)
100 to 500 atm **and** 400–550°C
units necessary – allow other correct values and units (1)

Q# 168/ ALvl Chemistry/2009/s/TZ 1/Paper 4/Q# 3/www.SmashingScience.org

(c) low temperature (1)
because forward reaction is exothermic (1)

high pressure (1)
because forward reaction goes to fewer molecules (1)
or shows a reduction in volume

increase [CO] **or** $[H_2]$
or remove CH_3OH (1)

correct explanation in terms of the effect of the change
on the position of equilibrium or on the rate of reaction (1)
(any two pairs) [4]

(ii)

	CO_2	+	H_2	$\rightleftharpoons$	CO	+	H_2O	
initial moles	0.50		0.50		0.20		0.20	
equil. moles	(0.50-x)		(0.50-x)		(0.20+x)		(0.20+x)	(1)
equil. concn.	$\frac{(0.50-x)}{1}$		$\frac{(0.50-x)}{1}$		$\frac{(0.20+x)}{1}$		$\frac{(0.20+x)}{1}$	

$K_c = \frac{[CO][H_2O]}{[CO_2][H_2]}$ (1)

$K_c = \frac{(0.20+x)^2}{(0.50-x)^2} = 1.44$ (1)

gives x = 0.18 (1)

at equilibrium,
$n(CO_2) = n(H_2) = 0.32$ **and**
$n(CO) = n(H_2O) = 0.38$ (1)

Allow ecf on wrong values of x that are less than 0.5. [7]

[Total: 13 max]