Student Number……...

Mark……...

Chemistry

2021 Term 4

Working Scientifically

General Instructions

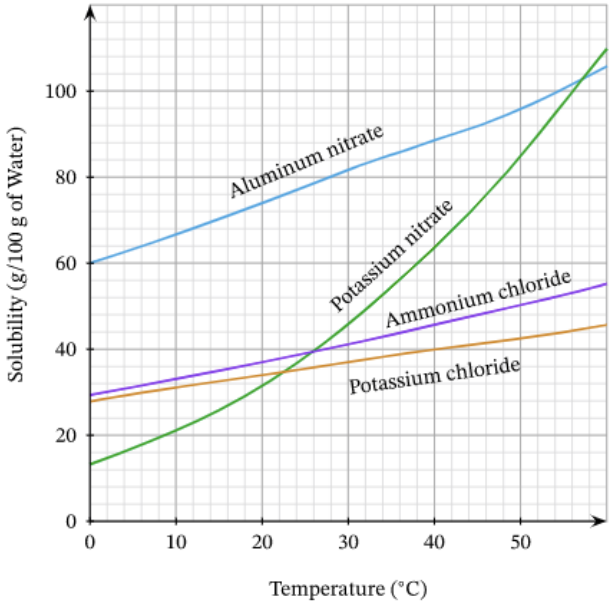
- Reading time – 5 minutes
- Working time – 70 minutes
- Write using black pen
- Draw diagrams using pencil
- NESA approved calculators may be used
- A Formulae sheet, data sheet and Periodic Table are provided
- Answer questions in the spaces provided. These spaces provide guidance for the expected length of your response
- Show all relevant working in questions involving calculations
- Extra working space is provided at the back of the exam booklet. If you use this space, clearly indicate which question you are answering.

Attempt Questions 1-8

Total Marks – 40

Question 1 (5 marks)

Show all relevant working to determine which of the salts below will have the greatest concentration of ions in mol L^{-1} at 50° C. **5**



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Question 2 (6 marks)

Silver carbonate is only slightly soluble in water at 25°C

(a) Write an ionic equation for the dissociation of solid silver carbonate in water. **1**

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(b) Write the solubility product expression, Ksp, for silver carbonate. **1**

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(c) Calculate the concentration of silver ions in a saturated solution of silver carbonate, in mol L^{-1}, at 25°C. **2**

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(d) Calculate the molar solubility of silver carbonate in a 0.15 mol L^{-1} sodium carbonate. solution. **2**

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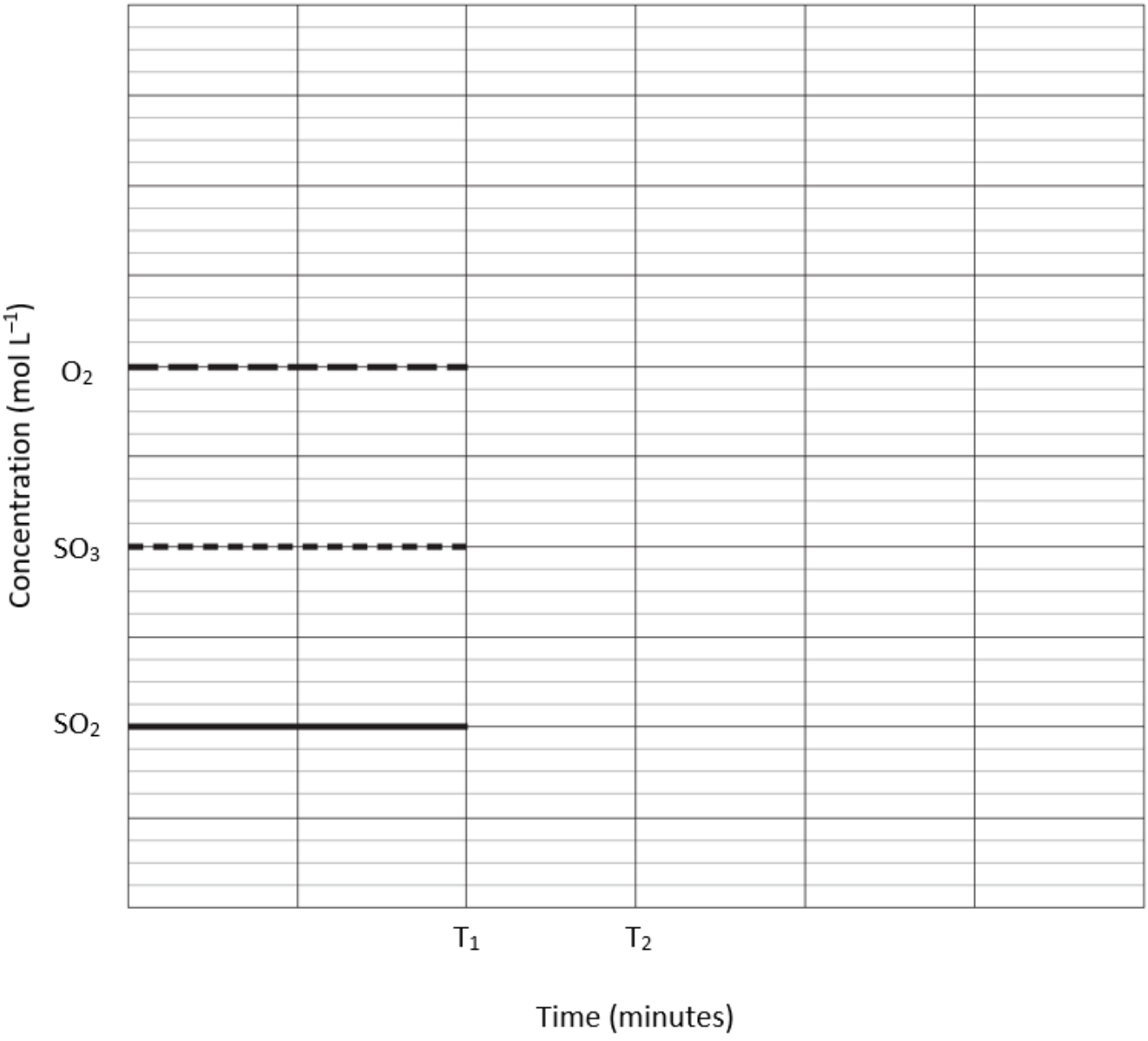
Question 3 (3 marks)

An investigation was carried out to track the changes in concentration of reactants and products for the equilibrium system provided.

$$2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$$

At time T_1, the volume of the container was decreased, causing the concentrations of the gases present to change by 25%, after which, the system underwent a change to re-establish equilibrium by time T_2. At this point, the concentration of oxygen gas was recorded to be one sixth higher than the initial amount.

Sketch the concentrations after time T_1 for each of the species until the end of the graph. **3**



Question 4 (4 marks)

Nitrosyl chloride was trapped in a 2 litre vessel with oxygen gas to make the equilibrium system shown in the chemical equation:

$$2\ NOCl(g) + O_2(g) \rightleftharpoons 2\ NO_2(g) + Cl_2(g)$$

In this experiment, 1.50 moles of nitrosyl chloride was allowed to react with 0.80 moles of oxygen gas. At equilibrium, the concentration of chlorine gas was found to be 0.30 mol L^{-1}.

Determine the value of the equilibrium constant for this reaction. **4**

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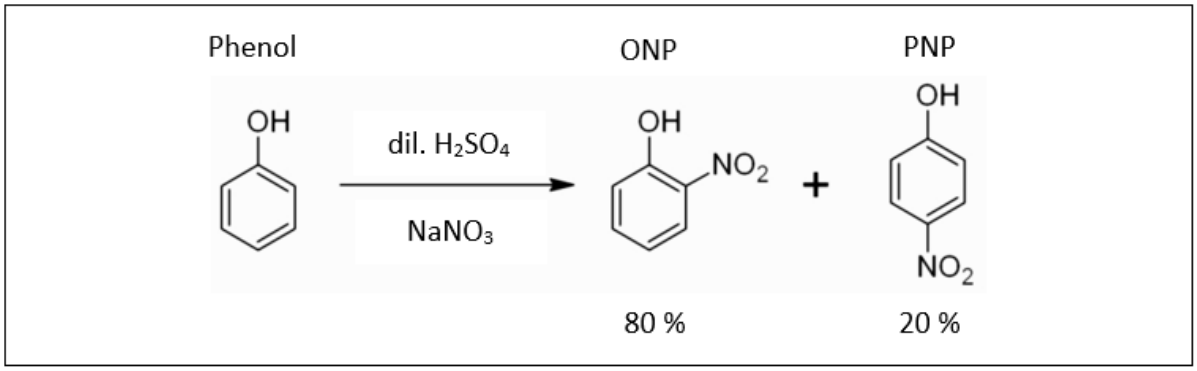
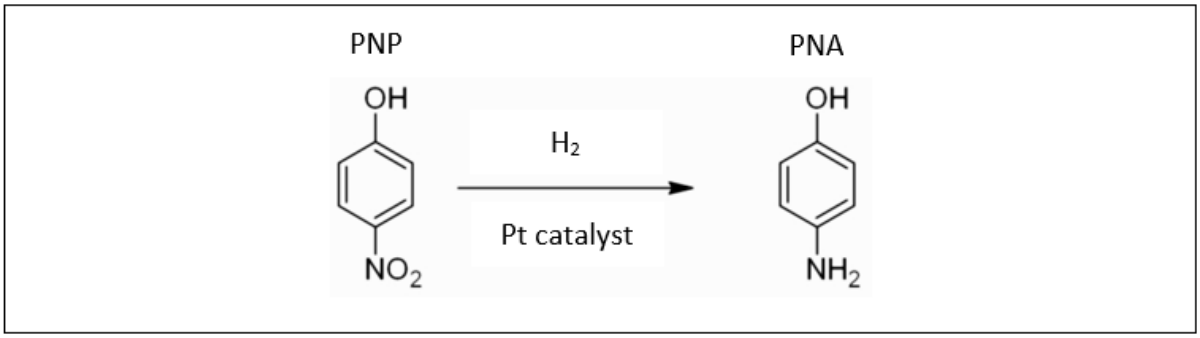
Question 5 (4 marks)

Paracetamol (acetaminophen) is a commercially available painkiller medication used to treat body aches and pains. It can be synthesised following the three-step process outlined in the series of reactions shown.

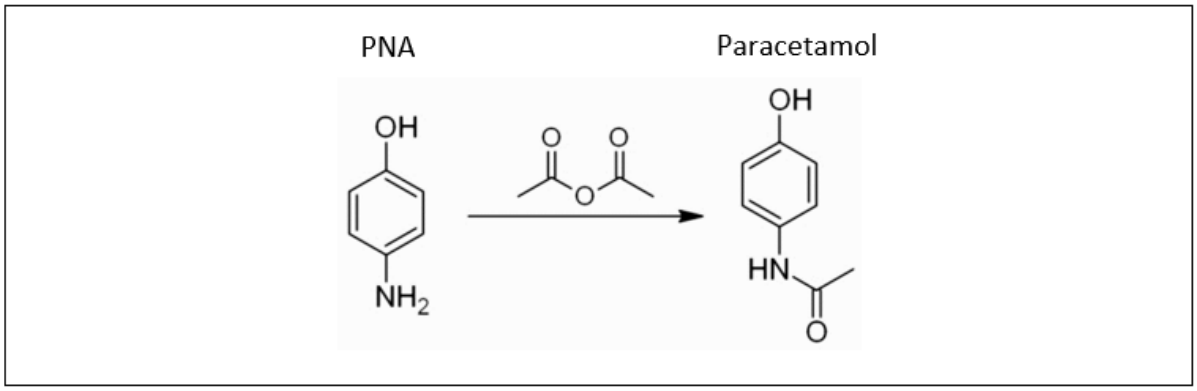
Step 1



Step 2



Step 3



(a) Evaluate the impact of step 1 on the overall yield of Paracetamol. **2**

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(b) Explain the beneficial design consideration applied to step 2. **2**

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Question 6 (4 marks)

Over 200 million tonnes of sulfuric acid is produced annually worldwide. Initially, sulfur is converted to sulfur dioxide:

$$S(s) + O_2(g) \rightarrow SO_2(g) \qquad \Delta H = -297 \text{ kJ mol}^{-1}$$

(a) Using the data below, determine whether the formation of sulfur dioxide is spontaneous at 298 K. **2**

Species	S (J K^{-1} mol^{-1})
S	31.8
O_2	205.2
SO_2	248.1

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(b) The sulfur dioxide is then passed over a V_2O_5 catalyst to form sulfur trioxde, in a step termed the Contact Process:

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \quad \Delta H = -197 \text{ kJ·mol}^{-1}$$

The sulfur trioxide ultimately combines with water through a series of steps to produce sulfuric acid.

In terms of collision theory, explain the effect of the V_2O_5 catalyst in the equilibrium reaction above. **2**

Question 6 continued on page 9

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Question 7 (2 marks)

A student wishes to set up a demonstration of dynamic equilibrium between copper sulfate solid and its ions:

$CuSO_4(s) \rightleftharpoons Cu^{2+}(aq) + SO_4^{2-}(aq)$

The student takes a beaker of distilled water, adds some solid copper sulfate, and covers the beaker with cling wrap.

(a) Identify ONE other requirement of the experimental method that must be made for this to be a valid demonstration of dynamic equilibrium. **1**

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(b) Clearly identify an observation the student could make to be certain that dynamic equilibrium had been reached. **1**

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Question 8 (12 marks)

The Haber process requires supplies of nitrogen and hydrogen, which are derived from air, water and natural gas.

The hydrogen is commonly derived from the reaction of methane (natural gas) with steam in a process called primary steam reforming.

The hydrogen is extracted from pressurised natural gas by reacting the natural gas with steam over a nickel catalyst at 750^{o}C in a furnace. Carbon monoxide and carbon dioxide are also formed, and the reaction is endothermic ($\Delta H = +210$ kJ mol^{-1}).

In the reaction one mole of methane gas reacts with one mole of steam to produce one mole of carbon monoxide and three moles of hydrogen gas. This reaction is reversible and reaches equilibrium in the reaction vessel.

(a) Write a balanced thermochemical equation for the reaction of methane with steam to produce carbon monoxide and hydrogen gas. Include states in the equation.
2

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(b) Le Chatelier's Principle states "*If a system is in equilibrium and a change is made that disturbs the equilibrium, then the system alters in such a way as to counteract the change and a new equilibrium is established".*

Account for the changes to the equilibrium system for the reaction of methane with steam for each of the following changes in the reaction vessel:

(i) Increasing the amount of steam **2**

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(ii) Increasing the pressure **2**

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(iii) Increasing the temperature **2**

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(iv) Removing hydrogen gas as it forms **2**

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(v) Adding more catalyst to the reaction vessel. **2**

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Working Scientifically - Extra writing space

If you use this space, clearly indicate which question you are answering.

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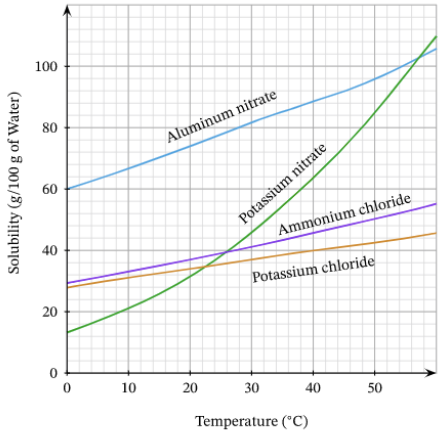
WS Term 4 Chemistry answers 2021

Question 1 (5 marks)

Show all relevant working to determine which of the salts below will have the greatest concentration of ions in mol L^{-1} at 50° C. **5**



Formula	Solubility at 50° (g)mass	MM	Moles m/MM	Most ions moles x number of ions	Concentration of ions in moles per litre
$Al(NO_3)_3$	96	26.98 + 3(14.01 +3(16))	0.451	0.451 x 4 = 1.80	18.0
KNO_3	84	39.1 + 14.01 + 3(16)	0.831	0.831 x 2 = 1.62	16.2
NH_4Cl	50	14.01 + 4(1.008) + 35.45	0.935	0.935 x 2 = 1.87	18.7
KCl	42	39.1 + 35.45	0.56	0.56 x 2 = 1.12	11.2

Ammonium chloride will have the greatest concentration of ions in solution.

Marking Criteria	*Mark(s)*
• Identifies the solution with the highest concentration of ions • 5 process steps shown with relevant working • Solubility from the graph(s), Molar mass(M), Moles(n), Number of ions(i), concentration in $molL^{-1}$ (c)	5
• One error in the calculations	4
• Most relevant working shown	3
• Some relevant working shown	2
• Any relevant information	1

Question 2 (6 marks)
Silver carbonate is only slightly soluble in water at 25°C

(a) Write an ionic equation for the dissociation of solid silver carbonate in water. **1**

$Ag_2CO_3\ (s) \rightleftarrows 2Ag^+\ (aq) + CO_3^{2-}\ (aq)$

Marking Criteria	*Mark(s)*
• Correct ionic equation with states and equilibrium arrows	1

(b) Write the solubility product expression, Ksp, for silver carbonate. **1**

$Ksp = [Ag^+]^2[CO_3^{2-}]$

Marking Criteria	*Mark(s)*
• Correct Ksp expression	1

(c) Calculate the concentration of silver ions in a saturated solution of silver carbonate, in mol L^{-1}, at 25°C. **2**

Let solubilty = s therefore

$[CO_3^{2-}] = s$ and $[Ag^+] = 2s$

$Ksp = 8.46 \times 10^{-12} = (2s)^2 \times s = 4s^3$

$s = 1.3 \times 10^{-4}$ mol L^{-1}

therefore $[Ag^+] = 2s = 2 \times 1.3 \times 10^{-4} = 2.6 \times 10^{-4}$ mol L^{-1}

Marking Criteria	*Mark(s)*
• Correct calculation with relevant working	2
• Some correct relevant calculation	1

(d) Calculate the molar solubility of silver carbonate in a 0.15 mol L^{-1} sodium carbonate. solution. **2**

$Ksp = 8.46 \times 10^{-12} = [Ag^+]^2[CO_3^{2-}]$

$[CO_3^{2-}] = 0.15 + s$ but as Ksp is very small, s is very small so disregard s

$Ksp = 8.46 \times 10^{-12} = [Ag^+]^2[0.15]$ (common ion effect)

$[Ag^+] = 7.50 \times 10^{-6}$

Therefore, molar solubility of $Ag_2CO_3 = 0.5 \times 7.50 \times 10^{-6}$

$= 3.75 \times 10^{-6}$

Marking Criteria	*Mark(s)*
• Correct calculation with relevant working	2

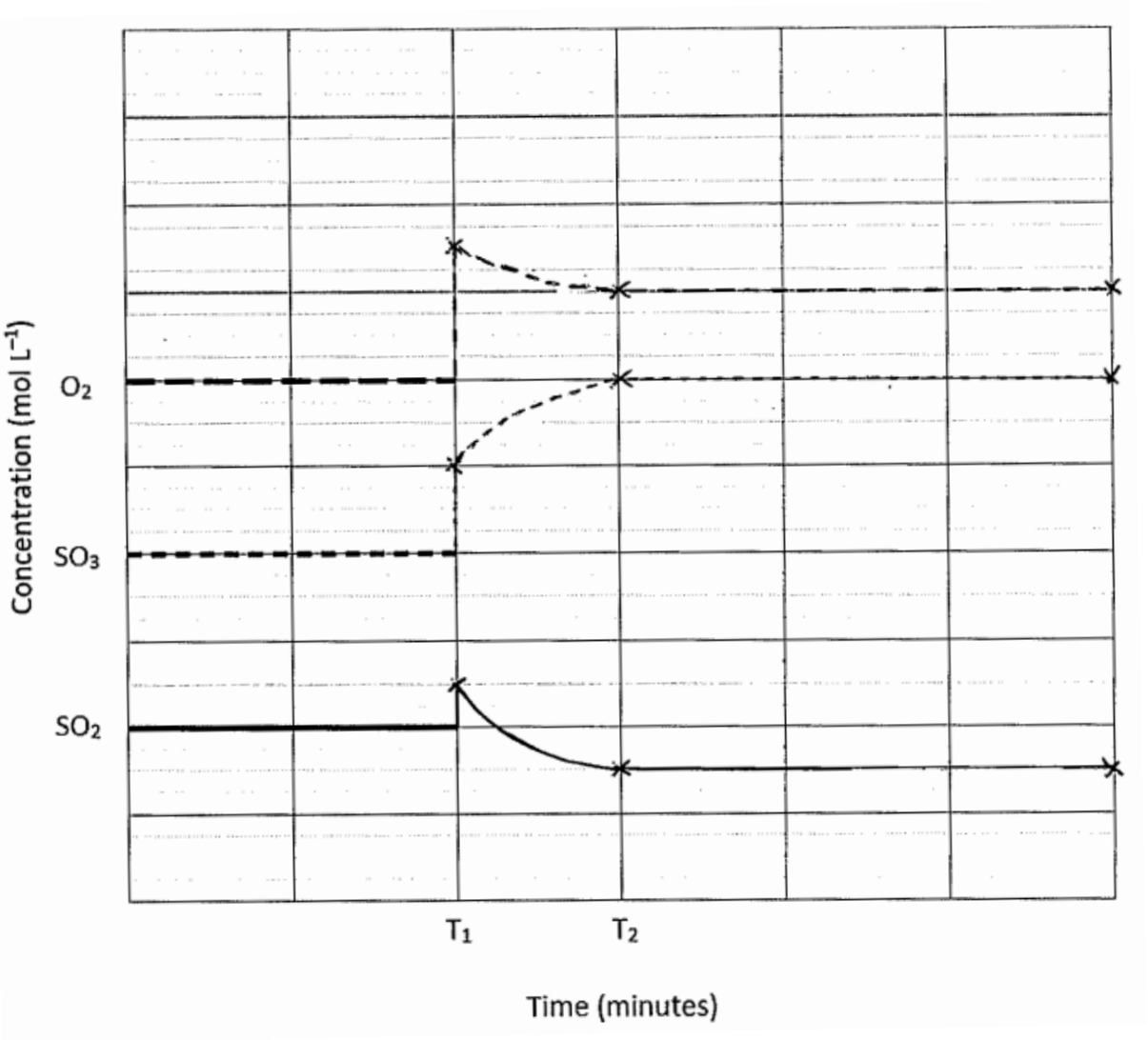
• Some correct calculation	1

Question 3 (3 marks)
An investigation was carried out to track the changes in concentration of reactants and products for the equilibrium system provided.

$$2\ SO_3(g) \rightleftharpoons 2\ SO_2(g) + O_2(g)$$

At time T_1, the volume of the container was decreased by 20 % after which the system underwent a change to re-establish equilibrium by time T_2. At this point, the concentration of oxygen gas was recorded to be one sixth higher than the initial amount.
Sketch the concentrations after time T_1 for each of the species until the end of the graph. **3**

Sample answer:



Marking Criteria	*Mark(s)*
• Correctly sketches the changes in concentration due to volume change and re-establishment of equilibrium (shift direction + stoichiometric ratio).	3
• Correctly sketches the changes in concentration due to volume change or re-establishment of equilibrium.	2
• Provides some correct features.	1

Question 4 (4 marks)

Nitrosyl chloride was trapped in a 2 litre vessel with oxygen gas to make the equilibrium system shown in the chemical equation:

$$2\ NOCl(g) + O_2(g) \rightleftharpoons 2\ NO_2(g) + Cl_2(g)$$

In this experiment, 1.50 moles of nitrosyl chloride was allowed to react with 0.80 moles of oxygen gas. At equilibrium, the concentration of chlorine gas was found to be 0.30 mol L^{-1}.
Determine the value of the equilibrium constant for this reaction. **4**

Sample answer:

	2 NOCl	O_2	2 NO_2	Cl_2
$[NOCl] = 1.50 / 2 = 0.75$ mol L^{-1}				
$[O_2] = 0.80 / 2 = 0.40$ mol L^{-1}				
initial	0.75 mol L^{-1}	0.40 mol L^{-1}	0 mol L^{-1}	0 mol L^{-1}
change	– 2x	– x	+ 2x	+ x
equilibrium	0.75 – 2x	0.40 – x	2x	x
since x = 0.30 mol L^{-1}				
	0.15 mol L^{-1}	0.10 mol L^{-1}	0.60 mol L^{-1}	0.30 mol L^{-1}

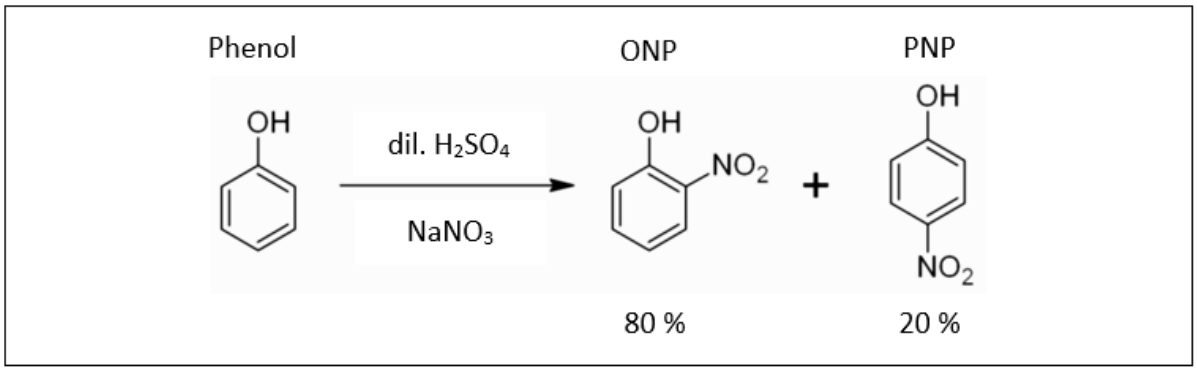
$K = [NO_2]^2\ [Cl_2] / [NOCl]^2\ [O_2] = (0.60)^2 \times (0.30) / (0.15)^2\ (0.10) = 48$

Marking Criteria	*Mark(s)*
• Correctly calculates the equilibrium constant, showing all relevant working (conversion to concentration, ICE table, K expression).	4
• Provides correct steps in the calculation of the equilibrium constant.	3
• Provides some relevant calculation steps.	2
• Provides some relevant information.	1

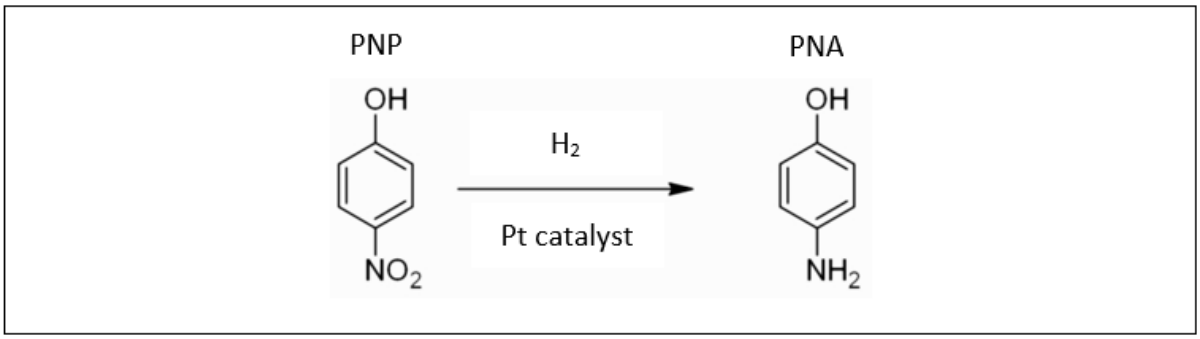
Question 5 (4 marks)

Paracetamol (acetaminophen) is commercially available painkiller medication used to treat body aches and pains. It can be synthesised following the three step process outlined in the series of reactions shown.

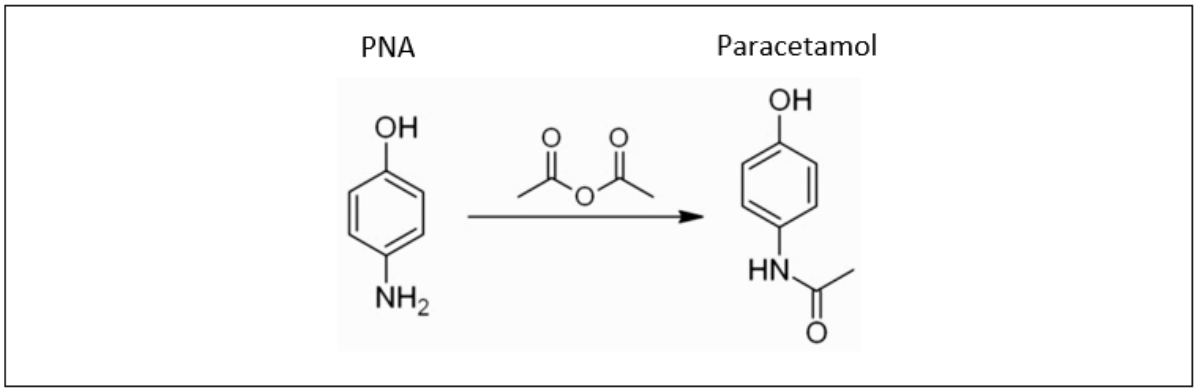
Step 1



Step 2



Step 3



(a) Evaluate the impact of step 1 on the overall synthesis of Paracetamol. **2**

Sample answer:

The first step limits the amount of Paracetamol that can be synthesised, as it produces two products, of which only the minor one is used for the remainder of the process. This converts 20 % of the starting material into the desired product used in the subsequent steps, which effectively reduces the overall yield of the process.

Marking Criteria	*Mark(s)*
• Explains the problem with Step 1 in relation to the synthesis process of Paracetamol.	2
• Provides some relevant information.	1

(b) Explain the beneficial design consideration applied to step 2. **2**

Sample answer:

A platinum catalyst is used in this step to improve the rate of reaction. This improves the efficiency of the process by reducing the time interval for this step, resulting in a more economical production of Paracetamol.

Marking Criteria	*Mark(s)*
• Identifies the design consideration applied to Step 2 and explains the benefit associated with use.	2
• Provides some relevant information	1

Question 6 (4 marks)

Over 200 million tonnes of sulfuric acid is produced annually worldwide. Initially, sulfur is converted to sulfur dioxide:

$S_{(s)} + O_{2(g)} \rightarrow SO_{2(g)}$, $\Delta H = -297$ kJ mol^{-1}

(a) Using the data below, determine whether the formation of sulfur dioxide is spontaneous at 298 K. **2**

Species	S (J K^{-1} mol^{-1})
S	31.8
O_2	205.2
SO_2	248.1

Marking Criteria	*Mark(s)*
• Correctly calculates ΔG • Correctly deduces spontaneity based on ΔG OR • Correctly calculates ΔS with units • Explains the effect of negative ΔH and positive ΔS on ΔG • Correctly deduces spontaneity based on ΔG	2
• Correctly calculates ΔG OR • Makes one error in calculation ΔG • Correctly deduces spontaneity based on ΔG	1

$\Delta G = \Delta H - T\,\Delta S$
$\Delta H = -297$ kJ mol^{-1}
T = 298 K
$\Delta S = S(SO_2) – S(S) – S(O_2) = 248.1-(205.2+31.8) = 11.1$
$\Delta G = -297 \times 10^3 – 11.3*298 = -300.3$ kJ mol^{-1}
ΔG is negative, therefore reaction is spontaneous

Marking comments: many students left out the units for ΔG, although it was not required, this is a terrible habit to develop. A significant number of students did not account for the fact that S is in J K^{-1} mol^{-1} and enthalpy and Gibbs free energy is in kJ mol^{-1}. A small number of students mixed up whether a negative ΔG meant that the reaction was spontaneous or not.

(b) The sulfur dioxide is then passed over a V_2O_5 catalyst to form sulfur trioxde, in a step termed the contact process:
$2\ SO_{2(g)} + O_{2(g)} \rightleftharpoons 2\ SO_{3(g)} : \Delta H = -197$ kJ·mol^{-1}
The sulfur trioxide ultimately combines with water through a series of steps to produce sulfuric acid.
In terms of collision theory, explain the effect of the V_2O_5 catalyst in the equilibrium reaction above. **2**

Marking Criteria	*Mark(s)*
• Relates collision theory to no change in equilibrium composition • Relates collision theory to shorter time to reach equilibrium	2
• One of the above OR Identifies no change to equilibrium composition and shorter time to equilibrium OR • Relates the use of a catalyst to a higher rate of successful collisions	1

Collision theory states that colliding particles will react if they approach one another with the correct orientation and have sufficient energy to overcome the activation energy. Adding the V_2O_5 catalyst will lower the activation energy of both the forward and reverse reactions. This will increase the reaction rate of both forward and reverse reaction by the same factor, leaving the position of the equilibrium unchanged, but bringing the system to equilibrium more quickly.
Marking comments: many students did not address the part of the question relating to equilibrium, or merely stated that the position of the equilibrium would not change without explaining why. Some students did not discuss collisions, even though they identified that the rate increased.

Question 7 (2 marks)
A student wishes to set up a demonstration of dynamic equilibrium between copper sulfate solid and its ions:
$CuSO_{4(s)} \rightleftharpoons Cu^{2+}_{(aq)} + SO_4^{2-}{}_{(aq)}$
The student takes a beaker of distilled water, adds some solid copper sulfate, and covers the beaker with cling wrap.

(a) Identify ONE other requirement of the experimental method that must be made for this to be a valid demonstration of dynamic equilibrium. **1**

Marking Criteria	*Mark(s)*
• Identifies necessary condition	1

A greater amount of solid copper sulfate must be added than can dissolve in the amount of water in the beaker at the temperature of the experiment OR the temperature must be kept constant.
Marking comments: the question was referring to the requirements for dynamic equilibrium to be established, answers referring to having the amount of $CuSO_4$ past the saturation point addressed the dynamic part, and answers referring to keeping the temperature constant/insulting the system ensured that K doesn't change. The system was closed already, answers referring to this were not awarded a mark. Cleaning the beaker is nice, but it is not a requirement for equilibrium to be established.

(b) Clearly identify an observation the student could make to be certain that dynamic equilibrium had been reached. **1**

Marking Criteria	*Mark(s)*
• Identifies suitable observation	1

The amount of undissolved solid remains constant OR the intensity of the colour of the solution remains unchanged.

Marking comments: Students need to be careful when discussing colour changes. Diluting a solution is not generally referred to as a colour change, so responses which referred to no colour change were not sufficiently clear to show that it was intensity which wouldn't change. When dynamic equilibrium is established, the shape of the solid can change.

Question 8 (12 marks)
The Haber process requires supplies of nitrogen and hydrogen which are derived from air, water and natural gas.
The hydrogen is commonly derived from the reaction of methane (natural gas) with steam in a process called primary steam reforming.
The hydrogen is extracted from pressurised natural gas by reacting the natural gas with steam over a nickel catalyst at 750^{o}C in a furnace. Carbon monoxide and carbon dioxide are also formed and the reaction is endothermic ($\Delta H = +210$ kJ/mol).
In the reaction one mole of methane gas reacts with one mole of steam to produce one mole of carbon monoxide and three moles of hydrogen gas. This reaction is reversible and reaches equilibrium in the reaction vessel.

(a) Write a balanced thermochemical equation for the reaction of methane with steam to produce carbon monoxide and hydrogen gas. Include states in the equation. **2**

(b) Le Chatelier's Principle states "*If a system is in equilibrium and a change is made that disturbs the equilibrium, then the system alters in such a way as to counteract the change and a new equilibrium is established".*

Explain the changes to the equilibrium system for the reaction of methane with steam for each of the following changes in the reaction vessel:

(i) Increasing the amount of steam **2**

(ii) Increasing the pressure **2**

(iii) Increasing the temperature **2**

(iv) Removing hydrogen gas as it forms **2**

(v) Adding more catalyst to the reaction vessel. **2**

Sample Answer :

(a) $CH_{4(g)} + H_2O_{(g)} \rightleftharpoons CO_{(g)} + 3H_2O_{(g)}$ $\Delta H = +210$ kJ/mol

Marking Criteria	*Mark(s)*
• (a) Correct balanced thermochemical equation with states	2
• ONE error or missing component in equation	1

(b) (i) Equilibrium will shift in the forward direction or to RHS to use some of the extra steam that has been added.

(ii) Equilibrium will shift in the backward direction or to the LHS to reduce the number of gaseous molecules and thus the pressure. LHS has 2 moles of gas and RHS had 4 moles of gas.

(iii) Equilibrium will shift in forward direction or to RHS to use some of the extra heat as this is an endothermic reaction.

(iv) Equilibrium will shift in forward direction or to the RHS to replace the hydrogen gas removed

(v) Equilibrium will be reached faster but the position will not be affected as catalyst does not affect position of equilibrium; only speeds up the rate of reaction in both directions.

Marking Criteria	*Mark(s)*
• (b) (i) Correct direction of shift and explanation	2
• Correct direction of shift	1
• (ii) Correct direction of shift and explanation	2
• Correct direction of shift	1

• (iii) Correct direction of shift and explanation	2
• Correct direction of shift	1
• (iv) Correct direction of shift and explanation	2
• Correct direction of shift	1
• (v) Correct direction of shift and explanation	2
• Correct direction of shift	1