Equilibrium Past Papers

1. In which of the following will an increase in pressure lead to an increase in concentration of the product(s)?

A $H_2(g) + Cl_2(g) \rightleftharpoons 2HCl(g)$

B $2N_2O_5(g) \rightleftharpoons 2N_2O_4(g) + O_2(g)$

C $N_2O_4(g) \rightleftharpoons 2NO_2(g)$

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

2. $C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g)$ $\Delta H° = +157\,kJ\,mol^{-1}$

The conditions favouring the highest equilibrium yield of ethene in the above reaction are

A low pressure and high temperature

B low pressure and low temperature

C high pressure and high temperature

D high pressure and low temperature.

3. Phosphoric acid is a weak acid and undergoes partial dissociation according to the equation

$$H_3PO_4 \rightleftharpoons H_2PO_4^- + H^+$$

The position of equilibrium would be shifted to the right by the addition of

A a catalyst

B sulfuric acid

C sodium hydroxide

D sodium dihydrogenphosphate.

4. Butanoic acid is a weak acid which dissociates as shown.

$$C_3H_7COOH(aq) + H_2O(\ell) \rightleftharpoons C_3H_7COO^-(aq) + H_3O^+(aq)$$

The equilibrium position can be shifted to the right by the addition of

A a catalyst

B sulfuric acid

C sodium hydroxide

D sodium butanoate.

5. Propanoic acid partially dissociates into ions in aqueous solution and an equilibrium is established.

Which of the following decreases in concentration when potassium propanoate is added to this equilibrium?

A Propanoate ions

B Hydronium ions

C Hydroxide ions

D Propanoic acid molecules

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

6. Which line in the table is correct for the concentration of $SO_3(g)$ at equilibrium and the equilibrium constant, K, when the pressure of the equilibrium mixture is increased at constant temperature?

	$[SO_3(g)]$ at equilibrium	Equilibrium constant, K
A	increase	no change
B	increase	increase
C	no change	increase
D	no change	no change

Equilibrium Past Papers

7. When sulfur dioxide and oxygen react the following equilibrium is established.

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

Which line in the table is correct if the temperature of the equilibrium mixture is increased?

	Equilibrium constant, K	*Concentration of SO_3 as temperature increases*
A	decreases	decreases
B	decreases	increases
C	increases	decreases
D	increases	increases

8. **Which change in reaction conditions will shift the position of equilibrium to the right in this reaction?**

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

A Increasing the temperature

B Removal of some oxygen gas

C Increasing the pressure

D Adding a catalyst

9. A reaction in dynamic equilibrium is one in which

A the concentration of the product is always independent of reaction conditions

B the enthalpy changes for the forward and the reverse reactions are equal

C the activation energies for the forward and the reverse reactions are equal

D the rates of the forward and the reverse reactions are equal.

10. $PCl_5 \rightleftharpoons PCl_3 + Cl_2$

Adding PCl_3 to the above system will

A increase the value of the equilibrium constant

B decrease the value of the equilibrium constant

C increase the concentration of PCl_5 and decrease the concentration of Cl_2

D decrease the concentration of PCl_5 and increase the concentration of Cl_2.

11. Hydrogen for use in ammonia production is produced by the endothermic reaction:

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g)$$

Which of the following will increase the equilibrium yield of hydrogen?

A Decrease the methane concentration

B Decrease the temperature

C Decrease the pressure

D Add a catalyst

12. $2NH_3(g) \rightleftharpoons N_2(g) + 3H_2(g) \quad \Delta H^\circ = 92\ kJ\ mol^{-1}$

The conditions favouring the decomposition of ammonia are

A low pressure and low temperature

B high pressure and low temperature

C low pressure and high temperature

D high pressure and high temperature.

13. Iodide ions are oxidised by acidified nitrite ions according to the equation

$$2NO_2^- + 2I^- + 4H^+ \rightarrow 2NO + I_2 + 2H_2O$$

Addition of sodium ethanoate to the reaction mixture slows down the formation of iodine.

The most likely explanation for this effect is that ethanoate ions

A remove iodine

B reduce the concentration of iodide ions

C react with nitrite ions

D react with hydrogen ions.

14. In the equilibrium $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ the forward reaction is endothermic.

Which one of the following causes an increase in the value of the equilibrium constant?

A The removal of NO_2

B An increase of pressure

C A decrease of temperature

D An increase of temperature

15. When one mole of phosphorus pentachloride was heated to 523 K in a closed vessel, 50% dissociated as shown.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g)$$

How many moles of gas were present in the equilibrium mixture?

A 0·5

B 1·0

C 1·5

D 2·0

Equilibrium Past Papers

16. $CH_3COOH + C_2H_5OH \rightleftharpoons CH_3COOC_2H_5 + H_2O$

The above reaction can be said to have reached equilibrium when

A the equilibrium constant K is equal to 1

B the reaction between the acid and the alcohol has stopped

C the concentrations of the products equal those of the reactants

D the rate of production of ethyl ethanoate equals its rate of hydrolysis.

17 When sulphur dioxide and oxygen react the following equilibrium is established.

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

The equilibrium constant for the reaction is 3300 at 630 °C and 21 at 850 °C.

Which line in the table is correct for the reaction?

	Sign of ΔH	Product yield as temperature increases
A	+	decreases
B	+	increases
C	–	decreases
D	–	increases

18 $N_2O_4(g) \rightleftharpoons 2NO_2(g) \quad \Delta H° = +57\ kJ\ mol^{-1}$

Which of the following will increase the equilibrium constant for the reaction?

A Use of a catalyst

B Increase of pressure

C Increase of temperature

D Decrease of temperature

19. **The equilibrium constant for a particular hydrolysis reaction has the value 3×10^4 at 25 °C. From this we can conclude that, at 25 °C, this hydrolysis reaction is**

A fast

B feasible

C exothermic

D endothermic.

20. When sulphur dioxide and oxygen react the following equilibrium is established.

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

The equilibrium constant for the reaction is 3300 at 630 °C and 21 at 850 °C.

Which line in the table is correct for the reaction?

	Sign of ΔH	Product yield as temperature increases
A	+	decreases
B	+	increases
C	–	decreases
D	–	increases

21. The reaction

$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$

has an equilibrium constant of 3·9 at 950 °C.

The equilibrium concentrations of CO(g), $H_2(g)$ and $H_2O(g)$ are given in the table.

Substance	Equilibrium concentration/mol l^{-1}
CO(g)	0·500
$H_2(g)$	0·100
$H_2O(g)$	0·040

What is the equilibrium concentration of $CH_4(g)$, in mol l^{-1}, at 950 °C?

A 0·049

B 0·200

C 4·90

D 20·0

22. At a particular temperature, 8·0 mole of NO_2 was placed in a 1 litre container and the NO_2 dissociated by the following reaction:

$2NO_2(g) \rightleftharpoons 2NO(g) + O_2(g)$

At equilibrium the concentration of NO(g) is 2·0 mol l^{-1}.

The equilibrium constant will have a value of

A 0·11

B 0·22

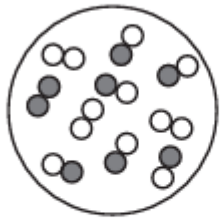
C 0·33

D 9·00.

Equilibrium Past Papers

23. The diagram below represents an equilibrium mixture for the reaction

$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$



What is the value of equilibrium constant?

A 0·083

B 0·50

C 2·0

D 12

24. $AgCl(s) \rightarrow Ag^+(aq) + Cl^-(aq)$

The solubility product (K_s) for silver chloride is given by the expression

$$K_s = [Ag^+(aq)]\,[Cl^-(aq)]$$

The formula mass of AgCl is 143·4.

$K_s = 1{\cdot}80 \times 10^{-10}$ at 25 °C.

The solubility of silver chloride, in mol l^{-1}, at 25 °C is

A $1{\cdot}80 \times 10^{-10}$

B $3{\cdot}60 \times 10^{-10}$

C $1{\cdot}34 \times 10^{-5}$

D $2{\cdot}68 \times 10^{-5}$.

25. The reaction

$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$

has an equilibrium constant of 3·9 at 950 °C.

The equilibrium concentrations of CO(g), $H_2(g)$ and $H_2O(g)$ are given in the table.

Substance	Equilibrium concentration/mol l^{-1}
CO(g)	$5{\cdot}0 \times 10^{-2}$
$H_2(g)$	$1{\cdot}0 \times 10^{-2}$
$H_2O(g)$	$4{\cdot}0 \times 10^{-3}$

What is the equilibrium concentration of $CH_4(g)$, in mol l^{-1}, at 950 °C?

A $2{\cdot}0 \times 10^{-7}$

B $4{\cdot}9 \times 10^{-5}$

C $3{\cdot}1 \times 10^{-5}$

D $4{\cdot}9 \times 10^{-1}$

26. The reaction

$$CO(g) + 3H_2(g) \rightleftharpoons CH_4(g) + H_2O(g)$$

has an equilibrium constant of 3·9 at 950 °C.

The equilibrium concentrations of CO(g), $H_2(g)$ and $H_2O(g)$ at 950 °C are given in the table.

Substance	Equilibrium concentration (mol l^{-1})
CO(g)	$5{\cdot}0 \times 10^{-2}$
$H_2(g)$	$1{\cdot}0 \times 10^{-2}$
$H_2O(g)$	$4{\cdot}0 \times 10^{-3}$

What is the equilibrium concentration of $CH_4(g)$, in mol l^{-1}, at 950 °C?

A $4{\cdot}9 \times 10^{-1}$

B $3{\cdot}1 \times 10^{-5}$

C $4{\cdot}9 \times 10^{-5}$

D $2{\cdot}0 \times 10^{-7}$

Equilibrium Past Papers

1. Dinitrogen tetroxide, $N_2O_4(g)$, dissociates to form nitrogen dioxide, $NO_2(g)$, according to the equation.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g)$$

0·28 mol of N_2O_4 gas is placed in an empty 1·00 litre flask and heated to 127 °C. When the system reaches equilibrium, 0·24 mol of NO_2 gas is present in the flask.

(*a*) Write down the expression for the equilibrium constant, K, for this reaction.

(*b*) Calculate the equilibrium constant, K, for the reaction at 127 °C. **3**

(c) At 25 °C, the numerical value of the equilibrium constant for this reaction is 0·12.
Explain whether the forward reaction is endothermic or exothermic. **1**

2. Consider the following reaction.

$$CS_2(g) + 4H_2(g) \rightleftharpoons CH_4(g) + 2H_2S(g)$$

At 900 °C the equilibrium concentrations are:

$[CS_2] = 0{\cdot}012\ \text{mol l}^{-1}$ $[H_2] = 0{\cdot}0020\ \text{mol l}^{-1}$
$[H_2S] = 0{\cdot}00010\ \text{mol l}^{-1}$ $[CH_4] = 0{\cdot}0054\ \text{mol l}^{-1}$

(*a*) Write down the expression for the equilibrium constant, K, for this reaction.

(*b*) Calculate the value of the equilibrium constant, K, at 900 °C.

Equilibrium Past Papers

3. The expression for the equilibrium constant of an esterification reaction is

$$K=\frac{[CH_3COOCH_2CH_3]\,[H_2O]}{[CH_3COOH]\,[CH_3CH_2OH]}$$

(*a*) Write the chemical equation for this esterification reaction.

(*b*) In an experiment to determine the value of the equilibrium constant, 0·70 moles of ethanoic acid and 0·68 moles of ethanol were mixed in a conical flask. The flask was stoppered to prevent the contents escaping and then placed in a water bath at 50 °C.

At equilibrium the mixture contained 0·24 moles of ethanoic acid.

(i) Why is it important to prevent the contents of the flask escaping?

(ii) Calculate K at 50 °C.

4. Difluoromethanimine, FN = CHF, can exist in two isomeric forms.

When a sample of the *trans*-isomer was dissolved in an organic solvent at 22 °C it was slowly converted into the *cis*-isomer. After 7 days, 95% of the *trans*-isomer had been converted and no further conversion occurred thereafter.

(*a*) Calculate the equilibrium constant for the conversion of *trans*-difluoromethanimine into its *cis*-isomer at 22 °C. **1**

(*b*) Suppose a sample of *cis*-difluoromethanimine was dissolved in the same organic solvent at 22 °C. Predict the percentage amount of the *cis*-isomer present in the solution after 7 days. **1**

Equilibrium Past Papers

5. Hydrogen gas and iodine gas combine directly to form hydrogen iodide, HI(g).

At constant temperature, an equilibrium is established.

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

(i) Write the expression for the equilibrium constant, *K*.

(ii) 0.25 moles of $H_2(g)$ and 0.25 moles of $I_2(g)$ were mixed in a sealed 1.0 litre reaction vessel. At equilibrium, 0.015 moles of $I_2(g)$ were present.

Calculate the equilibrium constant, *K*, for this reaction. **2**

6. Iodine solutions are prepared by dissolving iodine in aqueous potassium iodide. The following equilibrium is established.

$$I_2(aq) + I^-(aq) \rightleftharpoons I_3^-(aq)$$

(i) Write an expression for the equilibrium constant, K, for this reaction. **1**

(ii) A solution of iodine was prepared by dissolving iodine in $0{\cdot}239\ mol\,l^{-1}$ aqueous potassium iodide.

The following data was obtained by analysing the equilibrium mixture.

$$[I_2(aq)] = 1{\cdot}21 \times 10^{-3}\ mol\,l^{-1}$$
$$[I_3^-(aq)] = 0{\cdot}116\ mol\,l^{-1}$$

Calculate the equilibrium constant, K, for this reaction. **2**

Equilibrium Past Papers

7. Sulfur trioxide and sulfur dioxide are two oxides of sulfur.

Sulfur trioxide decomposes to form sulfur dioxide and oxygen.

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

(i) Write an expression for the equilibrium constant, K, for this reaction. **1**

(ii) In an experiment to determine the equilibrium constant, K, 0.700 moles of sulfur trioxide were placed in a sealed 1.00 litre container and heated to temperature T_1.

At equilibrium the mixture contained 0.125 moles of O_2.

Calculate the equilibrium constant, K, for the reaction at T_1. **2**

(iii) The experiment was repeated at the same temperature, T_1, using 0.700 moles of sulfur trioxide in a sealed 2.00 litre container.

State the effect of this change in volume on the value of the equilibrium constant, K. **1**

(iv) The experiment was then carried out using 0.700 moles of sulfur trioxide in a sealed 1.00 litre container at a different temperature, T_2.

The equilibrium constant, K, had a lower value at T_2 than at T_1.

Explain fully whether T_2 is a higher or lower temperature than T_1. **2**

Equilibrium Past Papers

8. Oceans are essential in reducing the concentration of carbon dioxide in the atmosphere. Around half of the carbon dioxide produced by burning fossil fuels dissolves in the surface water of oceans.

Carbon dioxide dissolves in water to form carbonic acid, $H_2CO_3(aq)$.

$$H_2O(\ell) + CO_2(g) \rightleftharpoons H_2CO_3(aq) \qquad \Delta H \text{ –ve}$$

Explain the effect rising seawater temperatures will have on the concentration of CO_2 dissolved in the oceans. **1**

9. Phosphorus forms different compounds with chlorine.

When heated, phosphorus pentachloride dissociates to form phosphorus trichloride and chlorine.

$$PCl_5(g) \rightleftharpoons PCl_3(g) + Cl_2(g) \qquad \Delta H = +124\,\text{kJ mol}^{-1}$$

In an experiment to determine the equilibrium constant, K, 0·100 mol of PCl_5 was placed in a sealed 1·00 litre flask and heated to 250 °C. At equilibrium 0·0420 mol of PCl_3 had been formed.

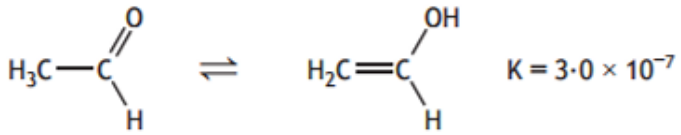
(i) Calculate the equilibrium constant, K, for the reaction at 250 °C. **3**

(ii) The temperature of the equilibrium mixture was increased to 400 °C.

Explain the effect of this change in temperature on the value of the equilibrium constant, K. **2**

10. Aldehydes and ketones can exist in two forms, a keto form and an enol form.

For example, the aldehyde ethanal exists in equilibrium with its enol form, ethenol.



$K = 3{\cdot}0 \times 10^{-7}$

ethanal (keto form) ⇌ ethenol (enol form)

These two different molecules are known as tautomers.

State which of the tautomers is the more abundant in this equilibrium. **1**

Equilibrium Past Paper Answers

1. D
2. A
3. C
4. C
5. **B**
6. A
7. A
8. C
9. D
10. D
11. C
12. C
13. D
14. D
15. C
16. D
17. **C**
18. C
19. B
20. **C**
21. A
22. A
23. **D**
24. D
25. B
26. C

1. a) $K = \frac{[NO_2]^2}{[N_2O_4]}$

b)

$$\underset{\substack{1mol\\0.12mol}}{N_2O_{4(g)}} \rightleftharpoons \underset{\substack{2mol\\0.24mol}}{2NO_{2(g)}}$$

∴ no of mol of N_2O_4 at equilibrium = 0.28mol − 0.12mol = 0.16mol

$$K = \frac{[NO_2]^2}{[N_2O_4]} = \frac{(0.24)^2}{0.16} = \frac{0.0576}{0.16} = 0.36$$

c) Forward reaction is endothermic as decreasing temperature favours reverse reaction

2a) $K = \frac{[CH_4]\,[H_2S]^2}{[CS_2]\,[H_2]^4}$

b) 281.25 $K = \frac{[CH_4]\,[H_2S]^2}{[CS_2]\,[H_2]^4} = \frac{(0.0054) \times (0.00010)^2}{(0.012) \times (0.0020)^4} = \frac{5.4 \times 10^{-11}}{1.9 \times 10^{-13}}$

3a $CH_3COOH + CH_3CH_2OH \longrightarrow CH_3COOCH_2CH_3 + H_2O$

b (i) System will not reach equilibrium

(ii) 4.0

Ethanoic Acid Remaining at equilibrium = 0.24mol
∴ Ethanoic acid reacted = 0.70 − 0.24mol = 0.46mol

$$\underset{\substack{1mol\\0.46mol\\\therefore 0.24mol\ remaining}}{CH_3COOH} + \underset{\substack{1mol\\0.46mol\\\therefore 0.22mol\ remaining}}{CH_3CH_2OH} \longrightarrow \underset{\substack{1mol\\0.46mol}}{CH_3COOCH_2CH_3} + \underset{\substack{1mol\\0.46mol}}{H_2O}$$

$$K = \frac{[CH_3COOCH_2CH_3]\,[H_2O]}{[CH_3COOH]\,[CH_3CH_2OH]} = \frac{0.46 \times 0.46}{0.24 \times 0.22} = 4.0$$

4a) 19 $K = \frac{[\text{cis-isomer}]}{[\text{trans-isomer}]} = \frac{95\%}{5\%} = 19$

b) 95% If starting position was 100% cis-isomer then the equilibrium would shift to left to get back to equilibrium position of 95% cis-isomer and 5% trans-isomer

Equilibrium Past Paper Answers

5. (i) $K = \dfrac{[HI]^2}{[H_2]\,[I_2]}$

(ii) 981.8

I_2 at start = 0.25mol I_2 at equilibrium = 0.015mol

$\therefore$ I_2 reacted = 0.25mol – 0.015mol = 0.235mol

H_2	+	I_2	$\rightleftharpoons$	$2HI$
1mol		1mol		2mol
0.235mol		0.235mol		0.470mol
(reacted)		(reacted)		(formed)

H_2 remaining at equilibrium = 0.25mol – 0.235mol = 0.015mol

$$K = \frac{[HI]^2}{[H_2]\,[I_2]} = \frac{(0.470)^2}{0.015 \times 0.015} = 981.8$$

6. (i) $K = \dfrac{[I_3^-]}{[I_2]\,[I^-]}$

(ii) 779

Assuming a 1 litre container:

$[I_2]$ 1.21×10^{-3} = 0.00121 mol l^{-1} (in question) $[I_3^-]$ = 0.116 mol l^{-1} (in question)

[KI] = 0.239 mol l^{-1} $\therefore$ $[I^-]$ = 0.239 mol l^{-1} (at start)

I_2	+	I^-	$\rightleftharpoons$	I_3^-
1mol		1mol		1mol
0.116mol		0.116mol		0.116mol
(used up)		(used up)		(formed)

but 0.116mol I^- used up in reaction so 0.123mol I^- remaining at equilibrium.

Assuming 1 litre container, $[I^-]$ at equilibrium is 0.123mol l^{-1}

$$K = \frac{[I_3^-]}{[I_2]\,[I^-]} = \frac{0.116}{0.00121 \times 0.123} = 779.4$$

7 (i) $K = \dfrac{[SO_2]^2[O_2]}{[SO_3]^2}$

(ii) 0.0386

$2SO_3$	$\rightleftharpoons$	$2SO_2$	+	O_2
2mol		2mol		1mol
0.25mol		0.25mol		0.125mol
(reacted)		(formed)		(formed)

no. of mol SO_3 unreacted = 0.700mol – 0.25mol = 0.45mol

$$K = \frac{[SO_2]^2[O_2]}{[SO_3]^2} = \frac{[0.25]^2 \times [0.125]}{[0.45]^2}$$

(iii) No effect

Only changes to temperature affect the equilibrium constant. Increasing volume will only decrease pressure and affect position of equilibrium.

(iv) reaction is endothermic Equilibrium shifts to the left

8. Concentration of dissolved CO_2 decreases as equilibrium moves to left.

9. (I) 0.0304

$$PCl_5 \rightleftharpoons PCl_3 + Cl_2$$

PCl_5	PCl_3	Cl_2
1mol	1mol	1mol
0.0420mol (reacted)	0.0420mol	0.0420mol

no. of mol PCl_5 unreacted = 0.1000mol – 0.0420mol = 0.0580mol

$$K = \frac{[PCl_3]\,[Cl_2]}{[PCl_5]} = \frac{[0.0420] \times [0.0420]}{[0.0580]} = 0.0304$$

(ii) More forward reaction
Value of K increases

Increase in temp favours the endothermic reaction (forward reaction)
More products formed and less reactants remain

10. Ethanal

As the value of K is well below 1 the equilibrium must lie well to the left.