7. Equilibria

7.1 Chemical equilibria- reversible reactions, dynamic equilibrium

Paper 1

Question Paper

1 When some solid $Ca_5(PO_4)_3OH$ is added to a beaker of water, an equilibrium is set up.

$$Ca_5(PO_4)_3OH(s) \rightleftharpoons 5Ca^{2+}(aq) + 3PO_4^{3-}(aq) + OH^-(aq)$$

Which compound, when added to the equilibrium mixture, increases the amount of $Ca_5(PO_4)_3OH(s)$ present?

A NH_3 **B** NH_4Cl **C** CH_3CO_2H **D** $NaCl$

2 Gaseous hydrogen and gaseous iodine react to form gaseous hydrogen iodide.

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

In an experiment, 2.0 mol of hydrogen and 2.0 mol of iodine are placed in a sealed container of volume 1.0 dm^3.

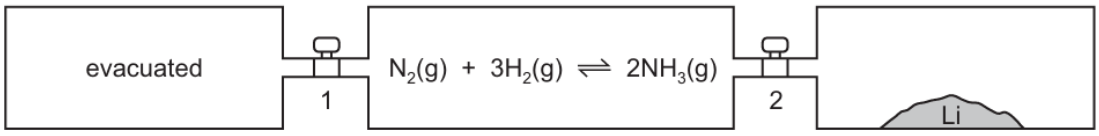
The K_c value for this reaction under the conditions used is 9.0.

How many moles of hydrogen iodide are present at equilibrium?

A 0.57 mol **B** 1.2 mol **C** 1.5 mol **D** 2.4 mol

3 Lithium reacts with nitrogen at room temperature to form solid Li_3N.

Three vessels of equal volume are connected by taps 1 and 2 as shown.



At the start, taps 1 and 2 are closed, the left-hand vessel is evacuated, the middle vessel has the indicated reaction at equilibrium and the right-hand vessel contains lithium only.

Which action would allow the equilibrium mixture to contain the **most** ammonia?

A Keep both taps 1 and 2 closed.

B Open both taps 1 and 2.

C Open tap 1 only.

D Open tap 2 only.

4 When 0.20 mol of hydrogen gas and 0.15 mol of iodine gas are heated at 723 K until equilibrium is established, the equilibrium mixture contains 0.26 mol of hydrogen iodide.

The equation for the reaction is as follows.

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

What is the correct expression for the equilibrium constant K_c?

A $\frac{2 \times 0.26}{0.20 \times 0.15}$ **B** $\frac{(2 \times 0.26)^2}{0.20 \times 0.15}$ **C** $\frac{(0.26)^2}{0.07 \times 0.02}$ **D** $\frac{(0.26)^2}{0.13 \times 0.13}$

5 An alcohol, ROH, reacts reversibly with ethanoic acid to produce an ester.

$$ROH(l) + CH_3COOH(l) \rightleftharpoons CH_3COOR(l) + H_2O(l)$$

3.0 mol of ROH, 2.0 mol of ethanoic acid and 1.0 mol of water are mixed together. At equilibrium, 1.5 mol of CH_3COOR is present.

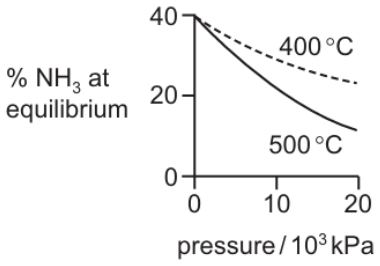
What is the value of the equilibrium constant, K_c, for this reaction?

A 0.20 **B** 0.25 **C** 2.00 **D** 5.00

6 Graphs can be drawn to show the percentage of ammonia at equilibrium when nitrogen and hydrogen are mixed at different temperatures and pressures.

Which diagram correctly represents these two graphs?

A



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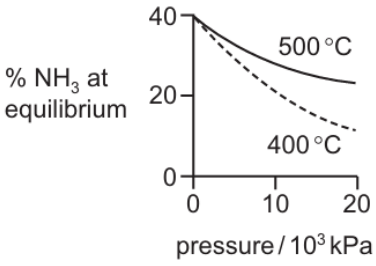

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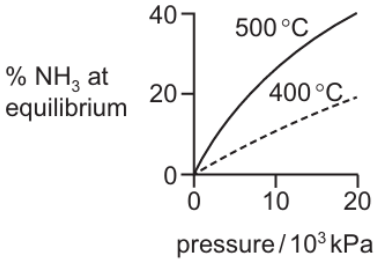

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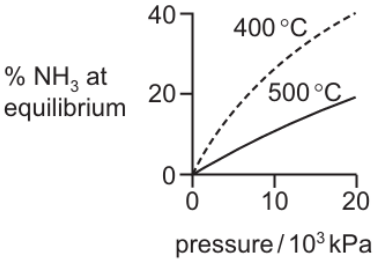


7 Which reaction has an equilibrium constant, K_p, that has no units?

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

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

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

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

8 Nitrogen dioxide, NO_2, exists in equilibrium with dinitrogen tetroxide, N_2O_4.

$$2NO_2(g) \rightleftharpoons N_2O_4(g) \qquad \Delta H = -57\,kJ\,mol^{-1}$$

Which conditions give the greatest percentage of $N_2O_4(g)$ at equilibrium?

	pressure	temperature
A	high	high
B	high	low
C	low	high
D	low	low

9 When an equimolar mixture of H_2 and I_2 react, the mole fraction of HI in the final mixture is x.

What is the equilibrium constant, K_p, for the reaction?

A $\dfrac{x^2}{(1-x)^2}$

B $\dfrac{x^2}{(1-2x)^2}$

C $\dfrac{4x^2}{(1-x)^2}$

D $\dfrac{4x^2}{(1-2x)^2}$

10 0.200 mol of sulfur dioxide and 0.200 mol of oxygen are placed in a 1.00 dm^3 sealed container. The gases are allowed to react until equilibrium is reached.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

At equilibrium there is 0.100 mol of SO_3 in the container.

What is the value of K_c?

A 0.150 $mol\,dm^{-3}$

B 0.800 $mol\,dm^{-3}$

C 1.25 $mol^{-1}\,dm^3$

D 6.67 $mol^{-1}\,dm^3$

11 For which equilibrium do both of the equilibrium constants K_c and K_p have no units?

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

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

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

D $SO_2(g) + \frac{1}{2}O_2(g) \rightleftharpoons SO_3(g)$

12 The Contact process takes place at a pressure between 100 000 Pa and 200 000 Pa. A catalyst is used.

Which statement is correct?

A A V_2O_5 catalyst is added to increase the equilibrium yield of the reaction.

B Changes in pressure have no effect on the position of equilibrium.

C The equilibrium yield of the reaction is very high under the conditions used.

D An iron catalyst is added to increase the rate of reaction.

13 In which equilibrium will an increase in pressure at constant temperature increase the yield of the products on the right-hand side of the equation?

A $CaCO_3(s) \rightleftharpoons CaO(s) + CO_2(g)$

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

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

D $3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g)$

14 Hydrogen iodide is added to an evacuated reaction vessel. The vessel is sealed and warmed. A decomposition reaction occurs. Hydrogen and iodine are formed. Some hydrogen iodide remains.

When equilibrium is established, the total pressure is 1.20×10^5 Pa. The partial pressure of hydrogen is 4.00×10^3 Pa.

Hydrogen iodide, hydrogen and iodine are all gaseous under the conditions used.

What is the value of K_p for the equilibrium at this temperature, assuming the decomposition is the forward reaction?

A 1.19×10^{-3} **B** 1.28×10^{-3} **C** 1.38×10^{-3} **D** 1.43×10^{-3}

15 In which equilibrium reaction is the position of equilibrium moved to the right-hand side by increasing the temperature and also by decreasing the pressure?

A $H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g)$ $\Delta H = 40\,kJ\,mol^{-1}$

B $N_2O_4(g) \rightleftharpoons 2NO_2(g)$ $\Delta H = 58\,kJ\,mol^{-1}$

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

D $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$ $\Delta H = -10\,kJ\,mol^{-1}$

16 Ethanol is produced industrially by reacting ethene and steam.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g)$$

K_p has a value of 1.8×10^{-5} and the partial pressures of the reactants at equilibrium are shown.

reactant	partial pressure / kPa
ethene	4.8×10^3
steam	2.8×10^3

Which row is correct?

	partial pressure of ethanol at equilibrium / kPa	units of K_p
A	2.42×10^2	kPa^{-1}
B	2.42×10^2	kPa
C	7.47×10^{11}	kPa^{-1}
D	7.47×10^{11}	kPa

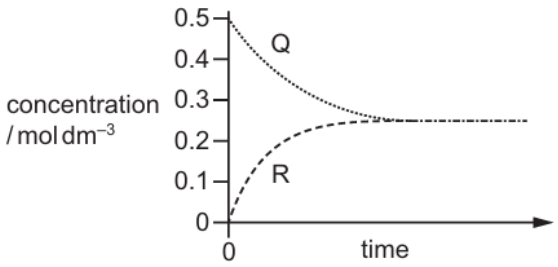
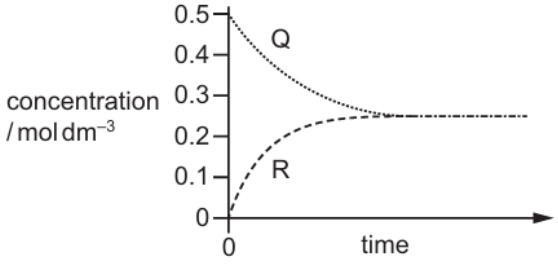
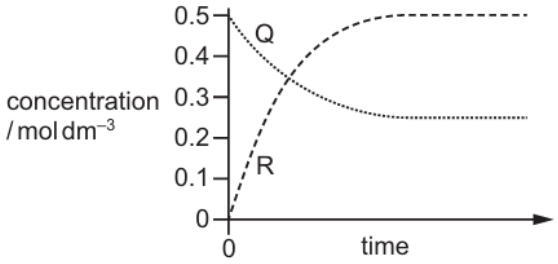
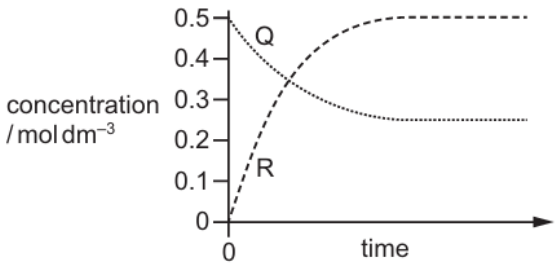
17 A dimer, Q, is stable when solid but a dynamic equilibrium is set up in solution.

$$Q(aq) \rightleftharpoons 2R(aq)$$

A solution of Q has an initial concentration of 0.50 mol dm^{-3}. When equilibrium has been reached, [Q(aq)] has fallen to 0.25 mol dm^{-3}.

The changes in [Q(aq)] and [R(aq)] are plotted against time until equilibrium is reached. The value of K_c is then calculated.

Which graph and value for K_c are correct?

	graph	K_c / mol dm^{-3}
A		1
B		0.25
C		1
D		2

18 Ethanoic acid is mixed with ethanol.

The ethanol is contaminated with a small amount of methanol.

The following equilibria are established.

$$CH_3CO_2H(l) + CH_3CH_2OH(l) \rightleftharpoons CH_3CO_2CH_2CH_3(l) + H_2O(l) \qquad K_c = K_1$$

$$CH_3CO_2H(l) + CH_3OH(l) \rightleftharpoons CH_3CO_2CH_3(l) + H_2O(l) \qquad K_c = K_2$$

Which statement about the equilibrium mixture is correct?

A Only ethyl ethanoate will be formed because there is much more ethanol present than methanol.

B In this mixture $\frac{[CH_3CO_2CH_2CH_3]}{[CH_3CO_2CH_3]} = \frac{K_1}{K_2}$.

C Adding water to the mixture will alter the mole ratio of the two esters.

D Adding methyl ethanoate to the mixture will increase the number of moles of ethyl ethanoate.

19 SO_3 is manufactured from SO_2 and O_2 in the Contact process.

The reaction is exothermic.

Which row shows the effect on the equilibrium yield obtained in the Contact process of increasing the temperature and of adding a vanadium(V) oxide catalyst?

	increasing the temperature	adding vanadium(V) oxide as catalyst
A	equilibrium yield decreases	equilibrium yield increases
B	equilibrium yield decreases	equilibrium yield unchanged
C	equilibrium yield increases	equilibrium yield unchanged
D	equilibrium yield increases	equilibrium yield increases

20 A synthesis for methanol is shown.

$$CO_2 + 3H_2 \rightleftharpoons CH_3OH + H_2O \qquad \Delta H = -49\,kJ\,mol^{-1}$$

Which conditions would produce the greatest yield of methanol at equilibrium?

	pressure	temperature / °C
A	high	80
B	high	20
C	low	80
D	low	20

21 Hydrogen and iodine can react reversibly to produce hydrogen iodide. The equation is shown.

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

4.00 mol of hydrogen gas and X mol of iodine vapour are mixed in a sealed container of volume 1.00 dm^3 at a temperature of 460 K. The system is allowed to reach equilibrium.

The equilibrium mixture contains 2.00 mol of hydrogen iodide. The equilibrium constant, K_c, for the reaction at 460 K is 4.0.

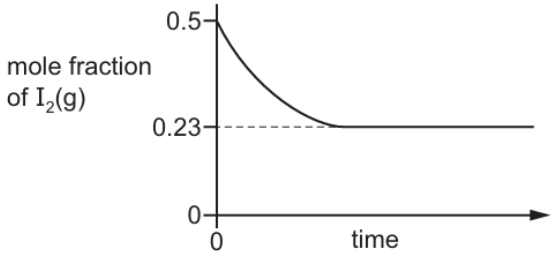
What is the value of X?

A 0.50 mol **B** 1.17 mol **C** 1.33 mol **D** 2.50 mol

22 The equation shows that $H_2(g)$ and $I_2(g)$ react to form an equilibrium mixture.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H^{\ominus} = -9.6\,kJ\,mol^{-1}$$

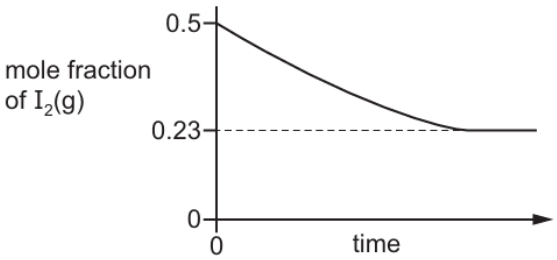
A mixture containing equal amounts of $H_2(g)$ and $I_2(g)$ is made at temperature T_1 and the composition of the mixture is monitored. A graph of the results is shown.



The experiment is repeated at a lower temperature, T_2.

Which new graph would be obtained?

A



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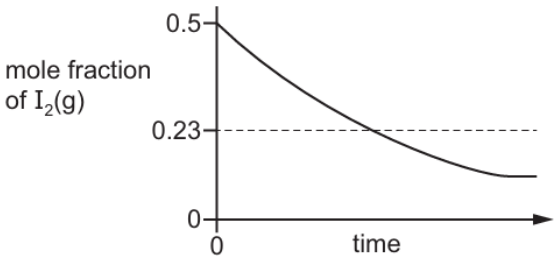

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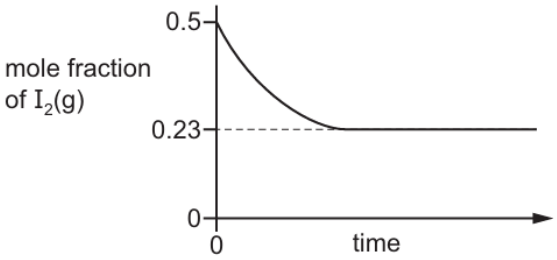

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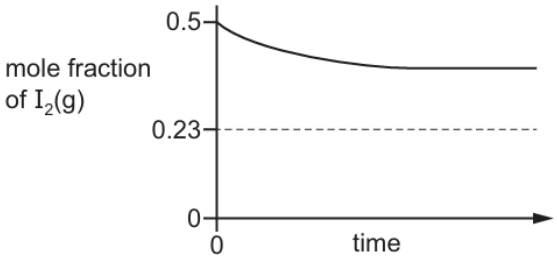


23 Silver chloride and silver iodide form equilibria when added to water.

$$AgCl(s) \rightleftharpoons Ag^+(aq) + Cl^-(aq) \qquad K_c = K_1$$

$$AgI(s) \rightleftharpoons Ag^+(aq) + I^-(aq) \qquad K_c = K_2$$

Each equilibrium position lies well to the **left**.

Silver iodide will not dissolve in aqueous ammonia. Silver chloride will dissolve in aqueous ammonia. Another equilibrium is formed.

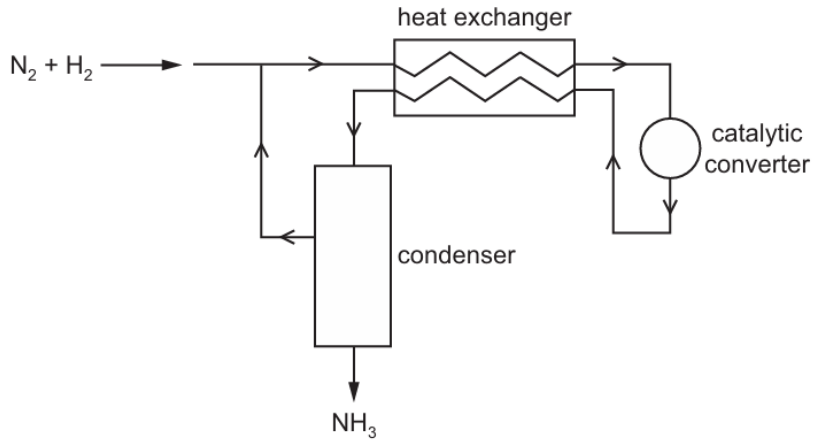
$$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) \qquad K_c = K_3$$

The position of this equilibrium lies to the **right**.

What is the order of magnitude for these three equilibrium constants?

	smallest →		largest
A	K_3	K_2	K_1
B	K_3	K_1	K_2
C	K_2	K_1	K_3
D	K_1	K_2	K_3

24 The diagram represents the Haber process for the manufacture of ammonia from nitrogen and hydrogen.



What is the purpose of the heat exchanger?

A to cool the incoming gas mixture to avoid overheating the catalyst

B to cool the reaction products and separate the NH_3 from unused N_2 and H_2

C to warm the incoming gas mixture and shift the equilibrium to give more NH_3

D to warm the incoming gas mixture and speed up the reaction

25 3.60 moles of hydrogen gas and 2.00 moles of iodine vapour are placed in a reaction vessel which is then sealed and maintained at a constant temperature.

The equation for the reaction is shown.

$$H_2 + I_2 \rightleftharpoons 2HI$$

At equilibrium, 3.20 moles of hydrogen remain. All reactants and products are gaseous.

What is the value of K_p under these conditions?

A 0.0313 **B** 0.125 **C** 0.156 **D** 8.00

26 In aqueous solution, sulfuric acid dissociates as shown.

$H_2SO_4 \rightarrow HSO_4^- + H^+$ This reaction goes to completion.

$HSO_4^- \rightleftharpoons SO_4^{2-} + H^+$ This reaction reaches equilibrium with constant K_c.

Analysis of a $2.00\,mol\,dm^{-3}$ solution of H_2SO_4 found the HSO_4^- concentration to be $1.988\,mol\,dm^{-3}$.

What is K_c?

A $1.381 \times 10^5\,dm^3\,mol^{-1}$

B $82.34\,dm^3\,mol^{-1}$

C $1.214 \times 10^{-2}\,mol\,dm^{-3}$

D $7.244 \times 10^{-5}\,mol\,dm^{-3}$

27 Sulfur dioxide and oxygen react to form sulfur trioxide. The reaction is reversible.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad K_p = 2.96 \times 10^{-9}\,Pa^{-1} \text{ at } 700\,^\circ C$$

The reaction is allowed to reach equilibrium at 700 °C. The partial pressure of $O_2(g)$ is 375 kPa and the partial pressure of $SO_3(g)$ is 20.3 kPa.

What is the partial pressure of $SO_2(g)$?

A 19.3 kPa **B** 609 kPa **C** 18 300 kPa **D** 609 000 kPa

28 Ethene can be oxidised to form epoxyethane, C_2H_4O.

$$C_2H_4(g) + \tfrac{1}{2}O_2(g) \rightleftharpoons C_2H_4O(g) \qquad \Delta H^{\ominus} = -107\,kJ\,mol^{-1}$$

Which set of conditions gives the greatest yield of epoxyethane at equilibrium?

	pressure	temperature / °C
A	high	100
B	high	200
C	low	100
D	low	200

29 What are the units of K_p for the reaction shown?

$$H_2O(g) + C(s) \rightleftharpoons H_2(g) + CO(g)$$

A Pa^{-1} **B** Pa **C** Pa^2 **D** no units

30 The catalysed formation of ammonia by the Haber process can be represented by the equation shown.

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

Which change in conditions will increase both the rate of formation and the equilibrium yield of ammonia?

A decrease in the temperature

B increase in the temperature

C increase in the pressure

D increase in the surface area of the catalyst

31 PCl_5 decomposes as shown.

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

1.0 mol of $PCl_5(g)$, 1.0 mol of $PCl_3(g)$ and 1.0 mol of $Cl_2(g)$ are placed in a container of volume 1 dm^3 at 250 °C and allowed to reach equilibrium.

At this temperature, the equilibrium mixture contains 1.8 moles of PCl_3.

What is the value of K_c at 250 °C?

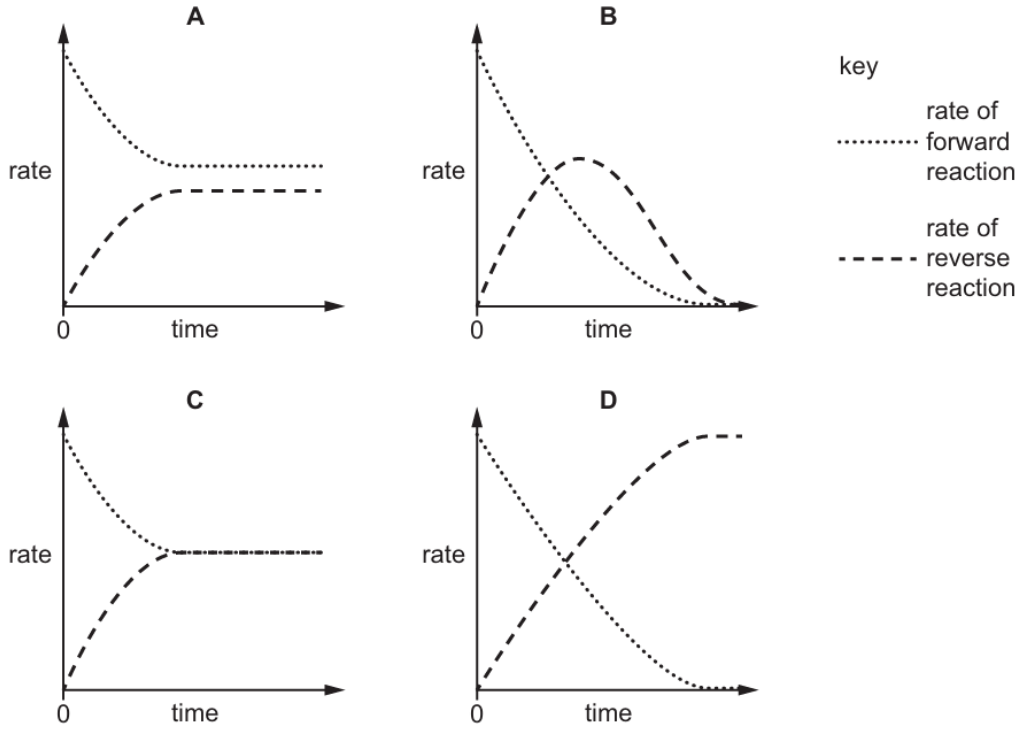
A 1 **B** 1.8 **C** 9 **D** 16.2

32 Two compounds X and Y react to produce compound Z. The reaction is reversible.

$$X + Y \rightleftharpoons Z$$

When X and Y are mixed together in a closed system a dynamic equilibrium is gradually established.

Which graph could represent the change in the rates of the forward and reverse reactions over time?



33 The reaction between sulfur dioxide and oxygen is reversible.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad K_c = 280\,\text{mol}^{-1}\,\text{dm}^3 \text{ at } 1000\,\text{K}$$

In an equilibrium mixture at 1000 K the sulfur dioxide concentration is $0.200\,\text{mol dm}^{-3}$ and the oxygen concentration is $0.100\,\text{mol dm}^{-3}$.

What is the sulfur trioxide concentration?

A $1.058\,\text{mol dm}^{-3}$

B $1.120\,\text{mol dm}^{-3}$

C $2.366\,\text{mol dm}^{-3}$

D $5.600\,\text{mol dm}^{-3}$

34 The decomposition of $SO_3(g)$ is a dynamic equilibrium.

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

What happens when the pressure of the system is increased?

A The rate of reaction will decrease and the position of the equilibrium will move to the left.

B The rate of reaction will decrease and the position of the equilibrium will move to the right.

C The rate of reaction will increase and the position of the equilibrium will move to the left.

D The rate of reaction will increase and the position of the equilibrium will move to the right.

35 Hydrogen iodide gas decomposes reversibly producing iodine vapour and hydrogen.

$$2HI(g) \rightleftharpoons I_2(g) + H_2(g) \qquad \Delta H = +12\,\text{kJ mol}^{-1}$$

The position of the equilibrium for this reaction may be altered by changing the external conditions.

Which row correctly describes the change in position of equilibrium?

	effect of increasing the pressure	effect of increasing the temperature
A	moves to the right	moves to the right
B	moves to the right	moves to the left
C	no change	moves to the right
D	no change	moves to the left

36 The reaction between sulfur dioxide and oxygen is reversible.

$$2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g) \qquad K_c = 280\,\text{mol}^{-1}\,\text{dm}^3 \text{ at } 1000\,\text{K}$$

In an equilibrium mixture at 1000 K the sulfur trioxide concentration is $6.00\,\text{mol dm}^{-3}$.

The sulfur dioxide concentration is twice the oxygen concentration.

What is the sulfur dioxide concentration?

A $0.175\,\text{mol dm}^{-3}$

B $0.254\,\text{mol dm}^{-3}$

C $0.318\,\text{mol dm}^{-3}$

D $0.636\,\text{mol dm}^{-3}$

37 Ethyl ethanoate undergoes the following reaction.

$$CH_3CO_2C_2H_5 + H_2O \rightleftharpoons C_2H_5OH + CH_3CO_2H \qquad K_c = 0.27$$

Equal amounts of ethanoic acid and ethanol were mixed together and allowed to reach equilibrium.

At equilibrium, the concentrations of both ethanoic acid and ethanol were 0.42 mol dm^{-3}.

What is the concentration of ethyl ethanoate at equilibrium?

A 0.22 mol dm^{-3}

B 0.65 mol dm^{-3}

C 0.81 mol dm^{-3}

D 1.54 mol dm^{-3}

38 In this question you should assume that all gases behave ideally.

Hydrogen and iodine react reversibly in the following reaction. The system reaches dynamic equilibrium.

$$H_2(g) + I_2(g) \rightleftharpoons 2HI(g) \qquad \Delta H = -9.5\ kJ\ mol^{-1}$$

Which statement **must** be true for the K_p of this equilibrium to be constant?

A The partial pressures of H_2, I_2 and HI are equal.

B The external pressure is constant.

C The forward and reverse reactions have stopped.

D The temperature is constant.

39 0.200 mol of sulfur dioxide and 0.200 mol of oxygen are placed in a 1.00 dm^3 sealed container. The gases are allowed to react until equilibrium is reached.

$$2SO_2 + O_2 \rightleftharpoons 2SO_3$$

At equilibrium there is 0.100 mol of SO_3 in the container.

What is the value of K_c?

A 0.150 mol dm^{-3}

B 0.800 mol dm^{-3}

C 1.25 mol^{-1} dm^3

D 6.67 mol^{-1} dm^3

40 In this question, all pressures are measured in atm.

The equation represents the equilibrium between three gaseous substances X, Y and Z.

$$X + 3Y \rightleftharpoons 2Z$$

At temperature T_1, the numerical value of K_p, the equilibrium constant, is 2.

At a higher temperature T_2, the partial pressures at equilibrium are as shown.

X	Y	Z
2	3	5

Which row is correct?

	the numerical value of K_p at T_2	the forward reaction is
A	54 / 25	endothermic
B	54 / 25	exothermic
C	25 / 54	endothermic
D	25 / 54	exothermic

41 Nitrogen and hydrogen can react together to form ammonia.

The formation of ammonia is exothermic.

The rate and yield of the reaction can be altered by changing the conditions under which the reaction is carried out.

Which row shows the effects of adding iron to the mixture **and** increasing the temperature?

	adding iron	increasing the temperature
A	has no effect on the equilibrium yield	reduces the equilibrium yield
B	increases the equilibrium yield	increases the equilibrium yield
C	increases the equilibrium yield	increases the rate
D	increases the rate	has no effect on the equilibrium yield

42 The gases X and Y react to form Z.

$$X(g) + Y(g) \rightleftharpoons Z(g)$$

An equilibrium mixture of these three gases is compressed at constant temperature.

What will be the changes in the mole fraction of Z and in K_p?

	mole fraction of Z	K_p
A	increase	increase
B	increase	no change
C	no change	increase
D	no change	no change

43 In a particular reversible reaction the yield of product is increased

- if the temperature is increased;
- if the pressure is decreased.

Which equation could describe this reversible reaction?

A $CH_4(g) + H_2O(g) \rightleftharpoons 3H_2(g) + CO(g)$ $\Delta H = +206\,kJ\,mol^{-1}$

B $4NH_3(g) + 3O_2(g) \rightleftharpoons 2N_2(g) + 6H_2O(g)$ $\Delta H = -227\,kJ\,mol^{-1}$

C $2NO_2(g) \rightleftharpoons N_2O_4(g)$ $\Delta H = -58\,kJ\,mol^{-1}$

D $3O_2(g) \rightleftharpoons 2O_3(g)$ $\Delta H = +143\,kJ\,mol^{-1}$