CAMBRIDGE INTERNATIONAL AS & A LEVEL CHEMISTRY · 9701

CHEMISTRY



EXAM QUESTION PACK

7 EQUILIBRIA

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Chapter 7

Equilibria

7.1 Chemical equilibria: reversible reactions, dynamic equilibrium

337. 9701_m22_qp_12 Q: 12

Hydrogen and iodine react to form hydrogen iodide in an exothermic reaction. The equation is shown.

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

A 1 m^3 reaction vessel contains H_2, I_2 and HI gases at equilibrium. The temperature is changed such that the total pressure in the 1 m^3 vessel doubles.

What is the effect on the value of K_p and on the position of equilibrium?

	effect on the value of K_p	effect on the position of equilibrium
A	decreases	moves left
B	increases	moves right
C	no change	moves left
D	no change	no change

---

338. 9701_m22_qp_12 Q: 24

The product of the Contact process is Z.

Which reaction or process leads to the formation of a gas that can neutralise an aqueous solution of Z?

A atmospheric lightning

B combustion of fuel in an internal combustion engine

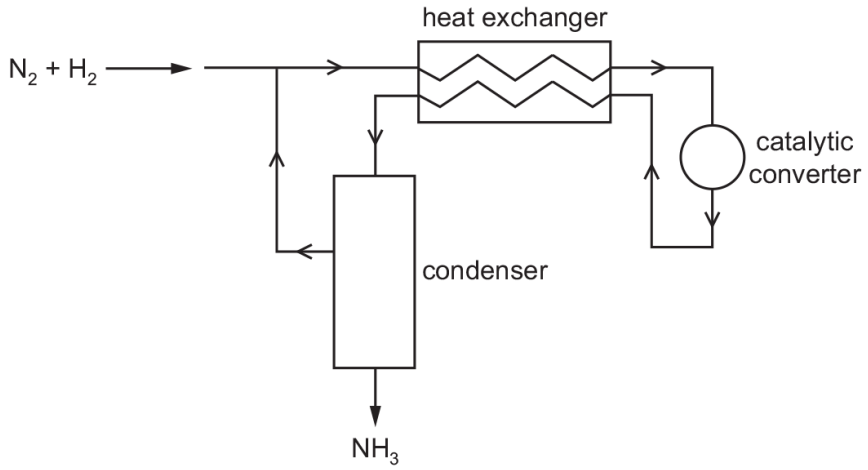
C the Haber process

D thermal decomposition of Group 2 nitrates

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339. 9701_s21_qp_11 Q: 10

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

---

340. 9701_s21_qp_12 Q: 10

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

---

341. 9701_s21_qp_13 Q: 9

Copper dissolves in dilute nitric acid producing a blue solution of $Cu(NO_3)_2$, water and nitrogen(II) oxide as the only products.

How many moles of acid react with three moles of copper in the balanced equation?

A 2 **B** 4 **C** 6 **D** 8

---

342. 9701_s21_qp_13 Q: 10

Nitrogen reacts with hydrogen to produce ammonia.

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

A mixture of 2.00 mol of nitrogen, 6.00 mol of hydrogen and 2.40 mol of ammonia is allowed to reach equilibrium in a sealed vessel of volume 1 dm^3. It is found that 2.32 mol of nitrogen were present in the equilibrium mixture.

Which expression will give the value of K_c?

A $\dfrac{(1.76)^2}{(2.32)(6.96)^3}$

B $\dfrac{(1.76)^2}{(2.32)(6.32)^3}$

C $\dfrac{(2.08)^2}{(2.32)(6.32)^3}$

D $\dfrac{(2.40)^2}{(2.32)(6.00)^3}$

---

343. 9701_s21_qp_13 Q: 11

Nitric acid is produced by oxidising ammonia. The first step is to react ammonia with oxygen in the presence of a catalyst to form nitrogen monoxide.

$$4NH_3(g) + 5O_2(g) \rightleftharpoons 4NO(g) + 6H_2O(g) \quad \Delta H = -1636\ kJ\ mol^{-1}$$

Which set of conditions will produce the greatest yield of nitrogen monoxide at equilibrium?

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

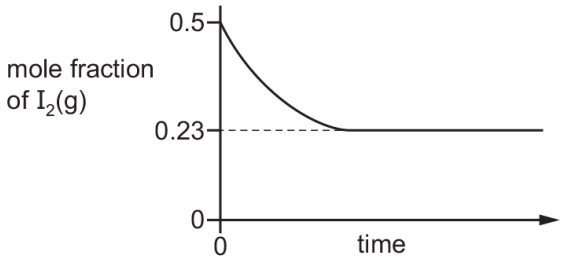
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344. 9701_w21_qp_11 Q: 10

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

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

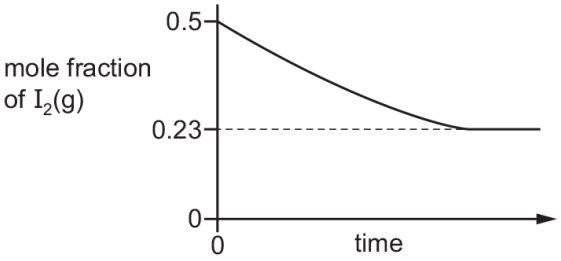
A mixture containing equal amounts of $H_2(g)$ and $I_2(g)$ is made at temperature T_1 and the composition of the mixture is monitored. A graph of the results is shown.



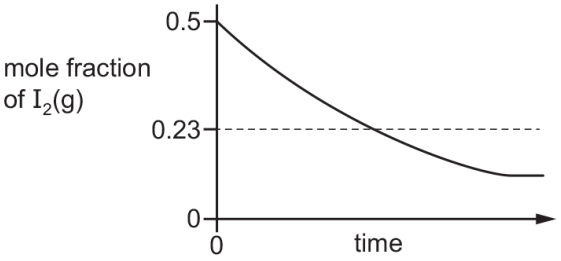
The experiment is repeated at a lower temperature, T_2.

Which new graph would be obtained?

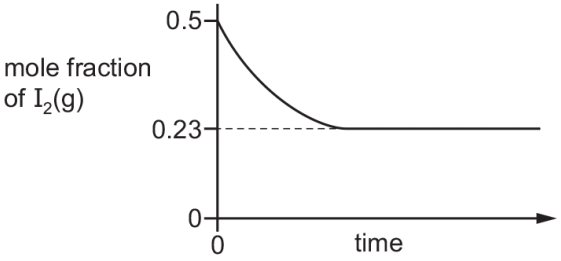
A



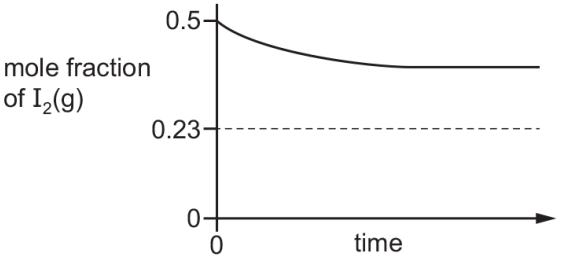
B



C



D



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345. 9701_m20_qp_12 Q: 6

The equation for the reaction between silver chloride and aqueous ammonia is shown.

$$AgCl(s) + 2NH_3(aq) \rightleftharpoons [Ag(NH_3)_2]^+(aq) + Cl^-(aq)$$

What are the units of K_c for this reaction?

A no units **B** $mol^{-1}\,dm^3$ **C** $mol\,dm^{-3}$ **D** $mol^2\,dm^{-6}$

---

346. 9701_m20_qp_12 Q: 11

The main stage in the Contact process is an equilibrium reaction.

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

Which row describes the effect of the named condition on the equilibrium yield?

	presence of catalyst	high pressure	high temperature
A	no effect on yield	decreases yield	increases yield
B	no effect on yield	increases yield	decreases yield
C	increases yield	decreases yield	increases yield
D	increases yield	increases yield	decreases yield

---

347. 9701_s20_qp_11 Q: 1

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

---

348. 9701_s20_qp_11 Q: 7

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

---

349. 9701_s20_qp_12 Q: 3

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

---

350. 9701_s20_qp_12 Q: 11

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

---

351. 9701_s20_qp_13 Q: 11

Two reactions are shown.

reaction 1 $X_2(g) + Y_2(g) \rightleftharpoons 2XY(g)$

reaction 2 $XY(g) \rightleftharpoons \frac{1}{2}X_2(g) + \frac{1}{2}Y_2(g)$

The equilibrium constant, K_p, for reaction 1 is 0.0052.

What is K_p for reaction 2?

A 2.6×10^{-3} **B** 13.9 **C** 192.3 **D** 384.6

---

352. 9701_w20_qp_11 Q: 10

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

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353. 9701_w20_qp_12 Q: 10

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

---

354. 9701_w20_qp_12 Q: 11

Ammonia is made by the Haber process. The reactants are nitrogen and hydrogen.

$$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g) \qquad \Delta H \text{ is negative}$$

What will increase the rate of the forward reaction?

A adding argon to the mixture but keeping the total volume constant

B decreasing the temperature

C increasing the total pressure by reducing the total volume at constant temperature

D removing ammonia as it is made but keeping the total volume of the mixture the same

---

355. 9701_w20_qp_12 Q: 14

$AgNO_3(aq)$ is added to a solution of a halide ion, $X^-(aq)$, and aqueous ammonia is then added.

The ionic equations for the two reactions that occur are shown.

$$Ag^+(aq) + X^-(aq) \rightleftharpoons AgX(s) \qquad \text{equilibrium 1}$$

$$Ag^+(aq) + 2NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq) \qquad \text{equilibrium 2}$$

Which statement is correct?

A The position of equilibrium 1 lies to the left when $X^- = I^-$.

B Increasing the concentration of ammonia causes the position of equilibrium 1 to move to the left.

C K_c for equilibrium 2 is larger when $X^- = Cl^-$ than when $X^- = I^-$.

D Equilibrium 2 is a redox reaction.

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356. 9701_m19_qp_12 Q: 11

When copper is added to a solution of silver ions, the following equilibrium is established.

$$Cu(s) + 2Ag^+(aq) \rightleftharpoons Cu^{2+}(aq) + 2Ag(s) \qquad K_c = 1.0 \times 10^5$$

What is the concentration of silver ions at equilibrium when $[Cu^{2+}] = 0.10\,mol\,dm^{-3}$?

A $5.0 \times 10^{-7}\,mol\,dm^{-3}$

B $5.0 \times 10^{-4}\,mol\,dm^{-3}$

C $1.0 \times 10^{-3}\,mol\,dm^{-3}$

D $1.0 \times 10^{2}\,mol\,dm^{-3}$

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357. 9701_s19_qp_11 Q: 10

Hydrogen iodide gas decomposes reversibly producing iodine vapour and hydrogen.

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

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

---

358. 9701_s19_qp_11 Q: 11

The reaction between sulfur dioxide and oxygen is reversible.

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

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

The sulfur dioxide concentration is twice the oxygen concentration.

What is the sulfur dioxide concentration?

A 0.175 mol dm^{-3}

B 0.254 mol dm^{-3}

C 0.318 mol dm^{-3}

D 0.636 mol dm^{-3}

---

359. 9701_s19_qp_12 Q: 10

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}

---

360. 9701_s19_qp_13 Q: 9

What is the correct expression for K_c for the reaction shown?

$$I_2(aq) + 2Fe^{2+}(aq) \rightleftharpoons 2I^-(aq) + 2Fe^{3+}(aq)$$

A $\dfrac{[2I^-][2Fe^{3+}]}{[I_2][2Fe^{2+}]}$ **B** $\dfrac{[I^-]^2[Fe^{3+}]^2}{[I_2][Fe^{2+}]^2}$ **C** $\dfrac{[I_2][2Fe^{2+}]}{[2I^-][2Fe^{3+}]}$ **D** $\dfrac{[I_2][Fe^{2+}]^2}{[I^-]^2[Fe^{3+}]^2}$

---

361. 9701_s19_qp_13 Q: 10

X and Y react together to form Z in a reversible reaction.

The equilibrium yield of Z is lower at higher temperature.

The equilibrium yield of Z is lower at lower pressure.

Which equation could represent this reaction?

A $X(g) + Y(g) \rightleftharpoons Z(g) \quad \Delta H = -100\,kJ\,mol^{-1}$

B $X(g) + Y(g) \rightleftharpoons Z(g) \quad \Delta H = +100\,kJ\,mol^{-1}$

C $X(s) + Y(g) \rightleftharpoons 2Z(g) \quad \Delta H = -100\,kJ\,mol^{-1}$

D $X(s) + Y(g) \rightleftharpoons 2Z(g) \quad \Delta H = +100\,kJ\,mol^{-1}$

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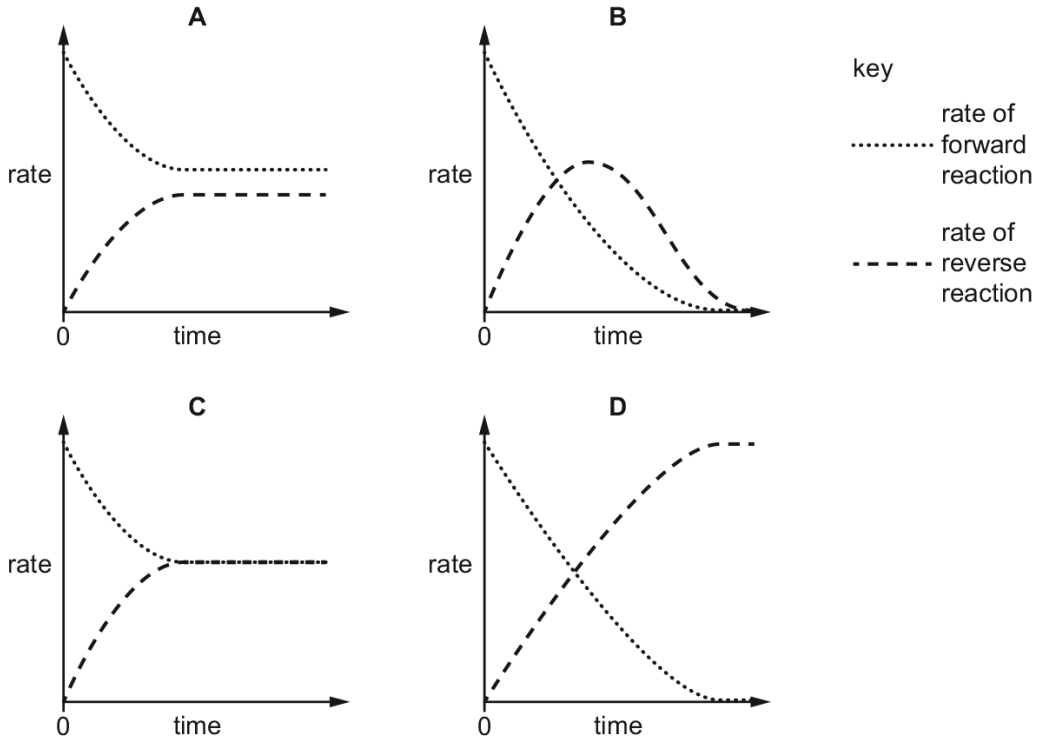
362. 9701_w19_qp_11 Q: 10

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?



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363. 9701_w19_qp_11 Q: 11

The reaction between sulfur dioxide and oxygen is reversible.

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

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

What is the sulfur trioxide concentration?

A 1.058 mol dm^{-3}

B 1.120 mol dm^{-3}

C 2.366 mol dm^{-3}

D 5.600 mol dm^{-3}

---

364. 9701_w19_qp_12 Q: 10

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.

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365. 9701_m18_qp_12 Q: 13

Which oxide is insoluble in aqueous sodium hydroxide?

A MgO **B** Al_2O_3 **C** P_4O_{10} **D** SO_2

---

366. 9701_m18_qp_12 Q: 14

X, Y and Z are three elements in the third period.

- X reacts with chlorine to give a liquid product.
- Y reacts with chlorine to give a solid product that dissolves in water to give a solution of pH 7.
- Z reacts with chlorine to give a solid product that dissolves in water to give a solution of pH 6.

Which elements are good conductors of electricity?

A X and Y **B** Y and Z **C** Y only **D** Z only

---

367. 9701_s18_qp_12 Q: 5

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

---

368. 9701_s18_qp_12 Q: 10

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

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369. 9701_s18_qp_13 Q: 9

Hydrogen is produced industrially from methane as shown in the equation.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H^\ominus = +205\,kJ\,mol^{-1}$$

Which conditions would most favour the formation of hydrogen?

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

---

370. 9701_s18_qp_13 Q: 10

The chemical equilibrium shown is formed when ammonia is produced in the Haber process.

$$N_2 + 3H_2 \rightleftharpoons 2NH_3$$

The following concentrations are found to be present at equilibrium under certain conditions.

N_2	H_2	NH_3
$0.200\,mol\,dm^{-3}$	$0.300\,mol\,dm^{-3}$	$0.600\,mol\,dm^{-3}$

What is the numerical value of K_c under these conditions?

A 0.0150 **B** 6.0 **C** 10.0 **D** 66.7

---

371. 9701_s18_qp_13 Q: 17

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?

A $K_1 > K_2 > K_3$

B $K_2 > K_1 > K_3$

C $K_3 > K_1 > K_2$

D $K_3 > K_2 > K_1$

---

372. 9701_s18_qp_13 Q: 18

Elements and their compounds are important as catalysts.

In which process is a compound used, rather than an element?

A catalytic converters

B Contact process

C Haber process

D hydrogenation of alkenes

---

373. 9701_w18_qp_11 Q: 9

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.

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374. 9701_w18_qp_11 Q: 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 $mol^{-1}\,dm^3$

---

375. 9701_w18_qp_12 Q: 9

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

---

376. 9701_m17_qp_12 Q: 3

Two moles of compound P were placed in a sealed container. The container was heated and P was partially decomposed to produce Q and R only. A dynamic equilibrium between P, Q and R was established.

At equilibrium x moles of R were present and the total number of moles present was $\left(2+\frac{x}{2}\right)$.

What is the equation for this reversible reaction?

A $P \rightleftharpoons 2Q + R$

B $2P \rightleftharpoons 2Q + R$

C $2P \rightleftharpoons Q + R$

D $2P \rightleftharpoons Q + 2R$

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377. 9701_m17_qp_12 Q: 11

Ammonia is manufactured from nitrogen and hydrogen using the Haber process.

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

What is the expression for K_c for this equilibrium?

A $\dfrac{2[NH_3(g)]}{[N_2(g)] + 3[H_2(g)]}$

B $\dfrac{2[NH_3(g)]}{[N_2(g)] \times 3[H_2(g)]}$

C $\dfrac{[NH_3(g)]^2}{[N_2(g)] + [H_2(g)]^3}$

D $\dfrac{[NH_3(g)]^2}{[N_2(g)] \times [H_2(g)]^3}$

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378. 9701_s17_qp_11 Q: 10

Methanol can be produced from hydrogen and carbon monoxide.

$$2H_2(g) + CO(g) \rightleftharpoons CH_3OH(g)$$

What is the expression for K_p for this reaction?

A $K_p = \dfrac{(2p_{H_2})^2 \times p_{CO}}{p_{CH_3OH}}$

B $K_p = \dfrac{(p_{H_2})^2 \times p_{CO}}{p_{CH_3OH}}$

C $K_p = \dfrac{p_{CH_3OH}}{(p_{H_2})^2 \times p_{CO}}$

D $K_p = \dfrac{p_{CH_3OH}}{p_{CO} \times (2p_{H_2})^2}$

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379. 9701_s17_qp_12 Q: 9

Hydrogen and carbon dioxide gases are mixed at 800 K. A reversible reaction takes place.

$$H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g)$$

At equilibrium, the partial pressures of H_2 and CO_2 are both 10.0 kPa. K_p is 0.288 at 800 K.

What is the partial pressure of CO in the equilibrium mixture?

A 5.37 kPa **B** 18.6 kPa **C** 28.8 kPa **D** 347 kPa

---

380. 9701_s17_qp_12 Q: 10

A reaction involved in the Contact process is shown.

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

The reaction is investigated at 200 kPa and 700 K and the value of the equilibrium constant, K_p, is found to be Y. The reaction is then investigated at 1000 kPa and 700 K and the value of K_p is found to be Z.

Which statement comparing Y and Z is correct?

A Y and Z are the same.

B Y is greater than Z.

C Z is 2.2 times greater than Y.

D Z is 5.0 times greater than Y.

---

381. 9701_s17_qp_13 Q: 9

Ammonia is produced by the Haber process.

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

A fault in the temperature control during the process resulted in the temperature changing to 600 °C for two hours.

What effect did this have on the ammonia production during this time?

A Ammonia was formed faster. The equilibrium yield decreased.

B Ammonia was formed faster. The equilibrium yield increased.

C Ammonia was formed slower. The equilibrium yield decreased.

D Ammonia was formed slower. The equilibrium yield increased.

---

382. 9701_s17_qp_13 Q: 10

For the reaction shown, an equilibrium is established at a temperature of 700 K.

The equilibrium constant, K_p, for the reaction is 9.80 kPa. The partial pressure of N_2O_4 at equilibrium is 80.0 kPa.

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

What is the partial pressure of NO_2 at equilibrium?

A 8.16 kPa **B** 28.0 kPa **C** 66.6 kPa **D** 784 kPa

---

383. 9701_w17_qp_11 Q: 9

Hydrogen iodide dissociates into hydrogen and iodine.

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

In an experiment, b mol of hydrogen iodide were put into a sealed vessel at pressure p. At equilibrium, x mol of the hydrogen iodide had dissociated.

Which expression for K_p is correct?

A $\frac{x^2}{(b-x)^2}$ **B** $\frac{x^2p^2}{(b-x)^2}$ **C** $\frac{x^2p^2}{4b(b-x)}$ **D** $\frac{x^2}{4(b-x)^2}$

---

384. 9701_w17_qp_12 Q: 9

Nitrogen dioxide, NO_2, is a brown gas.

Dinitrogen tetroxide, N_2O_4, is a colourless gas.

An equilibrium is established between NO_2 and N_2O_4 in a closed vessel.

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

Which row describes the effects of changing conditions on the colour of an equilibrium mixture of NO_2 and N_2O_4?

	increasing the pressure	increasing the temperature
A	colour becomes darker	colour becomes darker
B	colour becomes darker	colour becomes lighter
C	colour becomes lighter	colour becomes darker
D	colour becomes lighter	colour becomes lighter

---

385. 9701_m16_qp_12 Q: 11

In an experiment, 2.00 mol of hydrogen and 3.00 mol of iodine were heated together in a sealed container and allowed to reach equilibrium at a fixed temperature. The container had a fixed volume of 1.00 dm^3. At equilibrium, there were 2.40 mol of iodine present in the mixture.

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

What is the value of the equilibrium constant, K_c?

A 0.107 **B** 0.357 **C** 0.429 **D** 2.33

---

386. 9701_s16_qp_11 Q: 9

An aqueous solution was prepared containing a mixture of 1.0 mol of $AgNO_3$ and 1.0 mol of $FeSO_4$ in 1.00 dm^3 of water. When equilibrium was established, there was 0.44 mol of $Ag^+(aq)$ in the mixture.

$$Ag^+(aq) + Fe^{2+}(aq) \rightleftharpoons Ag(s) + Fe^{3+}(aq)$$

What is the numerical value of K_c?

A 0.62 **B** 1.40 **C** 1.62 **D** 2.89

---

387. 9701_s16_qp_11 Q: 10

The equation for the reaction between carbon monoxide and hydrogen is shown.

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

What are the units of K_p for this reaction?

A kPa **B** kPa^{-1} **C** kPa^2 **D** kPa^{-2}

---

388. 9701_s16_qp_12 Q: 10

When solid ammonium chloride dissociates at a certain temperature in a 0.500 dm^3 container, ammonia and hydrogen chloride are formed.

$$NH_4Cl(s) \rightleftharpoons NH_3(g) + HCl(g)$$

The initial amount of ammonium chloride was 1.00 mol, and when the system had reached equilibrium there was 0.300 mol of ammonium chloride.

What is the numerical value of K_c for this reaction under these conditions?

A 0.490 **B** 1.63 **C** 1.96 **D** 3.27

---

389. 9701_s16_qp_13 Q: 9

The equilibrium constant, K_c, for the reaction shown is 2 $mol^{-2}\,dm^6$, at 600 K.

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

What is the concentration of NH_3 at equilibrium, at 600 K, when the equilibrium concentrations of N_2 and H_2 are both 2 mol dm^{-3}?

A $\sqrt{8}$ mol dm^{-3} **B** $\sqrt{16}$ mol dm^{-3} **C** $\sqrt{32}$ mol dm^{-3} **D** 32 mol dm^{-3}

---

390. 9701_s16_qp_13 Q: 11

Catalysts are an important feature of many industrial processes and biochemical reactions.

Which row correctly describes the effect of a catalyst on a reversible chemical reaction?

	position of equilibrium	effect on value of ΔH
A	moved to right	decreased
B	unaffected	decreased
C	unaffected	increased
D	unaffected	unaffected

---

391. 9701_w16_qp_11 Q: 10

The table shows the partial pressures in an equilibrium mixture formed by the Haber process.

substance	partial pressure / kPa
nitrogen	7000
hydrogen	8000
ammonia	4000

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

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

A 4.46×10^{-9}

B 4.76×10^{-5}

C 7.14×10^{-5}

D 2.24×10^{8}

---

392. 9701_w16_qp_12 Q: 10

Nitrogen reacts with hydrogen to produce ammonia.

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

A mixture of 2.00 mol of nitrogen, 6.00 mol of hydrogen and 2.40 mol of ammonia is allowed to reach equilibrium in a sealed vessel of volume 1 dm^3. It was found that 2.32 mol of nitrogen were present in the equilibrium mixture.

What is the value of K_c?

A $\dfrac{(1.76)^2}{(2.32)(6.96)^3}$

B $\dfrac{(1.76)^2}{(2.32)(6.32)^3}$

C $\dfrac{(2.08)^2}{(2.32)(6.32)^3}$

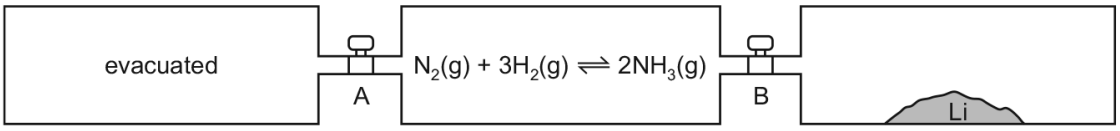
D $\dfrac{(2.40)^2}{(2.32)(6.00)^3}$

---

393. 9701_w16_qp_12 Q: 11

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

Three vessels of equal volume are connected by taps, A and B, as shown.



At the start, A and B 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 A and B closed.

B Open both A and B.

C Open A only.

D Open B only.

---

394. 9701_s15_qp_11 Q: 6

One mole of phosphorus(V) chloride, PCl_5, is heated to 600 K in a sealed flask of volume 1 dm^3. Equilibrium is established and measurements are taken.

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

The experiment is repeated with one mole of phosphorus(V) chloride heated to 600 K in a sealed flask of volume 2 dm^3.

How will the measurements vary?

A The equilibrium concentrations of $PCl_3(g)$ and $Cl_2(g)$ are higher in the second experiment.

B The equilibrium concentration of $PCl_5(g)$ is lower in the second experiment.

C The equilibrium concentrations of all three gases are the same in both experiments.

D The value of the equilibrium constant is higher in the second experiment.

---

395. 9701_s15_qp_11 Q: 9

One molecule of haemoglobin, Hb, can bind with four molecules of oxygen according to the following equation.

$$Hb(aq) + 4O_2(aq) \rightleftharpoons Hb(O_2)_4(aq)$$

When the equilibrium concentration of O_2 is 7.6×10^{-6} mol dm^{-3}, the equilibrium concentrations of Hb and $Hb(O_2)_4$ are equal.

What is the value of K_c for this equilibrium?

A 3.0×10^{20} **B** 1.3×10^{5} **C** 7.6×10^{-6} **D** 3.3×10^{-21}

---

396. 9701_s15_qp_12 Q: 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

---

397. 9701_s15_qp_12 Q: 9

When a sample of HI is warmed to a particular temperature the equilibrium below is established.

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

At this temperature, it is found that the partial pressure of HI(g) is 28 times the partial pressure of $H_2(g)$.

What is the value of K_p at this temperature?

A 1.28×10^{-3} **B** 0.035 **C** 28 **D** 784

---

398. 9701_w15_qp_11 Q: 2

Which set of conditions gives the highest yield of ammonia at equilibrium?

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

	catalyst	pressure	temperature
A	absent	high	low
B	absent	low	high
C	present	high	high
D	present	low	low

---

399. 9701_w15_qp_11 Q: 10

A mixture of nitrogen and hydrogen gases, at a temperature of 500 K, was put into an evacuated vessel of volume 6.0 dm^3. The vessel was then sealed.

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

The mixture was allowed to reach equilibrium. It was found that 7.2 mol of N_2 and 12.0 mol of H_2 were present in the equilibrium mixture. The value of the equilibrium constant, K_c, for this equilibrium is 6.0×10^{-2} at 500 K.

What is the concentration of ammonia present in the equilibrium mixture at 500 K?

A 0.58 mol dm^{-3}

B 0.76 mol dm^{-3}

C 3.5 mol dm^{-3}

D 27 mol dm^{-3}

---

400. 9701_w15_qp_12 Q: 8

Hydrogen can be obtained by reacting methane with steam.

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3H_2(g) \qquad \Delta H^{\ominus} = +210\,kJ\,mol^{-1}$$

Which conditions of pressure and temperature will give the greatest equilibrium yield of hydrogen?

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

---

401. 9701_w15_qp_12 Q: 9

Nitrogen monoxide reacts with oxygen in a reversible reaction according to the equation shown below.

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

The partial pressures of each of the components in an equilibrium mixture are shown in the table.

partial pressure NO / kPa	partial pressure O_2 / kPa	partial pressure NO_2 / kPa
10	30	20

What is the numerical value of the equilibrium constant, K_p, for this equilibrium?

A 6.67×10^{-2} **B** 1.33×10^{-1} **C** 7.50 **D** 15.0

7.2 Brønsted–Lowry theory of acids and bases

402. 9701_m22_qp_12 Q: 13

Diethylzinc, $(C_2H_5)_2Zn$, is added to NaOH(aq). Two reactions occur.

reaction 1 $(C_2H_5)_2Zn + H_2O \rightarrow ZnO + 2C_2H_6$

reaction 2 $H_2O + ZnO + 2OH^- \rightarrow Zn(OH)_4^{2-}$

In these reactions, which compounds act as Brønsted–Lowry acids?

	reaction 1	reaction 2
A	$(C_2H_5)_2Zn$	H_2O
B	H_2O	H_2O
C	H_2O	ZnO
D	the reaction is not acid / base	ZnO

---

403. 9701_m21_qp_12 Q: 9

In which reaction is water behaving as a Brønsted–Lowry base?

A $H_2O + Na \rightarrow NaOH + \frac{1}{2}H_2$

B $H_2O + H_3PO_4 \rightarrow H_3O^+ + H_2PO_4^-$

C $H_2O + CaO \rightarrow Ca(OH)_2$

D $NH_3 + [Cu(H_2O)_6]^{2+} \rightarrow NH_4^+ + [Cu(H_2O)_5(OH)]^+$

---

404. 9701_w21_qp_11 Q: 7

In order to determine the enthalpy of neutralisation of a strong acid and a strong alkali, 25.0 cm^3 of 2.00 mol dm^{-3} sodium hydroxide is added to 25.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid. The increase in temperature is 12 °C.

In a second experiment, the same method is used, but 50.0 cm^3 of 2.00 mol dm^{-3} sodium hydroxide is added to 50.0 cm^3 of 2.00 mol dm^{-3} hydrochloric acid.

What is the increase in temperature in the second experiment?

A 6 °C **B** 12 °C **C** 24 °C **D** 48 °C

---

405. 9701_s20_qp_13 Q: 6

Which solution has the lowest pH value?

A 0.01 mol dm^{-3} butanoic acid

B 0.01 mol dm^{-3} ethanoic acid

C 0.01 mol dm^{-3} hydrochloric acid

D 0.01 mol dm^{-3} sulfuric acid

---

406. 9701_m18_qp_12 Q: 15

A solution contains both $Mg^{2+}(aq)$ and $Sr^{2+}(aq)$ at the same concentration.

The solution is divided into two equal portions. Aqueous sodium hydroxide is added dropwise to one portion. Dilute sulfuric acid is added dropwise to the other portion.

Which row is correct?

	precipitate seen first when NaOH(aq) is added	precipitate seen first when $H_2SO_4(aq)$ is added
A	magnesium hydroxide	magnesium sulfate
B	magnesium hydroxide	strontium sulfate
C	strontium hydroxide	magnesium sulfate
D	strontium hydroxide	strontium sulfate

---

407. 9701_s18_qp_11 Q: 15

In which reaction does ammonia behave as a Brønsted-Lowry base?

A $NH_3 + CH_3CH_2Br \rightarrow CH_3CH_2NH_2 + HBr$

B $NH_3 + H_2O + CO_2 \rightarrow (NH_4)HCO_3$

C $2NH_3 + 2Na \rightarrow 2NaNH_2 + H_2$

D $4NH_3 + 3O_2 \rightarrow 2N_2 + 6H_2O$

---

408. 9701_s16_qp_13 Q: 10

Sulfur dioxide is used as a preservative in wine making.

The following equations describe the reactions that occur when sulfur dioxide dissolves in water.

$$H_2O + SO_2 \rightleftharpoons HSO_3^- + H^+$$
$$HSO_3^- + H^+ \rightleftharpoons SO_3^{2-} + 2H^+$$

Which statement about **these two reactions** is correct?

A HSO_3^- acts as a base.

B SO_2 acts as an oxidising agent.

C SO_3^{2-} acts as an acid.

D SO_3^{2-} acts as a reducing agent.

---

409. 9701_s15_qp_11 Q: 8

In which reaction is the underlined substance acting as a base?

A $HNO_3 + \underline{H_2SO_4} \rightarrow H_2NO_3^+ + HSO_4^-$

B $HSiO_3^- + \underline{HCN} \rightarrow CN^- + H_2O + SiO_2$

C $HNO_2 + \underline{HCO_3^-} \rightarrow H_2O + CO_2 + NO_2^-$

D $C_6H_5O^- + \underline{CH_2ClCO_2H} \rightarrow C_6H_5OH + CH_2ClCO_2^-$

Chapter 7

Equilibria

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7.1 Chemical equilibria: reversible reactions, dynamic equilibrium

26. 9701_s21_qp_23 Q: 2

Methanol, CH_3OH, is soluble in water because it forms hydrogen bonds with water molecules.

(a) Draw a fully labelled diagram to show how a hydrogen bond forms between a water molecule and a methanol molecule.

[3]

(b) Methanol has a melting point of –97.6 °C and a boiling point of 64.7 °C.

A sample of pure liquid methanol is added to a flask and then sealed. The sealed flask is left for several days at constant temperature. The vapour pressure is then measured as 17 kPa.

(i) Describe what is meant by the term *vapour pressure of methanol*.

.....

.....

..... [2]

(ii) Explain why some of the liquid becomes a vapour.

.....

.....

..... [1]

(iii) Suggest and explain why the vapour pressure of water at room temperature is lower than the vapour pressure of methanol at room temperature. Refer to the correct intermolecular forces in your answer.

.....

.....

..... [2]

(c) Methanol is made by reacting carbon monoxide with hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

Carbon monoxide and hydrogen react at 1.0×10^7 Pa and 200 °C. Eventually the reaction mixture reaches dynamic equilibrium.

The table shows the amounts of each species present in the mixture.

	CO(g)	H_2(g)	CH_3OH(g)
initial amount / mol	1.0	2.0	0
equilibrium amount / mol	0.030	0.060	0.97

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

.....

.....

..... [2]

(ii) Calculate the partial pressure of methanol vapour at equilibrium under these conditions. Show your working.

..... Pa [2]

(iii) Write an expression for the equilibrium constant, K_p, for this reaction. State the units in your answer.

K_p =

units = ... [2]

[Total: 14]

27. 9701_s18_qp_23 Q: 1

The elements sodium to chlorine, in the third period, all form oxides.

(a) Draw a diagram to show the shape of the molecule of each of the oxides, SO_3 and Cl_2O.
Name each shape.
In SO_3 each oxygen atom forms a double bond with the sulfur atom.

SO_3	Cl_2O
.....	.....

[4]

(b) (i) Explain why the melting point of MgO is higher than that of Na_2O.

.....

.....

.....

.....

..... [2]

(ii) Explain why the melting point of SiO_2 is much higher than that of SO_3.

.....

.....

.....

.....

.....

..... [2]

(c) SO_3 is produced by the reaction between SO_2 and O_2 in the Contact process. A dynamic equilibrium is established.

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

(i) Explain why increasing the total pressure, at constant temperature, increases the rate of production of SO_3 and increases the yield of SO_3.

rate .....

.....

.....

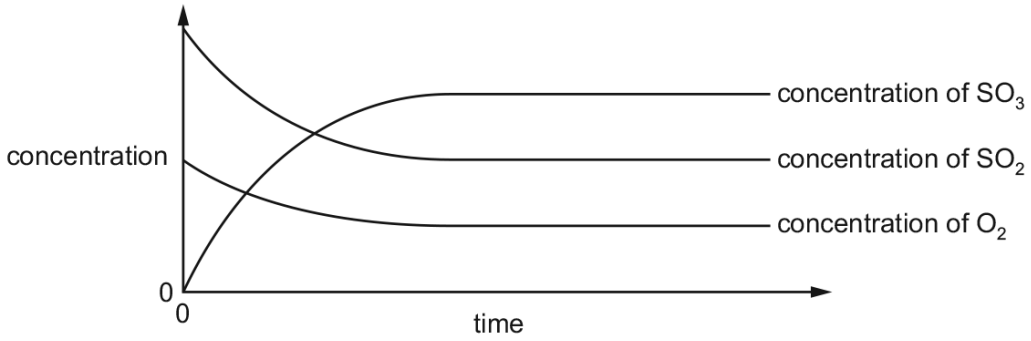
yield .....

.....

.....

[4]

The graph shows how the concentrations of all three species in the system change with time for a typical reaction mixture. The gradients of all three lines decrease with time and then level off in this dynamic equilibrium.



(ii) Explain why the gradients of the SO_2 and O_2 lines decrease with time.

.....

..... [2]

(iii) Explain why all three lines become horizontal.

.....

..... [1]

(iv) Suggest a reason why the initial gradient of the SO_2 line is steeper than that of the O_2 line.

.....

.....

..... [1]

(d) 2.00 moles of $SO_2(g)$ and 2.00 moles of $O_2(g)$ are sealed in a container with a suitable catalyst, at constant temperature and pressure. The resulting equilibrium mixture contains 1.98 moles of $SO_3(g)$.
The total volume of the equilibrium mixture is 40.0 dm^3.

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

(i) Write the expression for the equilibrium constant, K_c, for the reaction between $SO_2(g)$ and $O_2(g)$ to produce $SO_3(g)$.

K_c =

[1]

(ii) Calculate the amount, in moles, of $SO_2(g)$ and $O_2(g)$ in the equilibrium mixture.

$SO_2(g)$ = ... mol

$O_2(g)$ = ... mol
[2]

(iii) Use your answers to **(d)(i)** and **(d)(ii)** to calculate the value of K_c for this equilibrium mixture. Give the units of K_c.

K_c = ...

units = ...
[3]

[Total: 22]

28. 9701_w17_qp_22 Q: 2

At 450 K phosphorus(V) chloride, $PCl_5(g)$, decomposes to form phosphorus(III) chloride, $PCl_3(g)$, and chlorine, $Cl_2(g)$. A dynamic equilibrium is established as shown.

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

(a) The enthalpy change of formation of $PCl_3(g)$ under these conditions is given.

$$\Delta H_f\, PCl_3(g) = -320\,kJ\,mol^{-1}$$

Calculate the enthalpy change of formation of $PCl_5(g)$ under these conditions.

Include a sign with your answer.

enthalpy change = ... $kJ\,mol^{-1}$ [1]

(b) **(i)** State and explain the effect of increasing temperature on the rate of decomposition of $PCl_5(g)$.

.....

.....

..... [2]

(ii) State and explain the effect of increasing temperature on the percentage of $PCl_5(g)$ that decomposes.

.....

.....

..... [2]

(c) Explain the meaning of the term *dynamic equilibrium* and the conditions necessary for it to become established.

.....

.....

.....

..... [2]

(d) When 2.00 mol of $PCl_5(g)$ are decomposed at 450 K and 1.00×10^5 Pa the resulting equilibrium mixture contains 0.800 mol of $Cl_2(g)$.

(i) Calculate the partial pressure of phosphorus(V) chloride, $p PCl_5$, in this equilibrium mixture.

$p PCl_5$ = ... Pa [2]

(ii) Write the expression for the equilibrium constant, K_p, for the decomposition of $PCl_5(g)$.

K_p =

[1]

(iii) The partial pressures of $PCl_3(g)$ and of $Cl_2(g)$ in this equilibrium mixture are both 2.86×10^4 Pa.

Calculate the value of K_p and state its units.

K_p = ...

units = ...
[2]

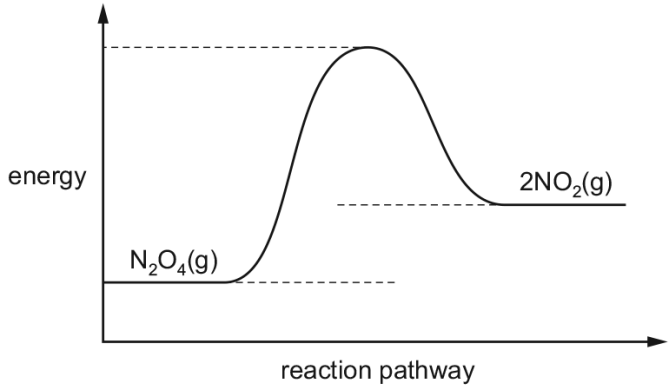
[Total: 12]

29. 9701_w16_qp_22 Q: 2

Dinitrogen tetraoxide, N_2O_4, and nitrogen dioxide, NO_2, exist in dynamic equilibrium with each other.

$$N_2O_4(g) \rightleftharpoons 2NO_2(g) \qquad \Delta H = +54\,kJ\,mol^{-1}$$

The energy profile for this reaction is shown.



(a) Add labelled arrows to the energy profile to indicate

- the enthalpy change of the reaction, ΔH,
- the activation energy of the forward reaction, E_a.

[2]

(b) 0.0500 mol of N_2O_4 was placed in a sealed vessel of volume 1.00 dm^3, at a temperature of 50 °C and a pressure of 1.68×10^5 Pa. The mass of the resulting equilibrium mixture was 4.606 g.

(i) Calculate the average molecular mass, M_r, of the resulting equilibrium mixture. Give your answer to **three** significant figures.

M_r = ... [2]

(ii) The number of moles of N_2O_4 that dissociated can be represented by n.

State, in terms of n, the amount, in moles, of NO_2 in the equilibrium mixture.

moles of NO_2 = ... [1]

The number of moles of N_2O_4 remaining at equilibrium is (0.05 – *n*).

(iii) State, in terms of *n*, the total amount, in moles, of gas in the equilibrium mixture.

[1]

(iv) State, in terms of *n*, the mole fraction of NO_2 in the equilibrium mixture.

[1]

In this equilibrium mixture, the mole fraction of NO_2 is 0.400.

(v) Use your answers to **(ii)** and **(iv)** to calculate the amount in moles of each gas in the equilibrium mixture. Give your answers to **three** significant figures.

amount of N_2O_4 = ... mol

amount of NO_2 = ... mol
[2]

(vi) Write the expression for the equilibrium constant, K_p, for this equilibrium.

K_p =

[1]

(vii) Use the total pressure of the mixture, 1.68×10^5 Pa, to calculate the value of the equilibrium constant, K_p, and give its units.

K_p = ...

units = ...
[3]

[Total: 13]

7.2 Ionic equilibria

30. 9701_s18_qp_21 Q: 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.

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

(a) (i) State the effect of a catalyst on a reaction.
Explain how a catalyst causes this effect.

.....

.....

.....

..... [2]

(ii) State the meaning of the term *heterogeneous* as applied to catalysts.

.....

.....

..... [1]

(b) Some bond energies are given.

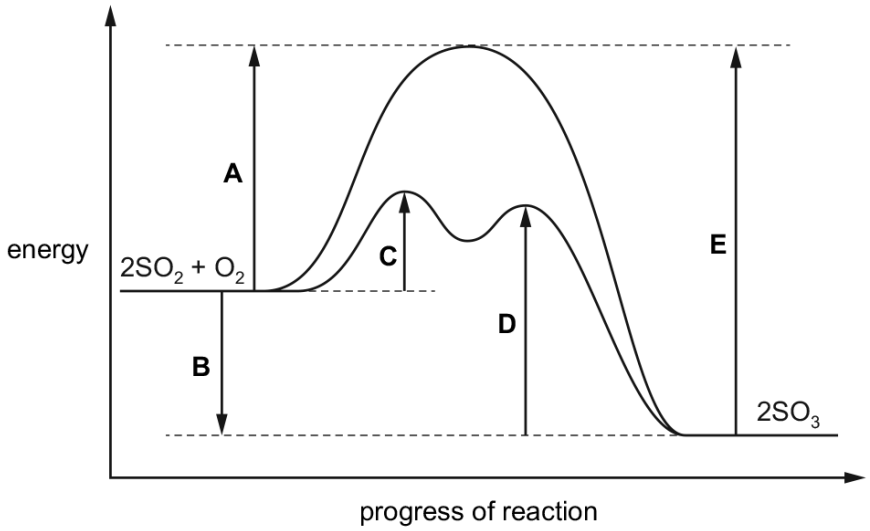
bond	bond energy / kJ mol^{-1}
S=O (in SO_2)	534
O=O	496

Use the data, and the enthalpy change for the conversion of sulfur dioxide into sulfur trioxide, to calculate a value for the S=O bond energy in SO_3.

S=O bond energy in SO_3 = ... kJ mol^{-1} [2]

The Contact process is usually carried out at a temperature of about 400 °C and a pressure just above atmospheric pressure. Using a higher or lower temperature and pressure would affect both the rate of production of sulfur trioxide and the yield of sulfur trioxide.

(c) A reaction pathway diagram for both the catalysed and uncatalysed reactions between SO_2 and O_2 is shown.



The letters **A–E** represent energy changes.

Complete the table by stating which letter, **A–E**, represents the energy change described.

energy change	letter
the energy change for the production of SO_3	
the activation energy for the production of SO_3 in the absence of a catalyst	
the activation energy for the first step in the **decomposition** of SO_3 in the presence of a catalyst	

[3]

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]

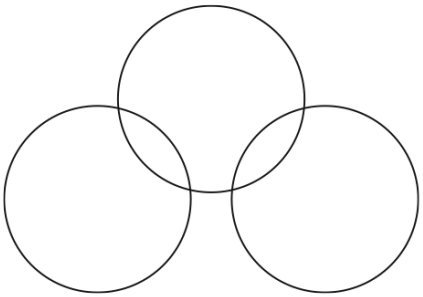
(e) The SO_3 produced is converted to sulfuric acid in two stages. In the first stage the SO_3 is reacted with concentrated sulfuric acid to produce oleum, $H_2S_2O_7$.
The oleum is then reacted with water to form sulfuric acid.

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.

(i) Complete the 'dot-and-cross' diagram to show the bonding in a molecule of SO_2. Show outer electrons only.



[1]

(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]

[Total: 20]

---

31. 9701_s18_qp_22 Q: 2

Ammonium iron(II) sulfate, $(NH_4)_2Fe(SO_4)_2$, has a relative formula mass, M_r, of 284.

(a) Define the term *relative formula mass*.

.....

.....

.....

..... [2]

(b) One of the cations in ammonium iron(II) sulfate is the ammonium ion, NH_4^+.

(i) Draw a 'dot-and-cross' diagram of an ammonium ion. Show outer shell electrons only.

Use × to show electrons from nitrogen.
Use ● to show electrons from hydrogen.

[2]

(ii) Suggest the shape of an ammonium ion and predict the bond angle.

shape .....

bond angle .....
[2]

(c) In aqueous solution the ammonium ion acts as a weak Brønsted-Lowry acid.

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

.....

.....

.....

..... [2]

(ii) Write an equation to show this behaviour of the ammonium ion in water. Include state symbols.

..... [2]

(d) Mohr's salt, $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$, is the hydrated form of ammonium iron(II) sulfate.

x represents the number of moles of water in 1 mole of the salt.

A student wanted to determine the value of x. 0.784 g of the hydrated salt was dissolved in water and this solution was acidified.

All of the solution was titrated with 0.0200 mol dm^{-3} potassium manganate(VII). 20.0 cm^3 of this potassium manganate(VII) solution was required for complete reaction with the Fe^{2+} ions.

(i) Use changes in oxidation numbers to balance the equation for the reaction taking place.

$MnO_4^-(aq)$ + ...$Fe^{2+}(aq)$ + ...$H^+(aq)$ → .....$Mn^{2+}(aq)$ + ...$Fe^{3+}(aq)$ + ...$H_2O(l)$

[1]

(ii) State the role of the Fe^{2+} ions in this reaction.

Explain your answer.

.....

..... [2]

(iii) Calculate the amount, in moles, of manganate(VII) ions that reacted.

amount = ... mol [1]

(iv) Calculate the amount, in moles, of Fe^{2+} ions in the sample of the salt.

amount = ... mol [1]

(v) Calculate the relative formula mass of $(NH_4)_2Fe(SO_4)_2 \cdot xH_2O$.

relative formula mass = ... [1]

(vi) Calculate the value of x.

x = ... [1]

[Total: 17]

1.

For which equilibrium does K_c have *no units*?

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

B $CH_3OH(l) + CH_3CO_2H(l) \rightleftharpoons CH_3CO_2CH_3(l) + H_2O(l)$

C $Cu^{2+}(aq) + 4NH_3(aq) \rightleftharpoons Cu(NH_3)_4^{2+}(aq)$

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

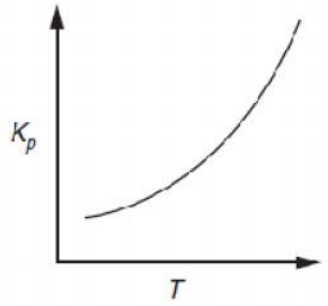
[2002 M/J (10)]

2.

The equilibrium constant K_p for the reaction

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

varies with temperature as shown in the diagram below.



Which conclusions can be drawn from this information?

1 The reaction is exothermic in the forward direction.

2 The equilibrium mixture contains a greater proportion of Z at higher pressures.

3 The equilibrium mixture contains a greater proportion of Z at higher temperatures.

[2002 M/J (34)]

3.

In an experiment, b mol of hydrogen iodide were put into a sealed vessel under pressure p. At equilibrium, x mol of the hydrogen iodide had dissociated, the reaction being represented by the following equation.

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

Which expression for K_p is correct?

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

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

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

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

[2002 O/N (11)]

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 is found to contain 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 $\dfrac{2 \times 0.26}{0.20 \times 0.15}$

B $\dfrac{(2 \times 0.26)^2}{0.20 \times 0.15}$

C $\dfrac{(0.26)^2}{0.07 \times 0.02}$

D $\dfrac{(0.26)^2}{0.13 \times 0.13}$

[2003 M/J (10)]

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5.

Why is ethanoic acid a stronger acid in liquid ammonia than in aqueous solution?

A Ammonia is a stronger base than water.

B Ammonium ethanoate is completely ionised in aqueous solution.

C Ammonium ethanoate is strongly acidic in aqueous solution.

D Liquid ammonia is a more polar solvent than water.

[2003 M/J (11)]

6.

It is suggested that the solid deposits of ammonium compounds on the leaves of trees found in areas of high pollution are caused by the following reaction.

$$2NH_3 + SO_3 + H_2O \rightarrow (NH_4)_2SO_4$$

Which of these take place in this reaction?

1 an acid-base reaction

2 ionic bond formation

3 oxidation and reduction

[2003 O/N (31)]

7.

One explanation of the explosion at the Chernobyl nuclear power plant in 1986 is that the graphite reactor overheated and reacted with the cooling water according to the following equation.

$$C(s) + H_2O(g) \rightleftharpoons H_2(g) + CO(g) \qquad \Delta H = +131\ kJ\,mol^{-1}$$

What are possible reasons why the forward reaction is more likely to occur at high temperature?

1 Hydrogen and carbon monoxide do not react at high temperature.

2 At lower temperature, the position of equilibrium lies too far to the left.

3 The energy of activation is high.

[2003 O/N (32)]

8.

When vanadium(II) compounds are dissolved in water, the following equilibrium is established.

$$V^{2+} + H_2O \rightleftharpoons V^{3+} + \tfrac{1}{2}H_2 + OH^-$$

What would alter the composition of the equilibrium mixture in favour of the V^{2+} ions?

A adding an acid

B adding a reagent that selectively precipitates V^{3+} ions

C allowing the hydrogen to escape as it forms

D making the solution more alkaline

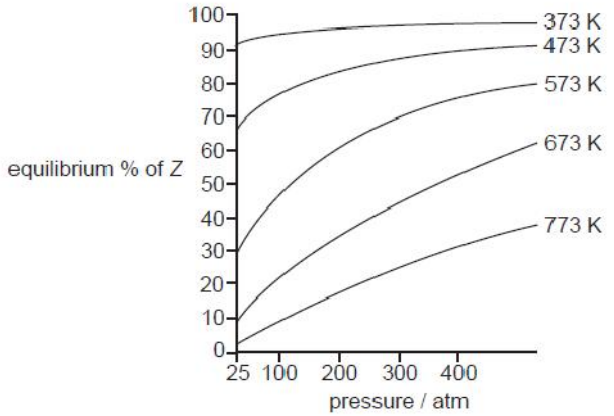
[2004 M/J (10)]

9.

In an industrial process, two gases *X* and *Y* react together to form a single gaseous product *Z*.

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

The percentage yield of product *Z* varies according to the pressure and the temperature as shown in the graphs.



Which statement about this equilibrium reaction is correct?

A Decreasing the temperature decreases the value of the equilibrium constant.

B Decreasing the temperature increases the rate of this reaction.

C Increasing the pressure increases the value of the equilibrium constant.

D The reaction is exothermic in the forward direction.

[2004 M/J (11)]

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10.

At high temperatures, steam decomposes into its elements according to the following equation.

$$2H_2O(g) \rightleftharpoons 2H_2(g) + O_2(g)$$

In one experiment at 1 atm pressure, it was found that 20 % of the steam had been converted into hydrogen and oxygen.

What are the values of the equilibrium partial pressures, in atm, of the components of this equilibrium?

	partial pressure of steam	partial pressure of hydrogen	partial pressure of oxygen
A	$\frac{0.80 \times 1}{1.0}$	$\frac{0.10 \times 1}{1.0}$	$\frac{0.10 \times 1}{1.0}$
B	$\frac{0.80 \times 1}{1.0}$	$\frac{0.133 \times 1}{1.0}$	$\frac{0.067 \times 1}{1.0}$
C	$\frac{0.80 \times 1}{1.0}$	$\frac{0.20 \times 1}{1.0}$	$\frac{0.10 \times 1}{1.0}$
D	$\frac{0.80 \times 1}{1.1}$	$\frac{0.20 \times 1}{1.1}$	$\frac{0.10 \times 1}{1.1}$

[2004 O/N (10)]

11.

Which statement concerning the equilibrium reaction below is true?

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$

A An increase in acid concentration will result in an increase in the concentration of $Cr_2O_7^{2-}(aq)$.

B A redox reaction is taking place.

C The addition of a catalyst will result in an increase in the concentration of $Cr_2O_7^{2-}(aq)$.

D The equilibrium constant, K_c, has no units.

[2004 O/N (11)]

12.

The dissociation of dinitrogen tetraoxide into nitrogen dioxide is represented by the equation below.

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

If the temperature of an equilibrium mixture of the gases is increased at constant pressure, will the volume of the mixture increase or decrease and why?

A The volume will increase, but only because of a shift of equilibrium towards the right.

B The volume will increase, both because of a shift of equilibrium towards the right and also because of thermal expansion.

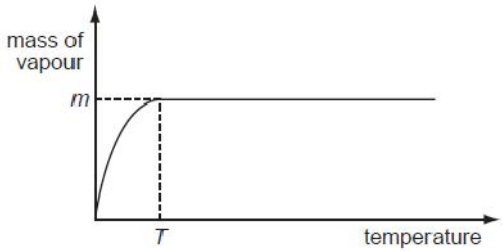
C The volume will stay the same, because any thermal expansion could be exactly counteracted by a shift of equilibrium towards the left.

D The volume will decrease, because a shift of equilibrium towards the left would more than counteract any thermal expansion.

[2005 M/J (10)]

13.

A quantity of solid *Y* was placed in a previously evacuated vessel and the apparatus was then held at a series of different temperatures. At each temperature, the mass of *Y* in the vapour state was calculated from pressure measurements. The results are shown below.



What can be deduced from the diagram?

1 The mass of *Y* used in the experiment was *m*.

2 The pressure of the vapour was constant for all temperatures above temperature *T*.

3 Liquid appeared at temperature *T*.

[2005 M/J (32)]

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14.

An experiment is set up to measure the rate of hydrolysis of methyl ethanoate.

$$CH_3CO_2CH_3 + H_2O \rightleftharpoons CH_3CO_2H + CH_3OH$$

The hydrolysis is found to be slow in neutral aqueous solution but it proceeds at a measurable rate when the solution is acidified with hydrochloric acid.

What is the function of the hydrochloric acid?

A to dissolve the methyl ethanoate

B to ensure that the reaction reaches equilibrium

C to increase the reaction rate by catalytic action

D to suppress ionisation of the ethanoic acid formed

[2005 O/N (10)]

15.

At a total pressure of 1.0 atm, dinitrogen tetraoxide is 50 % dissociated at a temperature of 60 °C, according to the following equation.

$$N_2O_4 \rightleftharpoons 2NO_2$$

What is the value of the equilibrium constant, K_p, for this reaction at 60 °C?

A $^1/_3$atm **B** $^2/_3$atm **C** $^4/_3$atm **D** 2 atm

[2006 M/J (10)]

16.

Swimming pool water can be kept free of harmful bacteria by adding aqueous sodium chlorate(I), NaOC*l*. This reacts with water to produce HOC*l* molecules which kill bacteria.

$$OCl\ (aq) + H_2O \rightleftharpoons OH\ (aq) + HOCl(aq)$$

In bright sunshine, the OC*l* ion is broken down by ultra-violet light.

$$OCl\ (aq) + \text{uv light} \rightarrow Cl\ (aq) + \tfrac{1}{2}O_2(g)$$

Which method would maintain the highest concentration of HOC*l*(aq)?

A acidify the pool water

B add a solution of chloride ions

C add a solution of hydroxide ions

D bubble air through the water

[2006 M/J (11)]

17.

The equilibrium constant, K_c, for the reaction to form ethyl ethanoate from ethanol and ethanoic acid, $C_2H_5OH + CH_3CO_2H \rightleftharpoons CH_3CO_2C_2H_5 + H_2O$, at 60 °C is 4.00.

When 1.00 mol each of ethanol and ethanoic acid are allowed to reach equilibrium at 60 °C, what is the number of moles of ethyl ethanoate formed?

A $\frac{1}{3}$ **B** $\frac{2}{3}$ **C** $\frac{1}{4}$ **D** $\frac{3}{4}$

[2006 O/N (11)]

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18.
Concentrated sulphuric acid behaves as a strong acid when it reacts with water.

$$H_2SO_4(l) + aq \rightarrow H^+(aq) + HSO_4(aq)$$

The HSO_4 ion formed behaves as a weak acid.

$$HSO_4(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$$

Which statements are true for 1.0 mol dm^{-3} sulphuric acid?

1 $[H^+(aq)]$ is high

2 $[SO_4^{2-}(aq)]$ is high

3 $[HSO_4(aq)] = [SO_4^{2-}(aq)]$

[2006 O/N (32)]

19.
Two equilibria are shown below.

reaction I $\quad 2X_2(g) + Y_2(g) \rightleftharpoons 2X_2Y(g)$

reaction II $\quad X_2Y(g) \rightleftharpoons X_2(g) + \frac{1}{2}Y_2(g)$

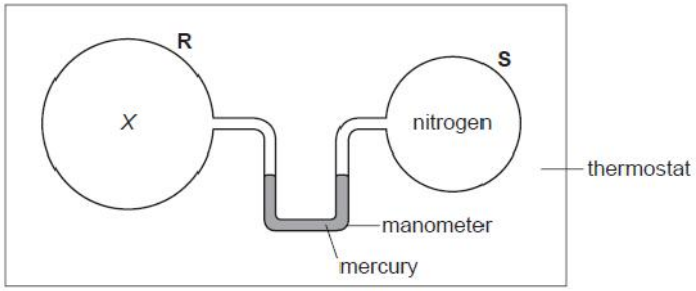
The numerical value of K_c for reaction I is 2.

Under the same conditions, what is the numerical value of K_c for reaction II?

A $\frac{1}{\sqrt{2}}$ **B** $\frac{1}{2}$ **C** $\frac{1}{4}$ **D** -2

[2007 M/J (9)]

20.
Two bulbs **R** and **S**, connected by a mercury manometer, are held in a thermostat, as shown. The volume of **R** is twice that of **S**. **R** contains gas, *X*, at the same pressure as the nitrogen in **S**.



When the temperature is increased, which gases in bulb **R** would cause the mercury level in the right-hand limb of the manometer to rise?

1 an equilibrium mixture $N_2F_4(g) \rightleftharpoons 2NF_2(g)$; ΔH positive

2 an equilibrium mixture $CH_3NC(g) \rightleftharpoons CH_3CN(g)$; ΔH negative

3 nitrogen

[2007 M/J (34)]

21.
Nitrogen dioxide decomposes on heating according to the following equation.

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

When 4 mol of nitrogen dioxide were put into a 1 dm^3 container and heated to a constant temperature, the equilibrium mixture contained 0.8 mol of oxygen.

What is the value of the equilibrium constant, K_c, at the temperature of the experiment?

A $\frac{0.8^2 \times 0.8}{4^2}$ **B** $\frac{1.6 \times 0.8}{2.4^2}$ **C** $\frac{1.6^2 \times 0.8}{4^2}$ **D** $\frac{1.6^2 \times 0.8}{2.4^2}$

[2007 O/N (10)]

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22.
Carbon monoxide burns readily in oxygen to form carbon dioxide.

What can be deduced from this information?

1 The +4 oxidation state of carbon is more stable than the +2 state.

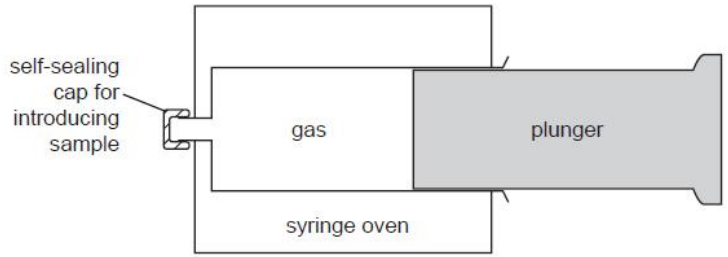
2 The standard enthalpy change of formation of carbon dioxide is more negative than that of carbon monoxide.

3 The value of the equilibrium constant for the reaction, $2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g)$, is likely to be high.

[2007 O/N (32)]

23.
Phosphorus pentachloride is introduced into an empty gas syringe which has a movable, tightly-fitting plunger. The gas is allowed to expand until equilibrium is reached at a temperature at which the phosphorus pentachloride partially dissociates.

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



Which statements are correct?

1 The equilibrium pressure inside the syringe will be greater than atmospheric pressure.

2 When the plunger is pushed in the equilibrium adjusts to produce more $PCl_5(g)$.

3 The volume of gas in the syringe at equilibrium will be greater than if no dissociation had occurred.

[2007 O/N (33)]

24.
For the reaction

$$W(aq) + 2X(aq) \rightleftharpoons 2Y(aq) + 3Z(aq)$$

what are the correct units for the equilibrium constant K_c?

A $mol\,dm^{-3}$ **B** $mol^2\,dm^{-6}$ **C** $mol^{-1}\,dm^3$ **D** $mol^{-2}\,dm^6$

[2008 M/J (11)]

25.
For the equilibrium $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, what will change the value of K_p?

A adding a catalyst

B adding more O_2

C increasing the pressure

D increasing the temperature

[2008 O/N (10)]

26.
Dinitrogen tetroxide dissociates into nitrogen dioxide on heating.

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

In an experiment the partial pressures of the gases at equilibrium were found to be NO_2, 0.33 atm; N_2O_4, 0.67 atm.

What is the numerical value of K_p at the temperature of the experiment?

A 0.16 **B** 0.49 **C** 0.65 **D** 2.03

[2008 O/N (11)]

27.
Under given conditions, what governs the rate of a forward reaction?

1 the activation energy of the reaction

2 the enthalpy change of the reaction

3 the equilibrium constant of the reaction

[2008 O/N (33)]

28.
The following reaction takes place using liquid ammonia as a solvent.

$$Na^+NH_2^- + NH_4^+Cl^- \rightarrow Na^+Cl^- + 2NH_3$$

Which statements best explain why this reaction should be classified as a Brønsted-Lowry acid-base reaction?

1 The ammonium ion acts as a proton donor.

2 Na^+Cl^- is a salt.

3 Ammonia is always basic.

[2009 M/J (34)]

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29.

The equilibrium

$$N_2(g) + O_2(g) \rightleftharpoons 2NO(g) \qquad \Delta H = +180\,kJ\,mol^{-1}$$

contributes to a series of reactions producing photochemical smog.

Which factors would affect the value of K_p of the above equilibrium?

	change in pressure	change in temperature	presence or absence of a catalyst
A	✓	✓	✗
B	✓	✗	✓
C	✗	✓	✓
D	✗	✓	✗

[2009 O/N-11 (8)]

30.

Which equilibria, in which all species are gaseous, would have equilibrium constants, K_p, with no units?

1 sulfur dioxide and oxygen in equilibrium with sulfur trioxide

2 hydrogen and iodine in equilibrium with hydrogen iodide

3 carbon monoxide and steam in equilibrium with carbon dioxide and hydrogen

[2009 O/N-11 (33)]

31.

The table gives the concentrations and pH values of the aqueous solutions of two compounds, X and Y. Either compound could be an acid or a base.

	X	Y
concentration	$2\,mol\,dm^{-3}$	$2\,mol\,dm^{-3}$
pH	6	9

Student P concluded that X is a strong acid.

Student Q concluded that the extent of dissociation is lower in X(aq) than in Y(aq).

Which of the students are correct?

A both P and Q

B neither P nor Q

C P only

D Q only

[2010 M/J-11 (10)]

32.

Swimming pool water can be kept free of harmful bacteria by adding aqueous sodium chlorate(I), NaOC*l*. This reacts with water to produce HOC*l* molecules which kill bacteria.

$$OCl^-(aq) + H_2O \rightleftharpoons OH^-(aq) + HOCl(aq)$$

In bright sunshine, the OCl^- ion is broken down by ultra-violet light.

$$OCl^-(aq) + \text{uv light} \rightarrow Cl^-(aq) + \tfrac{1}{2}O_2(g)$$

Which method would maintain the highest concentration of HOC*l*(aq)?

A acidify the pool water

B add a solution of chloride ions

C add a solution of hydroxide ions

D bubble air through the water

[2010 M/J-11 (11)]

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33.

The value of the equilibrium constant, K_c, for the reaction to form ethyl ethanoate from ethanol and ethanoic acid is 4.0 at 60 °C.

$$C_2H_5OH + CH_3CO_2H \rightleftharpoons CH_3CO_2C_2H_5 + H_2O$$

When 1.0 mol of ethanol and 1.0 mol of ethanoic acid are allowed to reach equilibrium at 60 °C, what is the number of moles of ethyl ethanoate formed?

A $\frac{1}{3}$ **B** $\frac{2}{3}$ **C** $\frac{1}{4}$ **D** $\frac{3}{4}$

[2010 O/N-11 (10)]

34.

Ethanol is manufactured by reacting ethene gas and steam in the presence of phosphoric(V) acid.

$$C_2H_4(g) + H_2O(g) \rightleftharpoons C_2H_5OH(g) \qquad \Delta H = -45\,kJ\,mol^{-1}$$

The reaction is carried out at 570 K and 60 atm.

What would be the consequences of carrying out the reaction at the same temperature but at a pressure of 200 atm?

1 The manufacturing costs would increase.

2 The maximum yield at equilibrium would be higher.

3 The reaction would proceed at a faster rate.

[2010 O/N-11 (31)]

35.

The following equilibrium is set up in a mixture of concentrated nitric and sulfuric acids.

$$HNO_3 + H_2SO_4 \rightleftharpoons H_2NO_3^+ + HSO_4^-$$

Which row correctly describes the behaviour of each substance in the equilibrium mixture?

	HNO_3	H_2SO_4	$H_2NO_3^+$	HSO_4^-
A	acid	acid	base	base
B	acid	base	base	acid
C	base	acid	acid	base
D	base	acid	base	acid

[2010 O/N-12 (9)]

36.

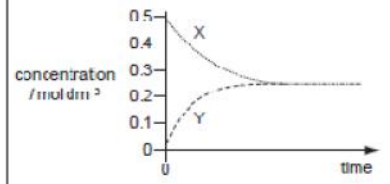
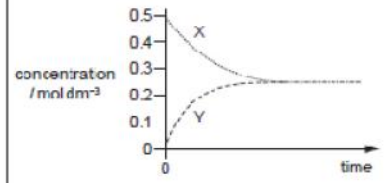
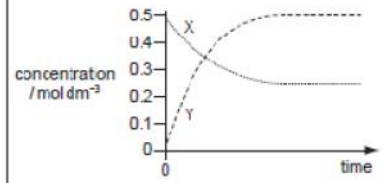
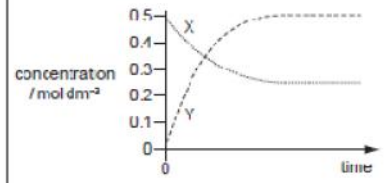
A dimer, X, is stable when solid but a dynamic equilibrium is set up in solution.

$$X(aq) \rightleftharpoons 2Y(aq)$$

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

The changes in [X(aq)] and [Y(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		2
C		1
D		2

[2010 O/N-12 (11)]

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37.
Which statement explains the observation that magnesium hydroxide dissolves in aqueous ammonium chloride, but not in aqueous sodium chloride?

A The ionic radius of the NH_4^+ ion is similar to that of Mg^{2+} but not that of Na^+.

B NH_4Cl dissociates less fully than NaCl.

C The Na^+ and Mg^{2+} ions are isoelectronic (have the same number of electrons).

D The NH_4^+ ion can donate a proton.

[2010 O/N-12 (15)]

38.
Which statements are correct in terms of the Brønsted-Lowry theory of acids and bases?

1 Water can act as either an acid or a base.

2 Sulfuric acid, H_2SO_4, does not behave as an acid when dissolved in ethanol, C_2H_5OH.

3 The ammonium ion acts as a base when dissolved in liquid ammonia.

[2011 M/J-11 (31)]

39.
The esterification reaction

$$\text{ethanol} + \text{ethanoic acid} \rightleftharpoons \text{ethyl ethanoate} + \text{water}$$

is an equilibrium. The forward reaction is exothermic.

How can the value of the equilibrium constant K_C be increased?

A by adding a little concentrated sulfuric acid as a catalyst

B by increasing the initial concentration of ethanol

C by lowering the temperature

D by raising the temperature

[2011 M/J-12 (4)]

40.
Sulfur dioxide is used as a preservative in wine making.

The following equations describe how sulfur dioxide dissolves.

$$H_2O + SO_2 \rightleftharpoons HSO_3^- + H^+$$

$$HSO_3^- + H^+ \rightleftharpoons SO_3^{2-} + 2H^+$$

Which statement about these two reactions is correct?

A HSO_3^- acts as a base.

B SO_2 acts as an oxidising agent.

C SO_3^{2-} acts as an acid.

D SO_3^{2-} acts as a reducing agent.

[2011 O/N-11 (8)]

41.
An aqueous solution was prepared containing 1.0 mol of $AgNO_3$ and 1.0 mol of $FeSO_4$ in 1.00 dm^3 of water. When equilibrium was established, there was 0.44 mol of $Ag^+(aq)$ in the mixture.

$$Ag^+(aq) + Fe^{2+}(aq) \rightleftharpoons Ag(s) + Fe^{3+}(aq)$$

What is the numerical value of K_c?

A 0.35 **B** 0.62 **C** 1.62 **D** 2.89

[2011 O/N-11 (9)]

42.
When gaseous iodine is heated with hydrogen at 450 °C, an equilibrium is established.

$$\underset{\text{colourless}}{H_2(g)} + \underset{\text{purple}}{I_2(g)} \rightleftharpoons \underset{\text{colourless}}{2HI(g)} \qquad \Delta H = +53\ \text{kJ mol}^{-1}$$

Which change of conditions will cause the purple colour of the equilibrium mixture to become paler?

A decrease in pressure

B decrease in temperature

C increase in pressure

D increase in temperature

[2011 O/N-11 (10)]

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43.
For the equilibrium $2SO_2(g) + O_2(g) \rightleftharpoons 2SO_3(g)$, what will change the value of K_p?

A adding a catalyst

B adding more O_2

C increasing the pressure

D increasing the temperature

[2011 O/N-12 (7)]

44.
For the reaction

$$W(aq) + 2X(aq) \rightleftharpoons 2Y(aq) + 3Z(aq)$$

what are the correct units for the equilibrium constant K_c?

A $mol\,dm^{-3}$ **B** $mol^2\,dm^{-6}$ **C** $mol^{-1}\,dm^3$ **D** $mol^{-2}\,dm^6$

[2011 O/N-12 (12)]

45.
Two moles of compound P were placed in a vessel. The compound P was partly decomposed by heating. A dynamic equilibrium between chemicals P, Q and R was established.

At equilibrium, x mol of R were present and the total number of moles present was $(2 + x)$.

What is the equation for this equilibrium?

A $P \rightleftharpoons 2Q + R$

B $2P \rightleftharpoons 2Q + R$

C $2P \rightleftharpoons Q + R$

D $2P \rightleftharpoons Q + 2R$

[2012 M/J-11 (9)]

46.
Two moles of compound P were placed in a vessel. The vessel was heated and compound P was partly decomposed to produce Q and R. A dynamic equilibrium between chemicals P, Q and R was established.

At equilibrium x moles of R were present and the total number of moles present was $(2 + \frac{x}{2})$.

What is the equation for this equilibrium reaction?

A $P \rightleftharpoons 2Q + R$

B $2P \rightleftharpoons 2Q + R$

C $2P \rightleftharpoons Q + R$

D $2P \rightleftharpoons Q + 2R$

[2012 M/J-12 (7)]

47.
Methanol is manufactured by reacting carbon dioxide and hydrogen.

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

What would increase the equilibrium yield of methanol in this process?

A adding a catalyst

B adding an excess of steam

C increasing the pressure

D increasing the temperature

[2012 M/J-12 (9)]

48.
Concentrated sulfuric acid behaves as a strong acid when it reacts with water.

$$H_2SO_4(l) + aq \rightarrow H^+(aq) + HSO_4^-(aq)$$

The HSO_4^- ion formed behaves as a weak acid.

$$HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$$

Which statements are true for $1.0\,mol\,dm^{-3}$ sulfuric acid?

1 $[H^+(aq)]$ is high

2 $[SO_4^{2-}(aq)]$ is high

3 $[HSO_4^-(aq)] = [SO_4^{2-}(aq)]$

[2012 M/J-12 (33)]

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49.

The table describes some of the chemistry and thermodynamic properties of the halogens.

process	name and symbol of quantity
$2HX(g) \rightarrow H_2(g) + X_2(g)$	enthalpy change of reaction, $\Delta H^{\ominus}$
$H_2(g) + X_2(g) \rightleftharpoons 2HX(g)$	equilibrium constant, K_p
$X(g) \rightarrow X^+(g) + e^-$	ionisation energy, $\Delta H_i^{\ominus}$

Which statements about the relative values of these quantities are correct?

1 $\Delta H^{\ominus}$ for HC*l* > $\Delta H^{\ominus}$ for HBr

2 K_p for HBr > K_p for HI

3 $\Delta H_i^{\ominus}$ for I > $\Delta H_i^{\ominus}$ for C*l*

[2012 O/N-13 (36)]

50.

An experiment is set up to measure the rate of hydrolysis of ethyl ethanoate.

$$CH_3CO_2C_2H_5 + H_2O \rightleftharpoons CH_3CO_2H + C_2H_5OH$$

The hydrolysis is found to be slow in neutral aqueous solution but it proceeds at a measurable rate when the solution is acidified with hydrochloric acid.

What is the function of the hydrochloric acid?

A to dissolve the ethyl ethanoate

B to ensure that the reaction reaches equilibrium

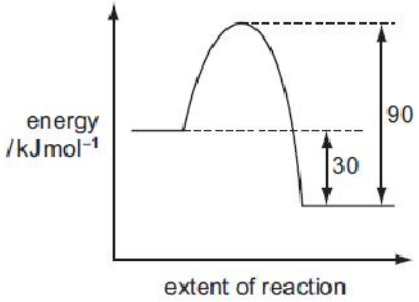
C to increase the reaction rate by catalytic action

D to suppress ionisation of the ethanoic acid formed

[2013 M/J-11 (6)]

51.

The diagram shows the reaction pathway for a reversible reaction.



Which statements are correct?

1 The enthalpy change for the backward reaction is +90 kJ mol^{-1}.

2 The forward reaction is exothermic.

3 The enthalpy change for the forward reaction is –30 kJ mol^{-1}.

[2013 M/J-12 (32)]

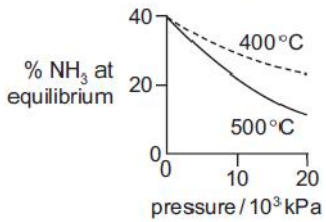
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52.

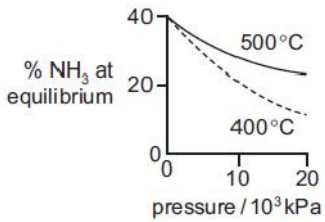
Graphs can be drawn to show the percentage of ammonia at equilibrium when nitrogen and hydrogen are mixed at different temperatures and pressures.

Which diagram correctly represents these two graphs?

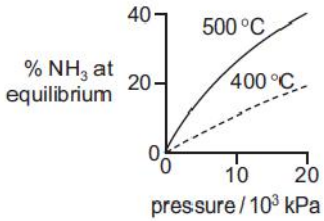
A



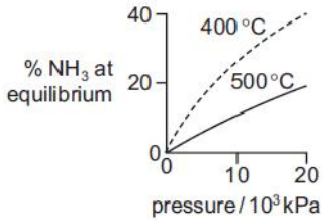
B



C



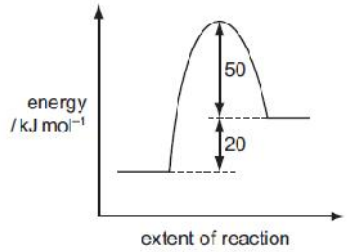
D



[2013 M/J-13 (17)]

53.

The reaction pathway for a reversible reaction is shown below.



Which statements are correct?

1 The enthalpy change for the backward reaction is –20 kJ mol^{-1}.

2 The forward reaction is endothermic.

3 The activation energy for the forward reaction is +70 kJ mol^{-1}.

[2013 M/J-13 (33)]

54.

Nitrogen reacts with hydrogen to produce ammonia.

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

A mixture of 2.00 mol of nitrogen, 6.00 mol of hydrogen, and 2.40 mol of ammonia is allowed to reach equilibrium in a sealed vessel of volume 1 dm^3 under certain conditions. It was found that 2.32 mol of nitrogen were present in the equilibrium mixture.

What is the value of K_c under these conditions?

A $\dfrac{(1.76)^2}{(2.32)(6.96)^3}$

B $\dfrac{(1.76)^2}{(2.32)(6.32)^3}$

C $\dfrac{(2.08)^2}{(2.32)(6.32)^3}$

D $\dfrac{(2.40)^2}{(2.32)(6.00)^3}$

[2013 O/N-11 (9)]

55.

What are necessary properties of a dynamic equilibrium?

1 Equal amounts of reactants and products are present.

2 Concentrations of reactants and products remain constant.

3 The rate of the forward reaction is the same as the rate of the reverse reaction.

[2013 O/N-11 (33)]

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56.

If N_2O_4 gas is placed in a sealed vessel the following equilibrium is established.

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

The forward reaction is endothermic.

What happens when the temperature is increased?

1 The equilibrium constant increases.

2 The partial pressure of NO_2 increases.

3 The activation energy is unchanged.

[2013 O/N-11 (34)]

57.

Nitrogen reacts with hydrogen to produce ammonia.

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

A mixture of 1.00 mol of nitrogen, 3.00 mol of hydrogen and 1.98 mol of ammonia is allowed to reach equilibrium in a sealed vessel under certain conditions. It was found that 1.64 mol of nitrogen were present in the equilibrium mixture.

What is the value of K_c under these conditions?

A $\dfrac{(0.70)^2}{(1.64)(4.92)^3}$

B $\dfrac{(1.34)^2}{(1.64)(3.64)^3}$

C $\dfrac{(1.64)(4.92)^3}{(0.70)^2}$

D $\dfrac{(1.64)(3.64)^3}{(1.34)^2}$

[2013 O/N-13 (10)]

58.

The following equilibrium is an exothermic reaction in the forward direction.

$$2CrO_4^{2-}(aq) + 2H^+(aq) \rightleftharpoons Cr_2O_7^{2-}(aq) + H_2O(l)$$

What happens when the concentration of CrO_4^{2-} ions **increases and** the temperature **decreases**?

1 The concentration of $Cr_2O_7^{2-}$ ions increases.

2 The equilibrium constant increases.

3 The activation energy decreases.

[2013 O/N-13 (34)]

59.

The equilibrium constant, K_c, for the reaction $H_2(g) + I_2(g) \rightleftharpoons 2HI(g)$, is 60 at 450 °C.

What is the number of moles of hydrogen iodide in equilibrium with 2 mol of hydrogen and 0.3 mol of iodine at 450 °C?

A $\dfrac{1}{100}$ **B** $\dfrac{1}{10}$ **C** 6 **D** 36

[2014 M/J-11 (10)]

60.

R and S react together.

$$R + S \rightleftharpoons T$$

Which factors affect the rate of the forward reaction?

1 the activation energy of the reaction

2 the enthalpy change of the reaction

3 the equilibrium constant of the reaction

[2014 M/J-11 (33)]

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61.

The Brønsted-Lowry theory describes acid and base character.

When concentrated sulfuric acid and concentrated nitric acid are mixed, the following reactions occur.

$$H_2SO_4 + HNO_3 \rightleftharpoons HSO_4^- + H_2NO_3^+$$

$$H_2NO_3^+ \rightleftharpoons H_2O + NO_2^+$$

$$H_2O + H_2SO_4 \rightleftharpoons HSO_4^- + H_3O^+$$

Which species are bases in these reactions?

1 HSO_4^-

2 HNO_3

3 NO_2^+

[2014 M/J-11 (34)]

62.

Hydrogen and carbon dioxide gases are mixed in equal molar amounts at 800K. A reversible reaction takes place.

$$H_2(g) + CO_2(g) \rightleftharpoons H_2O(g) + CO(g)$$

At equilibrium, the partial pressures of H_2 and CO_2 are both 10.0kPa. K_p is 0.288 at 800K.

What is the partial pressure of CO in the equilibrium mixture?

A 5.37 kPa **B** 18.6 kPa **C** 28.8 kPa **D** 347 kPa

[2014 M/J-12 (4)]

63.

The formation of hydrogen and ethyne, C_2H_2, from methane reaches dynamic equilibrium.

$$2CH_4(g) \rightleftharpoons 3H_2(g) + C_2H_2(g)$$

What are the units of K_c?

A $mol\,dm^{-3}$ **B** $mol^2\,dm^{-6}$ **C** $mol^3\,dm^{-9}$ **D** $mol^4\,dm^{-12}$

[2014 M/J-12 (7)]

64.

Sulfuric acid is a Brønsted-Lowry acid.

In which reactions is sulfuric acid behaving as an acid?

1 $H_2SO_4 + HNO_3 \rightarrow H_2NO_3^+ + HSO_4^-$

2 $H_2SO_4 + CO_3^{2-} \rightarrow CO_2 + H_2O + SO_4^{2-}$

3 $H_2SO_4 + MgO \rightarrow MgSO_4 + H_2O$

[2014 M/J-12 (34)]

65.

A reversible reaction is catalysed.

Which statements about the effects of the catalyst on this system are correct?

1 The catalyst alters the mechanism of the reaction.

2 The catalyst reduces the activation energy for both the forward and the backward reaction.

3 The catalyst alters the composition of the equilibrium mixture.

[2014 O/N-11 (33)]

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Further aspects of Equilibria - 2021

1. Nov/2020/Paper_41/No.4

(a) (i) Give the mathematical expression for each of the terms pH and K_w.

pH = ...

K_w = ...

[2]

(ii) Calculate the pH of 0.027 mol dm^{-3} NaOH(aq).

pH = ... [1]

(b) The K_a value of chloric(I) acid, HClO, is 3.72×10^{-8} mol dm^{-3}.

Calculate the pH of 0.010 mol dm^{-3} HClO(aq).

pH = ... [1]

(c) Water and octan-1-ol form two layers when mixed.

Ethanamide is more soluble in water than it is in octan-1-ol. When 1.00 g of ethanamide is added to 50.0 cm^3 of water and this is then shaken with 50.0 cm^3 of octan-1-ol, it is found that the water layer contains 0.935 g of ethanamide at equilibrium.

(i) Calculate the partition coefficient, K_{pc}, for ethanamide in water and octan-1-ol.

K_{pc} = ... [1]

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(ii) The 50.0 cm^3 of water containing 0.935 g of ethanamide is then shaken with 100.0 cm^3 of pure octan-1-ol under the same conditions.

Calculate the mass of ethanamide that is dissolved in the 100.0 cm^3 of octan-1-ol at equilibrium.

mass of ethanamide = ... g
[2]

[Total: 7]

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2. Nov/2020/Paper_42/No.2

(a) Write an expression for the K_a of the weak acid HA in terms of the concentrations of the species involved.

K_a =

[1]

(b) The hydroxylammonium ion, $HONH_3^+$, is a weak acid. A 1.00×10^{-3} mol dm^{-3} solution of hydroxylammonium ions has a pH of 4.41.

(i) Calculate the K_a of $HONH_3^+$.

K_a = ... [2]

(ii) Calculate the pK_a of $HONH_3^+$.

pK_a = ... [1]

(c) The solubility product of manganese(II) hydroxide, $Mn(OH)_2$, in water is 1.1×10^{-11} mol^3 dm^{-9} at 298 K.

Calculate the solubility of $Mn(OH)_2$ in water at 298 K.

solubility = ... mol dm^{-3} [2]

[Total: 6]

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3. March/2020/Paper_42/No.5b

(b) A buffer solution was prepared by dissolving 2.04 g of gallic acid in 250 cm^3 of a solution containing 0.0600 mol dm^{-3} of gallate ions, $C_7H_5O_5^-$.

$$C_7H_6O_5 \rightleftharpoons C_7H_5O_5^- + H^+ \qquad K_a = 3.89 \times 10^{-5} \text{ mol dm}^{-3} \text{ at } 298 \text{ K}$$

(i) Define the term *buffer solution*.

.....

.....

..... [2]

(ii) Calculate the pH of this buffer solution.

pH = ... [3]

(iii) Write **two** equations to show how a solution containing gallic acid, $C_7H_6O_5$, and gallate ions, $C_7H_5O_5^-$, acts as a buffer.

.....

.....

.....

..... [2]

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4. June/2020/Paper_41/No.6b,6g

(b) (i) The numerical values of K_a for methanoic acid, HCO_2H, and pyruvic acid, CH_3COCO_2H, are given.

acid	K_a
HCO_2H	1.78×10^{-4}
CH_3COCO_2H	4.07×10^{-3}

An equilibrium mixture containing the two acid-base pairs is formed.

$$HCO_2^- + CH_3COCO_2H \rightleftharpoons HCO_2H + CH_3COCO_2^-$$

Use the K_a values to calculate the equilibrium constant, K_{eq}, for this equilibrium.

K_{eq} = ... [1]

(ii) Use your value of K_{eq} to predict the position of this equilibrium. Indicate this by placing a tick (✓) in the appropriate box in the table. Explain your answer.

equilibrium lies to the left	equilibrium lies in the middle	equilibrium lies to the right

.....

.....

[1]

(iii) Ethanedioic acid, HO_2CCO_2H, has two dissociation constants, K_{a1} and K_{a2}, whose pK_a values are 1.23 and 4.19.

Suggest equations to show the two dissociations that give rise to these pK_a values.

pK_{a1} 1.23 .....

pK_{a2} 4.19 .....

[2]

(iv) State the mathematical relationship between pK_a and the acid dissociation constant K_a.

..... [1]

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(g) The ionic product, K_w, for D_2O has a value of $1.35 \times 10^{-15}\,mol^2\,dm^{-6}$ at 298 K.

(i) Write the expression for the K_w of D_2O.

K_w =

[1]

(ii) Calculate the pH of pure, neutral D_2O at 298 K.
Assume $[D^+]$ is equivalent to $[H^+]$ for pH calculations.

pH = ... [2]

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5. June/2020/Paper_41/No.8

(a) Explain what is meant by the term *buffer solution*.

.....

.....

..... [2]

(b) (i) Write an expression for the acid dissociation constant, K_a, for ammonium ions, $NH_4^+(aq)$.

K_a =

[1]

(ii) Write **two** equations to describe how a solution containing ammonium ions, $NH_4^+(aq)$, and ammonia, $NH_3(aq)$, can act as a buffer.

.....

..... [2]

(iii) The numerical value of K_a for $NH_4^+(aq)$ is 5.6×10^{-10} at 298 K.
A buffer solution was prepared by adding 0.80 dm^3 of 0.25 mol dm^{-3} ammonia, an excess, to 0.20 dm^3 of 0.20 mol dm^{-3} hydrochloric acid.

Calculate the pH of the buffer solution formed at 298 K.

pH = ... [3]

[Total: 8]

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1. Nov/2021/Paper_41/No.2

Solution **Y** is hydrochloric acid, HCl(aq). Solution **Z** is aqueous 4-chlorobutanoic acid, $Cl(CH_2)_3CO_2H$(aq). The pK_a of $Cl(CH_2)_3CO_2H$(aq) is 4.52. The pH of both solutions is 4.00.

(a) (i) Write an expression for the K_a of $Cl(CH_2)_3CO_2H$(aq).

K_a =

[1]

(ii) Write a mathematical expression to describe the relationship between K_a and pK_a.

..... [1]

(iii) Calculate $[H^+]$ in solutions **Y** and **Z**.

$[H^+]$ = ... $mol\,dm^{-3}$ [1]

(iv) Calculate the ratio $\frac{[HCl] \text{ dissolved in solution } \mathbf{Y}}{[Cl(CH_2)_3CO_2H] \text{ dissolved in solution } \mathbf{Z}}$.

$\frac{[HCl] \text{ dissolved in solution } \mathbf{Y}}{[Cl(CH_2)_3CO_2H] \text{ dissolved in solution } \mathbf{Z}}$ = ... [2]

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(b) A buffer solution of pH 5.00 is produced by adding sodium propanoate to 5.00 g of propanoic acid in 100 cm^3 of distilled water.

Calculate the mass of sodium propanoate that must be used to produce this buffer solution. The K_a of propanoic acid is 1.35×10^{-5} mol dm^{-3}.

[M_r: propanoic acid, 74.0; sodium propanoate, 96.0]

mass of sodium propanoate = ... g [3]

(c) Some dilute sulfuric acid is mixed with a small sample of the buffer solution described in **(b)**. The final pH of the mixture is close to 1.

Explain this observation.

.....

.....

.....

..... [2]

[Total: 10]

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2. Nov/2021/Paper_42/No.2

Ethoxyethane, $C_2H_5OC_2H_5$, can dissolve both in water and in octan-1-ol. The expression and numerical value for the partition coefficient of ethoxyethane between water and octan-1-ol are given. Water and octan-1-ol are immiscible.

$$K_{pc} = \frac{\text{concentration of } C_2H_5OC_2H_5 \text{ in octan-1-ol}}{\text{concentration of } C_2H_5OC_2H_5 \text{ in water}} = 6.760 \text{ at } 20\,^{\circ}C$$

(a) In an experiment, octan-1-ol at 20 °C is added to a solution of ethoxyethane in water at 20 °C. The mixture is analysed immediately and a value of K_{pc} is calculated.

The calculation is performed correctly; the value calculated is 5.625.

Explain why the value calculated is **less** than 6.760.

.....

..... [2]

(b) A second experiment is performed and the value of K_{pc} is found to be 6.760. The concentration of ethoxyethane in the octan-1-ol layer is 7.62 g dm^{-3}.

(i) Calculate the concentration, in g dm^{-3}, of ethoxyethane in the aqueous layer.

..... g dm^{-3} [1]

(ii) 100 cm^3 of the octan-1-ol layer is taken and shaken with 100 cm^3 of water.

Calculate the maximum amount, in mol, of ethoxyethane that can be extracted into the water.

..... mol [3]

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(c) An aqueous solution of lead(II) nitrate is mixed with an aqueous solution of sodium iodide. A yellow precipitate of lead(II) iodide is formed and is filtered out, leaving solution **X**.

The concentration of Pb^{2+} in solution **X** is 5.68×10^{-3} mol dm^{-3}.

The concentration of I^- in solution **X** is 4.20×10^{-4} mol dm^{-3}.

(i) Use these data to calculate a value for the solubility product, K_{sp}, of lead(II) iodide.

State the units of K_{sp}.

K_{sp} = ...

units = ...
[2]

(ii) Potassium iodide is very soluble in water.

Describe and explain what is seen if a few drops of saturated potassium iodide solution are added to a portion of solution **X**.

.....

.....

..... [2]

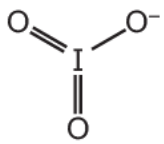
[Total: 10]

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3. March/2021/Paper_42/No.3

Iodates are compounds that contain the IO_3^- anion.

(a) The IO_3^- anion is shown.



Explain, with reference to the qualitative model of electron-pair repulsion, why the IO_3^- anion has a pyramidal shape.

.....

.....

..... [1]

(b) The reaction of iodine and hot aqueous sodium hydroxide is similar to that of chlorine and hot aqueous sodium hydroxide. Sodium iodate, $NaIO_3$, is formed as one of the products.

Suggest an equation for the reaction of iodine and hot aqueous sodium hydroxide.

..... [1]

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(c) The decomposition of hydrogen peroxide, H_2O_2, is catalysed by acidified IO_3^-.

H_2O_2 reduces acidified IO_3^- as shown.

$$5H_2O_2 + 2H^+ + 2IO_3^- \rightarrow I_2 + 5O_2 + 6H_2O$$

This reaction is followed by the oxidation of I_2 by H_2O_2.

half-equation	$E^\ominus$/V
$H_2O_2 + 2H^+ + 2e^- \rightleftharpoons 2H_2O$	+1.77
$IO_3^- + 6H^+ + 5e^- \rightleftharpoons \frac{1}{2}I_2 + 3H_2O$	+1.19
$O_2 + 2H^+ + 2e^- \rightleftharpoons H_2O_2$	+0.68

(i) Use the data to show that the separate reactions of H_2O_2 with IO_3^- and with I_2 are both feasible under standard conditions.

In your answer, give the equation for the reaction of H_2O_2 with I_2.

.....

.....

.....

.....

.....

..... [3]

(ii) Write the overall equation for the decomposition of H_2O_2 catalysed by acidified IO_3^-.

..... [1]

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(d) A student collects some data for the reaction of H_2O_2 with acidified IO_3^-, as shown in the table.

experiment	$[H_2O_2]$ / mol dm^{-3}	$[IO_3^-]$ / mol dm^{-3}	$[H^+]$ / mol dm^{-3}	initial rate of reaction / mol dm^{-3} s^{-1}
1	0.0500	0.0700	0.025	1.47×10^{-5}
2	0.100	0.0700	0.050	2.94×10^{-5}
3	0.100	0.140	0.025	5.88×10^{-5}
4	0.150	0.140	0.025	8.82×10^{-5}

(i) Use the data to determine the order of reaction with respect to $[H_2O_2]$, $[IO_3^-]$ and $[H^+]$.

Show your reasoning.

order with respect to $[H_2O_2]$ = ...

.....

.....

.....

order with respect to $[IO_3^-]$ = ...

.....

.....

.....

order with respect to $[H^+]$ = ...

.....

.....

.....

[3]

(ii) Use your answer to **(d)(i)** to write the rate equation for this reaction.

rate = ... [1]

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(iii) Calculate the value of the rate constant, k, using data from experiment 4 and your answer to **(d)(ii)**.

Give the units of k.

k = ...

units = ...
[2]

(e) $Pb(IO_3)_2$ is only sparingly soluble in water at 25 °C.

The solubility product, K_{sp}, of $Pb(IO_3)_2$ is 3.69×10^{-13} mol^3 dm^{-9} at 25 °C.

(i) Write an expression for the solubility product of $Pb(IO_3)_2$.

K_{sp} =

[1]

(ii) Calculate the solubility, in mol dm^{-3}, of $Pb(IO_3)_2$ at 25 °C.

solubility = ... mol dm^{-3} [2]

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(f) NH_4IO_3 is an unstable compound that readily decomposes when warmed. The decomposition reaction is shown.

$$NH_4IO_3(s) \rightarrow \tfrac{1}{2}N_2(g) + \tfrac{1}{2}O_2(g) + \tfrac{1}{2}I_2(g) + 2H_2O(l) \qquad \Delta H = -154.6\,kJ\,mol^{-1}$$

(i) Use the data in the table to calculate the entropy change of reaction, ΔS, of the decomposition of $NH_4IO_3(s)$.

compound	S / $J\,K^{-1}\,mol^{-1}$
$NH_4IO_3(s)$	42
$N_2(g)$	192
$O_2(g)$	205
$I_2(g)$	261
$H_2O(l)$	70

ΔS = ... $J\,K^{-1}\,mol^{-1}$ [2]

(ii) This reaction is feasible at all temperatures.

Explain why, using the data in **(f)** and your answer to **(f)(i)**.

.....

.....

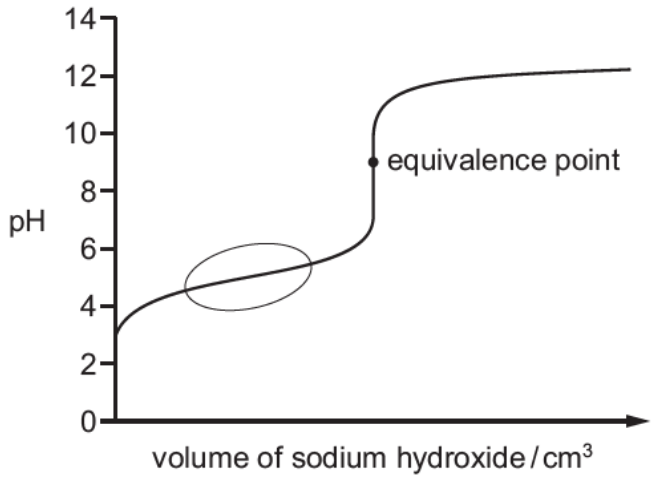
..... [1]

[Total: 18]

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4. June/2021/Paper_41/No.8

(a) The sketch graph for the titration of ethanoic acid, CH_3CO_2H, with sodium hydroxide is shown.



(i) In the region circled on the graph, identify the **two** organic species that are present in the solution. Explain why the pH of the mixture only changes slowly and gradually in this region when sodium hydroxide is being added.

two species present ....

.....

.....

.....

..... [3]

(ii) The equivalence point in this acid-base titration is where the two solutions have been mixed in exactly equal molar proportion.

Suggest why the pH is greater than 7 at the equivalence point in this titration.

.....

.....

.....

..... [1]

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(b) An impure sample of ammonium vanadate(V), NH_4VO_3, with mass 0.150 g, is dissolved in an excess of dilute acid.

In this solution all vanadium is present as VO_2^+ ions. An excess of zinc powder is added to the solution and all the VO_2^+ ions are reduced to V^{2+} ions. The mixture is filtered to remove any remaining zinc powder.

$$VO_2^+ + 4H^+ + 3e^- \rightarrow V^{2+} + 2H_2O$$

When the resulting solution is titrated, 20.10 cm^3 of 0.0250 mol dm^{-3} acidified MnO_4^- oxidises all V^{2+} ions back to VO_2^+ ions.

$$MnO_4^- + 8H^+ + 5e^- \rightleftharpoons Mn^{2+} + 4H_2O$$

Calculate the percentage by mass of NH_4VO_3 in the 0.150 g impure sample of NH_4VO_3.

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

[M_r: NH_4VO_3, 116.9]

percentage by mass of NH_4VO_3 = ... % [3]

[Total: 7]

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Equilibria - 2022 June A2 Chemistry 9701

1. June/2022/Paper_42/No.4(c)

(c) The buffer system in seawater contains a mixture of HCO_3^- and H_2CO_3.

equilibrium **5** $H_2CO_3 + H_2O \rightleftharpoons HCO_3^- + H_3O^+$

(i) Define a buffer solution.

.....

.....

..... [2]

(ii) Construct **two** equations to show how equilibrium **5** acts as a buffer solution.

.....

..... [2]

(iii) The $[HCO_3^-]/[H_2CO_3]$ ratio in a sample of seawater is 14.1.

Calculate the pH of this sample.
[pK_a: H_2CO_3, 6.35]

pH = ... [3]

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1. Nov/2022/Paper_41/No.4

(a) A sample of butanoic acid, $CH_3(CH_2)_2COOH$, is shaken with a mixture of two immiscible solvents, ethoxyethane and water. The solvents form two layers. The butanoic acid is distributed between the two layers, its concentration in ethoxyethane being higher than its concentration in water.

(i) State what is meant by partition coefficient.

.....

..... [1]

(ii) The partition coefficient, K_{pc}, for butanoic acid between ethoxyethane and water is 3.50.

A solution of 2.00 g of butanoic acid in 100 cm^3 ethoxyethane is added to water. This mixture is left until there is no further change in the concentration of butanoic acid in either solvent. The mass of butanoic acid dissolved in the ethoxyethane layer is now 1.62 g.

Calculate the volume of water used.

volume of water used = ... cm^3 [2]

(b) An aqueous solution of butanoic acid can be used to make a buffer solution.

(i) Define buffer solution.

.....

..... [1]

(ii) Suggest one organic compound, and one inorganic compound, that can be added to two different samples of aqueous butanoic acid to produce buffer solutions.

organic compound .....

inorganic compound .....

[1]

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(c) The solubility of aluminium hydroxide, $Al(OH)_3$, in water is 2.47×10^{-9} mol dm^{-3}.

(i) Give the expression for the solubility product, K_{sp}, of aluminium hydroxide.

K_{sp} =

[1]

(ii) Calculate the numerical value of the K_{sp} of aluminium hydroxide. Include the units of K_{sp} in your answer.

K_{sp} = ...

units = ...

[3]

[Total: 9]

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2. Nov/2022/Paper_42/No.4

(a) The value of the solubility product, K_{sp}, of iron(III) hydroxide, $Fe(OH)_3$, is given by the following expression.

$$K_{sp} = [Fe^{3+}][OH^-]^3 = 2.0 \times 10^{-39}\,mol^4\,dm^{-12}$$

(i) Calculate the solubility of $Fe(OH)_3$ in water.

solubility = ... $mol\,dm^{-3}$ [1]

(ii) Calculate the solubility of $Fe(OH)_3$ in $0.010\,mol\,dm^{-3}$ barium hydroxide, $Ba(OH)_2(aq)$.

solubility = ... $mol\,dm^{-3}$ [2]

(iii) $Fe(OH)_3$ is less soluble in $Ba(OH)_2(aq)$ than it is in pure water.

Name this effect.

..... [1]

(b) The numerical value of the K_a of HBrO is 2.00×10^{-9}.

X is a solution of HBrO which contains 4.00×10^{-3} mol of HBrO in $100\,cm^3$ of solution. In this solution the following equilibrium is established in which there are two conjugate acid-base pairs.

$$HBrO + H_2O \rightleftharpoons BrO^- + H_3O^+$$

(i) Define conjugate acid-base pair.

.....

..... [1]

(ii) Identify the two conjugate acid-base pairs shown in the equation above.

	acid	base
pair one	.....	.....
pair two	.....	.....

[1]

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(iii) Calculate the pH of solution **X**. Show all your working.

pH = ... [2]

(iv) A solution containing 2.00×10^{-3} mol of NaOH is added to solution **X**. A buffer solution is formed.

Calculate the pH of this buffer solution.

pH = ... [1]

[Total: 9]

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1. Nov/2023/Paper_9701/41/No.2

(a) Define K_w mathematically by completing the expression.

K_w = ...

[1]

(b) Two solutions, **V** and **W**, are described.

- **V** is HC*l*(aq).
- **W** is NaOH(aq).
- The concentration of HC*l* in **V** is the same as the concentration of NaOH in **W**.
- The pH values of **V** and **W** differ by exactly 11.00 at 298 K.

(i) Calculate the concentration of HC*l* in **V**.

concentration of HC*l* in **V** = ... $mol\,dm^{-3}$ [2]

(ii) Equal volumes of the two solutions **V** and **W** are mixed, giving solution **X**.

Name solution **X** and state its pH.

solution **X** ..... pH .....

[1]

(iii) A 1 cm^3 sample of 1.0 $mol\,dm^{-3}$ HNO_3 is added to 100 cm^3 of solution **X**, forming mixture **Y**.

A 1 cm^3 sample of 1.0 $mol\,dm^{-3}$ KOH is added to 100 cm^3 of solution **X**, forming mixture **Z**.

Estimate the pH of mixtures **Y** and **Z**. No calculations are required.

mixture **Y** ..... mixture **Z** .....

[1]

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(c) **(i)** CH_3CH_2COOH, CH_3CCl_2COOH and H_2SO_4 are all acidic.

Suggest the trend in the relative acid strength of these three compounds.

Explain your answer.

....
strongest acid weakest acid

explanation .....

.....

.....

.....

.....

[3]

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(ii) When concentrated H_2SO_4 is added to water a series of acid-base reactions occurs.

There are three conjugate acid-base pairs that can be identified during this series of reactions.

Write the formulae of these three conjugate acid-base pairs.

conjugate acid 1 ..... conjugate base 1 .....

conjugate acid 2 ..... conjugate base 2 .....

conjugate acid 3 ..... conjugate base 3 .....

[2]

(d) The partition coefficient, K_{pc}, of a substance, **Q**, between hexane and water is 7.84 at 298 K.

Q is more soluble in hexane than it is in water.

(i) Define partition coefficient, K_{pc}.

.....

..... [1]

(ii) 5.00 g of **Q** is shaken with a mixture of 100.0 cm^3 of water and 100.0 cm^3 of hexane at 298 K and left until there is no further change in concentrations.

Calculate the mass of **Q** dissolved in the water.

mass of **Q** = ... g [1]

(iii) A sample of **Q** is shaken with a different mixture of water and hexane and left until there is no further change in concentrations.

It is found that the mass of **Q** dissolved in each solvent is the same.

Use the K_{pc} value to suggest possible values for the volume of water used and the volume of hexane used.

volume of water = ... cm^3

volume of hexane = ... cm^3

[1]

(iv) **Q** is more soluble in hexane than it is in water.

It is suggested that **Q** is one of KC*l*, $CH_3(CH_2)_4OH$ or HCOOH.

Identify **Q**. Explain your answer.

.....

..... [1]

[Total: 14]

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2. Nov/2023/Paper_9701/42/No.2

Benzoic acid, C_6H_5COOH, is a weak acid. The K_a of benzoic acid is 6.31×10^{-5} mol dm^{-3} at 298 K.

A 1.00 dm^3 buffer solution is made at 298 K containing 1.00 g of C_6H_5COOH and a slightly greater mass of sodium benzoate, $C_6H_5COO^-Na^+$.

This buffer solution has a pH of 4.15.

(a) Define buffer solution.

.....

..... [1]

(b) Write equations to show how this solution acts as a buffer solution when the named substances are added to it:

(i) dilute aqueous sodium hydroxide

..... [1]

(ii) dilute aqueous nitric acid.

..... [1]

(c) Calculate the H^+ concentration and the C_6H_5COOH concentration in the buffer solution described. Use the expression for the K_a of C_6H_5COOH to calculate the concentration of $C_6H_5COO^-Na^+$ in the buffer solution.

Show your working and give each answer to a minimum of **three** significant figures.

$[H^+]$ = ... mol dm^{-3}

$[C_6H_5COOH]$ = ... mol dm^{-3}

$[C_6H_5COO^-Na^+]$ = ... mol dm^{-3}

[3]

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(d) A 10.0 cm^3 sample of the buffer solution is mixed with 10.0 cm^3 of 1.00 mol dm^{-3} KOH. Both solutions are at 298 K. A reaction is allowed to occur without stirring.

Two observations are recorded:

- the temperature, after the reaction is complete, is fractionally above 298 K
- the pH, after the reaction, is greater than 13.

Explain these two observations.

.....

.....

..... [2]

(e) Magnesium benzoate, $Mg(C_6H_5COO)_2$, has a solubility in water of less than 1.00 g dm^{-3} at 298 K.

$$K_{sp} = [Mg^{2+}][C_6H_5COO^-]^2 = 1.76 \times 10^{-7} \text{ at } 298\,K$$

(i) Calculate the solubility of $Mg(C_6H_5COO)_2$ in water at 298 K. Give your answer in g dm^{-3}.

Show your working.

[M_r: $Mg(C_6H_5COO)_2$, 266.3]

solubility = ... g dm^{-3} [2]

(ii) An excess of $Mg(C_6H_5COO)_2$ is added to a sample of 0.50 mol dm^{-3} $MgSO_4$ at 298 K.

State whether the equilibrium concentration of $Mg(C_6H_5COO)_2$ is higher than, the same as, or lower than your answer to **(i)**. Explain your answer.

The concentration is ..... the concentration in **(i)**.

explanation .....

.....

[1]

[Total: 11]

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3. June/2023/Paper_9701/41/No.5(d, e)

(d) Isocyanic acid, HNCO, can form cyanuric acid, $C_3H_3N_3O_3$, under certain conditions.

$C_3H_3N_3O_3$ has a cyclic structure containing alternating carbon and nitrogen atoms in the ring system.

Suggest a structure for cyanuric acid.

[1]

(e) Isocyanic acid, HNCO, is a weak acid.

$$HNCO + H_2O \rightleftharpoons H_3O^+ + NCO^- \qquad pK_a = 3.70 \text{ at } 25\,^\circ C$$

(i) Write the mathematical expressions for pK_a and pH.

pK_a = ...

pH = ...

[1]

(ii) Calculate the pH of 0.120 mol dm^{-3} HNCO(aq).
Give your answer to **three** significant figures.

pH = ... [2]

(iii) Calculate the percentage of HNCO molecules that are ionised in 0.120 mol dm^{-3} HNCO.

percentage ionisation of HNCO = ... [1]

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4. June/2023/Paper_9701/42/No.3(e)

(e) Silver sulfite, $Ag_2SO_3(s)$, is sparingly soluble in water.

(i) Give an expression for the solubility product, K_{sp}, of Ag_2SO_3.

K_{sp} =

[1]

(ii) Calculate the equilibrium concentration of Ag^+ in a saturated solution of Ag_2SO_3 at 298 K.

[K_{sp}: Ag_2SO_3, 1.50×10^{-14} mol^3 dm^{-9} at 298 K]

$[Ag^+]$ = ... mol dm^{-3} [1]

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5. March/2023/Paper_9701/42/No.6(d)

A student uses thin-layer chromatography (TLC) to analyse a mixture containing different metal cations. The student repeats the experiment using different solvents.

Fig. 6.1 shows the chromatogram obtained by the student using water as a solvent.

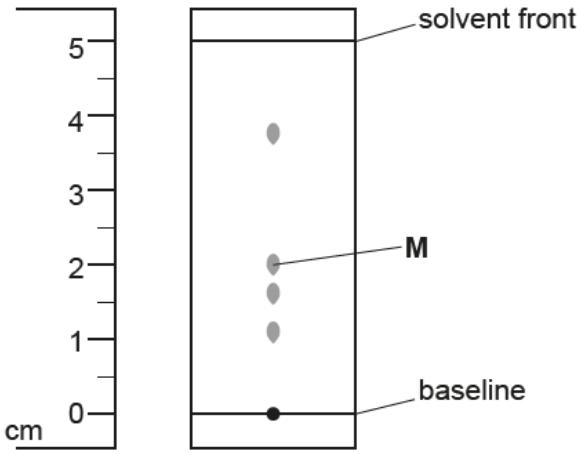


Fig. 6.1

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(d) In a third experiment, the pH of the mixture of metal ions is kept constant using a buffer solution.

The student prepares the buffer solution by mixing 20.0 cm^3 of 0.150 mol dm^{-3} KOH(aq) and 50.0 cm^3 of 0.100 mol dm^{-3} $C_8H_5O_4K$(aq).

$C_8H_5O_4K$ is a weak carboxylic acid that has pK_a = 5.40.

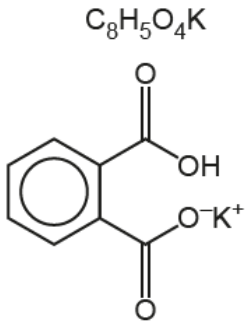


Fig. 6.2

(i) Complete the equation for the reaction of $C_8H_5O_4K$(aq) with KOH(aq).

$C_8H_5O_4K$ + ... [1]

(ii) Calculate the pH of the buffer solution. Show all your working.

pH = ... [4]

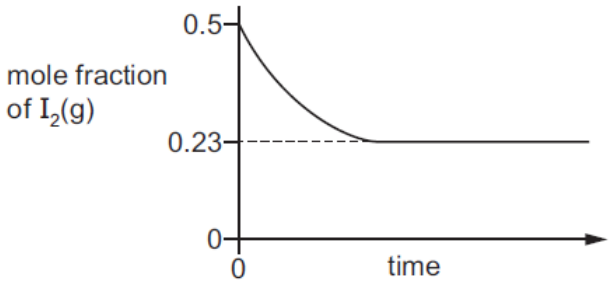
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1. Nov/2021/Paper_11/No.10

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

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

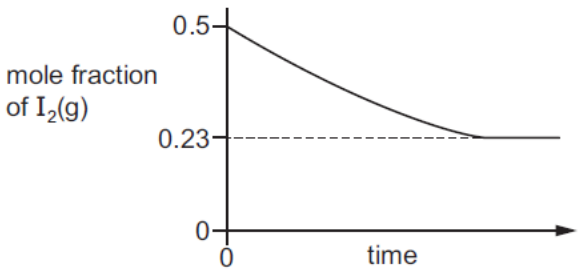
A mixture containing equal amounts of $H_2(g)$ and $I_2(g)$ is made at temperature T_1 and the composition of the mixture is monitored. A graph of the results is shown.



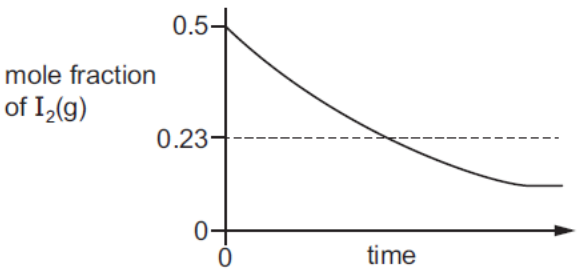
The experiment is repeated at a lower temperature, T_2.

Which new graph would be obtained?

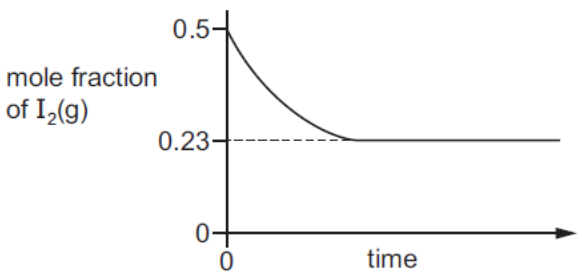
A



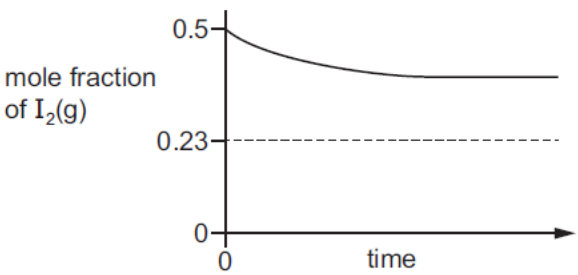
B



C

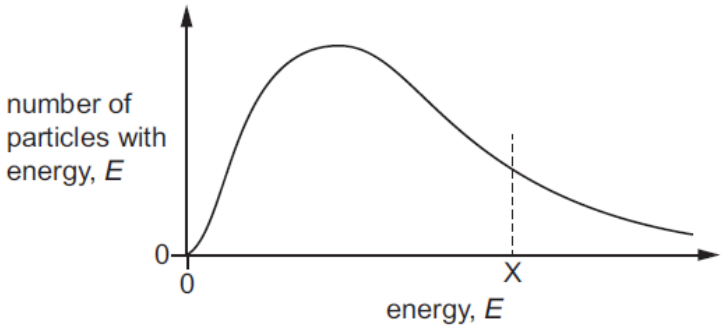


D



2. Nov/2021/Paper_11/No.11

The diagram shows the Boltzmann distribution of energies for a reactant gas. For a particular reaction, the activation energy is X.



Which change to the diagram occurs if an effective catalyst is added at the same temperature?

A More particles will possess higher values of *E*.

B The peak will move to the left.

C The peak will move to the right.

D The value of the activation energy decreases.

3. Nov/2021/Paper_11/No.32

Iron reacts with steam to produce hydrogen and an oxide of iron.

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

A system containing all four substances is at equilibrium.

Which changes will decrease the mass of Fe present at equilibrium?

1 addition of steam at constant pressure

2 increase in overall pressure

3 addition of an effective catalyst

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4. Nov/2021/Paper_12/No.16

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

5. Nov/2021/Paper_12/No.31

Four solutions, each of concentration 0.1 mol dm^{-3}, were tested with a pH meter. The results are shown.

solution	formula of acid or base	pH
acid 1	CH_3CO_2H	4
acid 2	HNO_3	1
base 1	CH_3NH_2	11
base 2	NaOH	14

Which statements explain these results?

1 Acid 2 has a lower pH than acid 1 because it is more soluble.

2 Base 2 has a higher concentration of hydroxide ions in solution than base 1.

3 Acid 1 dissociates less than acid 2.

6. Nov/2021/Paper_12/No.36

Which statements about ammonium chloride are correct?

1 It reacts with hot aqueous sodium hydroxide to produce an alkaline gas.

2 In solution, it reacts with aqueous silver nitrate to produce a white precipitate.

3 When solid, it reacts with concentrated sulfuric acid to produce chlorine.

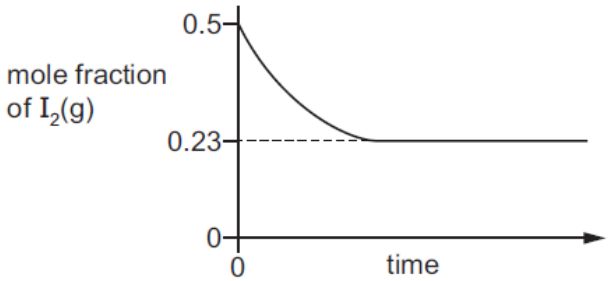
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7. Nov/2021/Paper_13/No.10

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

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

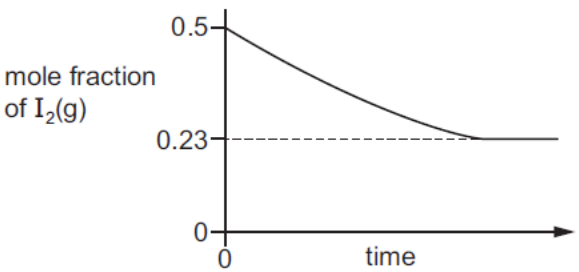
A mixture containing equal amounts of $H_2(g)$ and $I_2(g)$ is made at temperature T_1 and the composition of the mixture is monitored. A graph of the results is shown.



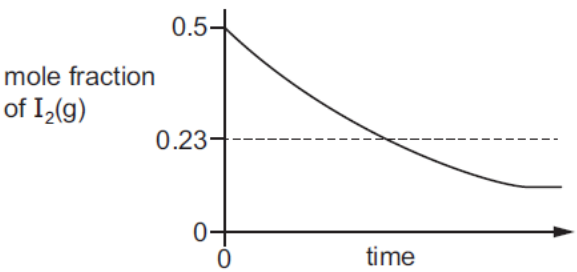
The experiment is repeated at a lower temperature, T_2.

Which new graph would be obtained?

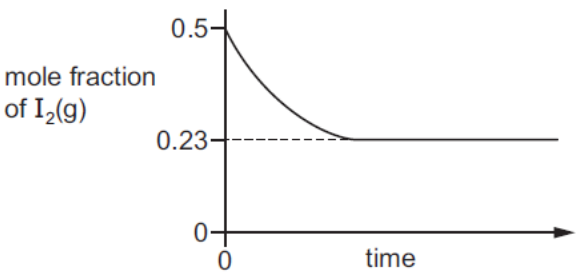
A



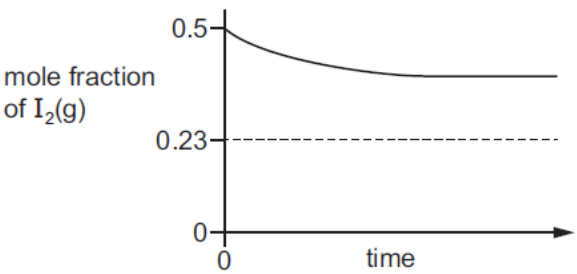
B



C

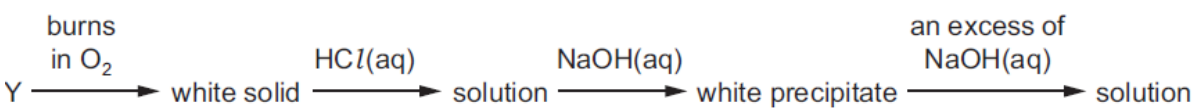


D



8. Nov/2021/Paper_13/No.11

An element, Y, reacts according to the following sequence.



What could be element Y?

A Na **B** Mg **C** Al **D** P

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9. March/2021/Paper_12/No.9

In which reaction is water behaving as a Brønsted–Lowry base?

A $H_2O + Na \rightarrow NaOH + \frac{1}{2}H_2$

B $H_2O + H_3PO_4 \rightarrow H_3O^+ + H_2PO_4^-$

C $H_2O + CaO \rightarrow Ca(OH)_2$

D $NH_3 + [Cu(H_2O)_6]^{2+} \rightarrow NH_4^+ + [Cu(H_2O)_5(OH)]^+$

10. March/2021/Paper_12/No.10

A large excess of marble chips is reacted with 25 cm^3 of 1.0 mol dm^{-3} hydrochloric acid at 40 °C.

How is the result different when the reaction is repeated with 60 cm^3 of 0.5 mol dm^{-3} hydrochloric acid at 40 °C?

A The reaction is faster and more of the products are made when the reaction is complete.

B The reaction is faster and less of the products are made when the reaction is complete.

C The reaction is slower and more of the products are made when the reaction is complete.

D The reaction is slower and less of the products are made when the reaction is complete.

11. March/2021/Paper_12/No.31

A sample of 17.15 mol HI(g) is in dynamic equilibrium with 2.27 mol $H_2(g)$ and 2.84 mol $I_2(g)$ in a volume of 1 m^3 at 764 K and 141 kPa.

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

Two equilibrium constants, K_c and K_p, can be calculated for this mixture.

Which statements about the equilibrium constants for this mixture are correct?

1 neither K_c nor K_p has any units

2 $K_c = 45.6$

3 $K_c > K_p$

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12. March/2021/Paper_22/No.1

The rate of chemical reactions is affected by changes in temperature and pressure.

(a) (i) Draw a curve on the axes to show the Boltzmann distribution of energy of particles in a sample of gaseous krypton atoms at a given temperature.

Label the curve **T1** and label the axes.



[2]

(ii) On the diagram in **(a)(i)**, draw a second curve to show the distribution of energies of the krypton atoms at a higher temperature.

Label the second curve **T2**. [1]

(b) The Boltzmann distribution assumes that the particles behave as an ideal gas.

(i) State **two** assumptions of the kinetic theory as applied to an ideal gas.

1 .....

.....

2 .....

.....

[2]

(ii) 2.00 g of krypton gas, Kr(g), is placed in a sealed 5.00 dm^3 container at 120 °C.

Calculate the pressure, in Pa, of Kr(g) in the container.
Assume Kr(g) behaves as an ideal gas.

Show your working.

pressure = ... Pa [3]

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(iii) State and explain the conditions at which krypton behaves most like an ideal gas.

.....

.....

.....

..... [2]

(c) Krypton reacts with fluorine in the presence of ultraviolet light to make krypton difluoride, $KrF_2(g)$.

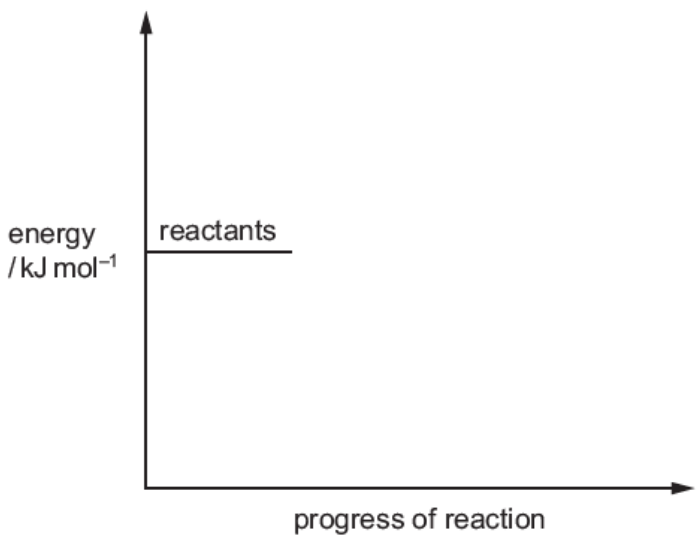
$$Kr(g) + F_2(g) \rightarrow KrF_2(g)$$

activation energy for the reaction, $E_a = +385\,kJ\,mol^{-1}$

enthalpy change of formation of KrF_2, $\Delta H_f = +60.2\,kJ\,mol^{-1}$

(i) Use this information to complete the reaction profile diagram for the formation of KrF_2. Label E_a and ΔH_f on the diagram.

Assume the reaction proceeds in one step.



[2]

(ii) Explain, in terms of activation energy, E_a, and the collision of particles, how an increase in temperature affects the rate of a chemical reaction.

.....

.....

.....

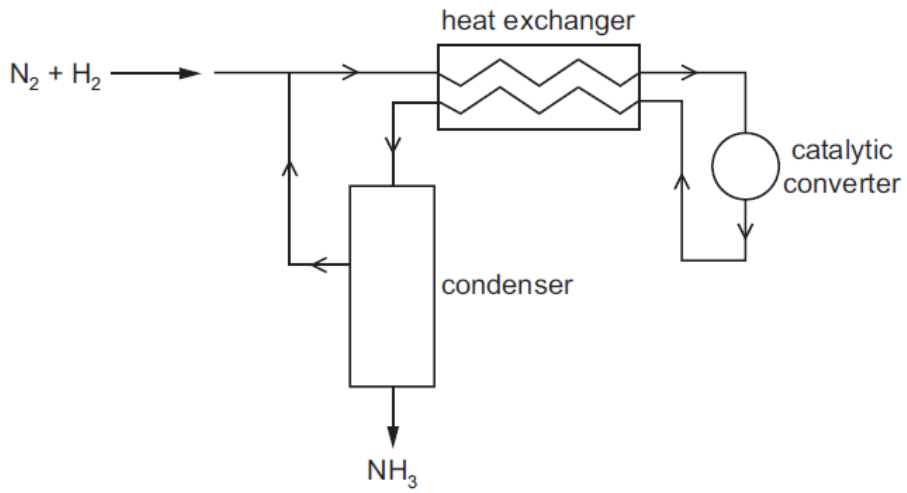
..... [2]

[Total: 14]

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13. June/2021/Paper_11/No.10

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

14. June/2021/Paper_12/No.10

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

15. June/2021/Paper_12/No.14

A farmer requires a solid compound to raise the pH of the soil in a field from 5.5 to above 6.0.

Which compound could the farmer use?

A $(NH_4)_2SO_4$ **B** NH_4NO_3 **C** $Ca(OH)_2$ **D** $Ca(NO_3)_2$

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16. June/2021/Paper_12/No.35

Which oxides will cause a change in pH when added to water?

1 CaO

2 Al_2O_3

3 SiO_2

17. June/2021/Paper_13/No.10

Nitrogen reacts with hydrogen to produce ammonia.

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

A mixture of 2.00 mol of nitrogen, 6.00 mol of hydrogen and 2.40 mol of ammonia is allowed to reach equilibrium in a sealed vessel of volume 1 dm^3. It is found that 2.32 mol of nitrogen were present in the equilibrium mixture.

Which expression will give the value of K_c?

A $\dfrac{(1.76)^2}{(2.32)(6.96)^3}$

B $\dfrac{(1.76)^2}{(2.32)(6.32)^3}$

C $\dfrac{(2.08)^2}{(2.32)(6.32)^3}$

D $\dfrac{(2.40)^2}{(2.32)(6.00)^3}$

18. June/2021/Paper_13/No.1

Compound X is an organic compound that contains 30.6% carbon, 3.8% hydrogen, 20.4% oxygen and 45.2% chlorine by mass.

What is the empirical formula of X?

A C_2H_3OCl **B** C_2H_4OCl **C** C_3H_4OCl **D** $C_4H_3O_2Cl_2$

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19. June/2021/Paper_23/No.2(c)

(c) Methanol is made by reacting carbon monoxide with hydrogen.

$$CO(g) + 2H_2(g) \rightleftharpoons CH_3OH(g)$$

Carbon monoxide and hydrogen react at 1.0×10^7 Pa and 200 °C. Eventually the reaction mixture reaches dynamic equilibrium.

The table shows the amounts of each species present in the mixture.

	CO(g)	$H_2(g)$	$CH_3OH(g)$
initial amount / mol	1.0	2.0	0
equilibrium amount / mol	0.030	0.060	0.97

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

.....

.....

..... [2]

(ii) Calculate the partial pressure of methanol vapour at equilibrium under these conditions. Show your working.

..... Pa [2]

(iii) Write an expression for the equilibrium constant, K_p, for this reaction. State the units in your answer.

K_p =

units = ... [2]

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Equilibria – 2022 June AS Chemistry 9701

1. June/2022/Paper_11/No.13

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.

2. June/2022/Paper_11/No.14

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

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3. June/2022/Paper_12/No.13

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

4. June/2022/Paper_12/No.14

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

5. June/2022/Paper_12/No.16

The Haber process for the manufacture of ammonia is represented by the equation shown.

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

Which statement is correct about this reaction when the temperature is increased?

A Both forward and backward rates increase.

B The backward rate only increases.

C The forward rate only increases.

D There is no effect on the backward or forward rates.

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6. June/2022/Paper_13/No.13

Which statement about acids and bases is **always** correct?

A An acid with two H atoms per molecule will be stronger than an acid with one H atom per molecule.

B A concentrated solution of a strong acid will have a lower pH than a dilute solution of a weak acid.

C A concentrated solution of a strong base will have a lower pH than a dilute solution of a weak base.

D A strong acid is more dissociated in solution than a strong base.

7. June/2022/Paper_13/No.14

The reaction between sulfur dioxide and oxygen is reversible.

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

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

The sulfur dioxide concentration is twice the oxygen concentration.

What is the sulfur dioxide concentration?

A 0.175 mol dm^{-3}

B 0.252 mol dm^{-3}

C 0.318 mol dm^{-3}

D 0.636 mol dm^{-3}

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8. June/2022/Paper_21/No.2(d)

(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 HCl(aq) is titrated with NH_3(aq) as described in **(d)**.

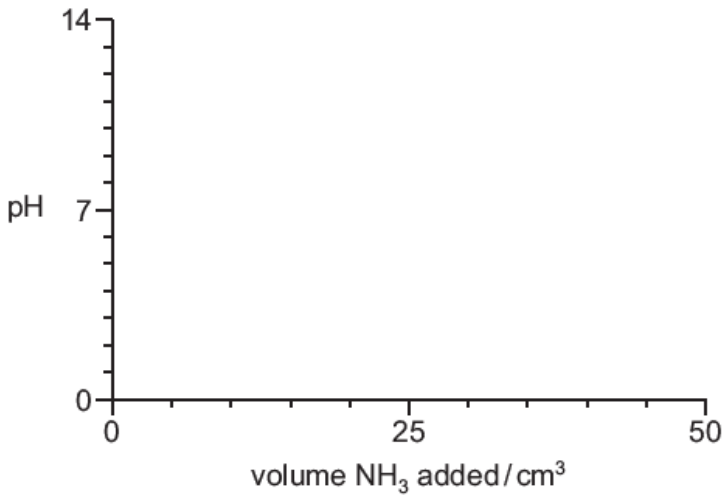


Fig. 2.1

[2]

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9. June/2022/Paper_22/No.3(a_ d)

(a) 0.025 mol of HI(g) is added to a closed vessel and left to reach dynamic equilibrium. The total pressure of the vessel is 100 kPa.

equation **1** $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$

(i) Explain what is meant by dynamic equilibrium.

.....

.....

..... [2]

(ii) Describe **one** difference in the initial appearance of the reaction mixture compared to the mixture at equilibrium.

..... [1]

(iii) Write an expression for K_p for the reaction described in equation **1**.

K_p =

[1]

(iv) At equilibrium the partial pressure of HI(g) is 86.4 kPa.

Calculate the amount of HI(g) present in the mixture at equilibrium. Show your working.

amount of HI(g) = ... mol [2]

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(b) Use equation **1** and the bond energy values in Table 3.1 to calculate the change in enthalpy, ΔH, for the thermal decomposition of 1 mole of HI(g). Show your working.

Table 3.1

bond	bond energy / kJ mol^{-1}
H–H	436
I–I	151
H–I	299

ΔH = ... kJ mol^{-1} [2]

(c) Describe the effect of increasing pressure on the value of K_p for the decomposition of HI(g).

..... [1]

(d) HC*l*(g) is prepared by adding NaC*l*(s) to concentrated H_2SO_4.

HI(g) is **not** prepared by adding NaI(s) to concentrated H_2SO_4 because the HI(g) produced also reacts with concentrated H_2SO_4.

(i) Identify the type of reaction that occurs when NaI(s) reacts with concentrated H_2SO_4 to form HI(g).

..... [1]

(ii) Write an equation for the reaction of HI(g) and concentrated H_2SO_4.

..... [1]

(iii) Explain why HI(g) reacts with concentrated H_2SO_4 whereas HC*l* does not.

..... [1]

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10. June/2022/Paper_22/No.3a(iii_ iv)

(iii) When **G**, $C_4H_{10}O$, is heated in a sealed container, an equilibrium mixture is produced.

$$C_4H_{10}O(g) \rightleftharpoons C_2H_6(g) + CO(g) + CH_4(g)$$

Complete the expression for the equilibrium constant, K_c, for this reaction.
State the units of K_c.

K_c =

units = ...
[2]

(iv) Thermal decomposition of **G** in the presence of I_2 affects the activation energy, E_a, for the reaction. Table 3.2 shows E_a for the thermal decomposition of **G** with and without I_2.

Table 3.2

reaction	E_a (with I_2) / kJ mol^{-1}	E_a / kJ mol^{-1}
$C_4H_{10}O(g) \rightarrow C_2H_6(g) + CO(g) + CH_4(g)$	143	224

State what effect adding I_2 to the reaction mixture has on the value of K_c.
Explain your answer.

.....

.....

.....

..... [2]

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Equilibria – 2022 Nov AS Chemistry 9701

1. Nov/2022/Paper_11/No.13

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

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

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

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

2. Nov/2022/Paper_11/No.14

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

3. Nov/2022/Paper_12/No.7

Hydrogen peroxide decomposes slowly at 20 °C to form water and oxygen.

$$2H_2O_2 \rightleftharpoons 2H_2O + O_2 \qquad \text{equilibrium constant} = K_c$$

The reaction is faster when a catalyst is present.

Which statement is correct?

A The catalyst alters the Boltzmann distribution so that the reactant molecules have more energy.

B The catalyst has no effect on the value of K_c.

C The catalyst increases the value of K_c.

D The catalyst provides a different reaction mechanism with a higher activation energy.

4. Nov/2022/Paper_12/No.8

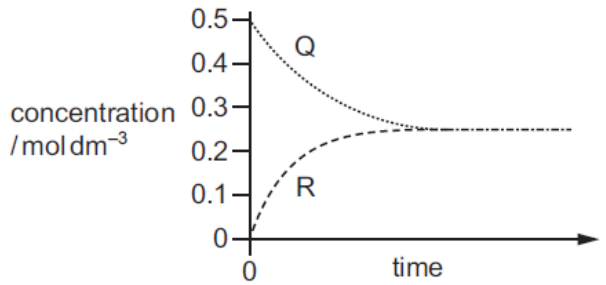
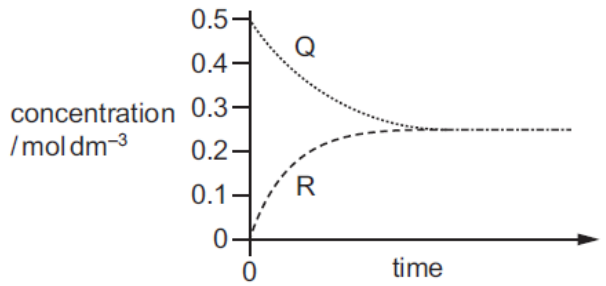
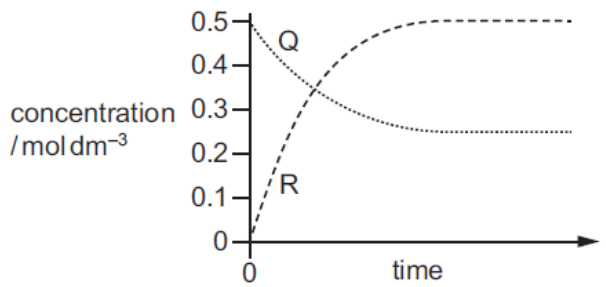
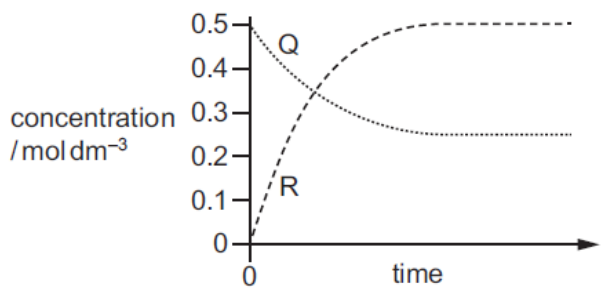
A dimer, Q, is stable when solid but a dynamic equilibrium is set up in solution.

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

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

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5. Nov/2022/Paper_12/No.11

The Haber process is carried out with a nitrogen partial pressure of 50 kPa, a hydrogen partial pressure of 150 kPa, a temperature of 400 °C and an iron catalyst.

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

If all other conditions are kept the same, which change will result in a raised activation energy?

A Both the nitrogen and hydrogen partial pressures are changed to 100 kPa.

B The iron is removed.

C The nitrogen partial pressure is increased to 150 kPa.

D The temperature is increased to 500 °C.

6. Nov/2022/Paper_22/No.1(c)

(c) NH_4^+ is a Brønsted–Lowry acid.

(i) Define Brønsted–Lowry acid.

.....

..... [1]

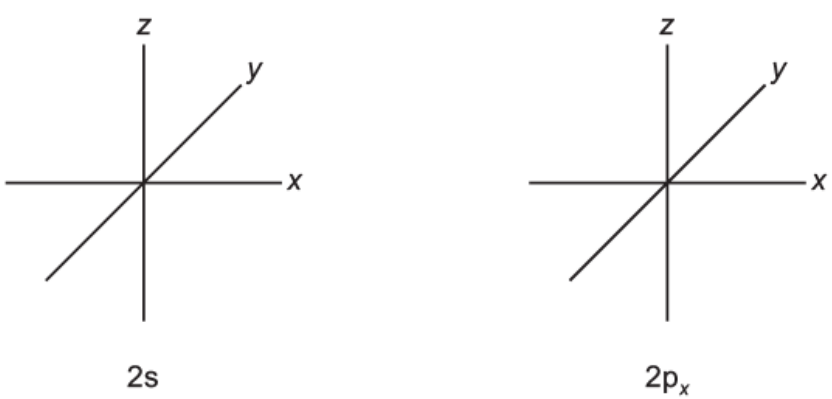
(ii) When $NH_4^+(aq)$ is heated with NaOH(aq), a pungent gas is produced.

Write an ionic equation for this reaction.

..... [1]

(iii) The nitrogen atom in NH_4^+ is sp^3 hybridised. sp^3 orbitals form from the mixing of one 2s and three 2p orbitals.

Sketch the shapes of a 2s and a $2p_x$ orbital on the axes in Fig. 1.1.



2s $2p_x$

Fig. 1.1

[2]

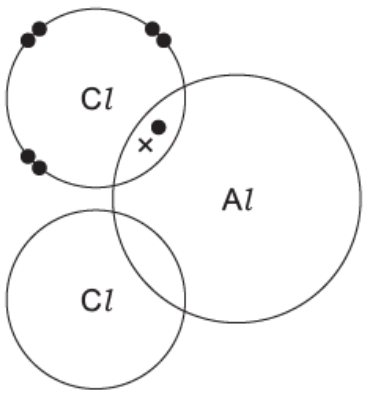
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7. Nov/2022/Paper_22/No.2(c)

(c) In the gas phase, $AlCl_3(g)$ exists at equilibrium with $Al_2Cl_6(g)$ as shown.

equation **1** $\quad 2AlCl_3(g) \rightleftharpoons Al_2Cl_6(g) \quad \Delta H_r = -63\,kJ\,mol^{-1}$

(i) Complete the dot-and-cross diagram to show the bonding in Al_2Cl_6.



[2]

(ii) State the effect of an increase in temperature on the equilibrium mixture in equation **1**. Explain your answer.

.....

..... [1]

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Equilibria – 2023 AS Chemistry 9701

1. Nov/2023/Paper_ 9701/11/No.12

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

2. Nov/2023/Paper_ 9701/11/No.13

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

3. Nov/2023/Paper_ 9701/12/No.14

A mixture of the three gases, oxygen, nitrogen and argon, is at a total pressure of 500 kPa. There is a total of 1.2 moles of gas in the mixture.

If the oxygen gas alone occupied the entire volume of the mixture, it would exert a pressure of 150 kPa.

At room conditions the amount of nitrogen gas in the mixture would occupy a volume of 5.76 dm^3.

What is the partial pressure of the argon gas in the mixture?

A 150 kPa

B 200 kPa

C 250 kPa

D 300 kPa

4. Nov/2023/Paper_ 9701/12/No.15

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}

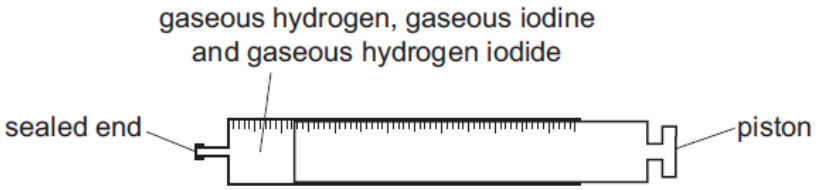
C 1.25 mol^{-1} dm^3

D 6.67 mol^{-1} dm^3

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5. Nov/2023/Paper_ 9701/12/No.17

The diagram shows a gas syringe with a free-moving piston. The syringe contains gaseous hydrogen, gaseous iodine and gaseous hydrogen iodide at equilibrium.



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

Three changes are listed.

1 increasing the total pressure by adding an inert gas and keeping the volume constant

2 increasing the pressure by adding more gaseous hydrogen iodide and keeping the volume constant

3 decreasing the volume by pushing the piston to the left

Which changes will result in an equilibrium position at which the rate of the forward reaction has increased?

A 2 only **B** 1 and 2 **C** 1 and 3 **D** 2 and 3

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6. Nov/2023/Paper_ 9701/22/No.2(a, b, c)

NO and NO_2 react at 25 °C to give N_2O_3 as shown in the equation.

$$NO(g) + NO_2(g) \rightleftharpoons N_2O_3(g) \qquad \Delta H = -7.2\,kJ\,mol^{-1}$$

The reaction is reversible and reaches equilibrium in a closed system.

(a) Fig. 2.1 shows how the rate of the forward reaction changes with time.

Initially, the rate of the reverse reaction is zero.

Complete Fig. 2.1 to sketch how the rate of the **reverse** reaction changes with time.

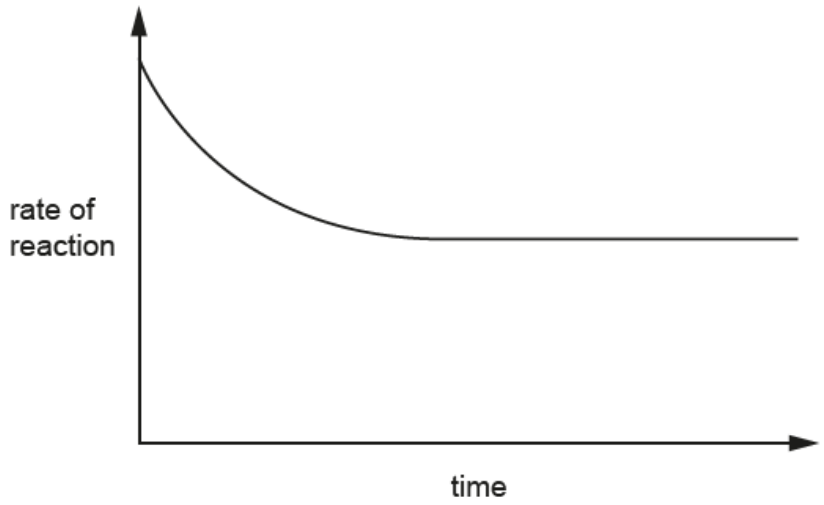


Fig. 2.1

[1]

(b) State how the position of equilibrium changes, if at all, when the reaction takes place at 100 °C.

Explain your answer.

Assume the pressure remains constant.

.....

.....

.....

..... [2]

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(c) Table 2.1 shows the composition of an equilibrium mixture of NO(g), NO_2(g) and N_2O_3(g) at 101 kPa.

Table 2.1

gas	number of moles at equilibrium / mol
NO	0.605
NO_2	0.605
N_2O_3	0.390

Calculate K_p, the equilibrium constant with respect to partial pressures.

Deduce the units of K_p.

K_p = ... units .....

[3]

7. June/2023/Paper_9701/11/No.4

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

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8. June/2023/Paper_9701/11/No.8

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.

9. June/2023/Paper_9701/12/No.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 $3Fe(s) + 4H_2O(g) \rightleftharpoons Fe_3O_4(s) + 4H_2(g)$

10. June/2023/Paper_9701/12/No.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}

11. June/2023/Paper_9701/13/No.15

Sulfur dioxide reacts with oxygen as shown.

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

Which change will move the equilibrium position to the right side and change the value of the equilibrium constant, K_c?

A the addition of a catalyst

B increasing the pressure of the reaction

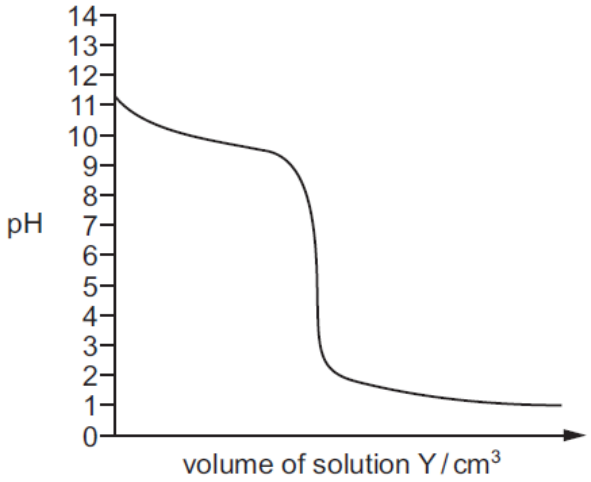
C decreasing the temperature of the reaction

D decreasing the concentration of product

12. June/2023/Paper_9701/13/No.16

Solutions X and Y both have a concentration of 0.10 mol dm^{-3}. A fixed volume of solution X is added to a conical flask, and solution Y is added from a burette to the conical flask. A titration is performed.

The diagram shows the pH titration curve for the acid–base reaction between the solutions.



What are solutions X and Y?

	solution X	solution Y
A	ammonia	nitric acid
B	ammonia	ethanoic acid
C	potassium hydroxide	nitric acid
D	potassium hydroxide	ethanoic acid

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13. June/2023/Paper_9701/23/No.4

(a) Hydrogen chloride gas is made in the laboratory by adding concentrated sulfuric acid to potassium chloride.

(i) Construct an equation for this reaction.

..... [1]

(ii) Explain why hydrogen iodide is **not** prepared by adding concentrated sulfuric acid to sodium iodide.

.....

..... [2]

(b) A sample of HI(g) is added to a 2.00 dm^3 sealed vessel at 764 K and allowed to reach equilibrium.

reaction 1 $2HI(g) \rightleftharpoons H_2(g) + I_2(g)$ $K_c = 0.0217$ at 764 K

At equilibrium the mixture contains 1.70 mol of HI(g).

(i) State **one** difference in the appearance of the initial reaction mixture compared to the mixture at equilibrium.

.....

..... [1]

(ii) Deduce the expression for equilibrium constant K_c for reaction 1.

$K_c =$

[1]

(iii) Calculate the concentration of I_2 present in the reaction mixture at equilibrium.
Show your working.

concentration of I_2 = ... mol dm^{-3} [3]

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(c) The experiment is repeated at 500 K. The value of K_c under these conditions is 0.00625.

(i) Describe the difference in the composition of the equilibrium mixture at 500 K compared to 764 K.

.....

..... [1]

(ii) Use Le Chatelier's principle to deduce whether the decomposition of HI(g) is endothermic or exothermic. Explain your answer.

.....

.....

..... [1]

[Total: 10]

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14. March/2023/Paper_9701/12/No.4

The table shows the partial pressures in an equilibrium mixture formed by the Haber process.

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

substance	partial pressure / kPa
nitrogen	7000
hydrogen	8000
ammonia	4000

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

A 4.46×10^{-9} **B** 4.76×10^{-5} **C** 7.14×10^{-5} **D** 2.24×10^{8}

15. March/2023/Paper_9701/12/No.5

A reversible reaction is shown.

$$2NOCl(g) \rightleftharpoons 2NO(g) + Cl_2(g) \qquad \Delta H = +77.0 \text{ kJ mol}^{-1}$$

Which change in conditions will move the position of equilibrium to the right and increase the value of the equilibrium constant?

A a decrease in pressure

B a decrease in temperature

C an increase in pressure

D an increase in temperature

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