

# Equilibria

## Question Paper 1

<b>Level</b>	International A Level
<b>Subject</b>	Chemistry
<b>Exam Board</b>	CIE
<b>Topic</b>	Equilibria
<b>Sub-Topic</b>	
<b>Paper Type</b>	Multiple Choice
<b>Booklet</b>	Question Paper 1

**Time Allowed:** 52 minutes

**Score:** /43

**Percentage:** /100

**Grade Boundaries:**

A*	A	B	C	D	E	U
>85%	77.5%	70%	62.5%	57.5%	45%	<45%

Section A

For each question there are four possible answers, **A**, **B**, **C**, and **D**. Choose the **one** you consider to be correct.

- 1 One mole of phosphorus(V) chloride,  $\text{PCl}_5$ , is heated to 600 K in a sealed flask of volume  $1 \text{ dm}^3$ . Equilibrium is established and measurements are taken.

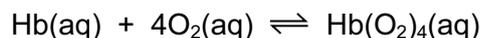


The experiment is repeated with one mole of phosphorus(V) chloride heated to 600 K in a sealed flask of volume  $2 \text{ dm}^3$ .

How will the measurements vary?

- A** The equilibrium concentrations of  $\text{PCl}_3(\text{g})$  and  $\text{Cl}_2(\text{g})$  are higher in the second experiment.  
**B** The equilibrium concentration of  $\text{PCl}_5(\text{g})$  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.
- 2 In which reaction is the underlined substance acting as a base?
- A**  $\text{HNO}_3 + \underline{\text{H}_2\text{SO}_4} \rightarrow \text{H}_2\text{NO}_3^+ + \text{HSO}_4^-$   
**B**  $\text{HSiO}_3^- + \underline{\text{HCN}} \rightarrow \text{CN}^- + \text{H}_2\text{O} + \text{SiO}_2$   
**C**  $\text{HNO}_2 + \underline{\text{HCO}_3^-} \rightarrow \text{H}_2\text{O} + \text{CO}_2 + \text{NO}_2^-$   
**D**  $\text{C}_6\text{H}_5\text{O}^- + \underline{\text{CH}_2\text{ClCO}_2\text{H}} \rightarrow \text{C}_6\text{H}_5\text{OH} + \text{CH}_2\text{ClCO}_2^-$

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



When the equilibrium concentration of  $\text{O}_2$  is  $7.6 \times 10^{-6} \text{ mol dm}^{-3}$ , the equilibrium concentrations of Hb and  $\text{Hb}(\text{O}_2)_4$  are equal.

What is the value of  $K_c$  for this equilibrium?

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

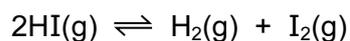
- 4 Nitrogen dioxide,  $\text{NO}_2$ , exists in equilibrium with dinitrogen tetroxide,  $\text{N}_2\text{O}_4$ .



Which conditions give the greatest percentage of  $\text{N}_2\text{O}_4(\text{g})$  at equilibrium?

	pressure	temperature
<b>A</b>	high	high
<b>B</b>	high	low
<b>C</b>	low	high
<b>D</b>	low	low

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

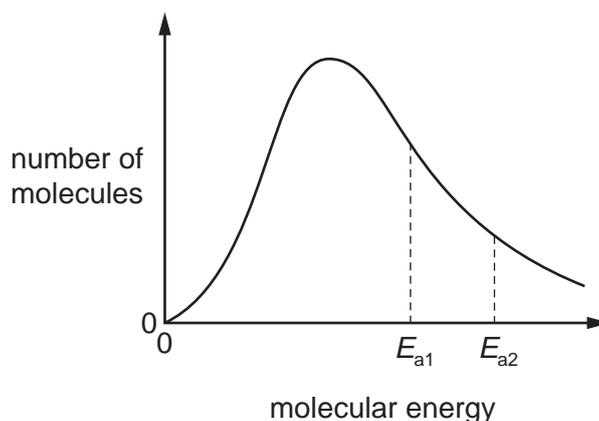


At this temperature, it is found that the partial pressure of  $\text{HI}(\text{g})$  is 28 times the partial pressure of  $\text{H}_2(\text{g})$ .

What is the value of  $K_p$  at this temperature?

- A**  $1.28 \times 10^{-3}$       **B** 0.035      **C** 28      **D** 784

- 6 The diagram shows the Boltzmann energy distribution curve for molecules of a mixture of two gases at a given temperature. For a reaction to occur the molecules must collide together with sufficient energy.



$E_a$  is used to represent the activation energy for the reaction between the gases. Of the two values shown, one is the activation energy for a catalysed reaction, the other for an uncatalysed reaction.

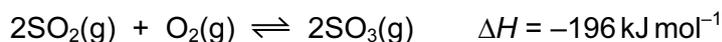
Which statement about  $E_{a1}$  is correct?

- A  $E_{a1}$  corresponds to a catalysed reaction with fewer effective collisions than the uncatalysed reaction.
  - B  $E_{a1}$  corresponds to an uncatalysed reaction with fewer effective collisions than the catalysed reaction.
  - C  $E_{a1}$  corresponds to a catalysed reaction with a greater number of effective collisions than the uncatalysed reaction.
  - D  $E_{a1}$  corresponds to an uncatalysed reaction with a greater number of effective collisions than the catalysed reaction.
- 7 Transition elements and their compounds are widely used as catalysts.

What is the identity and what is the oxidation number of the element present in the catalyst used in the Contact process?

	element	oxidation number
<b>A</b>	iron	0
<b>B</b>	iron	+3
<b>C</b>	vanadium	0
<b>D</b>	vanadium	+5

- 8 The Contact process is used in the manufacture of sulfuric acid. The equation for the main reaction is shown below.

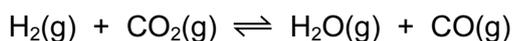


Which statement about this reaction is **incorrect**?

- A** Increased pressure gives a higher yield of  $\text{SO}_3$ .  
**B** Increased temperature gives a higher yield of  $\text{SO}_3$ .  
**C** In the forward reaction the oxidation state of sulfur changes from +4 to +6.  
**D** Vanadium(V) oxide is used as a catalyst.
- 9 The equilibrium constant,  $K_c$ , for the reaction  $\text{H}_2(\text{g}) + \text{I}_2(\text{g}) \rightleftharpoons 2\text{HI}(\text{g})$ , is 60 at  $450^\circ\text{C}$ .  
 What is the number of moles of hydrogen iodide in equilibrium with 2 mol of hydrogen and 0.3 mol of iodine at  $450^\circ\text{C}$ ?

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

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

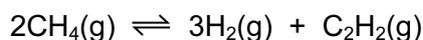


At equilibrium, the partial pressures of  $\text{H}_2$  and  $\text{CO}_2$  are both 10.0 kPa.  $K_p$  is 0.288 at 800 K.

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

- 11 The formation of hydrogen and ethyne,  $\text{C}_2\text{H}_2$ , from methane reaches dynamic equilibrium.

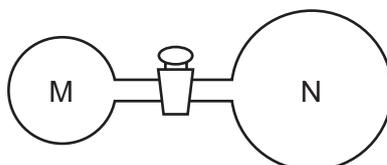


What are the units of  $K_c$ ?

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



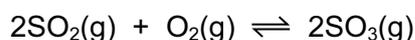
- 14 Two glass vessels M and N are connected by a closed valve.



M contains helium at 20 °C at a pressure of  $1 \times 10^5$  Pa. N has been evacuated, and has three times the volume of M. In an experiment, the valve is opened and the temperature of the whole apparatus is raised to 100 °C.

What is the final pressure in the system?

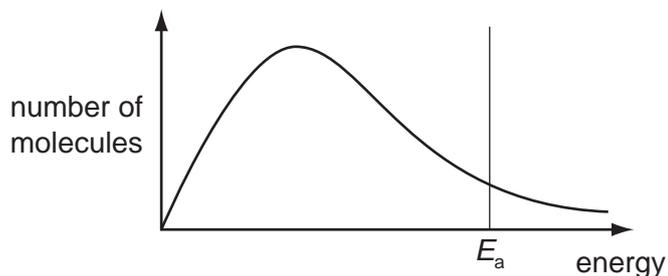
- A**  $3.18 \times 10^4$  Pa  
**B**  $4.24 \times 10^4$  Pa  
**C**  $1.25 \times 10^5$  Pa  
**D**  $5.09 \times 10^5$  Pa
- 15 Sulfur trioxide is manufactured from sulfur dioxide and oxygen, using the Contact process.
- Which condition affects the value of the equilibrium constant,  $K_c$ ?
- A** adjusting the temperature  
**B** increasing the pressure  
**C** removing  $\text{SO}_3$  from the equilibrium mixture  
**D** using a catalyst
- 16 The reaction between sulfur dioxide and oxygen is a dynamic equilibrium.



What happens when the pressure of the system is increased?

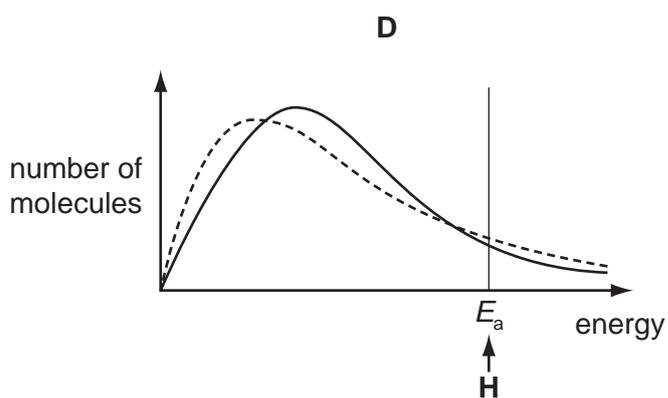
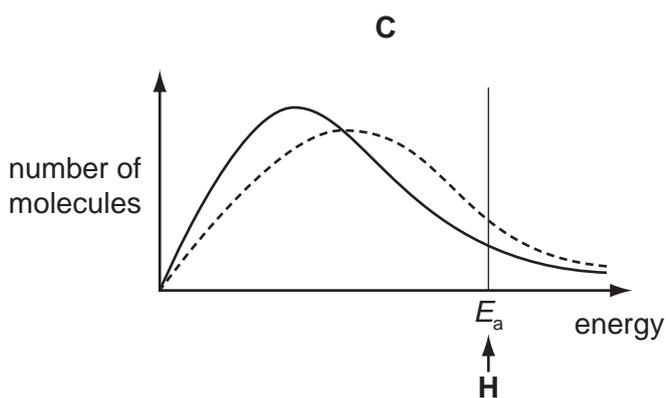
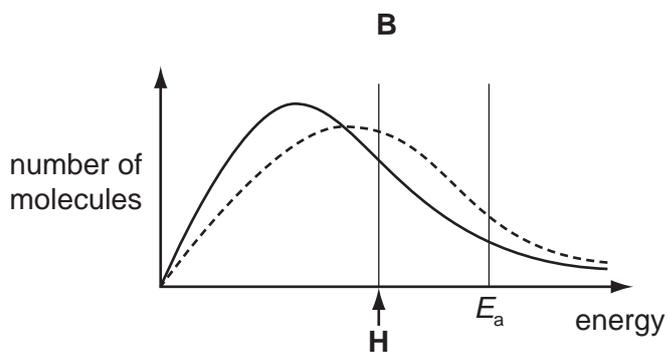
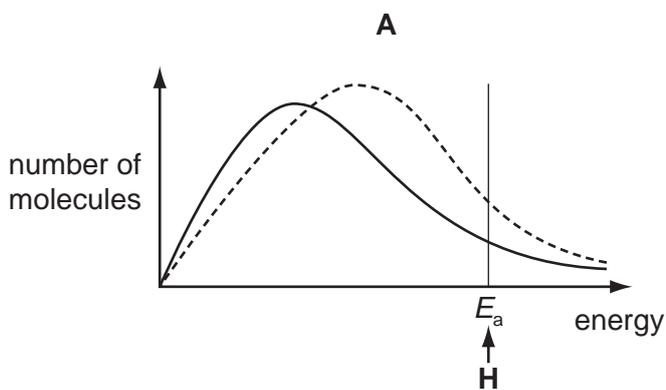
- A** The rate of reaction will decrease and the position of the equilibrium will move to the left.  
**B** The rate of reaction will decrease and the position of the equilibrium will move to the right.  
**C** The rate of reaction will increase and the position of the equilibrium will move to the left.  
**D** The rate of reaction will increase and the position of the equilibrium will move to the right.

- 17 The diagram represents, for a given temperature, the Boltzmann distribution of the kinetic energies of the molecules in a mixture of two gases that will react together. The activation energy for the reaction,  $E_a$ , is marked.

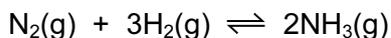


The dotted curves below show the Boltzmann distribution for the same reaction at a higher temperature. On these diagrams, **H** represents the activation energy at the higher temperature.

Which diagram is correct?



- 18 Nitrogen reacts with hydrogen to produce ammonia.



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  $1 \text{ dm}^3$  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?

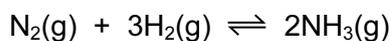
A  $\frac{(1.76)^2}{(2.32)(6.96)^3}$

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

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

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

- 19 Nitrogen reacts with hydrogen to produce ammonia.



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

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

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

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

20 Ammonia is manufactured by the Haber Process, in an exothermic reaction.

Assuming that the amount of catalyst remains constant, which change will **not** bring about an increase in the rate of the forward reaction?

- A decreasing the size of the catalyst pieces
- B increasing the pressure
- C increasing the temperature
- D removing the ammonia as it is formed

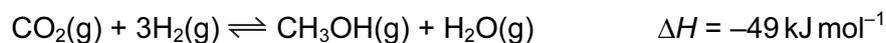
21 Two moles of compound P were placed in a vessel. The compound P was partly decomposed by heating. A dynamic equilibrium between chemicals P, Q and R was established.

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  $2P \rightleftharpoons Q + 2R$

22 Methanol is manufactured by reacting carbon dioxide and hydrogen.



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

23 Elements **X** and **Y** are both in period three.

When the chloride of **X** is added to water, it reacts and a solution of pH 2 is produced.

When the chloride of **Y** is added to water, it dissolves and a solution of pH 7 is produced.

Which statement explains these observations?

- A Both chlorides hydrolyse in water.
- B **X** is phosphorus and **Y** is aluminium.
- C **X** is silicon and **Y** is sodium.
- D **X** is sodium and **Y** is phosphorus.

24 In the Haber process, the reaction between the two gaseous reactants requires the use of a catalyst that contains a transition element.

What is the metal and in what mole ratio do the gases react?

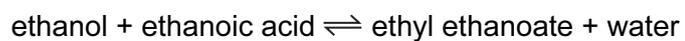
	metal	mole ratio
<b>A</b>	Fe	1:2
<b>B</b>	Fe	1:3
<b>C</b>	V	1:2
<b>D</b>	V	1:3

25 In the last century the Haber process was sometimes run at pressures of 1000 atm and higher. Now it is commonly run at pressures below 100 atm.

What is the reason for this change?

- A An iron catalyst is used.
- B Maintaining the higher pressures is more expensive.
- C The equilibrium yield of ammonia is increased at lower pressures.
- D The rate of the reaction is increased at lower pressures.

26 The esterification reaction



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

**Section B**

For each of the questions in this section, one or more of the three numbered statements **1** to **3** may be correct.

Decide whether each of the statements is or is not correct (you may find it helpful to put a tick against the statements that you consider to be correct).

The responses **A** to **D** should be selected on the basis of

<b>A</b>	<b>B</b>	<b>C</b>	<b>D</b>
<b>1, 2 and 3</b> are correct	<b>1 and 2</b> only are correct	<b>2 and 3</b> only are correct	<b>1 only</b> is correct

No other combination of statements is used as a correct response.

27 When added to water, which oxides will cause a change in the pH of the water?

- 1 SiO<sub>2</sub>
- 2 CaO
- 3 SO<sub>2</sub>

28 R and S react together.

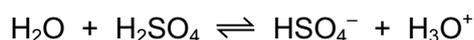
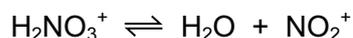
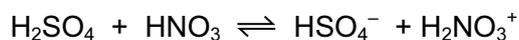


Which factors affect the rate of the forward reaction?

- 1 the activation energy of the reaction
- 2 the enthalpy change of the reaction
- 3 the equilibrium constant of the reaction

29 The Brønsted-Lowry theory describes acid and base character.

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



Which species are bases in these reactions?

- 1  $\text{HSO}_4^-$
- 2  $\text{HNO}_3$
- 3  $\text{NO}_2^+$

30 Sulfuric acid is a Brønsted-Lowry acid.

In which reactions is sulfuric acid behaving as an acid?

- 1  $\text{H}_2\text{SO}_4 + \text{HNO}_3 \rightarrow \text{H}_2\text{NO}_3^+ + \text{HSO}_4^-$
- 2  $\text{H}_2\text{SO}_4 + \text{CO}_3^{2-} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{SO}_4^{2-}$
- 3  $\text{H}_2\text{SO}_4 + \text{MgO} \rightarrow \text{MgSO}_4 + \text{H}_2\text{O}$

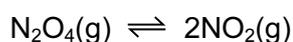
31 A reversible reaction is catalysed.

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.

- 32 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.

- 33 If  $\text{N}_2\text{O}_4$  gas is placed in a sealed vessel the following equilibrium is established.



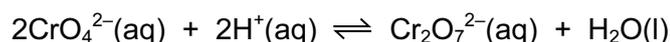
The forward reaction is endothermic.

What happens when the temperature is increased?

- 1 The equilibrium constant increases.
  - 2 The partial pressure of  $\text{NO}_2$  increases.
  - 3 The activation energy is unchanged.
- 34 Methanoic acid molecules,  $\text{HCO}_2\text{H}$ , and hydrogen carbonate ions,  $\text{HCO}_3^-$ , can both behave as acids.

Why does a solution of methanoic acid have a lower pH than a solution of sodium hydrogen carbonate of the same concentration?

- 1  $\text{HCO}_2\text{H}$  molecules dissociate more fully than  $\text{HCO}_3^-$  ions do.
  - 2 Each  $\text{HCO}_2\text{H}$  molecule has two hydrogen atoms; each  $\text{HCO}_3^-$  ion only has one.
  - 3 Methanoic acid is a weaker acid than sodium hydrogen carbonate.
- 35 The following equilibrium is an exothermic reaction in the forward direction.



What happens when the concentration of  $\text{CrO}_4^{2-}$  ions **increases and** the temperature **decreases**?

- 1 The concentration of  $\text{Cr}_2\text{O}_7^{2-}$  ions increases.
- 2 The equilibrium constant increases.
- 3 The activation energy decreases.

36 Which processes involve the conversion of sulfur dioxide into sulfur trioxide?

- 1 the combustion of sulfur contaminated fossil fuels
- 2 the Contact process for manufacturing sulfuric acid
- 3 the catalytic oxidation of sulfur dioxide by oxides of nitrogen

37 In the manufacture of sulfuric acid the reaction  $2\text{SO}_2(\text{g}) + \text{O}_2(\text{g}) \rightleftharpoons 2\text{SO}_3(\text{g})$  usually takes place at 400 °C and 1 atm pressure. In one industrial plant, it is decided to change the pressure to 20 atm.

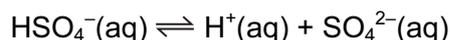
What will be the consequences of this change?

- 1 increased running costs
- 2 an increased percentage of sulfur trioxide in the equilibrium mixture
- 3 the rate of the backward reaction increases

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



The  $\text{HSO}_4^-$  ion formed behaves as a weak acid.



Which statements are true for 1.0 mol dm<sup>-3</sup> sulfuric acid?

- 1  $[\text{H}^+(\text{aq})]$  is high
- 2  $[\text{SO}_4^{2-}(\text{aq})]$  is high
- 3  $[\text{HSO}_4^-(\text{aq})] = [\text{SO}_4^{2-}(\text{aq})]$

39 Which statements are true about the Haber process for the manufacture of ammonia?

- 1 At higher temperatures, the yield goes down but the rate of production of ammonia is faster.
- 2 At higher pressures, the yield goes down but the rate of production of ammonia is faster.
- 3 In the presence of a catalyst, the yield goes down but the rate of production of ammonia is faster.

40 Which equations represent stages in the Contact process for manufacturing sulfuric acid?

- 1  $\text{SO}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{SO}_3$
- 2  $\text{SO}_2 + \text{H}_2\text{O} \rightarrow \text{H}_2\text{SO}_3$
- 3  $\text{H}_2\text{SO}_3 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{SO}_4$

41 When added to water, which oxides will **not** cause a change in pH?

- 1  $\text{Al}_2\text{O}_3$
- 2  $\text{SiO}_2$
- 3  $\text{P}_4\text{O}_{10}$

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

process	name and symbol of quantity
$2\text{HX}(\text{g}) \rightarrow \text{H}_2(\text{g}) + \text{X}_2(\text{g})$	enthalpy change of reaction, $\Delta H^\ominus$
$\text{H}_2(\text{g}) + \text{X}_2(\text{g}) \rightleftharpoons 2\text{HX}(\text{g})$	equilibrium constant, $K_p$
$\text{X}(\text{g}) \rightarrow \text{X}^+(\text{g}) + \text{e}^-$	ionisation energy, $\Delta H_i^\ominus$

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

- 1  $\Delta H^\ominus$  for HCl >  $\Delta H^\ominus$  for HBr
- 2  $K_p$  for HBr >  $K_p$  for HI
- 3  $\Delta H_i^\ominus$  for I >  $\Delta H_i^\ominus$  for Cl

43 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,  $\text{H}_2\text{SO}_4$ , does not behave as an acid when dissolved in ethanol,  $\text{C}_2\text{H}_5\text{OH}$ .
- 3 The ammonium ion acts as a base when dissolved in liquid ammonia.