INSIGHT

Trial Exam Paper

2009
CHEMISTRY
Written examination 2

Solutions book

This book presents:

- correct solutions with full working
- explanatory notes
- mark allocations
- tips and guidelines

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SECTION A – Multiple-choice questions

Question 1

The following equilibrium is established in a 2.0 L vessel:

$$2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g)$$

Which one of the following sets of conditions would be expected to push the equilibrium furthest to the right?

	Addition of chemical	Volume of reaction vessel
A.	nitrogen gas	increased
B.	**nitrogen gas**	**decreased**
C.	argon gas	increased
D.	argon gas	decreased

Answer is B.

Worked solution

- B is correct because nitrogen gas is a reactant, and the addition of a reactant will always push equilibrium to the right as the system adjusts to remove some of the added product. Also, decreasing the volume of the reaction vessel increases the total particle concentration, causing an equilibrium system to adjust itself to reduce the total particle concentration by shifting in the direction of fewest particles (if possible). In this reaction, the ratio of reactant particles to product particles is 3 : 2, so equilibrium is pushed to the right when the reaction vessel volume is decreased.
- A is incorrect because increasing the volume of the reaction vessel will not push equilibrium to the right because the right (i.e. the product side) has fewer particles than the reactant side. An increase in the volume of the reaction vessel decreases the total particle concentration, causing an equilibrium system to adjust itself in order to reduce the total particle concentration by shifting in the direction of fewest particles (if possible).
- C is incorrect because the addition of argon gas (which is a noble gas) is not a species represented in the chemical equation, and so the addition of argon gas will have no effect on the position of equilibrium. Also, an increase in the volume of the reaction vessel will not push equilibrium to the right because the right (i.e. the product side) has fewer particles than the reactant side.
- D is incorrect because the addition of argon gas (which is a noble gas) is not a species represented in the chemical equation, and so the addition of argon gas will have no effect on the position of equilibrium.

SECTION A – continued
TURN OVER

Question 2

Small amounts of hydrogen gas and iodine gas are added to an empty reaction vessel, in which they react according to the equation

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

Which one of the following actions will increase both the reaction rate and the amount of $H_2(g)$ in the mixture at equilibrium?

A. adding a catalyst and decreasing the volume of the reaction vessel

B. adding $I_2(g)$ and decreasing the volume of the reaction vessel

C. adding a catalyst and removing some HI(g)

D. **adding some HI and decreasing the volume of the reaction vessel**

Answer is D.

Worked solution

- D is correct because decreasing the volume of the reaction will increase the reaction rate due to an increased concentration of particles. Adding some HI, a product, will shift the equilibrium to the left, increasing the amount of $H_2(g)$ present at equilibrium.
- A is incorrect because although adding a catalyst will increase the rate of a reaction, it does not have an effect on the position of equilibrium. Decreasing the volume of the reaction vessel will also increase the reaction rate due to increased particle concentration. However, in this reaction the number of particles on the reactant side is equal to the number of particles on the product side, so a change in volume will not change the position of equilibrium.
- B is incorrect because adding $I_2(g)$, a reactant, will shift equilibrium to the right, thereby decreasing the amount of $H_2(g)$ in the mixture. Decreasing the volume of the reaction vessel will increase the reaction rate due to increased particle concentration. However, in this reaction the number of particles on the reactant side is equal to the number of particles on the product side, so a change in volume will not change the position of equilibrium.
- C is incorrect because although adding a catalyst will increase the rate of a reaction, it does not have an effect on the position of equilibrium. Removing some HI(g) will shift the position of equilibrium to the right, thereby decreasing the amount of $H_2(g)$.

Question 3

A number of factors will increase the rate of a reaction. The factors that cause an increase in reaction rate solely as the result of an increase in the frequency of collisions between particles are

I adding a catalyst.
II increased temperature.
III increased concentration of reactants.
IV increased surface area of reactants.

A. **III and IV only**
B. I and IV only
C. II, III and IV only
D. I, II, III and IV

Answer is A.

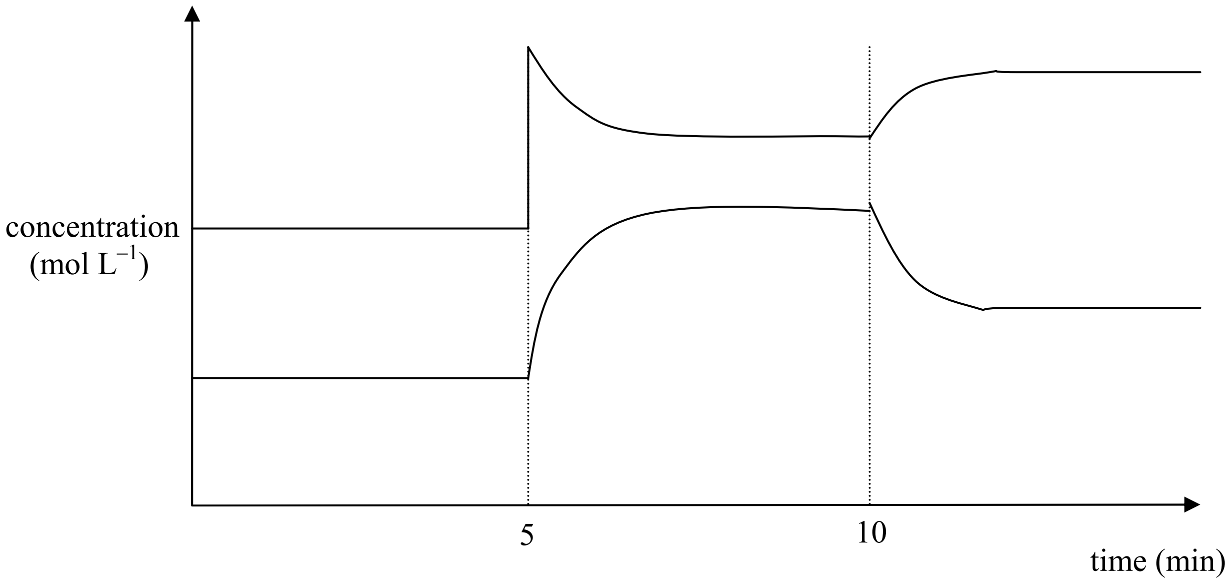
Worked solution

- A is correct because increasing the concentration of reactants means there are more particles present in a given volume; hence, collisions take place more frequently, increasing the reaction rate. Increasing the surface area of reactants makes more particles available to react which, again, increases the frequency of collisions and increases the reaction rate.
- B is incorrect because adding a catalyst increases the reaction rate by lowering the activation energy required for a particular collision to be successful, but does not increase the frequency of collisions. Note that increasing the concentration of reactants does, in fact, increase the rate solely by increasing the frequency of collisions, and so should be included.
- C is incorrect because increasing the temperature increases the rate primarily by giving reactant particles more energy, therefore making it easier to overcome the activation energy barrier.
- D is incorrect because adding a catalyst increases a reaction rate by lowering the activation energy required for a particular collision to be successful, but does not increase the frequency of collisions. In contrast, increasing the temperature increases the rate primarily by giving reactant particles more energy, therefore making it easier to overcome the activation energy barrier.

Question 4

Consider the graph below of the equilibrium system

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



Which one of the following could correctly describe the changes made to the mixture at 5 minutes and 10 minutes?

	5 minutes	10 minutes
A.	addition of NO_2	volume increase
B.	addition of NO_2	temperature decrease
C.	addition of N_2O_4	volume increase
D.	**addition of N_2O_4**	**temperature decrease**

Answer is D.

Worked solution

- D is correct. According to the equation, 1 mole of N_2O_4 will be produced for every 2 moles of NO_2 reacting. Therefore, the top line must be representing the concentration of N_2O_4 because when it changes concentration it changes to half the extent of the bottom line, hence the change at 5 minutes is addition of N_2O_4. At 10 minutes the change made has resulted in a more gradual response from the mixture, thus representing a temperature change.
- A is incorrect because the top line represents the concentration of N_2O_4, hence the change at 5 minutes is due to addition of N_2O_4. Also, the change made at 10 minutes is not a volume increase because not all species in the reaction showed a sudden decrease in concentration as expected.
- B is incorrect because the top line represents the concentration of N_2O_4 since, when it changes concentration, it changes to half the extent of the bottom line, so the change at 5 minutes is addition of N_2O_4.
- C is incorrect because the change made at 10 minutes is not a volume increase because not all the species in the reaction showed the sudden decrease in concentration that would have been expected.

Tips

- *The three general types of changes that can be made to an equilibrium mixture all have a different appearance on a concentration–time graph.*
- *The addition or removal of a specific product or reactant will show a sudden increase or decrease in the concentration of the species added or removed, whereas the concentrations of the other species present will change more gradually.*
- *Increasing or decreasing the volume will cause the concentrations of all species to show a sudden decrease or increase, followed by a gradual change as the equilibrium shifts in response to the increase or decrease.*
- *Changing the temperature shows a more gradual response in all species present. None of them have the sharp increase or decrease that is seen when volume change occurs.*

Question 5

Nitric oxide (NO) is a significant air pollutant produced as a byproduct when the internal combustion engines of cars reach high temperatures. The reaction is

$N_2 + O_2 \rightleftharpoons 2NO$

This reaction is most likely to be

A. **endothermic with a $\Delta H > 0$.**
B. exothermic with a $\Delta H > 0$.
C. endothermic with a $\Delta H < 0$.
D. exothermic with a $\Delta H < 0$.

Answer is A.

Worked solution

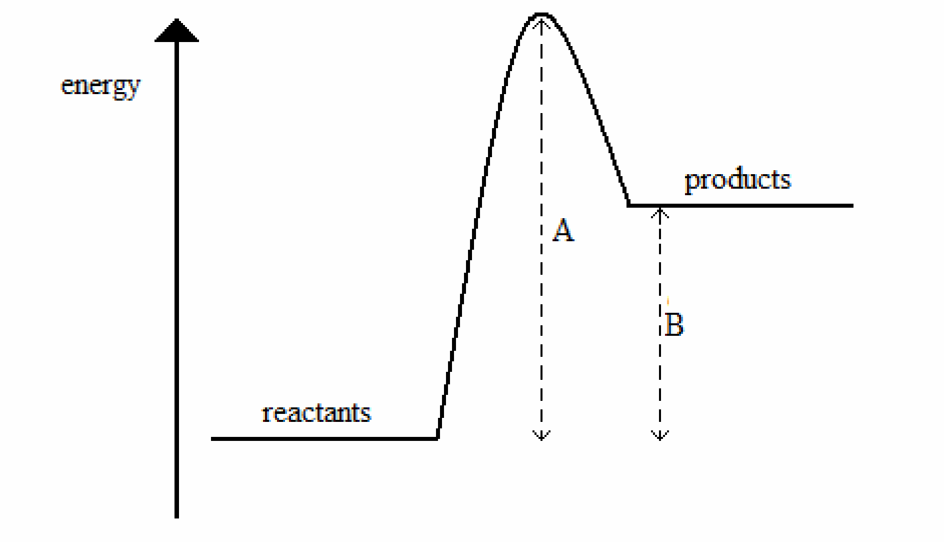
- A is correct because the fact that the forward reaction is favoured at high temperatures indicates it is endothermic in the forward direction, and all endothermic reactions have a ΔH value that is greater than 0.
- B is incorrect because the fact that the forward reaction is favoured at high temperatures indicates it is endothermic in the forward direction. Also, an exothermic reaction could not have a ΔH value that is greater than 0.
- C is incorrect because endothermic reactions have a ΔH value that is greater than 0.
- D is incorrect because the fact that the forward reaction is favoured at high temperatures indicates it is endothermic in the forward direction.

Tip

- *Remember that a negative ΔH value indicates a reaction is exothermic and a positive ΔH value indicates a reaction is endothermic. A forward reaction that is exothermic in the forward direction produces heat and increases the temperature of its surroundings. A forward reaction that is endothermic in the forward direction absorbs energy and lowers the temperature of its surroundings.*

Question 6

The energy changes for a particular reaction can be represented by the profile shown.



The reverse reaction is

A. exothermic with an activation energy that is equal to A.

B. exothermic with an activation energy that is equal to A–B.

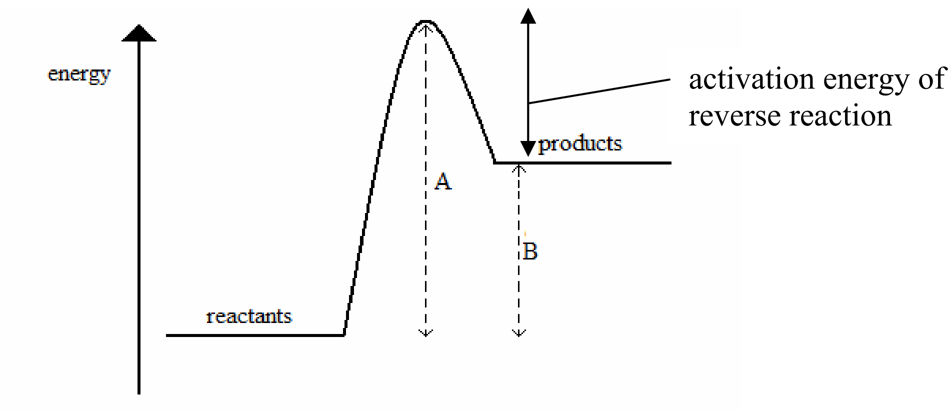
C. endothermic with an activation energy that is equal to A.

D. endothermic with an activation energy that is equal to A–B.

Answer is B.

Worked solution

- B is correct because in the *reverse* reaction the energy of the products is greater than the energy of the reactants, so energy is released during the reaction, making it exothermic. The activation energy is the energy difference between the energy of the reactants and the highest level in the profile, which in this case equals A–B.



- A is incorrect because although the reverse reaction is exothermic, the activation energy is equal to A–B.
- C is incorrect because in the reverse reaction the energy of the reactants is greater than the energy of the products, so energy is released during the reaction, making it exothermic.
- D is incorrect because in the reverse reaction the energy of the reactants is greater than the energy of the products, so energy is released during the reaction, making it exothermic.

Question 7

Consider the following reactions:

$NaOH(aq) + HCl(aq) \rightarrow NaCl(aq) + H_2O(l)$ ΔH_1

$NaOH(aq) + NH_4Cl(aq) \rightarrow NH_3(aq) + H_2O(l)$ ΔH_2

$HCl(aq) + NH_3(aq) \rightarrow NH_4Cl(aq)$ ΔH_3

The value of ΔH_3 will be equal to

A. $-\Delta H_1$

B. $-\Delta H_2$

C. $\mathbf{\Delta H_1 - \Delta H_2}$

D. $\Delta H_1 + \Delta H_2$

Answer is C.

Worked solution

- C is correct because the first reaction has to occur once and the second reaction has to occur once in reverse to create the third reaction. Thus, ΔH_3 will equal $\Delta H_1 + (-\Delta H_2)$; i.e. $\Delta H_1 - \Delta H_2$.
- A is incorrect because $-\Delta H_1$ will be the value of the reverse of the first reaction. This does not represent the third reaction.
- B is incorrect because $-\Delta H_2$ will be the value of the reverse of the second reaction. This does not represent the third reaction.
- D is incorrect because the second reaction needs to occur in reverse to create the third reaction, thus the value of ΔH_2 must be given the opposite sign before it is added to ΔH_1.

Question 8

Separate samples of 1.0 M solutions of HCl and CH_3COOH are diluted by a factor of ten. The change in pH units

A. **will be greater for HCl than for CH_3COOH.**

B. will be greater for CH_3COOH than for HCl.

C. will be the same for HCl and CH_3COOH.

D. cannot be determined for CH_3COOH.

Answer is A.

Worked solution

- A is correct because diluting a weak acid, such as CH_3COOH, increases the ionisation of the acid, thus increasing the concentration of H^+ ions and reducing the change in pH units, compared to dilution of a strong acid, such as HCl, which is already completely ionised.
- B is incorrect because the pH change caused by dilution will be greater for a strong acid compared to a weak acid.
- C is incorrect because the pH change caused by dilution will be greater for a strong acid compared to a weak acid.
- D is incorrect because the pH change can be determined using the K_a value of CH_3COOH. It actually does not need to be determined to qualitatively compare the change in pH units of the strong acid and the weak acid.

SECTION A – continued
TURN OVER

Questions 9 and 10 refer to the following information.

Nitrogen gas and oxygen gas can react according to the following equation:

$$2N_2(g) + O_2(g) \rightleftharpoons 2N_2O(g)$$

Question 9

Three different flasks, X, Y and Z, contain a mixture of N_2, O_2 and N_2O at equilibrium. The concentrations, in mol L^{-1}, of these components in each flask is shown below.

Flask	$[N_2(g)]$	$[O_2(g)]$	$[N_2O(g)]$
X	0.30	0.40	0.15
Y	0.60	0.10	0.15
Z	0.20	0.35	0.15

Which one of the flasks is at a different temperature compared to the other two?

A. X

B. Y

C. **Z**

D. Unable to be determined from the information given.

Answer is C.

Worked solution

- C is correct because flask Z has a calculated equilibrium constant (*K*) that is different from the *K* value for the other two flasks. *K* is calculated using the expression

$$K = \frac{[N_2O]^2}{[N_2]^2[O_2]}$$

Flask X $$K = \frac{(0.15)^2}{(0.30)^2(0.40)}$$
$$= 0.625\ M^{-1}$$

Flask Y $$K = \frac{(0.15)^2}{(0.60)^2(0.10)}$$
$$= 0.625\ M^{-1}$$

Flask Z $$K = \frac{(0.15)^2}{(0.20)^2(0.35)}$$
$$= 1.61\ M^{-1}$$

- A is incorrect because flask X has the same *K* value as flask Y, meaning they are at the same temperature.
- B is incorrect because flask Y has the same *K* value as flask X, meaning they are at the same temperature.
- D is incorrect because *K* can be calculated for each flask and then compared to each other to determine which two are at the same temperature.

Tip

- *Only a change in temperature can change the value of the equilibrium constant for a particular reaction.*

Question 10

A volume of 1.0 mol of gaseous N_2O is placed in an empty 2.0 L container. Once equilibrium is reached, 0.60 mol of N_2O remains. The equilibrium concentrations, in mol L^{-1}, of N_2 and O_2 are

	$[N_2(g)]$	$[O_2(g)]$
A.	**0.20**	**0.10**
B.	0.20	0.20
C.	0.30	0.15
D.	0.40	0.20

Answer is A.

Worked solution

- A is correct. It is useful to use an ICE table for these types of calculations. First, the initial amounts of all species and the equilibrium amount of $N_2O(g)$ are added to the table to obtain the change in $N_2O(g)$ of –0.40 mol. This value and the mole ratio from the equation are then used to determine the changes in the amounts of N_2 and O_2 so that their equilibrium amounts can be determined.

	$2N_2(g)$	$O_2(g)$	$2N_2O(g)$
Initial	0.0	0.0	1.0
Change	+0.40	+0.20	–0.40
Equilibrium	0.40	0.20	0.60

The concentrations are then determined using $c = \frac{n}{V}$.

- B is incorrect because $O_2(g)$ and $N_2O(g)$ react in the ratio 1 : 2, so only 0.20 mol of $O_2(g)$ is produced when $N_2O(g)$ decreased by 0.40 mol.
- C is incorrect because the equilibrium amount of $N_2O(g)$ is 0.60 mol, meaning the amount that has actually reacted is 1.0 – 0.60 = 0.40 mol. This amount of 0.40 mol is what needs to be used with the mole ratios to determine the amounts of the other species produced.
- D is incorrect because the reaction takes place in a 2.0 L container. The equilibrium amounts must be converted to concentrations using the equation $c = \frac{n}{V}$.

Question 11

Liquid ethanoic acid can react with ethanol to form the ester ethyl ethanoate, according to the following equation:

$CH_3COOH(l) + CH_3CH_2OH(l) \rightleftharpoons CH_3COOCH_2CH_3(l) + H_2O(l)$

At 25°C, the value of the equilibrium constant is 4.0.

What is the value of the equilibrium constant for the reaction below?

$3CH_3COOCH_2CH_3(l) + 3H_2O(l) \rightleftharpoons 3CH_3COOH(l) + 3CH_3CH_2OH(l)$

A. **0.016**
B. 0.083
C. –4.0
D. 64

Answer is A.

Worked solution

- A is correct. The K value of the reverse reaction, K_r, is the inverse of the K value of the forward reaction, K_f. Additionally, the tripling of the mole amounts in the equation requires the K_f value to be cubed; i.e. $K_r = \frac{1}{K_f^3} = \frac{1}{4.0^3} = 0.016$
- B is incorrect because the tripling of the mole amounts in the equation requires the K_f value to be cubed, not multiplied by three.
- C is incorrect because the K value of the reverse reaction is not simply the same value as the K value of the forward reaction but has the opposite sign, since the mol amounts have been tripled. Instead, it needs to be calculated using $K_r = \frac{1}{K_f^3} = \frac{1}{4.0^3}$.
- D is incorrect because the K value of a reverse reaction is the inverse of the K value of the forward reaction. This must be carried out as well as the cubing of the value due to the tripling of the mole amounts in the equation.

Question 12

The self-ionisation constant of pure water at 15°C is 4.51×10^{-15} M^2. The hydroxide ion concentration and pH will be

	$[OH^-]$	pH
A.	1.0×10^{-7} M	7.17
B.	1.0×10^{-7} M	7.00
C.	**6.7×10^{-8} M**	**7.17**
D.	6.7×10^{-8} M	7.00

Answer is C.

Worked solution

- C is correct according to the following:
  As $K_w = [H_3O^+][OH^-]$, then
  at 15°C $[H_3O^+] \times [OH^-] = 4.51 \times 10^{-15}$
  In pure water $[H_3O^+] = [OH^-]$, so
  $[OH^-]^2 = 4.51 \times 10^{-15}$
  $[OH^-] = \sqrt{4.51 \times 10^{-15}}$
  $= 6.7 \times 10^{-8}$ M
  $[H_3O^+] = [OH^-]$
  $= 6.7 \times 10^{-8}$ M
  $pH = -\log_{10}[H_3O^+]$
  $= -\log_{10}(6.7 \times 10^{-8})$
  $= 7.17$
- A is incorrect because $K_w = [H_3O^+][OH^-]$ and $[H_3O^+] = [OH^-]$, so $[OH^-] = 6.7 \times 10^{-8}$ M.
- B is incorrect because it is only at 25°C that $[H_3O^+]$ and $[OH^-] = 1.0 \times 10^{-7}$ M, giving a pH of 7.00. The self-ionisation of water is an endothermic reaction, so the K_w value varies with changes in temperature.
- D is incorrect because although $[OH^-] = 6.7 \times 10^{-8}$ M, the pH is not 7.00. The pH of pure water is only 7.00 at 25°C.

Question 13

A student conducted an experiment to determine the heat content of a dry biscuit. When a 3.5 g sample was combusted in a bomb calorimeter the temperature of the water inside the calorimeter rose from 16.0°C to 28.7°C. The calibration factor of the calorimeter was 2.95 kJ $°C^{-1}$.

The heat content of the biscuit, in kJ g^{-1}, is

A. **10.7**
B. 13.5
C. 24.2
D. 37.5

Answer is A.

SECTION A – Question 13 – continued
TURN OVER

Worked solution

- A is correct according to the steps below.

  Step 1: Calculate the energy, in kJ, produced by the sample.
  E = Calibration factor × ΔT
  = 2.95 × (28.7 – 16.0)
  = 2.95 × 12.7
  = 37.5 kJ

  Step 2: Calculate the heat energy of the biscuit.

  $$\text{Heat energy} = \frac{\text{Energy}}{\text{Mass (g)}}$$

  $$= \frac{37.5}{3.50}$$

  $= 10.7 \text{ kJ g}^{-1}$

- B is incorrect because 16.0°C is the initial temperature of the water, not the temperature change caused by the combustion of the dry biscuits.
  $\Delta T = 28.7 - 16.0 = 12.7$
- C is incorrect because 28.7°C is the highest temperature reached, not the temperature change caused by the combustion of the dry biscuits. $\Delta T = 28.7 - 16.0 = 12.7$
- D is incorrect because this is the energy released by the 3.5 g sample of dry biscuit. It is not the energy content in kJ g^{-1}.

Question 14

Which of the following processes will have a ΔH value with an opposite sign to the other three?

A. $CH_4(g) + O_2(g) \rightarrow CO_2(g) + H_2O(g)$

B. $N_2(g) \rightarrow N_2(l)$

C. $\mathbf{H_2O(s) \rightarrow H_2O(l)}$

D. $Mg(l) + Cl_2(g) \rightarrow MgCl_2(l)$

Answer is C.

Worked solution

- C is correct because the melting of water requires the absorption of energy, so is an endothermic reaction with a positive ΔH. Each of the other reactions is exothermic with a negative ΔH.
- A is incorrect because the combustion of methane is an exothermic reaction with a negative ΔH. Two of the other reactions are also exothermic.
- B is incorrect because the condensation of any gas into its liquid state is an exothermic process. Two of the other reactions are also exothermic.
- D is incorrect because according to the electrochemical series, Mg(l) and $Cl_2(g)$ will react spontaneously, releasing energy and making it exothermic with a negative ΔH. Two of the other reactions are also exothermic.

Question 15

The ability of secondary cells to be recharged is best explained by the fact that

A. the products of the discharge reaction come into contact with each other.

B. **the products of the discharge reaction do not migrate away from the electrodes.**

C. the polarity of the electrodes can be reversed.

D. the products of the discharge reaction move away from the electrodes used in the discharging reaction.

Answer is B.

Worked solution

- B is correct. It is because the products of the discharge reaction remain in contact with the electrodes that an external electrical source can be applied to convert these products back into reactants, thus recharging the cell.
- A is incorrect. The products of the discharge reaction will not react spontaneously with each other. An external electrical source must be applied to convert them back into reactants.
- C is incorrect because the polarity of any two electrodes can be reversed by attaching them to an external power source. This is not what enables secondary cells to be recharged.
- D is incorrect because if the products move away from the electrodes it makes the cell unable to be recharged by applying an external electrical source.

Question 16

To heat a 350 g block of copper by 35.0°C, 4.76 kJ of energy is required. The specific heat capacity of copper, in J g^{-1} $°C^{-1}$ is

A. 3.89×10^{-4}

B. **0.389**

C. 3.89

D. 389

Answer is B.

Worked solution

- B is correct according to the following:

$$E = SHC \times m \times \Delta T$$

$$4.76 \times 10^3 = SHC \times 350 \times 35.0$$

$$SHC = 0.389$$

- A is incorrect because the energy must be expressed in joules (J), not kJ, for use in this equation.
- C is incorrect because it is out by a factor of ten.
- D is incorrect because the mass must be expressed in grams (g), not kg, for use in this equation.

Question 17

Which of the following compounds would have the same product at the anodes but a different product at the cathodes when comparing the electrolysis of its molten state with the electrolysis of the compound in a 1.0 M aqueous solution?

A. sodium fluoride

B. zinc chloride

C. lead iodide

D. **potassium bromide**

Answer is D.

Worked solution

- D is correct because in aqueous solution, water will be reduced at the cathode in preference to K^+(aq) because the water is a stronger oxidant – therefore the cathode reactions are different. However, the anode reaction is the same in molten and aqueous forms because Br^-(aq) is a stronger reductant than water.
- A is incorrect because in aqueous solution, water will be reduced in preference to Na^+(aq) and will also be oxidised in preference to F^-(aq). The products at the anode and the cathode are both different.
- B is incorrect because in aqueous solution, water will be oxidised at the anode in preference to Cl^-(aq). The product at the anodes will be different.
- C is incorrect because Pb^{2+}(aq) is a stronger oxidant than water and I^-(aq) is a stronger reductant than water. The same products will be produced at the anode and cathode whether lead iodide is in its molten or aqueous form.

Explanatory notes

Response	**Products in molten state**		**Products in aqueous solution**		**Comment**
	At cathode	*At anode*	*At cathode*	*At anode*	
A	Na	F_2	H_2/OH^-	O_2/H^+	Different products for both scenarios since water is a stronger oxidant that Na^+ and a stronger reductant than F^-.
B	Zn	Cl_2	Zn	O_2/H^+	Same products for anode reaction but not the same products for cathode reaction since water is a stronger oxidant than Cl^-.
C	Pb	I_2	Pb	I_2	Same products for both scenarios since Pb^{2+} is strongest oxidant and I^- is strongest reductant, whether or not water is present.
D (correct response)	K	Br_2	H_2/OH^-	Br_2	Different products for cathode reaction since water is a stronger oxidant than K^+, but same products for anode reaction as Br^- is a stronger reductant than water.

Question 18

Silver metal is electroplated onto a copper ring, using a silver anode and a solution containing $Ag^+(aq)$ ions. During this process

A. $Ag^+(aq)$ ions move towards the anode.

B. the concentration of $Ag^+(aq)$ ions in the solution increases.

C. the concentration of $Ag^+(aq)$ ions in the solution decreases.

D. **the anode decreases in mass.**

Answer is D.

Worked solution

- D is correct because oxidation of silver occurs at the anode according to the equation $Ag(s) \rightarrow Ag^+(aq) + e^-$. The mass of the electrode will decrease as silver atoms are converted to aqueous ions.
- A is incorrect because the $Ag^+(aq)$ cations move towards the cathode, where they are reduced to silver atoms and plated onto the copper ring.
- B is incorrect because the concentration of $Ag^+(aq)$ ions remains constant. For every $Ag^+(aq)$ reduced to Ag(s) at the cathode, an $Ag^+(aq)$ is produced by the oxidation of Ag(s) at the anode.
- C is incorrect because the concentration of $Ag^+(aq)$ ions remains constant. For every $Ag^+(aq)$ reduced to Ag(s) at the cathode, an $Ag^+(aq)$ is produced by the oxidation of Ag(s) at the anode.

Question 19

Which of the following energy sources has the highest energy content per gram of fuel?

A. brown coal

B. natural gas

C. **nuclear fuel (uranium)**

D. biochemical fuels

Answer is C.

Worked solution

- C is correct because in nuclear fission a nuclear reaction occurs in which mass is converted to energy according to the equation $E = mc^2$. An extremely small change in mass will produce an enormous amount of energy.
- A is incorrect because nuclear fuel (uranium) has a higher energy content per gram of fuel than brown coal.
- B is incorrect because nuclear fuel (uranium) has a higher energy content per gram of fuel than natural gas.
- C is incorrect because nuclear fuel (uranium) has a higher energy content per gram of fuel than biochemical fuels.

Tip

- *The study design released by the Victorian Curriculum and Assessment Authority (VCAA) specifies that students should be able to compare the energy sources specifically of the four listed in this question in terms of their types, uses and sustainability.*

Question 20

Which of the following **cannot** be predicted correctly using the electrochemical series?

A. **Cu(s) and I_2(s) will react at a very fast rate.**

B. Ag(s) can react with Br(l).

C. In order to produce K(s), a molten reactant containing K^+(l) ions must be used.

D. A solution of H_2O_2(aq) can decompose to O_2(g) and H_2(g).

Answer is A.

Worked solution

- A cannot be predicted correctly because the electrochemical series does not give any indication of the rate at which a reaction will occur.
- B is a correct statement because Ag(s) is lower on the right side of the electrochemical series than Br_2(l), which is on the left, so it can be predicted that they will react.
- C is a correct statement because water is higher on the left of the electrochemical series than K^+(aq), making it a stronger oxidant that will always react preferentially. K^+(aq) will be reduced only when in molten form.
- D is a correct statement because H_2O_2(aq) is both an oxidant and a reductant. It is higher on the left of the electrochemical series than the right, so can react spontaneously to decompose to O_2(g) and H_2(g).

END OF SECTION A

SECTION B – Short-answer questions

Question 1

A 3.5 g piece of calcium carbonate was added to an excess volume of 1.0 M nitric acid.

The volume of carbon dioxide gas, at STP, produced during the reaction was measured and recorded.

a. Write an equation for the reaction between calcium carbonate and nitric acid.

Solution

$CaCO_3(s) + 2HNO_3(aq) \rightarrow Ca(NO_3)_2(aq) + H_2O(l) + CO_2(g)$

2 marks

Mark allocation

- 1 mark for correctly balanced equation.
- 1 mark for including correct state symbols for each species.

Explanatory notes

The general reaction to use here is:

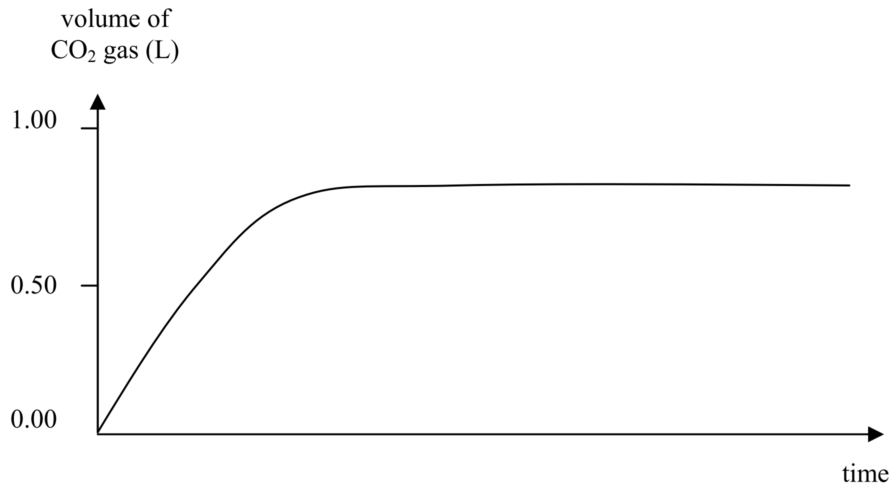
metal carbonate + acid → salt + water + carbon dioxide

Tip

- *Be sure to be confident with the valencies of ions, as well as the general reactions of acids, so that correct equations can be written.*

b. On the axes below, sketch the expected shape of the graph of volume of carbon dioxide against time for this experiment.

Solution



2 marks

Mark allocation

- 1 mark for correct shape; i.e. starting at zero and flattening off over time.
- 1 mark for the flattening off occurring close to 0.78 L.

Explanatory notes

Since the 3.5 g of calcium carbonate was the limiting reagent, the amount of carbon dioxide produced can be calculated.

$$n(CaCO_3) = \frac{m}{M}$$
$$= \frac{3.5}{40.1 + 12.0 + 3 \times 16.0}$$
$$= 0.035 \text{ mol}$$

$n(CO_2) : n(CaCO_3)$

1 : 1

So $n(CO_2) = 0.035$ mol

$V(CO_2)$ at STP $= n \times V_M$

$= 0.0350 \times 22.4$

$= 0.78$ L

Tip

- *Check the axes of graphs carefully to work out whether you need to calculate or use data from the question when sketching a graph.*

c. In a second experiment, another 3.5 g piece of calcium carbonate was added to the same volume of **heated** 1.0 M nitric acid. Explain why this second reaction will occur at a faster rate than the first.

Solution

Increasing the temperature means that reacting particles have more energy, and so can overcome the activation energy barrier more easily.

1 mark

Explanatory notes

Although the particles do move more quickly and collide more frequently, this does not explain the significant increase in rate caused by increasing the temperature. To obtain the mark, reference must be made to the ability to overcome the activation energy barrier more easily.

Total 2 + 2 + 1 = 5 marks

Question 2

a. 1-propanol is used to calibrate a bomb calorimeter. 1.86 g of 1-propanol is reacted with excess oxygen in the bomb calorimeter, causing the temperature of the surrounding water to increase from 22.4°C to 63.5°C.

Calculate the calibration factor of the bomb calorimeter, in kJ °C^{-1}.

Solution

The molecular formula of 1-propanol is C_3H_7OH.

$$\begin{aligned} n(C_3H_7OH) &= \frac{m}{M} \\ &= \frac{1.86}{60} \\ &= 0.031 \text{ mol} \end{aligned}$$

The molar enthalpy of combustion, ΔH_c, of 1-propanol is –2016 kJ mol^{-1} (as indicated in the VCE Chemistry data book).

$$\begin{aligned} \text{So, energy released by 1.86 g of sample} &= n \times \Delta H_C \\ &= 0.031 \times 2016 \\ &= 62.5 \text{ kJ} \end{aligned}$$

$$\begin{aligned} \text{Calibration factor} &= \frac{E}{\Delta T} \\ &= \frac{62.5}{63.5 - 22.4} \\ &= \frac{62.5}{41.1} \\ &= 1.52 \text{ kJ °C}^{-1} \end{aligned}$$

3 marks

Mark allocation

- 1 mark for correctly calculating the amount, in mol, of 1-propanol.
- 1 mark for correctly calculating the energy released by the sample of 1-propanol.
- 1 mark for correctly calculating the calibration factor.

Explanatory notes

The molar enthalpy of combustion of 1-propanol is in the VCE data book.

Tip

- *As a general rule, errors should be penalised only once. For example, consequential marks should be awarded if the amount, in mol, of 1-propanol is not correct but subsequent calculations are done correctly.*

b. A second bomb calorimeter of the same size and same manufacturer as the first is calibrated electrically. A charge of 3.55 A was passed through the heating element in the calorimeter at a voltage of 6.40 V for 4.00 minutes. The temperature of the surrounding water increased from 22.3°C to 25.6°C.

Calculate the calibration factor of this bomb calorimeter, in kJ $°C^{-1}$.

Solution

$$\begin{aligned} E &= VIt \\ &= 6.40 \times 3.55 \times 4.00 \times 60 \\ &= 5.45 \times 10^3 \text{ J} \\ &= 5.45 \text{ kJ} \end{aligned}$$

$$\begin{aligned} \text{Calibration factor} &= \frac{E}{\Delta T} \\ &= \frac{5.45}{25.6 - 22.3} \\ &= \frac{5.45}{3.30} \\ &= 1.65 \text{ kJ } °\text{C}^{-1} \end{aligned}$$

2 marks

Mark allocation

- 1 mark for correctly calculating the amount of energy.
- 1 mark for correctly calculating the calibration factor.

Tip

- *Numerical answers always should be expressed to the correct number of significant figures. The answer should have the same number of significant figures as the least precise data used in the calculation.*

c. Assuming the calculations were carried out correctly, give two reasons for any difference between the two calculated calibration factors.

Solution

Any two of:

lid on one was not placed correctly

lack of stirring

volume of water not measured correctly

incomplete combustion of 1-propanol

differences in the insulation of the sides of the calorimeter

other reasonable answer

2 marks

Mark allocation

- 1 mark for each correct reason, up to 2 marks.

Total 3 + 2 + 2 = 7 marks

Question 3

Solutions of equal concentrations of three different acids were compared. The acids were

I hydrochloric acid
II hydrofluoric acid
III hypochlorous acid

a. Which one of these three acids would have the highest pH? Give a reason for your answer.

Solution

III, hypochlorous acid because it is the weakest acid or it has the lowest K_a value.

2 marks

Mark allocation

- 1 mark for selecting the correct answer.
- 1 mark for correct reason.

Explanatory notes

Hydrochloric acid is a strong acid and completely ionises in water. It will have the lowest pH. Hydrofluoric acid and hypochlorous acid are both weak acids. The one with the lowest K_a value will ionise the least, and so have the lowest concentration of H^+ ions in solution and therefore the highest pH.

b. Calculate the pH of a 1.0 M solution of the weakest acid as identified in **Question 3a**.

Solution

Hypochlorous acid is the weakest acid.

$$K_a = \frac{[H^+]^2}{[acid]}$$

$$2.9 \times 10^{-8} = 2.9 \times 10^{-8} = \frac{[H^+]^2}{1.0}$$

$$[H^+]^2 = 2.9 \times 10^{-8} \times 1.0$$
$$= 2.9 \times 10^{-8}$$
$$[H^+] = \sqrt{2.9 \times 10^{-8}}$$
$$= 1.7 \times 10^{-4} \text{ M}$$
$$pH = -\log_{10}[H^+]$$
$$= -\log_{10}(2.9 \times 10^{-8})$$
$$= 3.8$$

2 marks

Mark allocation

- 1 mark for correct use of K_a value and acid concentration.
- 1 mark for correct use of the $pH = -\log_{10}[H^+]$ equation.
- Consequential marks awarded for correct pH of 1.0 M hydrofluoric acid.

Explanatory notes

The K_a value must be used when determining the pH of a weak acid. Weak acids do not ionise completely, so the concentration of the weak acid does not indicate the concentration of $[H^+]$ directly as it does with a strong acid.

c. Calculate the percentage ionisation of the weakest acid in a 1.0 M solution as identified in **Question 3a**.

Solution

$[H^+] = 1.7 \times 10^{-4}$ M

$$\text{Percentage ionisation} = \frac{[H^+]}{[acid]} \times 100$$
$$= \frac{1.7 \times 10^{-4}}{1.0} \times 100$$
$$= 0.017\%$$

2 marks

Mark allocation

- 1 mark for use of $[H^+]$ calculated in part b.
- 1 mark for correctly calculating percentage ionisation.

d. A volume of 100 mL of acid I is mixed with 100 mL of acid III. Will the resultant solution have a pH that is higher, lower or the same as the original solution of acid I? Give a reason for your answer.

Solution

Resultant solution will have a higher pH.
Acid III is a weak acid that does not ionise completely, so $[H^+]$ in the 200 mL solution will be less than $[H^+]$ in the 100 mL of acid I, which is a strong acid.

2 marks

Mark allocation

- 1 mark for stating it will have a higher pH.
- 1 mark for giving correct reason.

Total 2 + 2 + 2 + 2 = 8 marks

Question 4

Nitric oxide can be produced from nitrogen and oxygen according to the equation

$N_2(g) + O_2(g) \rightleftharpoons 2NO(g)$ ΔH is positive

Initially, a mixture of 0.10 M N_2, 0.050 M O_2 and 0.10 M NO was allowed to reach equilibrium in a 2.0 L vessel. Once equilibrium was established, it was found that the amount of NO had increased by 0.040 mol.

a. Calculate the value of the equilibrium constant for this reaction.

Solution

Using an ICE table:

	$N_2(g)$	$O_2(g)$	$2NO(g)$
Initial (mol)	$n = cV = 0.10 \times 2.0$ $= 0.20$	$= 0.050 \times 2.0$ $= 0.10$	$= 0.10 \times 2.0$ $= 0.20$
Change (mol)	–0.020	–0.020	+0.04
Equilibrium (mol)	0.18	0.080	0.24
Equilibrium concentration (M)	$c = \frac{n}{V} = \frac{0.18}{2.0}$ $= 0.090$ M	$= \frac{0.080}{2.0}$ $= 0.040$ M	$= \frac{0.24}{2.0}$ $= 0.12$ M

$$K = \frac{[NO]^2}{[N_2][O_2]}$$
$$= \frac{(0.12)^2}{(0.090)(0.040)}$$
$$= \frac{0.0144}{0.0036}$$
$$= 4.0$$

4 marks

Mark allocation

- 1 mark for correctly calculating changes of amounts of N_2 and O_2.
- 1 mark for correctly calculating equilibrium amounts of N_2, O_2 and NO.
- 1 mark for correct expression of the equilibrium constant.
- 1 mark for correctly calculating the equilibrium constant

b. The same reaction is repeated in a 4.0 L vessel. What would be the effect on the value of the equilibrium constant? Give an explanation for your answer.

Solution

No effect. Changing the volume will not change the *K* value OR only a change in temperature changes the *K* value.

1 mark

Explanatory notes

A reason must be given to obtain the mark.

Tip

- *Remember that only a change in temperature will change the value of an equilibrium constant.*

c. The same reaction is repeated at a much higher temperature. What would be the effect on the value of the equilibrium constant? Give an explanation for your answer.

Solution

The *K* value would increase. This is an endothermic reaction in the forward direction, so an increase in temperature would favour the endothermic forward reaction, causing a greater proportion of products at equilibrium.

2 marks

Mark allocation

- 1 mark for stating that *K* value would increase.
- 1 mark for giving correct explanation.

Explanatory notes

The stem of the question indicates this reaction has a positive ΔH, meaning it is endothermic. You should read questions very carefully, perhaps with a highlighter or underlining pen, so that important information such as this is not missed.

Total 4 + 1 + 2 = 7 marks

Question 5

In VCE Chemistry Unit 4, you were required to investigate the industrial production of a chemical selected from ammonia, ethene, sulfuric acid or nitric acid. Choose one of these chemicals and circle it in the list below.

ammonia   ethene   sulfuric acid   nitric acid

a. Write a balanced chemical equation for a reaction in the production process of which your chosen chemical is a product.

Solution

One of the following:

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

Ethene – Several cracking reactions will be appropriate

e.g. $C_2H_6(g) \rightleftharpoons C_2H_4(g) + H_2(g)$ or $C_3H_8(g) \rightleftharpoons C_2H_4(g) + CH_4(g)$

Sulfuric acid – $H_2S_2O_7(l) + H_2O(l) \rightarrow 2H_2SO_4(l)$

Nitric acid – $3NO_2(g) + H_2O(l) \rightarrow 2HNO_3(aq) + NO(g)$

1 mark

b. i. Give the name or formula of **one** waste chemical formed during the production of the chemical you have chosen.

Solution

One of the following:

Ammonia – CO_2, aqueous ammonia

Ethene – unreacted feedstock, ethyne, CO_2, H_2S, H_2, CH_4

Sulfuric acid – SO_2, spent catalyst

Nitric acid – NO, NO_2

1 mark

ii. Describe **one** way in which this waste chemical is safely managed or disposed of.

Solution

Ammonia – carbon dioxide waste can be liquefied and sold OR aqueous solutions of ammonia can be used in the manufacture of urea.

Ethene – unreacted feedstock is recycled back into the converter OR ethyne is converted to ethene OR CO_2 and H_2S are removed by treatment with NaOH(aq) OR hydrogen and methane are used as fuels for furnaces.

Sulfuric acid – SO_2 waste is recycled back to the converter for additional passes over the catalyst OR spent catalyst has vanadium removed before disposal in landfill.

Nitric acid – NO and NO_2 wastes can be heated with a fuel to reduce them to N_2.

1 mark

Mark allocation

- 1 mark for giving the correct name or formula of a waste species.
- 1 mark for giving correct method of management or disposal.

Explanatory notes

The method of management or disposal must be appropriate for the named chemical.

c. Write the chemical formula of **one** useful product formed from the chemical you have chosen.

Solution

One of the following:

Ammonia – NH_4NO_3, $(NH_4)_2SO_4$, $(NH_4)_3PO_4$, HNO_3

Ethene – C_2H_5OH, $-(C_2H_4)_n-$

Sulfuric acid – $H_2S_2O_7$, $(NH_4)_2SO_4$, $ZnSO_4$, and other metal sulfates

Nitric acid – NH_4NO_3, N_2O, $AgNO_3$, KNO_3, $NaNO_3$ and other metal nitrates

1 mark

Explanatory notes

Students need to discuss only their chosen chemical. The options for answers given in parts **a** and **b** may not contain all possible answers for each chemical, so student answers that differ should be considered carefully.

Total 1 + 2 + 1 = 4 marks

Question 6

Water can be electrolysed according to the reaction

$$2H_2O(l) \rightarrow 2H_2(g) + O_2(g)$$

a. i. Write a balanced equation for the reaction that occurs at the anode.

Solution

$2H_2O(l) \rightarrow O_2(g) + 4H^+(aq) + 4e^-$

1 mark

Explanatory notes

Oxidation occurs at the anode. The equation for the oxidation of H_2O is listed in the electrochemical series.

ii. Write a balanced equation for the reaction that occurs at the cathode.

Solution

$H_2O(l) + 2e^- \rightarrow H_2(g) + 2OH^-(aq)$

1 mark

Explanatory notes

Reduction occurs at the cathode. The equation for the reduction of $H_2O(l)$ is listed in the electrochemical series.

SECTION B – Question 6 – continued

A student wishes to electrolyse some water by setting up an electrolytic cell.

b. i. Circle the best solution below for the student to choose for the electrolyte in the cell.

deionised water sodium sulfate copper sulfate sodium iodide

Solution

sodium sulfate

1 mark

ii. Give an explanation for your choice.

Solution

Sodium sulfate will provide ions that can carry charge in the solution but which will not react in preference to the $H_2O(l)$.

2 marks

Mark allocation

- 1 mark for the electrolyte must have charged ions.
- 1 mark for the ions must not interfere with the oxidation or reduction of $H_2O(l)$.

Explanatory notes

Deionised water should not be used because it has had its ions removed and so will not readily carry charge. Therefore, it will not be as effective as an electrolyte.

Copper sulfate should not be used because copper ions are a stronger oxidant than $H_2O(l)$, and so would react preferentially.

Sodium iodide should not be used because iodide ions are a stronger reductant than $H_2O(l)$, and so would react preferentially.

Tip

- *Although water does produce some $H_3O^+(aq)$ and $OH^-(aq)$ ions by its self-ionisation reaction, they are at extremely low concentration and do not do a very effective job at carrying charge. It is better to use an aqueous electrolyte that will provide unreactive ions to carry the charge.*

c. An electrolytic cell is used for the extraction of copper metal from a solution of $CuCl_2$ and operates for 1.50 hours at a constant current of 18.5 A.

i. Calculate the quantity of electricity, in coulomb, that passes through the cell.

Solution

$$\begin{aligned} Q &= It \\ &= 18.5 \times 1.50 \times 60 \times 60 \\ &= 9.99 \times 10^4 \text{ C} \end{aligned}$$

1 mark

Explanatory notes

Time must be expressed in seconds for use in this equation.

ii. Assuming that 80.0% of the electricity passing through the cell is used in the electrolysis of $CuCl_2$, calculate the mass, in grams, of copper produced in this time.

Solution

Amount of electricity used

$= 80.0\%$ of 9.99×10^4

$= \dfrac{80}{100} \times 9.99 \times 10^4$

$= 7.99 \times 10^4$ C

$n(e^-) = \dfrac{Q}{F}$

$= \dfrac{7.99 \times 10^4}{96\,500}$

$= 0.828$ mol

Copper in $CuCl_2$ is in the oxidation state Cu^{2+}, so the half reaction is

$Cu^{2+}(aq) + 2e^- \rightarrow Cu(s)$

$n(\text{Cu}) = \dfrac{1}{2} \times n(e^-)$

$= \dfrac{1}{2} \times 0.828$

$= 0.414$ mol

$m(\text{Cu}) = nM$

$= 0.414 \times 63.6$

$= 26.3$ g

4 marks

Mark allocation

- 1 mark for using 80% of the electricity calculated in part **a**.
- 1 mark for calculating $n(e^-)$ correctly.
- 1 mark for calculating n(Cu) correctly.
- 1 mark for calculating m(Cu) correctly.

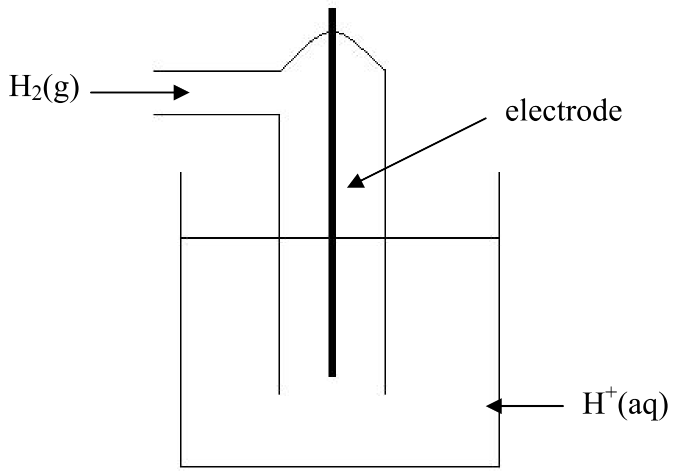
Total 2 + 3 + 5 = 10 marks

Question 7

The $H^+(aq)/H_2(g)$ half-cell is the standard half-cell used to obtain the E^o values listed in the electrochemical series.

a. i. Sketch and label a diagram of this half-cell.

Solution



1 mark

Explanatory notes

This is a (g)/(aq) half-cell, so the sketch must show that a gas electrode is used for $H_2(g)$.

ii. State the pH of the solution of $H^+(aq)$ ions required when this half-cell is used as a standard half-cell.

Solution

$$\begin{aligned} pH &= -\log_{10}[H^+] \\ &= -\log_{10}(1.0) \\ &= 0 \end{aligned}$$

1 mark

Explanatory notes

To be used as a standard, the concentration of the solution must be 1.0 M.

b. A galvanic cell consists of the following half-cells set up under standard conditions.

Half-cell 1: The $H^+(aq)/H_2(g)$ half cell described above.

Half-cell 2: An inert electrode in a solution containing $Cr^{2+}(aq)$ and $Cr^{3+}(aq)$ ions.

After some time, the pH in half-cell 1 has increased.

i. Which chemical species is the strongest oxidant in this galvanic cell? Give an explanation for your answer.

Solution

H^+ is the strongest oxidant.

An increase in pH indicates $[H^+]$ has decreased, so $H^+(aq)$ must have been reduced to $H_2(g)$. Reduction generally occurs to the strongest oxidant, so $H^+(aq)$ must be the strongest oxidant.

2 marks

Mark allocation

- 1 mark for stating that H^+ is the strongest oxidant.
- 1 mark for giving a correct reason.

ii. Give the equation for the half-reaction that takes place at the anode in this cell.

Solution

$Cr^{2+}(aq) \rightarrow Cr^{3+}(aq) + e^-$

1 mark

Explanatory notes

Oxidation always occurs at the anode. $H^+(aq)$ is the strongest oxidant and so is reduced, leaving the oxidation reaction to occur at the electrode in the $Cr^{2+}(aq)/Cr^{3+}(aq)$ half-cell. $Cr^{2+}(aq)$ must be oxidised at the anode.

c. A second galvanic cell consists of the following half-cells set up under standard conditions.

Half-cell 1: An electrode of X(s) in a solution containing $X^{2+}(aq)$ ions.

Half-cell 2: An inert electrode in a solution containing $Cr^{2+}(aq)$ and $Cr^{3+}(aq)$ ions.

The direction of electron flow is from the X(s) electrode towards the inert electrode.

i. Give the equation for the half-reaction that takes place at the cathode in this cell.

Solution

$Cr^{3+}(aq) + e^- \rightarrow Cr^{2+}(aq)$

1 mark

Explanatory notes

Electrons always flow in the direction of anode to cathode, so the inert electrode in the $Cr^{2+}(aq)/Cr^{3+}(aq)$ half-cell must be the cathode. Reduction always occurs at the cathode, so it must be $Cr^{3+}(aq)$ that is being reduced.

ii. Would you expect the standard E^o value of $X^{2+}(aq) + 2e^- \rightarrow X(s)$ to have a positive or negative value? Give an explanation for your answer.

Solution

A negative value.

$H^+(aq)$ is a stronger oxidant than $Cr^{3+}(aq)$, and $Cr^{3+}(aq)$ is a stronger oxidant than $X^{2+}(aq)$. This means the $X^{2+}(aq)/X(s)$ reduction reaction would be below the $H^+(aq)/H_2(g)$ oxidation reaction in the electrochemical series, giving it a negative E^o value.

2 marks

Mark allocation

- 1 mark for stating that it has a negative value.
- 1 mark for giving a correct explanation.

d. A nickel–metal hydride battery is a rechargeable galvanic cell used in laptop computers. A hydrogen-absorbing metal alloy is used for the negative electrode and NiO(OH)(s) is used for the positive electrode. When the cell is generating electricity the overall cell reaction is

H(absorbed on M) + NiO(OH)(s) $\rightarrow$ $Ni(OH)_2(s)$

The reaction at the negative electrode when the cell is generating electricity is

H(absorbed on M) + $OH^-(aq) \rightarrow H_2O(l) + e^-$

i. Write the equation for the half-reaction that takes place at the cathode when the cell is discharging.

Solution

$NiO(OH)(s) + H_2O(l) + e^- \rightarrow Ni(OH)_2(s) + OH^-(aq)$

1 mark

Explanatory notes

The oxidation and reduction half equations must add together to produce the overall equation.

ii. Write the equation for the half-reaction that takes place at the electrode connected to the positive terminal of the power supply when the cell is recharging.

Solution

$Ni(OH)_2(s) + OH^-(aq) \rightarrow NiO(OH)(s) + H_2O(l) + e^-$

1 mark

Explanatory notes

The electrode connected to the positive terminal becomes the anode when the cell is recharging and oxidation occurs at the anode. The recharging reactions are always a direct reverse of the discharging reactions.

Total 2 + 3 + 3 + 2 = 10 marks

Question 8

The solid oxide fuel cell (ZAFC) is a leading candidate for high-power applications, including large-scale electricity generating stations. The fuel cell has the following features:

- a ceramic solid as its electrolyte, in which oxide ions, O^{2-}, are able to move.
- an anode reaction of $H_2(g) + O^{2-}$(in ceramic) $\rightarrow H_2O(l) + 2e^-$
- hydrogen gas and oxygen gas are the reactants
- water is the only product.

a. Give a reason why the electrolyte in any fuel cell must contain an ion that is free to move.

Solution

It completes the circuit and allows current to flow.

1 mark

b. Give an equation for the reaction that takes place at the cathode of this cell. States are not required.

Solution

$O_2 + 4e^- \rightarrow 2O^{2-}$

1 mark

c. What distinguishes a fuel cell from other types of galvanic cells, such as primary and secondary cells?

Solution

A continuous flow of reactants.

1 mark

d. A particular cell operates at 0.650 V, delivering a current of 0.600 A for 3.00 hours.

i. Calculate the energy, in J, that would be provided by the cell in this time.

Solution

$E = VIt$
$= 0.650 \times 0.600 \times 3.00 \times 60 \times 60$
$= 4.21 \times 10^3$ J

1 mark

ii. Calculate the charge, in coulomb, produced by the cell.

Solution

$Q = It$
$= 0.600 \times 3.00 \times 60 \times 60$
$= 6.48 \times 10^3$ C

1 mark

e. Describe **one** disadvantage of a fuel cell, such as the solid ceramic fuel cell, over a coal-fired power station.

Solution

Expensive to replace electrodes

Less total energy available

1 mark

Total 1 + 1 + 1 + 2 + 1 = 6 marks

Question 9

Butane (C_4H_{10}) is commonly used as a fuel in portable camping stoves.

a. Determine the heat content of butane, in kJ g^{-1}.

Solution

$$\text{The heat of combustion, in kJ g}^{-1} = \frac{\text{Molar enthalpy, in kJ mol}^{-1}}{\text{Molar mass, in g mol}^{-1}}$$

$$= \frac{2874}{4 \times 12.0 + 10 \times 1.0}$$

$$= \frac{2874}{58.0}$$

$$= 49.6 \text{ kJ g}^{-1}$$

1 mark

Explanatory notes

The heat content of a substance is equivalent to the heat of combustion of the same substance, assuming complete reaction.

b. Calculate the mass, in grams, of butane required to heat a 500 mL container of water from 16.0°C to 100°C.

Solution

$$\begin{aligned} E &= m \times SHC \times \Delta T \\ &= 500 \times 4.18 \times (100 - 16.0) \\ &= 1.76 \times 10^5 \text{ J} \\ &= 176 \text{ kJ} \end{aligned}$$

$$m(\text{butane}) \text{ required} = \frac{176}{49.6} = 3.54 \text{ g}$$

2 marks

Tip

- *The specific heat capacity of water is included in the VCE data book.*

Total 1 + 2 = 3 marks

END OF SOLUTIONS BOOK