INSIGHT

Trial Exam Paper

2006
CHEMISTRY
Written examination 1

Solution book with worked solutions

This book presents:

- correct sample answers
- worked solutions showing you how to work through the questions.

SECTION A – Multiple-choice questions

Question 1

The compound in which nitrogen has the lowest oxidation number is

A. NO_2

B. NO_3^-

C. $\mathbf{N_2O}$

D. HNO_3

Answer is C

Worked solution

- Use the oxidation rules, primarily that H is nearly always +1 and O is nearly always –2 to determine the oxidation number of N. **Remember that in a neutral compound the sum of the oxidation numbers of individual elements is zero, and in a polyatomic ion the sum of the oxidation numbers equals the charge on the ion.**
- In A, the oxidation number of O is –2 giving a total of –4, so N is +4.
- In B, O is –2 giving a total of –6, so N is +5 as the sum of oxidation numbers must be –1, which is the charge on the ion.
- In C, O is –2, so each N is +1.
- In D, H is +1 and O is –2 with a total of –6, so N is +5.

Question 2

A 3.45 g sample of baby food is analysed for sodium chloride content. The sample is dissolved in water and filtered, then excess silver nitrate is added to the baby food solution to react according to the equation

$$NaCl(aq) + AgNO_3(aq) \rightarrow AgCl(s) + NaNO_3(aq)$$

The precipitate is washed, dried and weighed and found to have a mass of 0.45 g. The percentage, by mass, of sodium chloride in the baby food is closest to

A. 18%

B. 13%

C. **5%**

D. 0.8%

Answer is C

Worked solution

- This gravimetric analysis question requires the use of stoichiometry.
- Step 1: Calculate the number of moles of AgCl.

$$n(\text{AgCl}) = \frac{m}{M} = \frac{0.45}{143.4} = 3.1 \times 10^{-3} \text{ mol}$$

- Step 2: Calculate the number of moles of NaCl.
  The coefficients in a balanced chemical equation provide the ratio of amounts, in mol, of reactants and products.
  According to the equation provided:
  $n(\text{NaCl}) : n(\text{AgCl})$
  1 : 1
  So, $n(\text{NaCl}) = 3.1 \times 10^{-3}$ mol
- Step 3: Calculate the mass of NaCl.

$$m(\text{NaCl}) = nM = 3.1 \times 10^{-3} \times 58.5 = 0.18 \text{ g}$$

- Step 4: Calculate the percentage, by mass, of NaCl in the baby food.

$$\% \text{ NaCl} = \frac{m(\text{NaCl})}{m(\text{baby food})} \times 100 = \frac{0.18}{3.45} \times 100 = 5.3 \%$$

Question 3

The amount, in mol, of chloride ions present in 4.55 g of magnesium chloride is

A. 0.0477

B. 0.0761

C. **0.0955**

D. 0.152

Answer is C

Worked solution

- Magnesium chloride is an ionic compound of Mg^{2+} and Cl^- ions, hence its chemical formula is $MgCl_2$.
- Step 1: Calculate the amount, in mol, of $MgCl_2$.

$$n(\text{MgCl}_2) = \frac{m}{M} = \frac{4.55}{95.3} = 0.0477 \text{ mol}$$

- Step 2: Calculate the amount, in mol, of Cl^- ions.

$$n(\text{Cl}^-) = 2 \times 0.0477 = 0.0955 \text{ mol}$$

Question 4

A 4.00 g sample of a hydrocarbon contains 3.27 g of carbon. The empirical formula of the hydrocarbon is

A. CH

B. CH_2

C. CH_4

D. $\mathbf{C_3H_8}$

Answer is D

Worked solution

- A hydrocarbon is a compound containing only carbon and hydrogen.
- Step 1: Calculate the mass of hydrogen present.

$$m(\text{H}) = m(\text{sample}) - m(\text{C}) = 4.00 - 3.27 = 0.73 \text{ g}$$

- Step 2: Convert the masses of C and H to moles.

$$n(\text{C}) = \frac{3.27}{12.0} = 0.27 \text{ mol} \quad : \quad n(\text{H}) = \frac{0.73}{1.0} = 0.73 \text{ mol}$$

- Step 3: Divide each amount by the lowest value to find a ratio

$$\frac{0.27}{0.27} = 1 \quad : \quad \frac{0.73}{0.27} = 2.68$$

- Find the simplest whole number ratio.

1 : 2.68 is not a whole number ratio.
Hence, try multiplying both numbers by 2.
2 : 5.4 is not a whole number ratio.
Hence, try multiplying both numbers by 3.
3 : 8.0 is a whole number ratio.

Question 5

Propane gas undergoes combustion in oxygen according to the following equation.

$$C_3H_8(g) + 5O_2(g) \rightarrow 3CO_2(g) + 4H_2O(g)$$

The maximum volume, in litres, of oxygen that would be required to react with 100 g of propane at STP is

A. 50.9 L

B. 55.6 L

C. **255 L**

D. 279 L

Answer is C

Worked solution

- This is another stoichiometry question. On your data sheet you will find that at STP the volume of 1 mol of any gas is 22.4 L.
- Step 1: Calculate the number of moles of C_3H_8.

$$n(C_3H_8) = \frac{m}{M} = \frac{100}{44.0} = 2.27 \text{ mol}$$

- Step 2: Calculate the number of moles of O_2 required.
  $n(O_2) : n(C_3H_8)$
  5 : 1
  $n(O_2) = 5 \times 2.27 = 11.4$ mol
- Step 3: Calculate the volume of O_2 at STP.
  $V(O_2) = 11.4 \times 22.4 = 255$ L

Question 6

500 mL of 0.100 M NaOH is added to an amount of water at 25°C. The pH of the resultant solution is 12. The volume of water used is

A. 0.45 L

B. 0.50 L

C. **4.5 L**

D. 5.0 L

Answer is C

Worked solution

- Remember that pH is simply a convenient way of stating $[H_3O^+]$.
- Remember to read questions very carefully so that you don't miss important details such as volume of **water** used.
- Step 1: Calculate $[H_3O^+]$ in the resultant solution.

$$[H_3O^+] = 10^{-pH} = 10^{-12} \text{ M}$$

- Step 2: Calculate $[OH^-]$ in the resultant solution.
  Remember that at 25°C, $[H_3O^+][OH^-] = 10^{-14}$

$$[OH^-] = \frac{10^{-14}}{10^{-12}} = 10^{-2} \text{ M}$$

- Step 3: Calculate the volume of the resultant solution.
  The number of moles of OH^- does not change on dilution and
  $[OH^-] = [NaOH]$ so, $c_1V_1 = c_2V_2$
  $= 0.100 \times 0.500 = 0.01 \times V_2$
  $= V_2 = 5.0$ L
- Step 4: Calculate the volume of water used.
  $V(\text{water})$ used $= V(\text{solution}) - V(\text{NaOH})$
  $= 5.0 - 0.5$ L
  $= 4.5$ L

Question 7

50 mL of 0.0100 M hydrochloric acid and 50 mL of 0.0100 M sulfuric acid are mixed together. The pH of the resultant solution is

A. **1.8**

B. 2.0

C. 2.8

D. 3.0

Answer is A

Worked solution

- When acids are mixed together they do not react, however, the concentration of $[H_3O^+]$ changes and must be calculated to determine the pH.
- Remember that a monoprotic acid, such as HCl, can donate only one proton, whereas a diprotic acid, such as H_2SO_4 can donate two protons.
  $HCl(g) + H_2O(l) \rightarrow Cl^-(aq) + H_3O^+(aq)$
  $H_2SO_4(l) + 2H_2O(l) \rightleftharpoons SO_4^{2-}(aq) + 2H_3O^+(aq)$
- Step 1: Calculate the amount of hydrochloric acid added.
  $n(HCl) = cV$
  $= 0.0100 \times 0.050$ mol
  $= 0.00050$ mol
- Step 2: Calculate $n(H_3O^+)$ contributed by the monoprotic hydrochloric acid.
  $n(H_3O^+) = n(HCl)$
  $= 0.00050$ mol
- Step 3: Calculate the amount of sulfuric acid added.
  $n(H_2SO_4) = 0.050 \times 0.0100 = 0.00050$ mol
- Step 4: Calculate $n(H_3O^+)$ contributed by the diprotic sulfuric acid.
  $n(H_3O^+) = 2 \times n(H_2SO_4)$
  $= 2 \times 0.00050 = 0.0010$ mol
- Step 5: Calculate the total $n(H_3O^+)$ in the solution.
  $n(H_3O^+) = 0.00050 + 0.0010 = 0.0015$ mol
- Step 6: Calculate the total volume of the solution. $V = 0.050 + 0.050 = 0.10$ L
- Step 7: Calculate $[H_3O^+]$ in the solution.

$$[H_3O^+] = \frac{n}{V}$$
$$= \frac{0.0015}{0.010}$$
$$= 0.015 \text{ M}$$

- Step 8: Calculate pH.
  $pH = -\log_{10}[H_3O^+]$
  $= -\log_{10}(0.015)$
  $= 1.8$

Question 8

The self-ionisation constant of pure water at 55°C is 7.29×10^{-14} M^2. The hydroxide ion concentration and pH will be, respectively,

A. 1.0×10^{-7} M and 6.57

B. 1.0×10^{-7} M and 7.00

C. **2.7×10^{-7} M and 6.57**

D. 2.7×10^{-7} M and 7.00

Answer is C

Worked solution

- Remember that in pure water $[H_3O^+]$ and $[OH^-]$ are always equal.
- Step 1: Calculate $[OH^-]$.

  As $K_w = [H_3O^+][OH^-]$

  then at 55°C $[H_3O^+] \times [OH^-] = 7.29 \times 10^{-14}$

  $[OH^-]^2 = 7.29 \times 10^{-14}$

  $[OH^-] = \sqrt{7.29 \times 10^{-14}}$

  $= 2.7 \times 10^{-7}$ M
- Step 2: Calculate $[H_3O^+]$.

  $[H_3O^+] = [OH^-]$

  $= 2.7 \times 10^{-7}$
- Step 3: Calculate pH.

  $pH = -\log_{10}[H_3O^+]$

  $= -\log_{10}(2.7 \times 10^{-7})$

  $= 6.57$

Question 9

Which of the following analytical techniques would be used to identify a metal deficiency in the blood?

A. flame tests

B. high-performance liquid chromatography

C. gas-liquid chromatography

D. **atomic absorption spectroscopy**

Answer is D

Worked solution

- A deficiency of the metal in the blood suggests the concentration of the metal is very low.
- Identifying very low concentrations requires an instrument that is extremely sensitive in its detection.
- Atomic absorption spectroscopy is suitable for detecting metals at extremely low levels.
- Flame tests are also suitable for detecting metals, but only at reasonably high levels.
- Chromatography methods are suitable for the identification and measurement of mostly organic compounds.

Question 10

The process of addition polymerisation is used to produce an unbranched polyethene molecule containing 3300 carbon atoms. The number of water molecules eliminated in this process would be closest to

A. **0**

B. 2

C. 1650

D. 3300

Answer is A

Worked solution

- Addition polymerisation does not eliminate **any** atoms.
- Water is released only in condensation reactions such as the formation of polyester during which carboxy and hydroxy groups on adjacent molecules react to form ester linkages.
- Ethene molecules have a double carbon–carbon bond, which allows monomers to link together in the presence of a catalyst without the removal of any atoms.

Questions 11 and 12 refer to the following information.

Excess hydrochloric acid (HCl) is added to a sample of aluminium (Al) and allowed to react according to the chemical equation

$$2Al(s) + 6HCl(aq) \rightarrow 2AlCl_3(aq) + 3H_2(g)$$

250 mL of hydrogen gas is then collected at 23°C and 1.0 atm.

Question 11

The amount of hydrogen gas collected, in mol, would be closest to

A. 97

B. 0.13

C. $\mathbf{1.0 \times 10^{-2}}$

D. 1.0×10^{-4}

Answer is C

Worked solution

- Remember that when using the ideal gas equation temperature must be in K, pressure in kPa and volume in L.
- Step 1: Convert the pressure to kPa, temperature to K and volume to L for use in the ideal gas equation.

  Pressure in kPa = pressure in atm × 101.3
  = 1.0 × 101.3 kPa
  = 101.3 kPa

  $$\text{Volume in L} = \frac{\text{volume in mL}}{1000} = \frac{250}{1000} = 0.250 \text{ L}$$

  Temperature in Kelvin = temperature in °C + 273
  = 23 + 273
  = 296 K

- Step 2: Calculate the number of moles of hydrogen gas using the ideal gas equation.

  $$n(H_2) = \frac{pV}{RT} = \frac{101.3 \times 0.250}{8.31 \times 296} = 0.010 \text{ mol}$$

Question 12

The mass of aluminium, in grams, that reacts with the hydrochloric acid is closest to

A. 0.14
B. **0.18**
C. 0.27
D. 0.41

Answer is B

Worked solution

- Step 1: Calculate the number of moles of aluminium using the mole ratio from the chemical equation.

  $n(Al)$: $n(H_2)$
  2 : 3

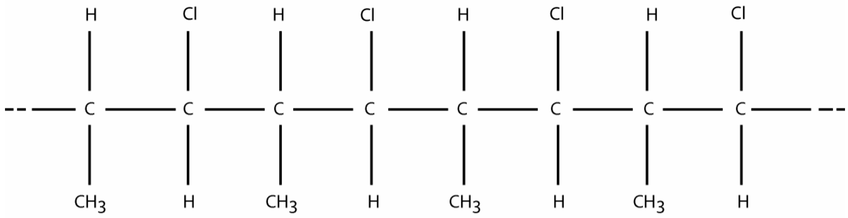
  $$n(Al) = \frac{2}{3} \times 0.010 = 0.0067 \text{ mol}$$

- Step 2: Calculate the mass of Al.

  $$m(Al) = nM = 0.0067 \times 27 = 0.18 \text{ g}$$

Question 13

Consider the polymer



The semi-structural formula of the monomer that underwent addition polymerisation to form this polymer is

A. CH_2CHCl

B. $CH_3CH_2CH_2Cl$

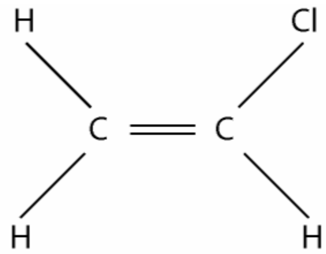
C. CH_2CClCH_3

D. $\mathbf{CH_3CHCHCl}$

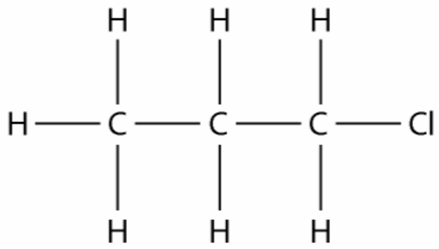
Answer is D

Worked solution

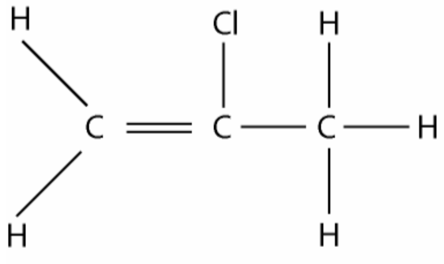
- The structural formulae of compounds A to D are shown below.



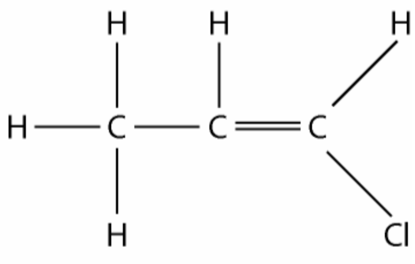
A



B



C



D

- A is missing the CH_3 group on the first carbon.
- Monomers for addition polymerisation must have a double carbon–carbon bond, so B can be eliminated.
- C has the CH_3 and Cl groups on the same carbon, which is incorrect.

Question 14

Consider the equilibrium

$$2HI(g) \rightleftharpoons H_2(g) + I_2(g); \qquad K = 6.3 \times 10^{-3} \text{ M at } 500 \text{ K}$$

A volume of 500 mL of a reaction mixture at equilibrium at 500 K contains 0.13 mol of H_2 and 0.80 mol of HI. The concentration of I_2, in M, will be

A. 0.031

B. 0.039

C. **0.062**

D. 0.12

Answer is C

Worked solution

- Step 1: Write the expression for the equilibrium constant.

$$K = \frac{[H_2][I_2]}{[HI]^2}$$

- Step 2: Calculate the concentrations, in M, of H_2 and HI.

$$[H_2] = \frac{n}{V} = \frac{0.13}{0.500} = 0.26 \text{ M}$$

$$[HI] = \frac{0.80}{0.500} = 1.6 \text{ M}$$

- Step 3: Calculate the concentration, in M, of I_2.

$$6.3 \times 10^{-3} = \frac{(0.26)[I_2]}{(1.6)^2}$$

$$[I_2] = \frac{(6.3 \times 10^{-3})(1.6)^2}{0.26} = 6.2 \times 10^{-2} \text{ M}$$

Question 15

Hydrocarbon molecules obtained from crude oil by fractional distillation can undergo catalytic cracking to produce smaller hydrocarbons. Which of the following is **not** a possible product of the catalytic cracking of octane?

A. propene

B. **carbon dioxide**

C. hydrogen

D. ethane

Answer is B

Worked solution

- Octane is a molecule containing the elements hydrogen and carbon only. Catalytic cracking uses a catalyst and does not have any other chemical reactants, therefore oxygen is not incorporated and carbon dioxide cannot be produced.

Question 16

How many different structural isomers exist with the molecular formula C_4H_9OH?

A. 1

B. 2

C. 3

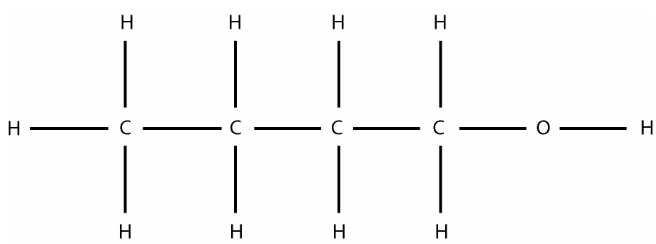
D. **4**

Answer is D

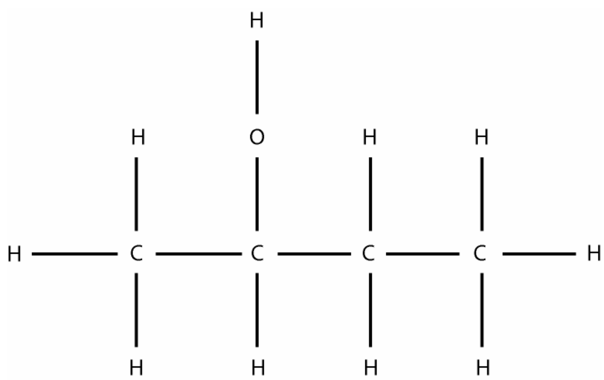
Worked solution

- Isomers are compounds with the same molecular formula that have different structural formulae.
- Semi-structural and structural formulae of the isomers are

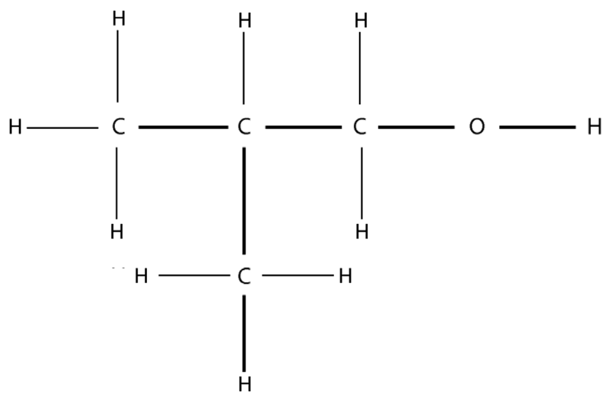
Isomer 1: $CH_3CH_2CH_2CH_2OH$



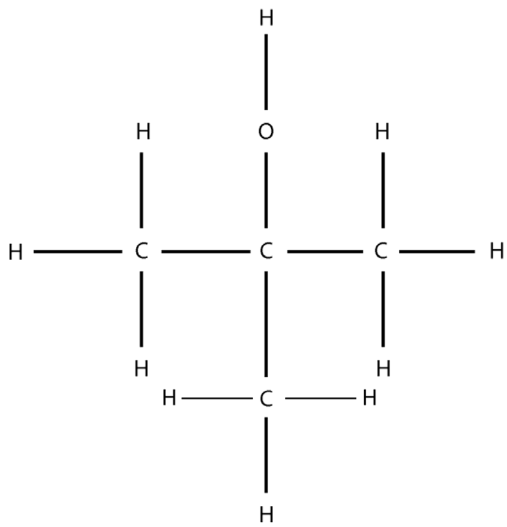
Isomer 2: $CH_3CHOHCH_2CH_3$



Isomer 3: $CH_3CH(CH_3)CH_2OH$



Isomer 4: $CH_3C(CH_3)OHCH_3$



SECTION A – continued

Question 17

Consider the reaction represented by the chemical equation

$$PCl_5(g) \leftrightharpoons PCl_3(g) + Cl_2(g); \qquad K_1 = 0.040 \text{ M at } 250°C$$

The equilibrium constant for the reaction represented by the chemical equation

$$2Cl_2(g) + 2PCl_3(g) \leftrightharpoons 2PCl_5(g)$$

at the same temperature would be closest to

A. **6.3×10^2**
B. 25
C. 13
D. 1.6×10^{-3}

Answer is A

Worked solution

- The second reaction is the reverse of the first, so its K value (K_2) will be the inverse of the first (K_1).
- The second reaction has double the number of moles compared with the first, so the K_2 value will also be the square of K_1.
- Putting these together

$$K_2 = \frac{1}{K_1^2}$$
$$= \frac{1}{(0.040)^2}$$
$$= 6.3 \times 10^2 \text{ M}^{-1}$$

Question 18

An aqueous mixture of two substances (X and Y) is subjected to paper chromatography. Component X of the sample bonded more strongly to the stationary phase than component Y.

Which of the following statements is correct?

A. Component X has a higher R_f value than component Y.
B. **If the same mixture was subjected to high-performance liquid chromatography (HPLC), component X would have a higher retention time than component Y.**
C. The relative R_f values of X and Y cannot be compared unless the distance travelled by the solvent front is known.
D. Component Y has undergone stronger adsorption to the stationary phase than component X.

Answer is B

Worked solution

- In paper and thin layer chromatography, the R_f value is indicative of how far a component has moved along the stationary phase. The less distance a component travels, the lower the R_f value. Hence, component X, which adsorbs more strongly to the stationary phase than component Y, will not travel as far as component Y in the same time and will have a lower R_f value. A and D can therefore be eliminated.
- Although the **actual** R_f values cannot be compared unless the distance travelled by the solvent front is known, the relative distances travelled can still be compared. C can be eliminated.
- In HPLC, the retention time is indicative of how long it takes the component to travel through the column. The slower the component travels, the longer it takes and the higher the retention time. Hence, component X, which adsorbs more strongly than component Y, will take longer to travel through the column and thus have a higher retention time.

Question 19

Consider the reaction represented by the chemical equation

$$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g); \qquad \Delta H = -564 \text{ kJ mol}^{-1}$$

Which of the following changes will decrease the amount of CO_2 in the reaction mixture?

A. adding more CO to the reaction vessel

B. adding an inert gas to the reaction vessel

C. decreasing the temperature of the reaction mixture

D. **doubling the volume of the reaction vessel**

Answer is D

Worked solution

- Le Chatelier's principle states that when an equilibrium system is subject to change it will adjust itself to partially oppose the effects of the change.
- Adding more CO adds a reactant. This will lead to a net forward reaction in order to remove some of the reactant. More product will be formed and the amount of CO_2 will increase.
- Adding an inert gas does not affect the partial pressures of the individual gases. The system will stay in equilibrium and there is no net forward or backward reaction. The amount of CO_2 will remain unchanged.
- The negative ΔH value indicates that this is an exothermic reaction. Decreasing the temperature for an exothermic reaction will result in a net forward reaction in order to produce more energy. The amount of CO_2 will increase.
- Doubling the volume of the reaction vessel will reduce the pressure in the reaction vessel. In this equation there are three gas particles on the reactant side to two gas particles on the product side. So, doubling the volume will result in a net backward reaction in order to increase the number of gas particles present and increase pressure. The amount of CO_2 will decrease.

Question 20

50 mL of 1.0 M HCl is added to 1.5 g of calcium carbonate chips.

Which of the following will **not** increase the initial rate of this reaction?

A. grinding the calcium carbonate chips into powder before adding the HCl

B. **adding 100 mL of 1.0 M HCl in place of 50 mL of 1.0 M HCl**

C. adding 50 mL of 2.0 M HCl in place of 50 mL of 1.0 M HCl

D. heating the HCl before adding it to the calcium carbonate

Answer is B

Worked solution

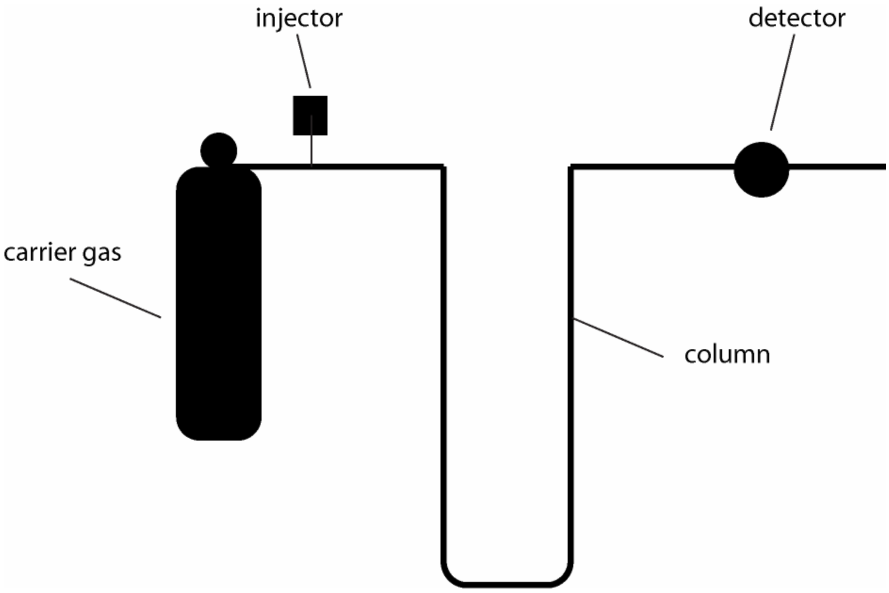
- According to collision theory, for this chemical reaction to occur the H^+ ions must collide with the $CaCO_3$ chips with enough energy to overcome the activation energy barrier. Increasing the rate of reaction requires either an increase in the frequency of collisions between the reactant particles or an increase in the proportion of collisions that are successful (i.e. have energy greater than the activation energy). This can be achieved by either increasing the surface area of solids, increasing the concentration of reactants or the pressure of gaseous reactants, increasing the temperature or the addition of a catalyst.
- Adding more 1.0 M solution provides more HCl particles but does not increase the concentration of HCl. Hence, there is no increase in the number of fruitful collisions and no increase in rate.
- Grinding the chips into powder increases the surface area so that more $CaCO_3$ particles are available for collision. Reaction rate will increase.
- Adding more concentrated HCl provides more HCl particles in the same volume. Hence, the frequency of collisions between HCl and $CaCO_3$ increases and the reaction rate will increase.
- Heating the HCl gives the particles more energy so that more HCl particles collide with $CaCO_3$ chips with enough energy to overcome the activation energy barrier. The proportion of fruitful collisions increases and reaction rate will increase.

END OF SECTION A

SECTION B – Short-answer questions

Asterisks indicate where marks are earned.

Question 1



Shown above is a simplified diagram of a gas-liquid chromatograph used to analyse a mixture of methanol (CH_3OH), ethanol (C_2H_5OH) and propanol (C_3H_7OH).

1a. i. What property shared by these compounds makes the mixture suitable for analysis using a gas chromatograph?

Answer

They can be vaporised easily without decomposing.*

1 mark

Tip

- *Remember that organic compounds are usually analysed by chromatography. The gas chromatograph can analyse compounds up to a molecular mass of about 300. Above this size, compounds are not usually vaporised readily, so high-performance liquid chromatography is used.*

1a. ii. Explain how this gas chromatograph is able to separate different components in a mixture.

Answer

The carrier gas is the mobile phase and carries the sample through the column.* The components of the sample undergo adsorption to and desorption from the stationary phase.* Separation occurs as the different components adsorb and desorb to different extents* and so travel along the column at different rates.

3 marks

Tip

- *When explaining how chromatography works, include key terms such as mobile phase, stationary phase, adsorption and desorption.*

1b. i. Place the three components in expected order from longest retention time (R_t) value to shortest.

Answer

Propanol, ethanol, methanol*

1 mark

1b. ii. Briefly explain your answer.

Answer

Propanol has the biggest molecules and so will be most attracted to the stationary phase and thus retarded. Methanol has the smallest molecules and so will be retarded the least.*

1 mark

Tip

- *As these compounds are all alcohols, the main difference between them is size. Size affects attraction between molecules; in gas chromatography smaller molecules are least attracted to the stationary phase and will move the most quickly through the column.*

1c. What effect would lengthening the column have on the R_t values of the components?

Answer

The R_t values will increase.*

1 mark

Tip

- *Remember that the* R_t *value is a measure of how long the component takes to travel through the column. A longer column will increase the travel time.*

Total 7 marks

Question 2

A newly released wine is tested for its alcohol (CH_3CH_2OH) content. A 25.00 mL sample is diluted to 250 mL in a volumetric flask. A 20.00 mL aliquot is taken from the diluted wine in the volumetric flask sample and titrated against a 0.100 M solution of $K_2Cr_2O_7$. The titration is then repeated carefully three more times. The table below gives the complete set of titres obtained.

	Titre (mL)
First titre	22.48
Second titre	22.46
Third titre	22.49
Fourth titre	23.14

The equation for the reaction is

$$3CH_3CH_2OH(aq) + 2Cr_2O_7^{2-}(aq) + 16H^+(aq) \rightarrow 4Cr^{3+}(aq) + 3CH_3COOH(aq) + 11H_2O(l)$$

2a. Examine the titres given and calculate the average titre, in millilitres, that would be used to calculate the ethanol concentration in the wine.

Answer

$$\text{Average titre} = \frac{22.48 + 22.46 + 22.49}{3} = 22.48 \text{ mL}^*$$

1 mark

Tip

- *The titre of 23.14 mL is not included in this calculation as it is not concordant with the other titres.*

2b. Calculate the number of moles of $Cr_2O_7^{2-}$ used in the titration.

Answer

$n(Cr_2O_7^{2-})$ used in titration $= cV$
$= 0.100 \times 0.02248$
$= 2.25 \times 10^{-3}$ mol*

1 mark

Tip

- *Remember that volume needs to be in litres.*

2c. Calculate the number of moles of CH_3CH_2OH present in the 20.00 mL aliquot of diluted wine.

Answer

From the equation, $n(Cr_2O_7^{2-}) : n(CH_3CH_2OH)$

$2 : 3$

$$n(CH_3CH_2OH) = \frac{3}{2} \times n(Cr_2O_7^{2-})$$

$$= \frac{3}{2} \times 2.25 \times 10^{-3}$$

$$= 3.37 \times 10^{-3} \text{ mol}^*$$

1 mark

2d. Calculate the alcohol concentration of the diluted wine.

Answer

$$c(CH_3CH_2OH) = \frac{n}{V}$$

$$= \frac{3.37 \times 10^{-3}}{0.0200}$$

$$= 0.169 \text{ M}^*$$

1 mark

Tip

- *Read the question carefully so you don't confuse the 20.00 mL aliquot of diluted wine with the first aliquot of 25.00 mL of undiluted wine.*

2e. Calculate the concentration of alcohol, in mol L^{-1}, of the original sample of wine.

Answer

$$c(CH_3CH_2OH) \text{ in wine} = 0.169 \times \frac{250}{25}$$

$$= 1.69 \text{ M}^*$$

1 mark

Tips

- *A 25.00 mL sample of the original wine is diluted to 250 mL (i.e. by a factor of 10). It must be 10 times (250/25) as concentrated as the diluted wine.*
- *The answer is given to three significant figures as the least precise data in the question has three significant figures.*

2f. There are a number of possible sources of experimental error when carrying out a titration. Several are listed in the table below. Indicate the effect each error would have on the final result by placing a tick in the appropriate box.

Answer

Experimental error	Calculated concentration of wine higher than it should be	Calculated concentration of wine lower than it should be
i. Distilled water is used for the final rinse of the burette.	✓*	
ii. The titration is continued past the endpoint.	✓*	
iii. Distilled water is used for the final rinse of the 20.00 mL pipette.		✓*

3 marks

Tips

- *In part **i**, the water drops remaining in the burette will dilute the $K_2Cr_2O_7$ solution. A higher volume will be required to reach the endpoint, making the calculated concentration of ethanol higher than it actually is.*
- *As a result of the error in part **ii**, the volume of $K_2Cr_2O_7$ solution used will be higher so, again, the calculated concentration of ethanol will be higher.*
- *In part **iii**, the remaining water will cause the amount of ethanol transferred to the conical flask to be slightly less than it should be. A lower volume of $K_2Cr_2O_7$ solution will be required to reach the endpoint, making the calculated concentration of ethanol lower than it actually is.*

Total 8 marks

Question 3

3a. Give concise explanations for each of the following.

3a. i. Carbon monoxide levels as low as 200 ppm (parts per million) can cause significant carbon monoxide poisoning.

Answer

Oxygen is carried to the cells of the body by oxyhaemoglobin. Carbon monoxide binds more strongly than oxygen to the haemoglobin molecules in the blood.* This causes a net backward reaction in the equilibrium: haemoglobin + oxygen ⇋ oxyhaemoglobin.*
Hence, less oxygen is carried to the cells and carbon monoxide poisoning occurs.

2 marks

Tip

- *Remember that the equilibrium constant for the reaction between carbon monoxide and haemoglobin is nearly 20 000 times greater than that for the reaction between oxygen and haemoglobin.*

3a. ii. Purple light, rather than green light, is used as the light source in the colorimetric analysis of a green solution of chlorophyll.

Answer

Chlorophyll solutions are green because chlorophyll transmits and reflects green light. As chlorophyll does not absorb green light, green light cannot be used for the colorimetric analysis.*
The light used in the colorimetric analysis must be strongly absorbed by the substance. Purple light is strongly absorbed by the green solution.*

2 marks

Tips

- *Remember that the observed colour of substances is a result of the light reflected and transmitted by the substance. The complementary colour of the observed colour is absorbed. The most strongly absorbed colour is used for analysis of concentration.*
- *Some other complementary colours are blue and orange, and blue-green and red.*
- *Remember that UV-visible spectrometry takes this a step further and selects the best* ***wavelength*** *of light absorbed.*

3a. iii. Sodium produces a yellow colour when heated in a flame, whereas copper produces a green colour.

Answer

The colours that metals produce in a flame are a result of excited electrons dropping from a high energy level to a lower energy level* and releasing the energy as light. Sodium and copper atoms have different electronic configurations,* so different colours result.

2 marks

3b. Write balanced chemical equations to demonstrate the following processes.

3b. i. The oxidation of manganese (II) ions (Mn^{2+}) to permanganate ions (MnO_4^-).

Answer

$Mn^{2+}(aq) + 4H_2O(l) \rightarrow MnO_4^-(aq) + 8H^+(aq) + 5e^-$**

2 marks

Tips

- *1 mark for correct chemical species, 1 mark for correct balancing*
- *The rules for writing half-equations in acidic media can be remembered by the acronym KOHES. Balance* ***K****ey elements first, then balance* ***O****xygen atoms by adding* H_2O *molecules, then balance* ***H****ydrogen by adding* H^+ *ions and, finally, balance charge by adding* ***E****lectrons. Don't forget* ***S****tates.*

3b. ii. Sulfuric acid acting as a dehydrating agent.

Answer

An example is $C_{12}H_{22}O_{11}(s) \xrightarrow{H_2SO_4(l)} 12C(s) + 11H_2O(l)^*$

1 mark

Tips

- *There are other correct reactions.*
- *The sulfuric acid is (l) rather than (aq).*
- *Water is always a product of dehydration. The other product is whatever remains after the maximum possible number of H_2O molecules is removed.*

3b. iii. The thermal cracking of pentane to produce ethene and one other product.

Answer

$C_5H_{12}(g) \rightleftharpoons C_2H_4(g) + C_3H_8(g)^*$

1 mark

Tips

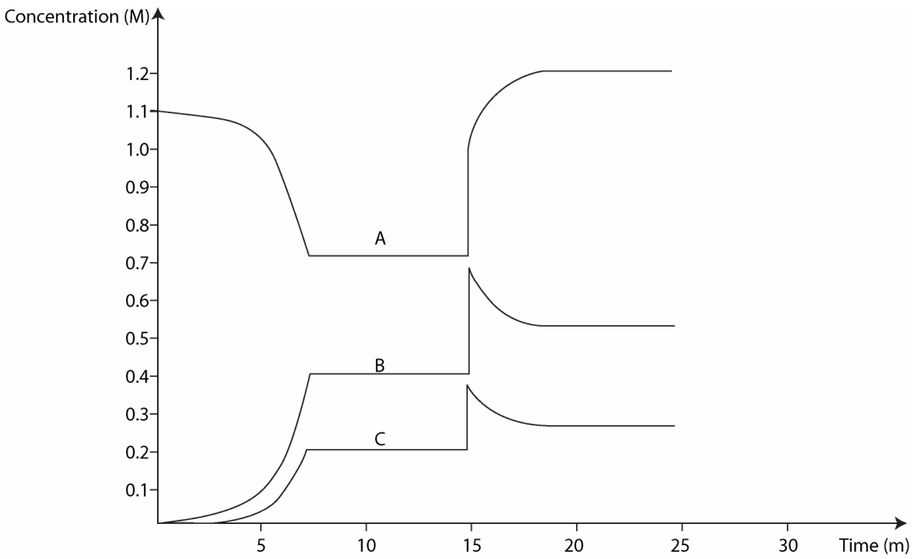
- *Thermal cracking uses high temperatures. There is no other reactant.*
- *The unknown product is deduced by balancing the number of atoms on both sides of the equation.*

Total 10 marks

Question 4

Consider the equilibrium

$2CO(g) + O_2(g) \rightleftharpoons 2CO_2(g)$; $\Delta H = -564 \text{ kJ mol}^{-1}$



4a. What change occurred at the 5-minute mark?

Answer

A catalyst was added.*

1 mark

Tips

- *Concentrations were not at equilibrium before this point as the concentrations were not yet constant.*
- *Remember that a catalyst will speed up the rate of reaction without affecting the point of equilibrium.*
- *At the 5-minute mark there is a significant increase in the rate of change of concentration.*

4b. Identify components A, B and C by writing the formula of each in the space provided.

Answer

A = CO_2*

B = CO*

C = O_2*

3 marks

Tips

- *Component A is on one side of the equation whereas components B and C are together on the other, so component A must be CO_2.*
- *The initial concentrations of components B and C were zero. At equilibrium, the concentration of component B has increased to 0.4 M and the concentration of component C has increased to 0.2 M. Component B is being produced at twice the rate of component C, so component B must be CO and component C must be O_2.*

4c. Write an expression for the equilibrium constant for this reaction.

Answer

$$K = \frac{[CO_2]^2}{[CO]^2[O_2]}\ ^*$$

1 mark

4d. Calculate the value of the equilibrium constant at the 10-minute mark.

Answer

The equilibrium constant is calculated with concentrations that are read from the graph at the 10-minute mark.

$$K = \frac{[CO_2]^2}{[CO]^2[O_2]}$$
$$= \frac{(0.7)^2}{(0.4)^2(0.2)}$$
$$= 15.3\ M^{-1*}$$

1 mark

4e. i. What change was made to the equilibrium mixture at the 15-minute mark?

Answer

The volume was decreased,* causing the concentration of each species to increase.

1 mark

4e. ii. Briefly explain why the system responded to this change in the manner shown.

Answer

The decrease in volume caused an increase in pressure. The system adjusted by decreasing pressure by moving to the product side, which has fewer particles.*

1 mark

4f. At the 25-minute mark the temperature of the reaction mixture was decreased.

4f. i. State Le Chatelier's principle.

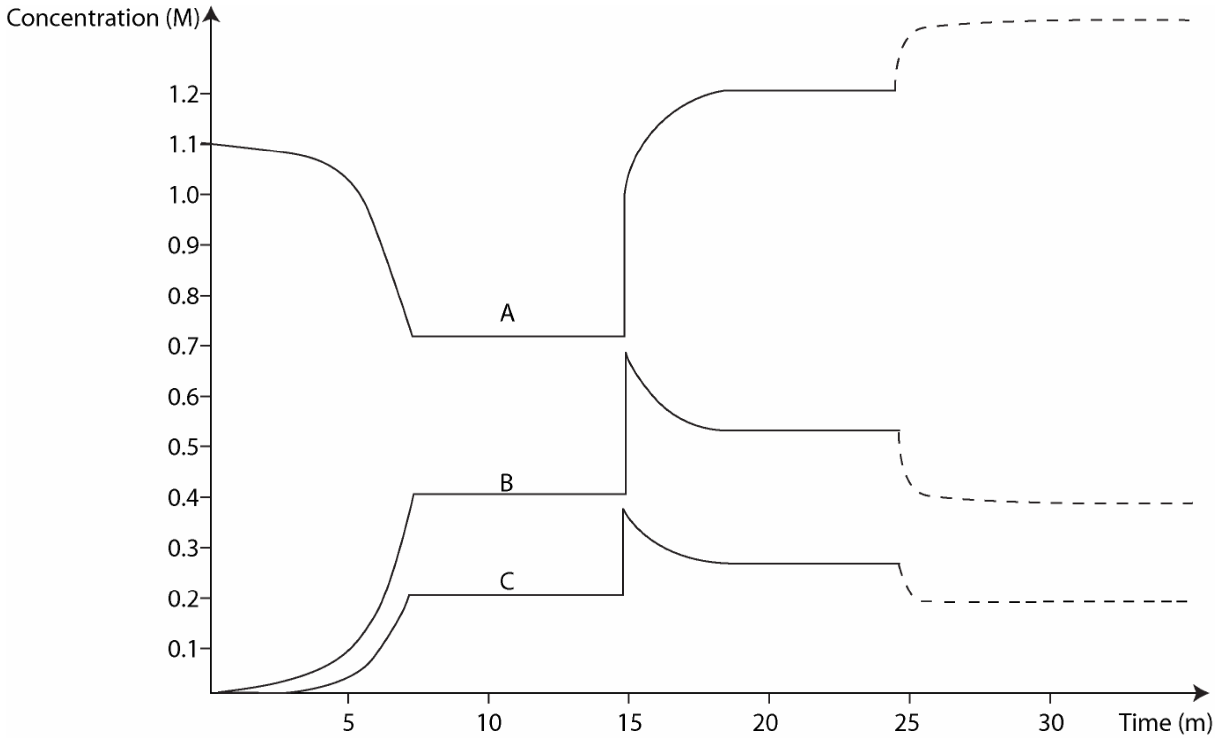
Answer

When an equilibrium system is subject to change it will adjust itself to partially oppose the effects of the change.*

1 mark

4f. ii. Indicate, by continuing each line on the graph, what effect the temperature decrease will have on the concentration of each species.

Answer



* For showing the gradual increase of [CO_2], the gradual decrease of [CO] and [O_2] and the re-establishment of equilibrium.

* For showing that the decrease of [CO] is equivalent to the increase of [CO_2] and twice as big as the decrease in [O_2].

2 marks

Tip

- *The negative* ΔH *value tells us that the reaction is exothermic and so will respond to a temperature decrease by moving in a net forward direction.*

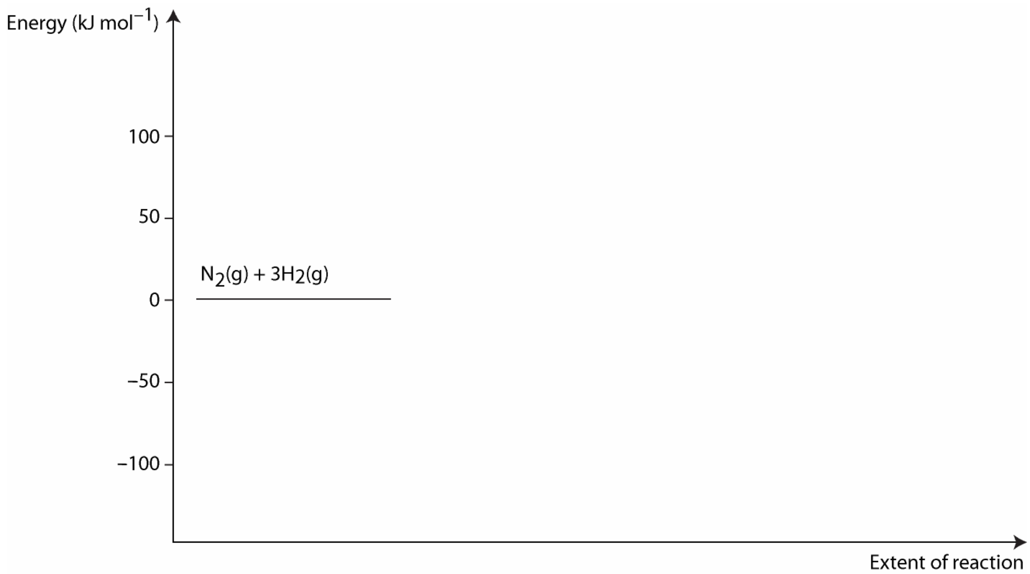
Total 11 marks

Question 5

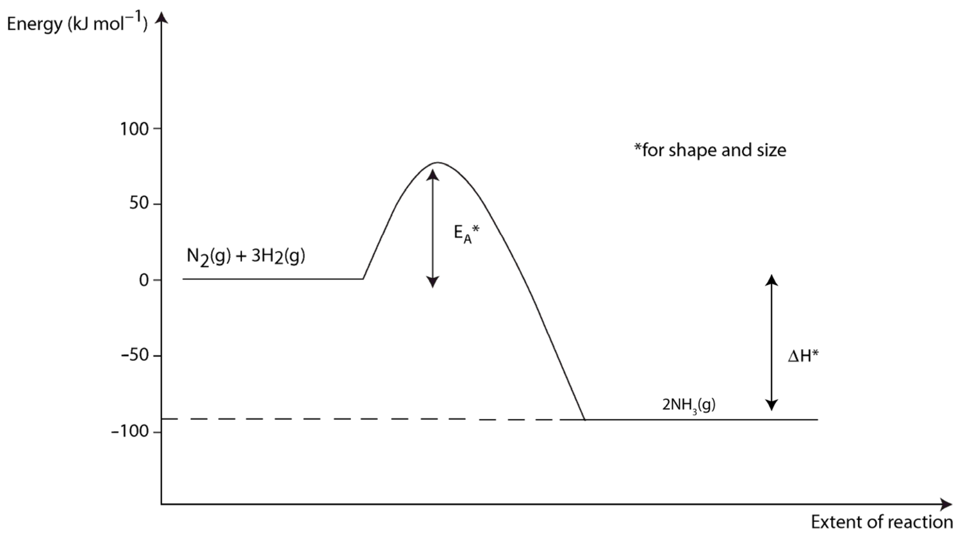
The Haber process uses nitrogen and hydrogen gas to produce ammonia. The equation for this reaction is given below.

$N_2(g) + 3H_2(g) \rightleftharpoons 2NH_3(g)$; $\Delta H = -91 \text{ kJ mol}^{-1}$

5a. Complete the energy profile on the graph below to represent the energy changes over the course of this reaction. Clearly label the activation energy and ΔH.



Answer



3 marks

Tip

- *Remember that the negative ΔH value indicates that the reaction is exothermic and so the energy of the products is 91 kJ less than the energy of the reactants.*

5b. During the industrial production of ammonia, a fast reaction rate is highly desired. A catalyst is added and high temperatures are used.

5b. i. Explain why adding a catalyst increases the reaction rate.

Answer

A catalyst offers an alternative reaction pathway with a lower activation energy.*

1 mark

Tip

- *Note that a catalyst does not increase the number of collisions; it increases the proportion of successful collisions.*

5b. ii. Explain why increasing the temperature increases the reaction rate.

Answer

The increased temperature increases the particles' kinetic energy. The particles collide with more energy so more collisions are able to overcome the activation energy barrier* resulting in a greater proportion of successful collisions. In addition, the faster-moving particles collide more often,* which also contributes to the faster rate.

2 marks

Tip

- *Remember to make clear reference to collision theory, particularly the proportion of collisions with energy greater than the activation energy, when you explain how reaction rates can be increased.*

Total 6 marks

Question 6

Methanoic acid (HCOOH), which is present in some ant stings, is a weak acid in water.

6a. Explain the meaning of the term 'weak acid'.

Answer

A weak acid does not completely ionise in water.*

OR

A weak acid does not readily donate its protons.*

OR

A weak acid has a low K_a value.*

1 mark

6b. Write an equation that demonstrates the ionisation of methanoic acid in water.

Answer

$HCOOH(l) + H_2O(l) \leftrightharpoons HCOO^-(aq) + H_3O^+(aq)$*

1 mark

Tips

- *Remember to use the equilibrium arrow to indicate that methanoic acid is a weak acid.*
- *All carboxylic acids are monoprotic acids, donating a proton from the carboxyl group. The other hydrogen atoms on the molecule are bonded more strongly and cannot be donated.*

6c. Methanoic acid has an acidity constant of 1.8×10^{-4} at 25°C. Calculate the pH of a 0.100 M solution of methanoic acid.

Answer

Step 1: Calculate $[H_3O^+]$.

$K_a = \dfrac{[HCOO^-][H_3O^+]}{[HCOOH]}$ *

The usual assumptions about weak acids are made, that is, $[HCOO^-] = [H_3O^+]$ and that there is minimal ionisation. So $[CH_3COOH]$ at equilibrium = 0.100 M.

$$1.8 \times 10^{-4} = \frac{[H_3O^+]^2}{0.100}$$

$$[H_3O^+]^2 = 0.100 \times 1.8 \times 10^{-4}$$

$$[H_3O^+] = \sqrt{1.8 \times 10^{-5}}$$

$$= 4.24 \times 10^{-3}\ M^*$$

Step 2: Calculate the pH.

$$pH = -\log_{10}[H_3O^+]$$

$$= -\log_{10}(4.24 \times 10^{-3})$$

$$= 2.4^*$$

3 marks

Total 5 marks

Question 7

Ethyl ethanoate is the ester responsible for the apple smell in many synthetic food items. The laboratory production of ethyl ethanoate from a sample of ethene gas follows a series of steps.

Step 1: Conversion of ethene to ethanol.

7a. i. Write a balanced equation for this reaction.

Answer

$$CH_2CH_2(g) + H_2O(g) \xrightarrow{H_3PO_4} CH_3CH_2OH(aq)^*$$

1 mark

Tip

- *Don't forget the catalyst!*

7a. ii. This can be classified as what type of reaction?

Answer

This can be classified as an addition reaction.*

1 mark

Tip

- *The H_2O is added to the ethene across the double bond. No atoms are replaced or removed. Hence, it is an addition reaction.*

Step 2: Conversion of some of the ethanol to ethanoic acid

7b. Give the name or formula of an oxidising agent suitable for this reaction that is used in the laboratory.

Answer

Dichromate ion, $Cr_2O_7^{2-}$*

OR

Permanganate ion, MnO_4^{2-}*

Tip

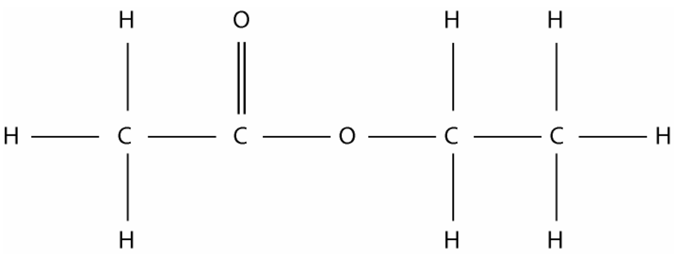
- *Answers such as $K_2Cr_2O_7$ or K_2MnO_4 are also acceptable.*

1 mark

Step 3: Reaction between ethanol and ethanoic acid to produce ethyl ethanoate

7c. i. Draw a full structural formula of ethyl ethanoate.

Answer



1 mark

7c. ii. Give the name or formula of a laboratory catalyst suitable for this reaction.

Answer

Concentrated sulfuric acid, $H_2SO_4(l)$*

1 mark

7c. iii. This can be classified as what type of reaction?

Answer

Esterification*

OR

Condensation*

1 mark

Tip

- *A condensation reaction is a reaction in which a small molecule is eliminated. In this case, the small molecule is water.*

Total 6 marks

SECTION B – continued

Question 8

Part of the contact process used for the industrial production of sulfuric acid from mined sulfur is the oxidation of sulfur dioxide in the converter.

8a. Write a balanced chemical equation for this reaction.

Answer

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

1 mark

8b. Name the catalyst used in this process.

Answer

Vanadium oxide*

1 mark

8c. The temperature in the converter is between 400°C and 500°C despite the fact that a higher temperature would deliver a faster reaction rate. Explain why a higher temperature is not used.

Answer

A higher temperature would reduce the equilibrium yield of SO_3* because the reaction is exothermic.*

2 marks

Tip

- *Increasing the temperature causes the reaction to shift in the endothermic direction, which in this case would cause a net backward reaction. Thus, the amount of product would decrease.*

8d. It is desirable in this process to maximise contact between the catalyst and the reactant. Explain how this is achieved.

Answer

The catalyst is spread in beds so that surface area is maximised.*

1 mark

8e. If the reaction occurred under high pressure, this would also increase the equilibrium yield. Give a reason why higher pressures are not used in industry.

Answer

Using higher pressure would add unnecessarily to the cost, as high yields can be achieved under normal atmospheric pressure.*

1 mark

Total 6 marks

END OF SOLUTIONS BOOK