YEAR 12 *Trial Exam Paper*

2016
CHEMISTRY

Written examination

Solutions book

This book presents:

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

SECTION A – Multiple-choice questions

Question 1

Answer: A

Worked solution

A is correct. The mole ratio between $KMnO_4$ and HCl is 2:16 or 1:8.

72 mole of HCl will require $72 \times \frac{1}{8}$ mole of $KMnO_4$ = 9 mole.

HCl is therefore the limiting reagent and 1 mole of $KMnO_4$ is in excess.

B is incorrect as HCl is the limiting reagent.
C is incorrect as HCl is the limiting reagent.
D is incorrect as HCl is the limiting reagent.

Question 2

Answer: C

Worked solution

C is correct.

$n(Cl_2)$ formed = $n(KMnO_4) \times \frac{5}{2} = 0.562 \times \frac{5}{2} = 1.405$ mol

$V = n \times 22.4$ at STP = $1.405 \times 22.4 = 31.5$ L

A is incorrect as it assumes a mole ratio of 1:1.
B is incorrect as 31.5 is the correct answer.
D is incorrect as 31.5 is the correct answer.

Question 3

Answer: D

Worked solution

D is correct. The oxidation number of manganese in

$KMnO_4$ is $(+1 + x - 8) = 0$

Therefore $x = +7$: Mn^{7+}

In $MnCl_2$, the oxidation number of Mn is +2. This can be determined from the formula $MnCl_2$ where the chloride ion is Cl^-.
A decrease in oxidation number is associated with reduction.

A is incorrect as this is a redox reaction.
B is incorrect as manganese in $KMnO_4$ starts at +7, not +6.
C is incorrect as manganese is reduced.

Question 4

Answer: B

Worked solution

B is correct. The number of mole of gas will be

$$n = \frac{V}{22.4} = \frac{11.2}{22.4} = 0.50 \text{ mol}$$

If the number of mole is known and the mass also, the molar mass can be calculated.

$$M = \frac{m}{n} = \frac{23}{0.5} = 46 \text{ g mol}^{-1}$$

NO_2 is the only gas on the list with a molar mass of 46 g mol^{-1}.

A is incorrect as molar mass of O_2 is 32 g mol^{-1}.
C is incorrect as molar mass of O_3 is 48 g mol^{-1}.
D is incorrect as molar mass of SO_2 is 64 g mol^{-1}.

Question 5

Answer: C

Worked solution

C is correct. From the data book, if methyl red is yellow, the pH is likely to be above 6.3.

If phenol red is yellow, the pH is likely to be less than 6.8.

These two pieces of information place the pH between 6.3 and 6.8.

A is incorrect as the pH has to be above 6.3 for methyl red to be yellow.
B is incorrect as the pH has to be less than 6.8 for phenol red to be yellow.
D is incorrect as it is wrong on both ends of the pH scale.

Tip

- *This question is another example of how many times the data book can be used to answer a question. The pH transition values for common indicators are included in a table in the data book. Be very familiar with its contents.*

Question 6

Answer: A

Worked solution

A is correct. All atoms are balanced and the number of electrons correctly balances the charges present.

B is incorrect as the number of electrons should be 2.
C is incorrect as several atoms are not balanced.
D is incorrect as the electrons should be on the left side of the equation.

Tip

- *There are likely to be several instances where you will have to write balanced equations for polyatomic ions. This process usually follows three steps:*
  1. *Balance the O atoms, using water.*
  2. $IO_4^-(aq) \rightarrow IO_3^-(aq) + H_2O(l)$
  3. *Balance the H atoms in water, using* H^+ *on the opposite side.*

     $IO_4^-(aq) + 2H^+(aq) \rightarrow IO_3^-(aq) + H_2O(l)$
  4. *Balance the charges.*

     $IO_4^-(aq) + 2H^+(aq) + 2e^- \rightarrow IO_3^-(aq) + H_2O(l)$

Question 7

Answer: C

Worked solution

C is correct. When 80 mL of water is added, the volume of the solution will change from 20 mL to 100 mL. As this is a change of a factor of 5, the concentration will drop by a factor of 5. This can be checked using $c_1V_1 = c_2V_2$.

$c_1V_1 = c_2V_2$

$0.020 \times 0.5 = c_2 \times 0.100$

$c_2 = \dfrac{0.02 \times 0.5}{0.1} = 0.1$ M

$\text{pH} = -\log_{10} 0.1 = 1$

A is incorrect as the pH must be higher if the concentration of acid has dropped.
B is incorrect as pH is 1.
D is incorrect as pH is 1.

Question 8

Answer: D

Worked solution

D is correct.

$n(\text{ethene}) = \frac{1.4}{28} = 0.05$ mol

$n(\text{ethanol}) = n(\text{ethene}) = 0.05$ mol

$m(\text{ethanol}) = n \times M = 0.05 \times 46 = 2.3$ g

A is incorrect as the mass of ethanol cannot equal the mass of ethene when the molecular formulas are different.
B is incorrect as 2.3 g is the correct answer.
C is incorrect as 2.3 g is the correct answer.

Question 9

Answer: B

Worked solution

B is correct. When amino acids combine, an amine group combines with a carboxyl group to form an amide bond. The amide bond in paracetamol could be made this way.

A is incorrect as paracetamol is not a dipeptide.
C is incorrect as the reaction between an amine and an alkanol will not produce an amide linkage.
D is incorrect as it should be an amine group, not an amide group.

Question 10

Answer: C

Worked solution

C is correct. Working from left to right on the molecule, the semi-structural formula is $CH_3CONHC_6H_4OH$

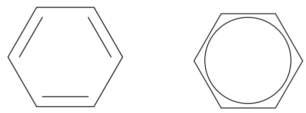
The molar mass will be $(8\times12+9+2\times16+14)$ = 151 g mol^{-1}

Note: the hexagonal structure is that of benzene. In this molecule it will have a formula of C_6H_4.

A is incorrect as 151 is the only possible answer.
B is incorrect as 151 is the only possible answer.
D is incorrect as two hydrogen atoms on benzene have been substituted from the benzene molecule.

Tips

- *It is assumed you are familiar with the structure of benzene. It has a hexagon structure with alternating double bonds. It is shown as either of the two forms below:*



- *The molecular formula of benzene is C_6H_6.*

Question 11

Answer: B

Worked solution

B is correct. The formula of ethanoic acid is CH_3COOH or $C_2H_4O_2$. This molecule has an empirical formula matching CH_2O.

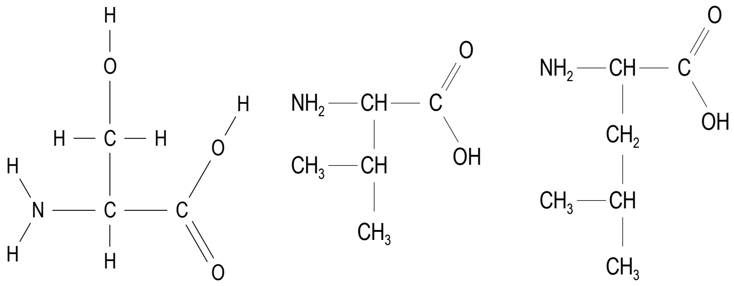
A is incorrect as ethanol has an empirical formula of C_2H_6O.
C is incorrect as stearic acid has an empirical formula of $C_9H_{18}O$.
D is incorrect as glycerol has an empirical formula of $C_3H_8O_3$.

Question 12

Answer: A

Worked solution

A is correct. The amino acids can be identified by breaking the molecule between each –NH–CO– bond. This yields the amino acids shown below, which are serine, valine and leucine.



B is incorrect as the amino acids are listed in the wrong sequence.
C is incorrect as isoleucine is not present.
D is incorrect as two of the amino acids are incorrect.

Question 13

Answer: D

Worked solution

D is correct. If the amino acids are identified as S, V and L, the six combinations are SVL, SLV, VSL, VLS, LVS, LSV.

A is incorrect as there are six possible tripeptides.
B is incorrect as there are six possible tripeptides.
C is incorrect as reversing each sequence gives a different product, e.g. VSL is not the same as LSV.

Tip

- *The reaction between two different amino acids will produce two different dipeptides. Be alert for questions testing this knowledge. Example: glycine reacting with alanine can produce two different dipeptides, glycine–alanine and alanine–glycine.*

Question 14

Answer: D

Worked solution

D is correct. The first linkage is an amide linkage found in proteins, the second is an ester found in a triglyceride and the third is an ether linkage from a polysaccharide.

A is incorrect as the second linkage is not found in a polysaccharide.
B is incorrect as the second and third linkages are incorrect.
C is incorrect as the first linkage is from a protein, not an amino acid.

Question 15

Answer: C

Worked solution

C is correct. The molecular formula will be $C_{20}H_{38}O_2$.

Oleic acid has a formula $C_{17}H_{33}COOH$. Ethanol is C_2H_6O.
When they combine, water is eliminated so the molecular formula is
$C_{20}H_{40}O_3 - H_2O = C_{20}H_{38}O_2$.

A is incorrect as it is an empirical formula.
B is incorrect as the number of carbon atoms is incorrect.
D is incorrect as it does not consider the water molecule eliminated.

Question 16

Answer: A

Worked solution

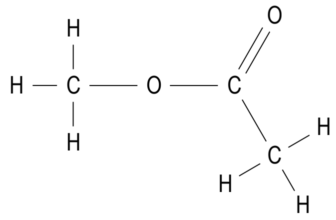
A is correct. There is a broad band around 3300 cm^{-1}. This corresponds to a hydroxyl (alkanol) group. The only alternative that is an alkanol is propan-2-ol.

B is incorrect as the hydroxyl peak in propanoic acid would be at 3000 cm^{-1}.
C is incorrect as methyl propanoate does not contain any hydroxyl groups and therefore will not produce a broad absorbance around 3300 cm^{-1}.
D is incorrect as the hydroxyl peak in butanoic acid would be at 3000 cm^{-1}.

Question 17

Answer: C

Worked solution
C is correct. Methyl ethanoate (drawn below) will have two hydrogen environments and no splitting.



A is incorrect as ethane would have one hydrogen environment only.
B is incorrect as ethanol would have three different hydrogen environments, not two.
D is incorrect. Ethanoic acid has only two hydrogen environments but the shift of the carboxyl group would be around 11, not 3.8.

Question 18

Answer: D

Worked solution

D is correct. The temperature has increased; therefore the average kinetic energy increases. This does not mean every particle is moving faster; many are but not all.

A is incorrect. The temperature has not doubled as it has gone from 299°K to 325°K.
B is incorrect as the temperature has not doubled.
C is incorrect as a percentage of the particles are moving faster but not all.

Question 19

Answer: D

Worked solution

D is correct. The chemistry data book provides the K_a value for each acid. Ethanoic acid is the weakest acid, therefore it will have the highest pH and the greatest $[OH^-]$. Methanoic acid is the strongest acid, therefore it will have the highest $[H_3O^+]$.

A is incorrect as methanoic acid will have the lowest $[OH^-]$.
B is incorrect as benzoic acid is not the strongest acid so will not have the highest $[H_3O^+]$.
C is incorrect as methanoic acid has the lowest pH.

Question 20

Answer: B

Worked solution

B is correct. The pH has increased as the temperature dropped. This means the $[H_3O^+]$ has dropped. Therefore the value of K_w is lower at the lower temperature. This is consistent with an endothermic reaction.

A is incorrect as the percentage ionisation has dropped as the temperature dropped.
C is incorrect as pure water will remain neutral.
D is incorrect as the concentrations of hydronium ions, $[H_3O^+]$, and hydroxide ions, $[OH^-]$ will remain equal in pure water.

Question 21

Answer: C

Worked solution

C is correct. The concentrations given need to be tested in each equilibrium expression to see if they provide a value of 0.5. As shown below, reaction C produces a value of 0.5.

$$K = \frac{[SO_3]^2}{[SO_2]^2[O_2]} = \frac{2^2}{2^2 \times 2} = 0.5$$

A is incorrect as it would produce a K value of 1.
B is incorrect as it would produce a K value of 2.
D is incorrect as it would produce a K value of 0.25.

Question 22

Answer: A

Worked solution

A is correct. $n(\mathrm{C}) = \frac{1000000}{12} = 83\,333$ mol

From the data book, 394 kJ of energy is released from each mole of carbon, therefore

Energy released = $n \times 394$ = 32 833 333 kJ = 32.8 GJ

B is incorrect as it is the energy released from one mole only.
C is incorrect as the units are out by a factor of 1000.
D is incorrect as the units have not been calculated correctly.

Tip

- *The SI prefixes used for large numbers are provided in a table on page 5 of the data book. Like all things in the data book, there is an expectation that you are familiar with its contents.*

Question 23

Answer: B

Worked solution

B is correct.

Energy per mole = $\frac{E}{n} = \frac{18.3}{0.05}$ = 366 kJ mol^{-1}

Equation for reaction between sodium and water is:

$2Na(s) + 2H_2O(l) \rightarrow 2NaOH(aq) + H_2(g)$

Therefore $\Delta H = 2 \times 366 = –732$ kJ mol$^{–1}$

A is incorrect as the balanced equation is not taken into account.
C is incorrect as the reaction is exothermic.
D is incorrect as the value of ΔH is too high.

Question 24

Answer: A

Worked solution

A is correct.

Energy per mole = $\frac{5750}{0.002}$ = 2 875 000 J = 2875 kJ mol$^{–1}$

From the chemical data book, this matches butane.

B is incorrect as the molar enthalpy does not match ethanol.
C is incorrect as the molar enthalpy does not match methane.
D is incorrect as the molar enthalpy does not match hydrogen.

Question 25

Answer: D

Worked solution

D is correct. The half equation shown in D can be added to the half-equation provided to produce the correct overall equation as shown below:

$2MnO_2(s) + H_2O(l) + 2e^– \rightarrow 2OH^-(aq) + Mn_2O_3(s)$

$\underline{Zn(s) + 2OH^–(aq) \rightarrow ZnO(s) + H_2O(l) + 2e^–}$

$Zn(s) + 2MnO_2(s) \rightarrow ZnO(s) + Mn_2O_3(s)$

A is incorrect as the half-equation is not balanced.
B is incorrect as the half-equation is not balanced.
C is incorrect as it is an oxidation reaction and it is not balanced.

Question 26

Answer: A

Worked solution

A is correct.
If cadmium reacts with $CoCl_2$, it is more reactive than cobalt.
If cadmium does not react with $BaCl_2$, then barium is more reactive than cadmium.
The order of reactivity between the three metals is therefore (most reactive to least) barium, cadmium and cobalt.
The strongest oxidant will be the ion of the least reactive metal, Co^{2+}.

B is incorrect as Co metal is not an oxidant.
C is incorrect as Ba^{2+} is the weakest oxidant.
D is incorrect as Ba metal is not an oxidant.

Tips

- *This question is made easier if you are aware that:*
  - *the more reactive metal can replace a less reactive metal in solution*
  - *the more reactive a metal, the lower its half equation on the electrochemical series*
  - *you need to be specific when identifying oxidants or reductants; Co and Co^{2+} are very different answers.*

Question 27

Answer: C

Worked solution

C is correct. No scale is given on the vertical axis but the graph for sodium or lithium can be used to establish values.
One mole of sodium weighs 23 g. This information allows you to discern that one mole of electrons is producing around 40 g of the third metal.
Each metal has to be tested to see if this data matches it.
Potassium has a charge of +1, so 1 mole of electrons will produce 1 mole of potassium, which is 39 g.
A value of 39 matches that of potassium.

A is incorrect as the molar mass of silver is far greater than 39.
B is incorrect. Magnesium has a charge of +2 so 1 mole of electrons would produce 0.5 mole of magnesium and the mass would be around 12.2 g, not 39.
D is incorrect as the charge on calcium is +2 and half a mole of calcium has a mass of 20 g, not 39 g.

Question 28

Answer: B

Worked solution

B is correct. Lithium and sodium ions have the same oxidation state, so the number of mole of each will be the same:

$Li^{+} + e^{-} \rightarrow Li$

$Na^{+} + e^{-} \rightarrow Na$

A is incorrect as metals with a different oxidation state will produce a different number of mole of metal.
C is incorrect as the gradient will be the same.
D is incorrect as the gradient will be the same.

Question 29

Answer: D

Worked solution

D is correct. $n_e = \frac{48300}{96500} = 0.50$ mol
Each alternative needs to be tested to find the correct solution.
For aluminium, the half equation is $Al^{3+} + 3e^{-} \rightarrow Al$

$n(Al) = \frac{1}{3} \times 0.5 = 0.166$ mol
mass = $n \times M$ = 0.166 × 27 = 4.50 g, matching the mass in the question.

A is incorrect. The mass of sodium produced from 48 300 C would be greater than 4.5 g.
B is incorrect. The mass of calcium produced from 48 300 C would be greater than 4.5 g.
D is incorrect. The mass of copper produced from 48 300 C would be greater than 4.5 g.

Question 30

Answer: B

Worked solution

B is correct. LiCl is the only solution that will produce a gas at both electrodes. Water will react before lithium ions or chloride ions react, producing the gases hydrogen and oxygen.

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

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

A is incorrect as iodine will form at the anode.
C is incorrect as copper will deposit at the cathode.
D is incorrect as zinc metal will form at the cathode.

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SECTION B

Question 1a.i.

Worked solution

$Ba(NO_3)_2(aq) + H_2SO_4(aq) \rightarrow BaSO_4(s) + 2HNO_3(aq)$

Mark allocation: 1 mark

- 1 mark for correct formulas and states

Explanatory notes

Barium nitrate is added to provide barium ions to form a precipitate of barium sulfate. Barium sulfate is insoluble. The other product is nitric acid.

Question 1a.ii.

Worked solution

$Ba^{2+}(aq) + SO_4^{2-}(aq) \rightarrow BaSO_4(s)$

Mark allocation: 1 mark

- 1 mark for correct formulas and states

Explanatory notes

A partial ionic equation shows only the species that change in the reaction. In this case, barium ions and sulfate ions react to form barium sulfate as a precipitate.

Question 1a.iii.

Worked solution

$n(BaSO_4) = \dfrac{0.444}{233.4} = 0.00190$ mol

$n(H_2SO_4) = n(BaSO_4) = 0.00190$ mol

$c(H_2SO_4) = \dfrac{n}{V} = \dfrac{0.00190}{0.02} = 0.0951$ M

Mark allocation: 3 marks

- 1 mark for calculation of number of mole of barium sulfate, $n(BaSO_4)$
- 1 mark for recognising that $n(BaSO_4) = n(H_2SO_4)$
- 1 mark for calculation of concentration of sulfuric acid, $c(H_2SO_4)$

Explanatory notes

The precipitate is $BaSO_4$. The mass of precipitate can be used to calculate $n(BaSO_4)$ as 0.00190 mol.
The balanced equation shows that $n(H_2SO_4) = n(BaSO_4) = 0.00190$ mol.
The volume of sulfuric acid of 20 mL can be used to calculate the concentration of the sulfuric acid as 0.0951 M.

Tip

- *There are two very common precipitation reactions used in exam questions. They are: the addition of barium nitrate to solutions containing sulfate ions to form $BaSO_4$ and the addition of silver nitrate to chloride solutions to precipitate AgCl.*

Question 1b.i.

Worked solution

$H_2SO_4(aq) + 2NaOH(aq) \rightarrow Na_2SO(aq) + 2H_2O(l)$

Mark allocation: 1 mark

- 1 mark for correctly balanced equation with states

Question 1b.ii.

Worked solution

$n(\text{NaOH}) = c \times V = 0.32 \times 0.0248 = 0.00794$ mol

$n(H_2SO_4) = ½\, n(\text{NaOH}) = ½ \times 0.00794 = 0.00397$ mol

$c(H_2SO_4) = \dfrac{n}{V} = \dfrac{0.00397}{0.02} = 0.198$ M

Mark allocation: 3 marks

- 1 mark for calculation of number of mole of sodium hydroxide, n(NaOH)
- 1 mark for calculation of number of mole of sulfuric acid, $n(H_2SO_4)$
- 1 mark for calculation of concentration of sulfuric acid, $c(H_2SO_4)$

Explanatory notes

This is a straightforward titration calculation. The number of mole of NaOH can be calculated as the concentration is given and the titre. Be careful to halve the number of mole of NaOH to get $n(H_2SO_4)$. The concentration of H_2SO_4 can then be calculated.

Question 1c.i.

Worked solution

If the concentration of sulfuric acid obtained in part b. is correct, then the amount of barium nitrate added in part a. is insufficient. A greater volume of barium nitrate should have been added to ensure all the barium sulfate was precipitated.

Mark allocation: 1 mark

- 1 mark for identifying that insufficient $Ba(NO_3)_2$ was added

Explanatory notes

The issue is with the amount of barium nitrate, $Ba(NO_3)_2$, added. In a gravimetric analysis the chemical added to cause a precipitate needs to be in excess.
If the concentration of sulfuric acid is 0.198 M, then
$n(H_2SO_4)$ in the 20 mL sample is $c \times V = 0.198 \times 0.02 = 0.00396$ mol

The amount of $n(Ba(NO_3)_2)$ added was
$n = c \times V = 0.03 \times 0.1 = 0.00300$ mol

This is not sufficient to precipitate all of the barium sulfate.

Question 1c.ii.

Worked solution

The mass of precipitate obtained will be lower than it should be. This will cause the calculated concentration of sulfuric acid to be low.

Mark allocation: 1 mark

- 1 mark for stating the concentration of sulfuric acid obtained will be low

Explanatory notes

If insufficient $Ba(NO_3)_2$ is added, less precipitate is formed than should be.
This leads to a low value for the concentration of the sulfuric acid.

Question 2a.i.

Worked solution

$COOH^+$

Mark allocation: 1 mark

- 1 mark for fragment of $COOH^+$ (CO_2H^+). Positive charge must be included in the answer. (There are other possible structures that might be consistent with an *m/z* ratio of 45.)

Explanatory notes

$COOH^+$ has a mass of (12 + 2 × 16 + 1) = 45. Any fragment passing through a mass spectrometer must have a positive charge.

Question 2a.ii.

Worked solution

Given the relative molecular mass of 74, the empirical formula is also the molecular formula, $C_3H_6O_2$.

Mark allocation: 1 mark

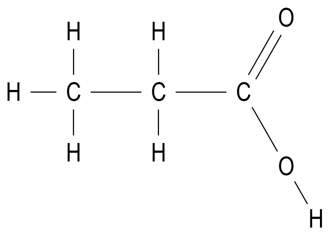
- 1 mark for $C_3H_6O_2$

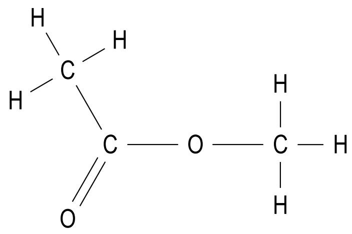
Explanatory notes

The parent molecular ion represents a molecule of molar mass 74 g mol^{-1}. A molecule with empirical formula $C_3H_6O_2$ will have the same molar mass. Therefore, the empirical and molecular formulas are the same.

Question 2a.iii.

Worked solution





Mark allocation: 2 marks

- 1 mark for each correct structure

Explanatory notes

Two structures matching this molecular formula of $C_3H_6O_2$ are those of propanoic acid and methyl ethanoate. There are other possible structures.

Question 2b

Worked solution

The molecule will be a carboxylic acid as it has a broad peak at 3000 cm^{-1} characteristic of the hydroxyl group on a carboxylic acid.

Mark allocation: 1 mark

- 1 mark for reference to a broad peak at 3000 cm^{-1} indicating a hydroxyl group that is part of a carboxylic acid. Response must state that it is an –OH (acid) peak.

Explanatory notes

Carboxylic acids and esters will both have a peak around 1750 cm for a carbonyl (–C=O) group but the carboxylic acid will also have a broad peak around 3000 cm^{-1} due to the hydroxyl group characteristic of carboxylic acids.

Tip

- *The use of infrared spectroscopy to distinguish esters from carboxylic acids is very common. Be ready to look for a broad band on the spectrum at 3300 c–$^{-1}$ for an alkanol or 3000 c^{-1} for the hydroxyl group in a carboxylic acid.*

Question 2c.

Worked solution

propanoic acid

Mark allocation: 1 mark

- 1 mark for stating propanoic acid

Explanatory notes

Propanoic acid is the only possible carboxylic acid that has a molecular formula of $C_3H_6O_2$.

Question 2d.i.

Worked solution

The hydroxyl group that is part of the carboxyl group will have a shift around 11.8 ppm.

Mark allocation: 1 mark

- 1 mark for stating –OH (acid), or hydroxyl group belonging to a carboxylic acid

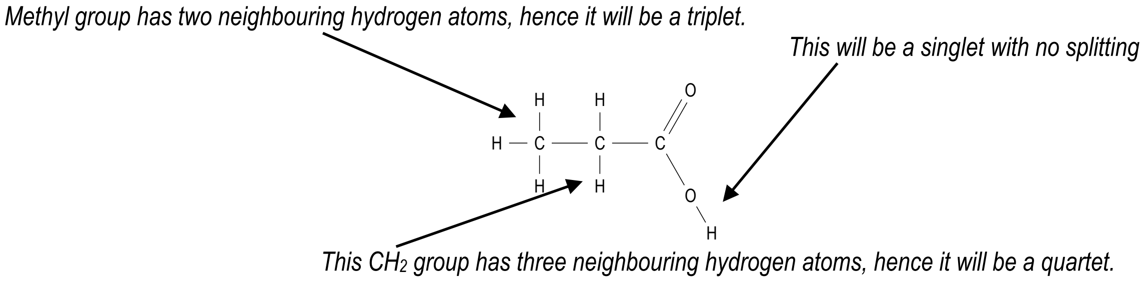
Explanatory notes

11.8 is a very large shift, matching the shift for a hydrogen atom in a carboxyl group.

Question 2d.ii.

Worked solution

The molecule has three different hydrogen environments, hence the three different sets of peaks.



Mark allocation: 3 marks

- 1 mark for each correct environment with explanation, e.g. CH_3 has two neighbouring hydrogen atoms, hence it will be a triplet

Explanatory notes

Propanoic acid has three different hydrogen environments, leading to three sets of peaks.
When hydrogen is separated from the molecule by an oxygen atom, there is no splitting.
The hydroxyl group will lead to a singlet. The other peaks will be split according to the *n*+1 rule, where the number of peaks is one more than the number of neighbouring hydrogen atoms.

Question 3a.i.

Worked solution

Methyl propanoate

Mark allocation: 1 mark

- 1 mark for the correct name

Explanatory notes

Esters can be made from a reaction between an alkanol and a carboxylic acid, in this case a reaction between methanol and propanoic acid. The alkanol is named first, hence the name of the ester is methyl propanoate.

Question 3a.ii.

Worked solution

C_2H_4O

Mark allocation: 1 mark

- 1 mark for the empirical formula of C_2H_4O

Explanatory notes

The molecular formula can be found by counting up the atoms. This gives $C_4H_8O_2$. The empirical formula is C_2H_4O.

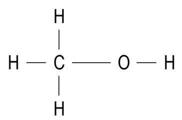
Tip

- *Before the exam, practise drawing some esters and also the molecules they are formed from. Students very often make mistakes with the ester bonds.*

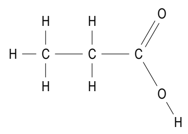
Question 3b.i.

Worked solution

alkanol



carboxylic acid



Mark allocation: 2 marks

- 1 mark for a correct structure of methanol.
- 1 mark for a correct structure of propanoic acid

Explanatory notes

Methanol is an alkanol and propanoic acid is a carboxylic acid.

Question 3b.ii.

Worked solution

$$CH_4O(l) + C_3H_6O_2(l) \xrightarrow{H_2SO_4(l)} C_4H_8O_2(aq) + H_2O(l)$$

Mark allocation: 2 marks

- 1 mark for a correct balanced equation
- 1 mark for identifying sulfuric acid as the catalyst, which must not have (aq) as the state

Explanatory notes

The structures drawn for part i. can be used to write the formulas of methanol and propanoic acid. When they react, water is also formed. The catalyst is concentrated sulfuric acid.

Question 3c.

Worked solution

$2CH_4O(l) + 3O_2(g) \rightarrow 2CO_2(g) + 4H_2O(g)$

Mark allocation: 1 mark

- 1 mark for a balanced equation

Explanatory notes

Combustion reactions produce carbon dioxide gas and water, if excess air is present. To balance the equation correctly, follow the process of balancing carbon atoms first, then hydrogen and then oxygen.

Question 3d.i.

Worked solution

$CH_3CH_2COOH(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + CH_3CH_2COO^-(aq)$

Mark allocation: 1 mark

- 1 mark for a correctly balanced equation

Explanatory notes

Most carboxylic acids are weak acids. They ionise in water to form a hydronium ion and a carboxylate ion.

Question 3d.ii.

Worked solution

$$K_a = \frac{[H_3O^+][CH_3CH_2COO^-]}{[CH_3CH_2COOH]}$$

Mark allocation: 1 mark

- 1 mark for a correct expression for K_a

Explanatory notes

The expression for K_a is derived from the ionisation reaction. This is a standard expression for K_a.

Question 4a.

Worked solution

H_2O_2. If hydrogen is +1, oxygen must be –1.

Mark allocation: 1 mark

- 1 mark for correct oxidation state

Explanatory notes

The name peroxide is given to oxygen compounds where oxygen has the unusual oxidation state of –1.

Question 4b.i.

Worked solution

$\underline{H_2O_2}(aq) + 2H^+(aq) + 2e^- \rightarrow 2H_2O(l)$

$O_2(g) + 2H^+(aq) + 2e^- \rightarrow \underline{H_2O_2}(aq)$

Hydrogen peroxide should be able to react with itself spontaneously. When it does, the two half-equations are:

$H_2O_2(aq) + 2H^+(aq) + 2e^- \rightarrow 2H_2O(l)$

$H_2O_2(aq) \rightarrow O_2(g) + 2H^+(aq) + 2e^-$

and the overall equation is $2H_2O_2(aq) \rightarrow 2H_2O(l) + O_2(g)$

Mark allocation: 2 marks

- 1 mark for identifying the correct half-equations
- 1 mark for the overall equation

Explanatory notes

H_2O_2 appears in two separate half-equations, one at 1.77 V and the other at 0.68 V. The two half-equations should produce a spontaneous reaction. When the half-equations are combined, the overall reaction is decomposition to water and oxygen.

Question 4b.ii.

Worked solution

The electrochemical series gives no indication of reaction rate. Hydrogen peroxide does in fact react spontaneously but the reaction rate is very slow.

Mark allocation: 1 mark

- 1 mark for the stating that the electrochemical series does not indicate the rate of a reaction

Explanatory notes

The electrochemical series indicates if two chemicals can react in a spontaneous reaction. However, it does not give any indication of the likely rate of the reaction.

Question 4b.iii.

Worked solution

It can be stored in a refrigerator. The lower temperature reduces the average kinetic energy of the particles. There will be fewer collisions and a lower proportion of particles will have sufficient energy to overcome the activation energy.

Mark allocation: 1 mark

- 1 mark for an answer such as lowering the temperature; the answer must be explained in terms of collision theory

Explanatory notes

Hydrogen peroxide is usually sold in dark containers and should be stored in cool conditions. The dark container prevents the energy from light acting as a catalyst for the reaction and refrigeration works by lowering the average kinetic energy of the particles.

Question 4c

Worked solution

Potatoes contain an enzyme that speeds up the rate of the reaction. The enzyme catalyses the decomposition reaction, providing an alternative reaction pathway of lower activation energy.

Marking allocation: 2 marks

- 1 mark for stating that potato must contain an enzyme that catalyses this reaction (students are not expected to know the name of the enzyme)
- 1 mark for explaining the mechanism of a catalyst

Explanatory notes

Potatoes contain the enzyme catalase. It acts as a catalyst for the decomposition of hydrogen peroxide. A catalyst offers an alternative reaction pathway.

Question 5a

Worked solution

The reaction of two glucose molecules is a condensation reaction. A water molecule is formed as well as a disaccharide. The mass of the disaccharide will be equal to the mass of two glucose molecules minus the mass of a water molecule. The molar mass is therefore 342 g mol^{-1}.

Mark allocation: 2 marks

- 1 mark for referring to the formation of water
- 1 mark for explaining that the mass of water needs to be taken into account

Explanatory notes

A condensation reaction will produce water; therefore the mass of the disaccharide will be less than the combined mass of the reactants.

Question 5b

Worked solution

Plant oils contain a higher proportion of unsaturated fatty acids than fats or oils obtained from animals. The presence of carbon-to-carbon double bonds prevents the molecules packing as tightly so the melting point of plant oils is lower than that of animal fats. With a lower melting point, plant oils are more suited to cold climates. Biodiesel formed from animal fats is prone to solidify in cold climates, making it an unsuitable fuel.

Mark allocation: 2 marks

- 1 mark for explaining the unsaturated nature of plant oils
- 1 mark for linking this to a lower melting point

Explanatory notes

Plant oils are generally unsaturated molecules. Unsaturated molecules do not pack together tightly so the forces between the molecules are lower, making the melting point lower. A lower melting point is advantageous for running a vehicle in cold conditions. Biodiesel derived from animals might freeze in the fuel tank, making it unusable.

Question 5c

Worked solution

The sodium salt of aspirin is an ionic compound. Ionic compounds can form ion–dipole bonds easily with water, increasing the solubility compared to standard molecular aspirin.

Mark allocation: 2 marks

- 1 mark for stating that the salt produced is an ionic substance
- 1 mark for explaining how this increases solubility in water

Explanatory notes

Standard aspirin is a molecular substance that dissolves slowly in water. When it is converted to an ionic salt, its solubility increases as the ion can form ion-dipole bonds with water. The more soluble the aspirin is, the faster it will act in the body.

Question 5d

Worked solution

The strand of DNA with the higher melting point is likely to contain a higher proportion of cytosine and guanine bases than the other strand. Cytosine and guanine form three hydrogen bonds between each base while adenine and thymine form only two. Increasing the number of hydrogen bonds between the bases increases the amount of energy required to disrupt them, increasing the melting point.

Mark allocation: 2 marks

- 1 mark for stating that the proportion of cytosine–guanine bases is the reason for the difference
- 1 mark for extending the discussion to the extra hydrogen bonds present

Explanatory notes

The bases in DNA will be either C to G or A to T. C to G bases form three hydrogen bonds but A to T bases form only two. The melting point of DNA strands increases as the C to G proportion increases.

Question 6a

Worked solution

17.5 µg mL^{-1}

Mark allocation: 1 mark

- 1 mark for plotting the absorbance of 4.1 on the graph. This gives a concentration of 17.5 µg mL^{-1} (accept a range between 17 and 18)

Explanatory notes

The concentration is obtained by plotting the absorbance on the graph. This is done by extending a line across from 4.1 on the *y*-axis and then drawing a line down to the *x*-axis.

Question 6b

Worked solution

Concentration is 17.5 µg mL^{-1}.
In a 100 mL sample the mass of lead will be 100 × 17.5 = 1750 µg = 1.75 mg

Mark allocation: 1 mark

- 1 mark for a correct answer in mg

Explanatory notes

The concentration in the sample is 17.5 µg in each mL.
In a 100 mL sample, the mass will be 100 × 17.5 = 1750 µg = 1.75 mg

Question 6c

Worked solution

$$\% \text{ lead} = \frac{0.00175 \times 100}{2} = 0.086\%$$

Mark allocation: 1 mark

- 1 mark for calculation consistent with answer to part b

Explanatory notes

The original paint sample was 2 g. The percentage of lead is the mass of lead over two made into a percentage.

Question 7a.

Worked Solution

$COCl_2(g)$ ⇄	$CO(g)$ +	$Cl_2(g)$	
0.5	0	0.6	start
		0.68	change of 0.08
0.42	0.08	0.68	equilibrium

$$K = \frac{[CO][Cl_2]}{[COCl_2]} = \frac{0.68 \times 0.08}{0.42} = 0.13 \text{ M}$$

Mark allocation: 3 marks

- 1 mark for calculating the amount of CO
- 1 mark for calculating the amount of $COCl_2$
- 1 mark for calculating *K*

Explanatory notes

The initial amount of CO is not an equilibrium amount so cannot be substituted into the expression for *K*. The grid above is needed to calculate the amounts at equilibrium of the $COCl_2$ and CO.
The amount of chlorine gas changes by 0.08 mol. So the amount of phosgene must drop by the same amount.

Question 7b.

Worked solution

The number of mole of chlorine has dropped. Therefore the back reaction was favoured. If the back reaction has been favoured, then the pressure must have been increased. An increase in pressure favours the back reaction as there is one reactant molecule for every two product molecules. An increase in pressure is due to a decrease in volume.

Mark allocation: 1 mark

- 1 mark for a decrease in volume with a valid explanation

Explanatory notes

Le Chatelier's Principle states a system will partially oppose a change in equilibrium. If the pressure is increased, the reaction will move to produce fewer particles and this will be in the reverse direction. There is one reactant molecule compared to two product molecules.

Question 8a.

Worked solution

$HOCl(aq) + H_2O(l) \rightleftarrows H_3O^+(aq) + OCl^-(aq)$

Mark allocation: 1 mark

- 1 mark for a correct equation. Equilibrium arrow must be shown

Explanatory notes

This is a standard reaction for a weak acid in water: the H^+ is donated to water, leaving OCl^-.

Question 8b.i.

Worked solution

From the data book, $K_a = 2.9 \times 10^{-8}$

For 0.1 M solution

$$K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = \frac{x \times x}{0.1} = \frac{x^2}{0.1} = 2.9 \times 10^{-8}$$

$x^2 = 2.9 \times 10^{-9}$

$x = 5.39 \times 10^{-5}$

$$\% \text{ ionisation} = \frac{5.39 \times 10^{-5} \times 100}{0.1} = 0.054\%$$

For 0.0001 M solution

$$K_a = \frac{[H_3O^+][OCl^-]}{[HOCl]} = \frac{x \times x}{0.0001} = \frac{x^2}{0.0001} = 2.9 \times 10^{-8}$$

$x^2 = 2.9 \times 10^{-12}$

$x = 1.70 \times 10^{-6}$

$$\% \text{ ionisation} = \frac{1.70 \times 10^{-6} \times 100}{0.0001} = 1.70\%$$

[HOCl](M)	**$[H_3O^+]$(M)**	**Percentage ionisation**
0.1 M	5.39×10^{-5}	0.054
0.0001 M	1.70×10^{-6}	1.70

Mark allocation: 4 marks

- 1 mark for each of the four values in the table; consequential marking applies to the values of percentage ionisation obtained

Explanatory notes

The wording of this question leads you to the process to apply. The reference to K_a and to your data book hints to you to use the formula for K_a to calculate the $[H_3O^+]$ in both solutions. To complete the second column of the table you need to know that the % ionisation

of an acid is = $\frac{[H_3O^+]}{[\text{acid}]} \times \frac{100}{1}$

Tip

- *The percentage ionisation calculation is an example where consequential marking is applied. If your answer for the $[H_3O^+]$ is wrong but you apply the correct process to that answer, you are awarded the mark for the percentage ionisations.*

Question 8b.ii.

Worked solution

The percentage ionisation for the 0.1 M solution is 0.054%. This is a very low figure and the assumption that the concentration of HOCl is unchanged is justified.
For the 0.0001 M solution the percentage ionisation is approaching 2%. The HOCl concentration at equilibrium should not be assumed to be equal to that of the initial concentration.

Mark allocation: 2 marks

- 1 mark for recognising that the question refers to the value of the percentage ionisation figures
- 1 mark for differentiating between the two solutions

Explanatory notes

The K_a values can be used to determine the $[H_3O^+]$ at equilibrium as shown above.

The percentage ionisation is calculated from the formula = $\frac{[H_3O^+ \text{equilibrium}]}{[\text{acid}]} \times \frac{100}{1}$.

As the concentration of a weak acid becomes more dilute, the percentage ionisation increases.

Question 9a.i.

Worked solution

Gas generated from the decomposition of organic matter in an oxygen-free environment.

Mark allocation: 1 mark

- 1 mark for explanation that biogas is formed from decomposition of rotting matter

Explanatory notes

The action of bacteria on organic matter can release methane or biogas. The process is conducted in anaerobic conditions.

Question 9a.ii.

Worked solution

It can be replenished in a relatively short period of time.

Mark allocation: 1 mark

- 1 mark for explanation that biogas supplies can be replenished in a relatively short period of time

Explanatory notes

An energy supply is considered renewable if supplies of the fuel can be replenished at a similar rate to which they are used.

Tip

- *It sounds very easy to explain what a renewable fuel is; however, students always struggle to find the right words. The fact that it can be replenished at a sustainable rate is usually a safe response – that 'it can be recycled' is not.*

Question 9b.

Worked solution

i. reaction at the anode: $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

ii. reaction at the cathode: $CH_4(g) + 8OH^-(aq) \rightarrow CO_2(g) + 6H_2O(l) + 8e^-$

iii. $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

Mark allocation: 3 marks

- 1 mark for each correct equation

Explanatory notes

The overall equation in a methane fuel cell will be the same as the equation for the combustion of methane: $CH_4(g) + 2O_2(g) \rightarrow CO_2(g) + 2H_2O(l)$

The half-equation for the reaction of oxygen can be obtained from the electrochemical series with a voltage of 0.4 V: $O_2(g) + 2H_2O(l) + 4e^- \rightarrow 4OH^-(aq)$

The half-equation for methane is: $CH_4(g) + 8OH^-(aq) \rightarrow CO_2(g) + 6H_2O(l) + 8e^-$

Question 10a.

Worked solution

The partial ionic equation for the reaction between hydrochloric acid and sodium hydroxide is
$H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$
The partial ionic equation for the reaction between nitric acid and potassium hydroxide will be exactly the same, hence the same value of ΔH is expected.

Mark allocation: 2 marks

- 1 mark for each partial ionic equation. (Both equations will be the same)
- 1 mark for stating that both reactions will have this same partial equation

Explanatory notes

For any acid/hydroxide combination, the reaction will be the same one:
$H_3O^+(aq) + OH^-(aq) \rightarrow 2H_2O(l)$

Question 10b.i.

Worked solution

$[H_3O^+][OH^-] = 10^{-14}$
$[H_3O^+] \times 0.136 = 10^{-14}$
$[H_3O^+] = \frac{10^{-14}}{0.136} = 7.35 \times 10^{-14}$
$pH = -\log_{10}(7.35 \times 10^{-14}) = 13.1$

Mark allocation: 2 marks

- 1 mark for the calculation of $[H_3O^+]$
- 1 mark for the pH

Explanatory notes

NaOH is a base, so the $[H_3O^+]$ needs to be calculated to determine the pH. Since the solution is at 25°C, the formula $[H_3O^+][OH^-] = 10^{-14}$ can be used.

Tip

- *A quick way to calculate the pH of a base is to treat it as an acid, work out the pH but then subtract your answer from 14.*
  - *For this question –log(0.136) = 0.89.*
    14 – 0.89 = 13.1

Question 10b.ii.

Worked solution

n(HCl) = $c \times V$ = 0.05 × 0.128 = 0.00640 mol
n(NaOH) = $c \times V$ = 0.04 × 0.136 = 0.00544 mol

The NaOH is the limiting reagent, so calculations need to be based on its number of mole.

Energy released = $\Delta H \times n$ = 57.2 × 0.00544 = 0.311 kJ = 311 J

Mark allocation: 3 marks

- 1 mark for calculation of n(HCl)
- 1 mark for calculation of n(NaOH)
- 1 mark for using the n(NaOH) to calculate the energy released

Explanatory notes

Differing amounts of HCl and NaOH are used in the experiment. The chemical that is the limiting reagent is the one that will determine the amount of energy released. NaOH is the limiting reagent.

Question 10b.iii.

Worked solution

$E = 4.18 \times m \times \Delta T$

$311 = 4.18 \times 90 \times \Delta T$

$\Delta T = 0.827^{o}C$

Mark allocation: 2 marks

- 1 mark correct formula
- 1 mark for calculation of answer

Explanatory notes

The formula $E = 4.18 \times m \times \Delta T$ can be used to determine the change in temperature. The energy released has already been calculated and the volume of solution will be equal to the volume of HCl added to the volume of NaOH = 90 mL.
Since the solution is mainly water, 90 mL can be assumed to be 90 g in mass.

Question 11a.

Worked solution

$2Li(s) + 2H_2O(l) \rightarrow 2LiOH(aq) + H_2(g)$

Lithium reacts explosively with water. Production of hydrogen gas in an enclosed object is also a problem.

Mark allocation: 2 marks

- 1 mark for the equation
- 1 mark referring to either the reaction of lithium with water or the presence of hydrogen gas

Explanatory notes

Lithium reacts vigorously with water. This is a dangerous reaction in itself for the amount of energy released but the formation of explosive hydrogen gas presents further issues.

Question 11b.

Worked solution

anode: $Li \rightarrow Li^+ + e$

cathode: $S + 2e \rightarrow S^{2-}$

Mark allocation: 2 marks

- 1 mark for each correct equation

Explanatory notes

Lithium metal is reacting to form lithium ions. The half-equation for this reaction is on the electrochemical series. This reaction is oxidation, therefore it occurs at the anode.
Sulfur reacts at the cathode to form S^{2-} ions. The charge on sulfur can be deduced from the formula of Li_2S.

Question 11c.

Worked solution

$8Li_2S \rightarrow 16Li + S_8$

Mark allocation: 1 mark

- 1 mark for reversing the equation supplied in the question

Explanatory notes

The recharging equation is the reverse of the discharge equation.

Question 11d.

Worked solution

$Q = It = 2.5 \times 15 \times 60 = 2250$ coulomb

$$n(\text{e}) = \frac{Q}{96500} = 0.0233 \text{ mol}$$

$$n(\text{Li}) = n(\text{e}) = 0.0233 \text{ mol}$$

$$m(\text{Li}) = n \times M = 0.0233 \times 6.9 = 0.16 \text{ g}$$

Mark allocation: 3 marks

- 1 mark for calculation of the charge
- 1 mark for calculating number of mole of lithium
- 1 mark for calculation of mass

Explanatory notes

The charge can be calculated from the current and time values.
The amount of charge provides the number of mole of electrons.
Lithium ions have a charge of +1 so the number of mole of lithium equals the number of mole of electrons.

Question 12a.

Worked solution

Possible half-equations are:

$Cl_2(g) + 2e^- \rightleftharpoons 2\underline{Cl^-}(aq)$

$O_2(g) + 4H^+(aq) + 4e^- \rightleftharpoons \underline{2H_2O}(l)$

$\underline{Ni^{2+}}(aq) + 2e^- \rightleftharpoons Ni(s)$

$\underline{2H_2O}(l) + 2e^- \rightleftharpoons H_2(g) + 2OH^-(aq)$

Therefore reactions occurring are:

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

cathode: $Ni^{2+}(aq) + 2e^- \rightarrow Ni(s)$

overall equation: $2H_2O(l) + 2Ni^{2+}(aq) \rightarrow O_2(g) + 4H^+(aq) + 2Ni(s)$

Mark allocation: 4 marks

- 1 mark for evidence of choosing the relevant half-equations
- 1 mark for correct anode reaction
- 1 mark for correct cathode reaction
- 1 mark for correct overall equation

Explanatory notes

There are four relevant half-equations that need to be lined up in order of electrochemical series voltage. From this list the strongest oxidant, Ni^{2+}, will react with the strongest reductant, H_2O.

The reaction of Ni^{2+} to Ni is reduction and it occurs at the cathode.

The reaction of water is oxidation and it will occur at the anode.

For the overall equation, the electrons need to be balanced. Two nickel ions are needed to balance the production of oxygen gas.

Question 12b.

Worked solution

anode: colourless gas forming

cathode: silver metal forming on the electrode

Mark allocation: 2 marks

- 1 mark for stating a colourless gas evolves at the anode
  (No mark for stating 'oxygen gas' is evolved: an observer could not identify the colourless gas as oxygen.)
- 1 mark for stating that a grey or silver metal is deposited on the cathode

Explanatory notes

Anode: oxygen gas and hydrogen ions are produced. An observer will see a colourless gas evolved but will not see any evidence of hydrogen ion formation.
Cathode: nickel metal is deposited. It will appear as a silver metal.

Question 12c.

Worked solution

$n(\text{Ni}) = \frac{2.5}{58.7} = 0.0426$ mol

$n(O_2) = \frac{1}{2}\, n(\text{Ni}) = 0.5 \times 0.0426 = 0.0213$ mol

$V = n \times 24.5 = 0.0213 \times 24.5 = 0.522$ L

Mark allocation: 3 marks

- 1 mark for calculating n(Ni)
- 1 mark for calculating $n(O_2)$
- 1 mark for volume calculation

Explanatory notes

The same number of mole of electrons passes through the anode as the cathode.
Finding the number of mole of nickel metal deposited can be used to find the number of mole of electrons.
The number of mole of oxygen gas is half the number of mole of nickel metal:

$$n(O_2) = \frac{1}{2}\, n(\text{Ni})$$

The volume of oxygen gas can be determined using $V = n \times 24.5$ since SLC conditions are used.

END OF SOLUTIONS BOOKLET

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