

CHEMISTRY VCE UNITS 3&4 DIAGNOSTIC TOPIC TESTS 2008

TEST 1: GRAVIMETRIC AND VOLUMETRIC ANALYSIS

TOTAL 35 MARKS (45 MINUTES)

Student's Name: _____ Teacher's Name: _____

Directions to students

Write your name and your teacher's name in the spaces provided above.
Answer all questions in the spaces provided.

SECTION A: MULTIPLE-CHOICE QUESTIONS

Instructions for Section A

For each question in Section A, choose the response that is correct and circle your choice.

Choose the response that is **correct** or **best answers** the question.

A correct answer scores 1, an incorrect answer scores 0.

Marks will **not** be deducted for incorrect answers.

No marks will be given if more than one answer is completed for any question.

Question 1

Methanethiol is a colourless gas with a foul odour similar to that produced by rotting cabbages. It is used as an additive to natural gas supplies so that any leak will be quickly detected by its odour. This compound contains 25.0% carbon, 8.30% hydrogen and 66.7% sulfur.

The empirical formula of methanethiol is

- A. CHS
- B. CH₃S
- C. CH₄S
- D. C₃HS₈

Question 2

Which of the following equations represents a redox reaction?

- A. $3\text{NO}_2(\text{g}) + \text{H}_2\text{O}(\text{l}) \rightarrow 2\text{HNO}_3(\text{aq}) + \text{NO}(\text{g})$
- B. $\text{Na}_2\text{CO}_3(\text{aq}) + \text{CaCl}_2(\text{aq}) \rightarrow \text{CaCO}_3(\text{s}) + 2\text{NaCl}(\text{aq})$
- C. $\text{C}_2\text{H}_5\text{Cl}(\text{g}) + \text{NaOH}(\text{aq}) \rightarrow \text{C}_2\text{H}_5\text{OH}(\text{aq}) + \text{NaCl}(\text{aq})$
- D. $\text{HNO}_3(\text{aq}) + \text{KOH}(\text{aq}) \rightarrow \text{KNO}_3(\text{aq}) + \text{H}_2\text{O}(\text{l})$

Question 3

In performing a gravimetric analysis, which of the following pieces of equipment would **definitely** be required?

- A. pipette
- B. burette
- C. conical flask
- D. analytical mass balance

Question 4

A sample of the manganese ore pyrolusite was dissolved in acid to liberate the $\text{Mn}^{2+}(\text{aq})$ ions which were then oxidised to $\text{Mn}^{7+}(\text{aq})$ and finally precipitated as Mn_2O_7 .

Given that a 5.00 g sample of the ore generated a precipitate of 0.232 g of Mn_2O_7 , the percentage mass of manganese in the pyrolusite ore is

- A. $\frac{0.232 \times 54.9 \times 2 \times 100}{221.8 \times 5.00}$
- B. $\frac{0.232 \times 54.9 \times 100}{221.8 \times 2}$
- C. $\frac{0.232 \times 100}{5.00}$
- D. $\frac{0.232 \times 221.8 \times 2 \times 100}{54.9 \times 5.00}$

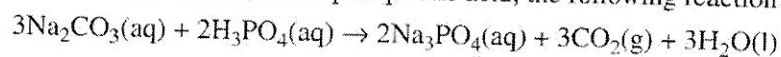
Question 5

Which of the following criteria is **not** essential in order that a substance can be described as a primary standard?

- A. It must be of known chemical formula.
- B. It must have a low molecular weight.
- C. It must not react with moisture or with atmospheric gases.
- D. It must be highly pure and readily available.

Questions 6 and 7 refer to the following information.

When sodium carbonate solution is treated with phosphoric acid, the following reaction occurs.



Question 6

The volume of 0.455 M H_3PO_4 required to exactly neutralise 17.3 mL of 0.582 M Na_2CO_3 solution is

- A. 14.8 mL.
- B. 22.1 mL.
- C. 33.2 mL.
- D. 44.3 mL.

Question 7

The reaction from **Question 6** was carried out at a pressure of 110 kPa and a temperature of 35°C.

The volume of carbon dioxide gas produced was

- A. 26.7 mL.
- B. 30.0 mL.
- C. 235 mL.
- D. 705 mL.

Question 8

A gravimetric analysis was performed to determine the sulfur content of a sample of fertiliser.

Which of the following steps was **not** carried out during this procedure?

- A. The fertiliser sample was dissolved in water and filtered to remove any insoluble impurities.
- B. The precipitate was dried and weighed to constant mass.
- C. A quantity of barium chloride was added to the filtrate to generate a precipitate of barium sulfate.
- D. The filtrate was titrated against barium chloride using a suitable indicator to determine the endpoint.

Questions 9 and 10 refer to the following information.

Acid–base indicator	Colour change (low pH → high pH)	pH range
thymol blue	red → yellow	1.2–2.8
methyl red	pink → yellow	4.4–6.2
phenolphthalein	colourless → red	8.3–10.0
alizarin yellow	yellow → lilac	10.1–12.0

Question 9

Which of the four indicators in the table above would be most suitable for estimating the equivalence point in the titration of a 20.00 mL aliquot of a 0.100 M standard solution of HCl with a 0.100 M solution of the weak base ammonia?

- A. thymol blue
- B. methyl red
- C. phenolphthalein
- D. alizarin yellow

Question 10

Four titrations are set up in which 25.00 mL aliquots of a standardised solution of 0.100 M hydrochloric acid is titrated with approximately 0.1 M solutions of sodium hydroxide. Each titration uses a different indicator from the table above.

Which of the following statements is accurate with respect to the colour of the indicator at the endpoint of the reaction?

- A. The thymol blue indicator will still be red in colour.
- B. The methyl red indicator will be peach coloured (half way between red and yellow).
- C. The phenolphthalein will have just turned pink.
- D. The alizarin yellow will have turned lilac.

SECTION B: SHORT-ANSWER QUESTIONS

Instructions for Section B

Answer **all** questions in the spaces provided.

To obtain full marks you should

- give simplified answers with an appropriate number of significant figures to all numerical questions; unsimplified answers will not be given full marks.
- show all working in your answers to numerical questions. No credit will be given for an incorrect answer unless it is accompanied by details of the working.
- make sure chemical equations are balanced and that the formulas for individual substances include an indication of state; for example $\text{H}_2(\text{g})$; $\text{NaCl}(\text{s})$.

Question 1

A naturally occurring compound is known to contain the elements carbon, hydrogen, nitrogen and oxygen. To determine its empirical formula, 7.116 g of the compound was completely burnt in oxygen to produce 5.038 g of liquid water and 6.855 L of a gaseous mixture containing only nitrogen and carbon dioxide. This gaseous mixture was then bubbled through a concentrated solution of sodium hydroxide to remove the carbon dioxide. 0.9791 L of nitrogen gas (N_2) was left unreacted. All gas volumes are given at standard laboratory conditions (SLC).

- a. Use the mass of water produced to calculate the mass of hydrogen present in the compound.

1 mark

- b. Use the volume of carbon dioxide produced to calculate the mass of carbon present in the compound.

2 marks

- c. Use the volume of nitrogen gas (N_2) produced to calculate the mass of nitrogen present in the compound.

1 mark

- d. Determine the mass of oxygen present in the compound.

1 mark

e. Determine the empirical formula of the compound.

2 marks

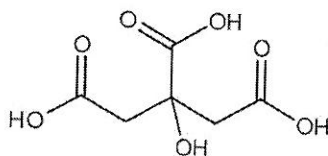
f. Given that the relative molecular mass of the compound is 89, determine its molecular formula.

1 mark

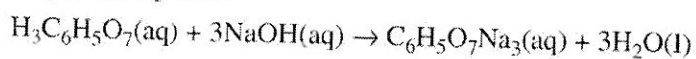
Total 8 marks

Question 2

Citric acid is a tricarboxylic acid found in many fruits and vegetables, particularly in lemons and oranges. The structure of citric acid is shown below.



A 20.00 mL aliquot of citric acid is titrated with 31.82 mL of 0.338 M sodium hydroxide to reach equivalence point according to the equation



Use this information to determine the concentration of the citric acid solution.

Total 3 marks

Question 3

The phosphate component of a sample of clothes washing detergent is determined by gravimetric analysis by precipitating the phosphate as magnesium pyrophosphate ($\text{Mg}_2\text{P}_2\text{O}_7$). A 3.28 g sample of detergent is dissolved in water, filtered to remove insoluble impurities and treated with sodium pyrophosphate to produce a precipitate of $\text{Mg}_2\text{P}_2\text{O}_7$. The precipitate was then washed with distilled water and left to dry. The precipitate was weighed several times over the next few hours and the results recorded below.

Weighing number	Mass (g)
1	0.280
2	0.264
3	0.255
4	0.253
5	0.255

- a. Why was it necessary to weigh the precipitate more than once?

1 mark

- b. Calculate the mass of magnesium pyrophosphate precipitate formed.

1 mark

- c. Calculate the mass of phosphorus in the sample of detergent.

2 marks

- d. Determine the percentage mass of phosphorus (as phosphate) in the detergent.

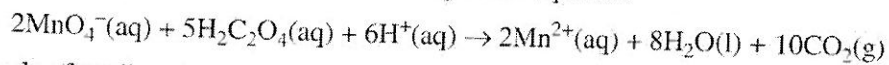
2 marks

- e. State **one** possible source of error in this determination that would result in a higher percentage mass of phosphorus than was actually present in the detergent.

1 mark
Total 7 marks

Question 4

Oxalic acid ($\text{H}_2\text{C}_2\text{O}_4$) reacts readily with strong oxidants such as acidified potassium permanganate in a highly exothermic (heat producing) reaction according to the equation



An impure sample of oxalic acid of mass 7.18 g is dissolved in approximately 40 mL of deionised water in a volumetric flask and is then made up to 250.0 mL. A 20.00 mL aliquot of this solution is then titrated against a 0.100 M freshly prepared acidified potassium permanganate solution. The endpoint was reached when 17.9 mL of $\text{MnO}_4^-(\text{aq})$ had been added and the solution retained a permanent pink colour.

- a. Write the partial redox equation that represents the oxidation process in this reaction.

1 mark

- b. Calculate the amount (in mol) of $\text{MnO}_4^-(\text{aq})$ required to reach the endpoint.

- c. Determine the amount (in mol) of oxalic acid in the aliquot.

1 mark

- d. Determine the mass of pure oxalic acid in the original sample.

2 marks

- e. Hence determine the percentage of pure oxalic acid in the sample.

1 mark

- f. State **one** source of error that could affect the accuracy of this determination.

1 mark

Total 7 marks

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TEST 1: GRAVIMETRIC AND VOLUMETRIC ANALYSIS

SUGGESTED SOLUTIONS AND MARKING SCHEME

SECTION A: MULTIPLE-CHOICE QUESTIONS

Question 1 C

$$\text{C:H:S} = \frac{25.0}{12.0} : \frac{8.30}{1.00} : \frac{66.7}{32.1} = 2.08:8.30:2.08 = 1:4:1$$

The empirical formula is CH_4S .

A common error in the determination of empirical formulas is to determine the percentage ratio rather than the mole ratio. In this case the ratio 25.0:8.30:66.7 leads to an answer of C_3HS_8 , which cannot be feasible in terms of bonding, so the answer is not **D**.

A ignores the percentage composition altogether and simply lists the elements present, so it is incorrect.

B looks correct as the sulfur atom has replaced one of the hydrogen atoms in methane and hence the new name is 'methane with thiol', the suffix thiol being derived from the Greek term for sulfur. Nevertheless, sulfur forms two bonds and so the formula is wrong.

Question 2 A

A redox reaction always involves a change in oxidation numbers.

In **A**, the oxidation number of nitrogen changes from +4 (NO_2) to +5 (HNO_3) and +2 (NO). Nitrogen undergoes both oxidation and reduction.

B is a precipitation reaction. There is no change in oxidation number.

C is an organic substitution reaction. There is no change in oxidation number.

D is an acid/base reaction. A transfer of protons (H^+) occurs.

Question 3 D

Pipettes, burettes and conical flasks are all widely used in volumetric analyses and might possibly be useful for a gravimetric analysis, but only the analytical mass balance is essential. Once a precipitate has been formed in gravimetric (from the Latin *gravis* = heavy and *metros* = to measure) analysis it must be dried and accurately weighed to constant mass.

Question 4 **A**

$$n(\text{Mn}_2\text{O}_7) = \frac{m}{M} = \frac{0.232}{221.8}$$

$$n(\text{Mn}^{2+}) = n(\text{Mn}) = \frac{2 \times 0.232}{221.8}$$

$$\text{mass of Mn} = n \times M = \frac{2 \times 0.232 \times 54.9}{221.8}$$

$$\% \text{ mass of Mn in ore} = \frac{2 \times 0.232 \times 54.9 \times 100}{221.8 \times 5.00}$$

In **B**, there was a division by 2, even though there are two atoms of manganese in every one particle of Mn_2O_7 . **C** is the percentage mass of the entire precipitate, rather than the manganese. In **D**, the formula for determining the number of mole of Mn_2O_7 precipitate formed is confused as $m \times M$ and so is incorrect.

Question 5 **B**

To be able to function as a primary standard and so make up solutions of accurately known concentrations that will remain stable over time, a chemical needs to be highly pure, have known chemical formula and not be reactive with moisture or atmospheric gases and so **A**, **C** and **D** are all correct.

It is preferable that the compound has a relatively high molecular mass as this will proportionately reduce mass measurement errors. Low molecular masses will magnify such errors. For example, suppose compound **A** has a molecular mass of 20 and compound **B** a molecular mass of 200. A weighing error of 0.5 g will cause an error of 2.5% if compound **A** is used but only 0.25% for compound **B**.

Question 6 **A**

$$n(\text{Na}_2\text{CO}_3) = c \times V = 0.582 \times 0.0173 = 0.0101 \text{ mol}$$

$$\text{From the equation, } n(\text{H}_3\text{PO}_4) \text{ required} = \frac{2}{3} \times n(\text{Na}_2\text{CO}_3) = 0.00671 \text{ mol}$$

$$V(\text{H}_3\text{PO}_4) = \frac{n}{c} = \frac{0.00671}{0.455} = 0.0148 \text{ L} = 14.8 \text{ mL}$$

If the mole ratio of H_3PO_4 to Na_2CO_3 is ignored the $n(\text{H}_3\text{PO}_4)$ is the same as $n(\text{Na}_2\text{CO}_3)$ and the calculated volume of acid required is 22.1 mL (so **B** is incorrect). If the mole ratio is taken as 3:2 (instead of the correct ratio 2:3), the calculated volume of acid required is 33.2 mL (so **C** is incorrect). If the mole ratio is taken as 2:1, the calculated volume of acid required is 44.3 mL (so **D** is incorrect).

Question 7 **C**

$$\text{From the equation, } n(\text{CO}_2) \text{ produced} = \frac{3}{3} \times n(\text{Na}_2\text{CO}_3) = 0.0101 \text{ mol}$$

$$pV = nRT, \text{ so } V = \frac{nRT}{p} = \frac{0.0101 \times 8.31 \times 308}{110} = 235 \text{ mL}$$

If the mole ratio of Na_2CO_3 to CO_2 is taken as 3:1 (instead of the correct ratio 3:3 or 1:1) the calculated volume of carbon dioxide gas produced is 705 mL (so **D** is incorrect). If the temperature is taken as 35°C rather than 308 K when using $PV = nRT$, the calculated volume of carbon dioxide gas produced is 26.7 mL (so **A** is incorrect). If the formula $PV = nRT$ is incorrectly transposed to $V = \frac{nRP}{T}$, the calculated volume of carbon dioxide gas produced is 30.0 mL (so **B** is incorrect).

Question 8 **D**

In gravimetric analyses the substance to be analysed is dissolved in water, filtered to remove insoluble impurities and reacted with a suitable precipitating agent, so **A** and **C** are correct. Once formed, the precipitate is collected, dried and weighed, so **B** is also correct. Titration using a suitable indicator is part of volumetric procedures, not gravimetric analysis, so the required answer is **D**.

Question 9 **B**

At the equivalence point for a volumetric analysis, the number of mole of reactants are in stoichiometric ratio according to the equation.

The equation to represent the reaction is $\text{HCl(aq)} + \text{NH}_3(\text{aq}) \rightarrow \text{NH}_4^+(\text{aq}) + \text{Cl}^-(\text{aq})$.

At the equivalence point, all of the HCl and NH_3 have been consumed, but the conjugate acid of the weak base NH_3 has been formed. Therefore the NH_4^+ causes the pH of the resulting solution to drop below 7. The most suitable indicator is one which changes pH just below 7. Methyl red is the correct answer.

Even though ammonia is a weak base it will still react to completion in the presence of the strong acid HCl. At equivalence point the acid does not 'win' and so does not produce an acidic solution with a low pH. If this was the case, thymol blue would be the correct response. Conversely, if some of the weak base ammonia were still present at equivalence point the solution would be slightly alkaline and phenolphthalein would be the most suitable indicator. Alizarin yellow would only be correct if a strongly alkaline solution was present at equivalence point. As we are reacting a strong acid with a weak base this result is difficult to imagine.

Question 10 **C**

The endpoint in a volumetric analysis is that point at which the indicator changes colour. Ideally it should occur directly after the equivalence point. The equivalence point for a volumetric analysis is that stage when the number of mole of reactants are in stoichiometric ratio according to the equation. For this reaction of a strong acid with a strong base, the solution at equivalence point is neutral. The equation to represent the reaction is $\text{HCl(aq)} + \text{NaOH(aq)} \rightarrow \text{NaCl(aq)} + \text{H}_2\text{O(l)}$.

At the endpoint a small excess of NaOH is present, as NaOH was added to the solution of HCl. This will cause the pH to be greater than 7 and the phenolphthalein indicator will turn from colourless to pink. The correct answer is **C**.

Thymol blue indicator will turn yellow at a low pH of around 2 and so will definitely not be blue at a pH of above 7, so **A** is incorrect. Methyl red will be peach coloured at a pH of about 5 (within the range 4.4 to 6.2). It will be yellow at a pH of above 7, so **B** is incorrect. Alizarin yellow indicator will turn lilac at a pH in excess of 12. It will still be yellow at a pH of around 8, so **D** is incorrect.

SECTION B: SHORT-ANSWER QUESTIONS

Question 1

- a. $n(\text{H}_2\text{O}) = \frac{m}{M} = \frac{5.038}{18.0} = 0.2799 \text{ mol}$
 $\therefore n(\text{H}) = 0.5598 \text{ mol}$
 $\therefore m(\text{H}) = 0.5598 \text{ g}$ 1 mark
- b. $V(\text{CO}_2) = V(\text{gaseous mixture}) - n(\text{N}_2) = 6.855 \text{ L} - 0.9791 \text{ L} = 5.876 \text{ L}$ 1 mark
 $n(\text{CO}_2) = \frac{V}{V_M} = \frac{5.876}{24.5} = 0.2398 \text{ mol}$
 $\therefore n(\text{C}) = 0.2398 \text{ mol}$
 $\therefore m(\text{C}) = n \times M = 0.2398 \times 12.0 = 2.878 \text{ g}$ 1 mark
- c. $n(\text{N}_2) = \frac{V}{V_M} = \frac{0.9791}{24.5} = 0.03996 \text{ mol}$
 $\therefore n(\text{N}) = 0.07993 \text{ mol}$
 $\therefore m(\text{N}) = n \times M = 0.07993 \times 14.0 = 1.119 \text{ g}$ 1 mark
- d. $m(\text{O}) = 7.116 - 0.5598 - 2.878 - 1.119 = 2.559 \text{ g}$ 1 mark
- e. $\text{C:H:N:O} = \frac{2.878}{12.0} : \frac{0.5598}{1.00} : \frac{1.119}{14.0} : \frac{2.559}{16.0}$ 1 mark
 $= 0.2398 : 0.5598 : 0.0799 : 0.1599$
 $= \frac{0.2398}{0.0799} : \frac{0.5598}{0.0799} : \frac{0.0799}{0.0799} : \frac{0.1599}{0.0799}$
 $= 3 : 7 : 1 : 2$
 The empirical formula is $\text{C}_3\text{H}_7\text{NO}_2$. 1 mark
- f. $M(\text{C}_3\text{H}_7\text{NO}_2) = 3 \times 12 + 7 \times 1 + 14 + 2 \times 16 = 89$, and so the molecular formula is the same as the empirical formula: $\text{C}_3\text{H}_7\text{NO}_2$. 1 mark

Total 8 marks

Question 2

- $n(\text{NaOH}) = c \cdot V = 0.338 \times 0.03182 = 0.0108 \text{ mol}$ 1 mark
- From the equation, $n(\text{H}_3\text{C}_6\text{H}_5\text{O}_7)$ required $= \frac{1}{3} \times n(\text{NaOH}) = 3.59 \times 10^{-3} \text{ mol}$ 1 mark
- $c(\text{H}_3\text{C}_6\text{H}_5\text{O}_7) = \frac{n}{V} = \frac{3.59 \times 10^{-3}}{0.02000} = 0.179 \text{ M}$ 1 mark

Total 3 marks

Question 3

- a. The precipitate may still have been wet and so it needed to be weighed to constant mass to ensure that all water had been removed. 1 mark
- b. mass of magnesium pyrophosphate precipitate $= \frac{0.255 + 0.253 + 0.255}{3} = 0.254 \text{ g}$ 1 mark
- c. $n(\text{Mg}_2\text{P}_2\text{O}_7) = \frac{m}{M} = \frac{0.254}{222.6} = 1.14 \times 10^{-3} \text{ mol}$, so $n(\text{P}) = 2 \times 1.14 \times 10^{-3} = 2.28 \times 10^{-3} \text{ mol}$ 1 mark
 mass of phosphorus $= n \times M = 2.28 \times 10^{-3} \times 31.0 = 0.0707 \text{ g}$ 1 mark

- d. $n(\text{P}) = n(\text{PO}_4^{3-}) = 2.28 \times 10^{-3} \text{ mol}$
 $\therefore \text{mass of phosphate} = n \times M = 2.28 \times 10^{-3} \times 95.0 = 0.217 \text{ g}$ 1 mark
 $\therefore \% \text{ mass of phosphate in detergent} = \frac{0.217}{3.28} \times \frac{100}{1} = 6.61\%$ 1 mark
- e. Any one of:
- The precipitate may not have been fully dried before weighing.
 - Other agents in the detergent may have also reacted with the sodium pyrophosphate to produce more precipitate.
 - The precipitate may not have been effectively washed to remove any adsorbed ions of unreacted sodium pyrophosphate or other components of the detergent.
 - any other appropriate answer
- 1 mark
Total 7 marks

Question 4

- a. $\text{H}_2\text{C}_2\text{O}_4(\text{aq}) \rightarrow 2\text{CO}_2(\text{g}) + 2\text{H}^+(\text{aq}) + 2\text{e}^-$ 1 mark
- b. $n(\text{MnO}_4^-) = c \cdot V = 0.100 \times 0.0179 \text{ mol} = 1.79 \times 10^{-3} \text{ mol}$ 1 mark
- c. From the equation, $n(\text{H}_2\text{C}_2\text{O}_4) = \frac{5}{2} \times n(\text{MnO}_4^-) = 4.48 \times 10^{-3} \text{ mol}$ 1 mark
- d. $n(\text{H}_2\text{C}_2\text{O}_4) \text{ in original sample} = \frac{250.0}{20.00} \times 4.48 \times 10^{-3} = 0.0559 \text{ mol}$ 1 mark
 $\therefore \text{mass of oxalic acid} = n \times M = 0.0559 \times 90.0 = 5.03 \text{ g}$ 1 mark
- e. $\% \text{ mass of pure oxalic acid in sample} = \frac{5.03}{7.18} \times \frac{100}{1} = 70.1\%$ 1 mark
- f. Any one of:
- The endpoint of the reaction (when the colour change was first noted) may not have been accurately determined.
 - There may have been other reductant species in the impure oxalic sample that also reacted with the permanganate ions.
 - There may have been inaccuracies in reading volumes of solutions or masses of reactants.
 - Permanganate solutions react with atmospheric oxygen and so the concentration of this solution may not have been accurately known.
 - any other appropriate answer

1 mark
Total 7 marks