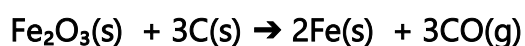


Item 1

A Ugandan steel manufacturing company in Jinja Industrial Park has just received a firm export order for 50 tonnes of iron to be delivered within the next production cycle. The company uses locally sourced iron ore that is only 75 % Fe₂O₃ by mass (the remaining 25 % is inert impurity). The reduction process relies on charcoal (assumed pure carbon) in a blast-furnace-type operation according to the simplified overall reaction:



The procurement officer must decide how much charcoal to purchase, while the environmental compliance officer is concerned about the large volume of carbon dioxide that will be emitted and the resulting carbon tax liability (2 500 UgX per tonne of CO₂ released). Management is under pressure to keep production costs low and meet environmental regulations before the order can be fulfilled.

The production manager has invited your A-Level Chemistry class to review the process data and provide a full technical evaluation ahead of the urgent procurement and compliance meeting scheduled for next week. As the head of your Chemistry study group, the teacher has selected you to produce a technical report advising the procurement and environmental compliance officer.

Task

Prepare a technical report for the procurement and environmental compliance team.

Expected Learner Response

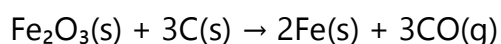
Charcoal Procurement, Carbon Dioxide Emissions and Carbon Tax Assessment for 50 Tonnes Iron Production.

Prepared for: Procurement Officer and Environmental Compliance Officer
Jinja Steel Manufacturing Company.

Date: _____

1. Introduction.

The company has received an export order for 50 tonnes of iron. The iron ore available is only 75 % Fe₂O₃ by mass (25 % inert impurity). Reduction is carried out using charcoal (pure carbon) according to the simplified blast-furnace reaction:



This report calculates the exact quantity of charcoal required, the total carbon dioxide emitted, the resulting carbon tax liability at 2 500 UgX per tonne of CO₂, and provides evidence-based recommendations for cost control and environmental protection.

2. Calculations and Results

2.1 Mass of charcoal required.

Mass of iron required = 50 tonnes = 50 000 kg = 5.0×10^7 g

Molar mass of Fe = 56 g mol⁻¹

Moles of Fe = $\frac{5.0 \times 10^7}{56} = 892857 \text{ mol}$

From the balanced equation:

2 mol Fe are produced from 3 mol C

Moles of C required = $\frac{3}{2} \times 892857 = 1339286 \text{ mol}$

Molar mass of C = 12 g mol⁻¹

Mass of charcoal required = $1\,339\,286 \times 12 = 16\,071\,429 \text{ g} = 16.071$ tonnes.

For the charcoal that is only 75% carbon mass required is $\frac{16.071}{0.75} = 21.428 \text{ tonnes}$

2.2 Carbon dioxide emissions

From the equation, 3 mol CO are produced per 2 mol Fe

Moles of CO produced = $\frac{3}{2} \times 892857 = 1339286 \text{ mol}$

Assuming complete oxidation of CO to CO₂ in the exhaust gases:

Moles of CO₂ = 1 339 286 mol

Molar mass of CO₂ = 44 g mol⁻¹

Mass of CO₂ emitted = $1\,339\,286 \times 44 = 58\,928\,584 \text{ g} = 58.93$ tonnes.

2.3 Carbon tax liability

Tax rate = 2 500 UgX per tonne of CO₂

Total carbon tax = $58.93 \times 2\,500 = \text{UgX } 147\,325\,000$.

3. Discussion

The calculations assume 100 % conversion efficiency and that all carbon monoxide is eventually converted to carbon dioxide in the furnace exhaust. The 75 % purity of the ore was taken into account by basing the calculation solely on the actual mass of Fe₂O₃ required to produce 50 tonnes of iron. The inert impurity does not participate in the reaction and does not affect the stoichiometry.

4. Environmental and Health Management Concerns

The process releases approximately 58.93 tonnes of CO₂ per 50-tonne batch. This contributes to greenhouse gas emissions and attracts a significant carbon tax. Charcoal production itself may involve deforestation, while CO₂ and other furnace gases affect air quality in the Jinja industrial area.

5. Recommendations

- 5.1. Purchase 16.071 tonnes of charcoal.
- 5.2. Budget at least UgX 147 325 000 for carbon tax on this order.
- 5.3. Install or improve CO₂ capture and monitoring systems to reduce actual emissions and tax liability.
- 5.4. Explore partial substitution of charcoal with hydrogen-based reduction technologies in future upgrades.
- 5.5. Conduct energy-efficiency audits to minimise charcoal consumption per tonne of iron produced.
- 5.6. Engage in reforestation programmes to offset the environmental impact of charcoal use.

6. Conclusion

Producing 50 tonnes of iron will require approximately 16.071 tonnes of charcoal and will generate a carbon tax of UgX 147 325 000. Immediate action on emission reduction and process optimisation is recommended to control costs and meet environmental standards.

Scoring guide:

Basis	Scoring criteria
Interpretation of the scenario (Understanding of the industrial context and what is required)	<p>Score 5 Accurately interprets the production order, the 75 % purity of the ore, the given reaction, the need for charcoal mass/budget, CO₂ emissions and carbon tax. Clear aim and links all parts to the company's crisis.</p> <p>Score 4 – 3 Interprets the scenario and requirements well; minor gaps in linking purity or reaction to calculations.</p> <p>Score 3 – 2 States the general purpose but weak connection to the full industrial problem.</p> <p>Score 2 Misinterprets the task (e.g. ignores purity or tax).</p> <p>Score 1 No relevant interpretation of the scenario. </p>

<p>Analysing the situation (Correct stoichiometry, mass of charcoal, CO₂ mass and tax calculations)</p>	<p>Score 5 – 4 All calculations correct: mass of charcoal = 16.071 tonnes; mass of CO₂ = 58.93 tonnes; tax = 147 325 000 UgX. Full working shown with correct use of 75 % purity (if applied) and balanced equation.</p> <p>Score 3 - 2 Calculations mostly correct; minor arithmetic or rounding errors only.</p> <p>Score 2 Major errors in stoichiometry or units but some correct steps.</p> <p>Score 1 Serious errors in mole ratios or final values.</p>
<p>Logical flow of ideas (Sequence of calculations from known to unknown)</p>	<p>Score 5 All calculations correct: mass of charcoal = 16.071 tonnes; mass of CO₂ = 58.93 tonnes; tax = 147 325 000 UgX. Full working shown with correct use of 75 % purity (if applied) and balanced equation.</p> <p>Score 4 – 3 Calculations mostly correct; minor arithmetic or rounding errors only.</p> <p>Score 2 Major errors in stoichiometry or units but some correct steps.</p> <p>Score 1 Serious errors in mole ratios or final values.</p>
<p>Scientific Communication (Organisation, terminology, use of data, structure of report)</p>	<p>Score 5 Report is exceptionally well-organised (clear headings, equations), uses precise chemical terminology and presents all data clearly.</p> <p>Score 4 – 3 Report well-structured and mostly clear; minor issues with section labelling or terminology.</p> <p>Score 2 Report has basic structure but limited use of equations.</p> <p>Score 1 Report lacks clear structure; terminology inconsistent.</p> <p>Score 0 Report incoherent or unreadable.</p>

Recommendations for optimisation (Environmental protection and practical advice)	Score 5 Excellent, evidence-based recommendations for reducing charcoal use, lowering CO ₂ emissions and meeting environmental regulations, with realistic suggestions linked to the company's operations.
	Score 4 Good recommendations with some environmental focus; minor gaps.
	Score 3 – 2 Basic recommendations mentioned but superficial.
	Score 1 Recommendations weak or unrelated to the scenario.

Item 2

A copper refining and export company is facing a major quality-control crisis. International buyers have questioned the purity and isotopic composition of recent copper shipments. The company's analytical laboratory has used a mass spectrometer on a representative sample and provided the following isotopic data for copper:

Isotope	Isotopic mass
⁶³ Cu	62.93
⁶⁵ Cu	64.93

Management needs a full scientific explanation of how the mass spectrometer works, in determining the accurate relative atomic mass of an element; how the percentage abundances can be determined when the relative atomic mass is known, and an evaluation of the strengths and limitations of using mass spectrometry for routine industrial quality control before the next shipment is approved.

Task

As a student of Chemistry, analyse this situation and provide a write up of a technical report for the quality-control and export team of the company.

Expected Response

Determination of Accurate Relative Atomic Mass of Copper and Evaluation of Mass Spectrometry for Industrial Quality Control

Prepared for: Quality-Control and Export Team

Copper Refining and Export Company

Date: _____

1. Executive Summary

The company is experiencing a quality-control crisis due to buyer concerns about the purity and isotopic composition of copper shipments. Mass spectrometric data for the two naturally occurring isotopes of copper (^{63}Cu and ^{65}Cu) have been provided. This report explains the operating principle of a mass spectrometer, shows how the accurate relative atomic mass is calculated from isotopic masses and abundances, demonstrates how percentage abundances can be determined when the relative atomic mass is known, and evaluates the strengths and limitations of mass spectrometry for routine industrial quality control.

2. Principle and Mechanism of Mass Spectrometry

A mass spectrometer determines relative atomic masses by separating ions according to their mass-to-charge ratio (m/z). The fundamental process involves four main stages:

Vaporisation and ionisation: The copper sample is vaporised and bombarded with high-energy electrons, forming positively charged ions (mainly Cu^+).

Acceleration: The ions are accelerated through an electric field to give them the same kinetic energy.

Deflection: The ions enter a magnetic field where they are deflected along circular paths whose radii are proportional to the mass – charge ratios. Lighter ions ($^{63}\text{Cu}^+$) are deflected more than heavier ions ($^{65}\text{Cu}^+$).

Detection: The separated ions strike a detector, producing a signal proportional to their abundance. The resulting mass spectrum shows peaks at $m/z = 62.93$ and 64.93 .

3. Calculation of Accurate Relative Atomic Mass

The accurate relative atomic mass (A_r) is the weighted average of the isotopic masses according to their abundances:

$$A_r = \frac{\sum(\text{isotopic mass} \times \text{percentage abundance})}{100}$$

Using the given isotopic masses:

^{63}Cu : 62.93

^{65}Cu : 64.93

The internationally accepted A_r of copper is 63.5. Substituting into the equation allows calculation of the percentage abundances. (Section 4)

4. Determination of Percentage Abundances from Known A_r

Let the percentage abundance of $^{63}\text{Cu} = x \%$

Then the percentage abundance of $^{65}\text{Cu} = (100 - x) \%$

$$63.5 = \frac{62.93x + 64.93(1 - x)}{100}$$

$x = 71.5\%$ (^{63}Cu)

Therefore, % abundance of $^{65}\text{Cu} = 28.5\%$.

5. Evaluation of Mass Spectrometry for Industrial Quality Control

Advantages

- Extremely accurate and precise for isotopic masses and abundances.
- Can detect very small differences in isotopic composition, which is critical for verifying purity and origin of copper.
- Fast once the sample is prepared; suitable for high-throughput quality control.
- Non-destructive when only small samples are used and requires only minute amounts of the test sample.

Limitations

- Very expensive equipment and requires highly trained operators.
- Needs high vacuum and careful sample preparation.
- Not suitable for routine daily checks on every shipment due to cost and time.
- Can be affected by instrumental errors or contamination if not properly calibrated.

6. Recommendations

- Adopt mass spectrometry as the primary verification method for export shipments to rebuild buyer confidence because it is very accurate.
- Use the calculated abundances (approximately 69–71 % ^{63}Cu and 29–31 % ^{65}Cu) as the standard reference for future batches.
- Combine mass spectrometry with cheaper routine tests (e.g., density or conductivity) for day-to-day quality control.
- Invest in staff training.

7. Conclusion

Mass spectrometry provides the most reliable method for determining accurate relative atomic mass and isotopic composition. The company should use the data and calculations in this report to verify and certify future shipments, thereby resolving the current quality-control crisis and strengthening its position in the international market.

Scoring guide

Basis	Criteria
Interpretation of the scenario	<p>Score 5 Fully interprets the quality-control crisis and clearly links all required elements (mass spectrometer mechanism, Ar calculation, abundance calculation from known Ar, and evaluation).</p> <p>Score 4 Interprets the scenario well with only minor gaps in linking to the company's crisis.</p> <p>Score 3 General understanding of the task but weak connection to the industrial context.</p> <p>Score 2 – 1 Misinterprets the task or omits key requirements.</p> <p>Score 0 No relevant interpretation.</p>
Analysis of data (application).	<p>Score 5 Correctly uses isotopic masses, calculates Ar using weighted average, solves for % abundances from Ar = 63.5 with full working, and accurately explains mass spectrometer mechanism.</p> <p>Score 4 Calculations mostly correct; minor arithmetic errors only.</p> <p>Score 3 – 2 Some correct steps but significant errors in abundance calculation or mechanism.</p> <p>Score 1 Major errors in calculations or mechanism description.</p> <p>Score 0 No meaningful analysis.</p>
Logical flow of ideas	<p>Score 5 Clear, logical sequence: scenario → mass spectrometer principle → Ar calculation → abundance calculation from known Ar → evaluation. All steps explained with equations and units.</p> <p>Score 4 – 3 Logical sequence with only minor omissions.</p> <p>Score 2 Basic sequence but some steps out of order.</p> <p>Score 1 Ideas scattered and illogical.</p>

Scientific Communication	<p>Score 5 Report exceptionally well-organised (headings, equations, clear layout), uses precise terminology, and presents data professionally.</p> <p>Score 4 Report well-structured and mostly clear.</p> <p>Score 3 Basic structure; terminology mostly correct but limited visuals/equations.</p> <p>Score 2 – 1 Poor organisation; terminology inconsistent.</p>
Recommendations	<p>Score 5 Excellent, evidence-based recommendations for industrial use of mass spectrometry, clearly addressing quality control and export needs.</p> <p>Score 4 Good recommendations with some practical focus.</p> <p>Score 3 – 2 Basic recommendations mentioned but superficial.</p> <p>Score 1 Recommendations weak or unrelated.</p>

Item 3

It has been established by the physical sciences that some elements like sodium have identical atoms of mass 23u in nature while others like magnesium and lithium do not. Those of magnesium have mass, 23.99, 24.99 and 25.98 and occur in a natural sample at rates of 78.99%, 10.00% and 11.01% respectively.. The average atomic mass of lithium is 6.94 and its atoms have masses of 6 and 7. To Nahabwe Justine, a new comer to your class, this poses a problem in her understanding. She wonders (i) how does it happen that an element can have different atoms and (ii) how then can the mass of one atom of an element with different atoms be worked out. She also insists that in a natural sample, all atoms whether identical or not must occur at the same rate.

Task

As a student of Chemistry help Justine understand by writing a brief technical write up that answers Justine's questions.

Technical write up

Explaining Isotopes and Relative Atomic Mass to Nahabwe Justine

Dear Justine,

I am happy to help you understand why some elements (like sodium) have identical atoms while others (like magnesium and lithium) have atoms of different masses, and how we still arrive at a single relative atomic mass for each element.

1. Why some elements have identical atoms and others do not

Atoms of the same element always have the same number of protons (same atomic number). However, they can have different numbers of neutrons.

Atoms with the same atomic number but different mass numbers are called isotopes.

- Sodium has only one naturally occurring isotope: all its atoms have 11 protons and 12 neutrons, giving a mass of 23 u. That is why all sodium atoms are identical.
- Magnesium has three isotopes:
 ^{24}Mg (mass 23.99 u)
 ^{25}Mg (mass 24.99 u)
 ^{26}Mg (mass 25.98 u)

Lithium has two isotopes: ^6Li (mass 6 u) and ^7Li (mass 7 u).

Isotopes occur because neutrons can vary while the number of protons (which defines the element) stays the same.

2. How the relative atomic mass is calculated.

The relative atomic mass (A_r) of an element is the weighted average of the masses of its isotopes, taking into account their natural abundances (percentage occurrence).

Example with magnesium (using the data you were given):

$A_r(\text{Mg}) = (\text{mass of } ^{24}\text{Mg} \times \% \text{ abundance}) + (\text{mass of } ^{25}\text{Mg} \times \% \text{ abundance}) + (\text{mass of } ^{26}\text{Mg} \times \% \text{ abundance})$

$$A_r = \frac{\sum(\text{isotopic mass} \times \text{percentage abundance})}{100}$$
$$A_r = \frac{(23.99 \times 78.99) + (24.99 \times 10.00) + (25.98 \times 11.01)}{100}$$

$$A_r = 24.31$$

Example with lithium ($A_r = 6.94$):

Let % abundance of ${}^6\text{Li} = x$

Then % abundance of ${}^7\text{Li} = 100 - x$

$$6.94 = (6 \times x + 7 \times (100 - x)) / 100$$

$$694 = 6x + 700 - 7x$$

$$694 - 700 = -x$$

$$x = 6 \%$$

Therefore, lithium is approximately 6 % ${}^6\text{Li}$ and 94 % ${}^7\text{Li}$. This weighted average gives the value 6.94 that we use in calculations.

3. Addressing your concern about equal abundances

You thought that in a natural sample all atoms (whether identical or not) must occur at the same rate. This is not correct. Isotopes of the same element are formed by different nuclear processes in stars and supernovae, so nature produces them in unequal proportions. Magnesium has far more ${}^{24}\text{Mg}$ than ${}^{25}\text{Mg}$ or ${}^{26}\text{Mg}$, and lithium is mostly ${}^7\text{Li}$. Only sodium happens to have just one stable isotope.

4. Conclusion.

Elements can have different atoms (isotopes) because of varying numbers of neutrons.

The relative atomic mass is a weighted average that reflects the natural abundances of those isotopes.

Mass spectrometry is the instrument that measures both the masses and the abundances of isotopes, allowing us to calculate accurate relative atomic masses for use in chemistry.

I hope this clears up the confusion.

Scoring Guide

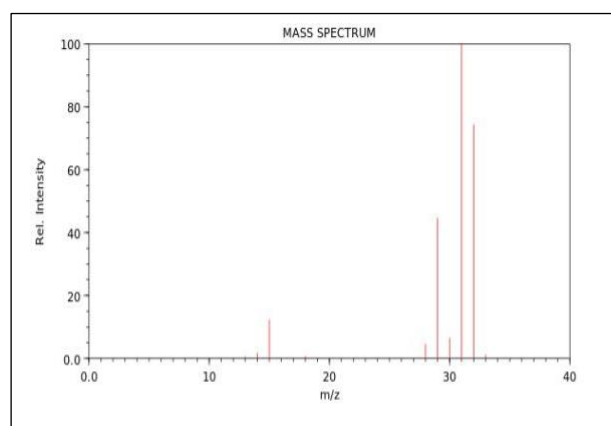
Basis	Scoring criteria
Interpretation of the scenario / task	Score 5 – 4 Fully interprets Justine's three specific questions and links them clearly to the concepts of isotopy, calculation of relative atomic mass, and the misconception about equal abundances. Score 3 Interprets the questions well with only minor gaps. Score 2 Identifies the main questions but weak or incomplete linkage. Score 1

	Misinterprets or omits one or more of Justine's questions.
Analysis of data / application	<p>Score 5 – 4 Correctly uses magnesium data to calculate A_r, solves for lithium abundances using $A_r = 6.94$, and explains the weighted-average concept with accurate working.</p> <p>Score 3 Calculations mostly correct; minor arithmetic errors only.</p> <p>Score 2 Some correct steps but significant errors in abundance calculation.</p> <p>Score 1 – 0 Major errors in calculations or fails to show working; No meaningful analysis or calculations.</p>
Logical flow of ideas	<p>Score 5 – 4 Clear, logical sequence: definition of isotopes → examples (Na, Mg, Li) → calculation of A_r for Mg → calculation for Li → correction of misconception. All steps explained clearly.</p> <p>Score 3 Logical sequence with only minor omissions.</p> <p>Score 2 Basic sequence but some ideas out of order.</p> <p>Score 1 - 0 Ideas scattered and illogical; No logical flow.</p>
Scientific Communication	<p>Score 5 – 4 Write-up is well-organised, uses precise terminology (isotope, relative atomic mass, weighted average, abundance), and is easy to understand for a newcomer.</p> <p>Score 3 Write-up is clear and mostly well-structured.</p> <p>Score 2 Basic structure; terminology mostly correct but some confusion.</p> <p>Score 1 – 0 Poor organisation or inconsistent terminology. Write-up incoherent or difficult to follow.</p>
Addressing the questions and recommendations	<p>Score 5 Fully and accurately answers all three of Justine's questions, corrects the misconception clearly, and provides helpful, encouraging explanations.</p>

	<p>Score 4 Good answers to all questions; minor gaps in clarity or completeness.</p> <p>Score 3 – 2 Answers most questions but superficial or misses one. Answers are weak or incomplete.</p> <p>Score 1 – 0 Does not address the questions meaningfully.</p>
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Item 4

The Kampala Metropolitan Police recently raided an illegal bar in the suburbs, seizing barrels of homemade alcohol being sold as "local gin." Laboratory analysis revealed the presence of an adulterant liquid Q (suspected to be methanol) mixed with ethanol. The police forensic lab performed mass spectrometry on Q, producing the following fragmentation pattern.



The forensic team is unfamiliar with interpreting mass spectra and has asked for chemistry student assistance to identify Q quickly, explain the fragmentation, and recommend urgent public health measures to prevent further poisoning. Most of the team does not appreciate how the mass spectrometer works or why it is valuable for identifying dangerous adulterants in illicit alcohol. The challenge is to use the spectrum data to confirm Q's identity, explain the key fragments, and propose solutions to stop the distribution of adulterated alcohol while educating the public and authorities on detection methods.

Task

As a chemistry student assisting the police forensic team, write a concise explanatory report you would submit to the officers and health officials and community leaders.

Expected learner response

Technical Report

Identification of Adulterant Q in Seized Illicit Alcohol and Public Health Recommendations

Submitted to:

Kampala Metropolitan Police Forensic Team, Health Officials and Community Leaders

Date: _____

1. Executive Summary

Laboratory analysis of the seized "local gin" shows the presence of an adulterant liquid Q mixed with ethanol. Mass spectrometric data confirm that Q is methanol (CH_3OH). This report explains how the mass spectrometer works, interprets the fragmentation pattern, identifies Q, and provides urgent evidence-based recommendations to protect the public from methanol poisoning.

2. Principle of Mass Spectrometry

A mass spectrometer identifies substances by separating and detecting ions according to their mass-to-charge ratio (m/z). The main stages are:

Vaporisation and ionisation: The sample is vaporised and bombarded with high-energy electrons that not only ionise the molecules but cause bonds to break to form positively charged molecular ions and fragments.

Acceleration: Ions are accelerated by an electric field.

Deflection: Ions pass through a magnetic field; lighter ions are deflected more than heavier ones to move in a circular path. The radii of these paths are proportional to the mass – charge ratios of the ions.

Detection: Ions strike a detector, producing a spectrum of peaks showing relative abundance versus m/z .

3. Identification of Q and Interpretation of the Mass Spectrum

The molecular ion peak at $m/z = 32$ corresponds to the relative molecular mass of methanol (CH_3OH).

Key fragments observed:

m/z 32 due to molecular ion $[\text{CH}_3\text{OH}]^+$;

m/z 31 due to loss of H atom forming $[\text{CH}_2\text{OH}]^+$;

m/z 29 due to further fragmentation to $[\text{CHO}]^+$

m/z 15 due to $[\text{CH}_3]^+$

These characteristic peaks confirm that Q is methanol, not ethanol (which would show a molecular ion at m/z 46). Methanol is highly toxic and was deliberately added to increase the alcohol strength cheaply.

4. Why Methanol is Dangerous

Methanol is metabolised in the body to formaldehyde and formic acid, causing blindness, organ failure and death even in small doses. Its presence in illicit alcohol explains reported cases of poisoning.

5. Recommendations.

- Immediately destroy all seized barrels and trace the supply chain to prevent further distribution.
- Launch a public awareness campaign warning communities about the dangers of homemade alcohol and advising them to buy only from licensed vendors.
- Equip police and public health laboratories with basic mass spectrometers or portable IR spectrometers for rapid field testing of suspected alcohol.
- Collaborate with the National Drug Authority to enforce stricter licensing and random testing of spirit manufacturers.
- Educate bar owners and distillers on safe production practices and the severe legal consequences of methanol adulteration.

Conclusion

The adulterant Q has been identified as methanol using mass spectrometry. Immediate action on seizure, public education and improved detection is essential to prevent further loss of life and restore public confidence in locally produced beverages.

Scoring Guide

Basis	Scoring criteria
Interpretation of the scenario / task	Score 4 – 5 Fully interprets the police raid, forensic problem, and the need to identify Q, explain the mass spectrometer, interpret fragments, and give public health recommendations. Clear aim linked to the crisis. Score 3 Identifies the main task but weak connection to the real-world poisoning crisis. Score 2 – 1 Misinterprets or omits key requirements (e.g. forgets health recommendations).
Analysis of data / application	Score 5 – 4 Correctly identifies Q as methanol ($M_r = 32$), explains key fragments (m/z 32, 31, 29, 15) with accurate reasoning, and describes the mass spectrometer mechanism clearly.

	<p>Score 3 Analysis mostly correct; minor inaccuracies in fragment assignment.</p> <p>Score 2 Identifies methanol but incomplete or incorrect fragment explanation.</p> <p>Score 1 – 0 Major errors in identification or mechanism; No meaningful analysis of the spectrum. </p>
Logical flow of ideas	<p>Score 5 – 4 Clear, logical sequence: scenario → mass spectrometer principle → spectrum interpretation → identification → recommendations. All steps explained coherently.</p> <p>Score 3 Logical flow with only minor omissions.</p> <p>Score 2 – 1 Basic sequence but some ideas out of order; Ideas scattered and illogical.</p>
Scientific Communication	<p>Score 5 - 4 Report is well-organised (headings, clear explanations), uses precise terminology (molecular ion, fragment, m/z), and is easy for non-chemists (police/health officials) to understand. Report well-structured and mostly clear.</p> <p>Score 3 – 2 Basic structure; terminology mostly correct but some confusion.</p> <p>Score 1 – 0 Poor organisation or inconsistent terminology. Report incoherent or difficult to follow.</p>
Recommendations	<p>Score 5 – 4 Excellent, evidence-based, practical recommendations for immediate action, public education, enforcement and prevention, clearly linked to the crisis.</p> <p>Score 3 – 2 Good recommendations with some practical focus. Basic recommendations mentioned but superficial.</p> <p>Score 1 Recommendations weak or unrelated to the scenario.</p>

Item 5

A youth group is working out the formulation of a pH stabilizer for male hormone enhancement juice they are to put on the market. They plan to use an ethanoic acid – sodium ethanoate buffer. To prepare this buffer, they are to first be sure about the quality of an ethanoic acid solution (vinegar) they bought from downtown Kampala. The labels on the cans indicate that the vinegar is 0.05M. To standardise the vinegar, they plan to carry out an acid – base titrimetry using sodium hydroxide solution they have had in storage for over a month and methyl orange as indicator.

Tasks

- a) Explain to the youth group, the shortcomings if any of using their sodium hydroxide solution as a reagent in this situation and propose any mitigation measures you think useful.
- b) In their titration, they found that 25.0 cm³ of the 0.025 M sodium hydroxide required 18.60 cm³ of the vinegar solution for the titration to reach endpoint. Assess the accuracy of the labels on the vinegar cans, clearly explaining your method.

Expected response

Technical write up

Prepared for: The Youth Group formulating pH stabilizer for male hormone enhancement juice

Date: _____

1. Executive Summary

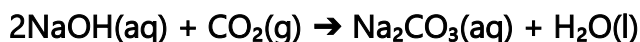
The vinegar you purchased is labelled 0.05 M ethanoic acid, but titration results show it is actually approximately 0.034 M Your stored sodium hydroxide solution is also unsuitable for accurate standardisation because it has likely absorbed atmospheric carbon dioxide. This report explains the problems with the NaOH, proposes mitigation measures, assesses the accuracy of the vinegar label, and gives the correct concentration you should use in your buffer formulation.

2. Shortcomings of Using Stored Sodium Hydroxide Solution

Sodium hydroxide is a strong base but is not stable when stored for long periods. The main problems are:

- As pellets, it is deliquescent, it absorbs water vapour becoming wet and affecting accurate weighing

- It's solutions readily absorb carbon dioxide from the air to form sodium carbonate:



The presence of sodium carbonate reduces the effective concentration of NaOH available in solution.

Your titration results will be inaccurate (the volume of vinegar required will appear higher than it should, leading to an under-estimation of the true ethanoic acid concentration).

3. Assessment of Vinegar Label Accuracy

Titration data:

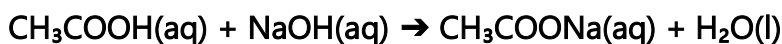
Volume of NaOH used = 25.0 cm³ of 0.025 M solution

Volume of vinegar used = 18.60 cm³

Calculation:

$$\text{Amount of NaOH} = \frac{25 \times 0.025}{1000} = 0.000625 \text{ mol}$$

From the equation :



1 mol NaOH reacts with 1 mol CH₃COOH

Therefore, moles of ethanoic acid in 18.60 cm³ vinegar = 0.000625 mol.

Concentration of ethanoic acid in the vinegar is $\frac{0.000625 \times 1000}{18.60} = 0.0336 \text{ mol dm}^{-3}$ which is approximately 0.034 M.

The vinegar is only 67 % of the concentration stated on the label (0.034 M instead of 0.05 M). The label is inaccurate and overstates the true strength.

4. Recommended Mitigation Measures

- Standardise the sodium hydroxide solution before use against a primary standard such as potassium hydrogen phthalate (KHP).
- Use freshly prepared sodium hydroxide solution whenever possible.
- If storage is unavoidable, keep the sodium hydroxide solution in an airtight container with a soda-lime guard tube to absorb carbon dioxide.
- Use phenolphthalein indicator for this titration because it is between a weak acid and a strong base.
- For highest accuracy, consider using a different primary standard solution instead of the stored NaOH.

This will ensure your pH stabilizer performs reliably and safely in the final juice product.

Scoring Guide

Basis	Scoring criteria
Interpretation of the scenario / task	<p>Score 5 Fully interprets the youth group's formulation crisis, correctly identifies the two tasks (shortcomings of stored NaOH and titration calculation), and links everything to the need for accurate buffer preparation.</p> <p>Score 4 – 3 Interprets the scenario well with only minor gaps in linking to product development.</p> <p>Score 2 Identifies the main tasks but weak connection to the real-world formulation problem.</p> <p>Score 1 – 0 Misinterprets or omits one of the two tasks; No relevant interpretation.</p>
Analysis of data / application	<p>Score 5 – 4 Correctly explains the chemical reason why stored NaOH is unreliable (CO₂ absorption), proposes appropriate mitigation measures, performs accurate titration calculation (0.0336 M / 0.034 M), and clearly states the label is inaccurate.</p> <p>Score 3 – 2 Calculation and explanation mostly correct; minor arithmetic errors only.</p> <p>Score 1 Some correct steps but significant errors in concentration or mitigation suggestion.</p>
Logical flow of ideas	<p>Score 5 – 4 Clear, logical sequence: problem with NaOH → mitigation → titration data analysis → concentration calculation → implications for buffer → recommendations. All steps explained with correct equations and units.</p> <p>Score 3 Logical sequence with only minor omissions.</p> <p>Score 2 Basic sequence but some steps out of order.</p> <p>Score 1 – 0 Ideas scattered and illogical; No logical flow.</p>
Recommendations	<p>Score 5 – 4 Excellent, practical, evidence-based recommendations for accurate standardisation and safe product formulation, clearly linked to the youth group's project.</p>

	<p>Score 3 Good recommendations with some practical focus.</p> <p>Score 2 Basic recommendations mentioned but superficial.</p> <p>Score 1 – 0 Recommendations generic, weak or unrelated; No recommendations.</p>
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Item 6

To do a quality control on a batch of calcium oxide claimed to be 99% pure by the supplier, bought by a poultry farm to be used as a chicken feed additive, the farm nutritionist has proposed an acid – base titrimetry on a sample of the calcium oxide following the procedure below:

Accurately weigh 1.4g of the calcium oxide and dissolve them in 100 cm³ of a 1M hydrochloric acid. Make up the solution to 250 cm³ in a volumetric flask using distilled water. Titrate the resultant solution against a 0.2M sodium hydroxide solution using phenolphthalein indicator.

Tasks

- a) Explain the method proposed by the nutritionist showing why it works.
- b) If in the titration, 20.0 cm³ of the sodium hydroxide required 17.7 cm³ of the resultant solution in the flask, assess the claims of the supplier and advise accordingly

Expected Learner Response

Technical write up

Quality Control Assessment of Calcium Oxide Batch for Poultry Feed Additive

Prepared for: The Nutritionist and Management of the Poultry Farm

Date: _____

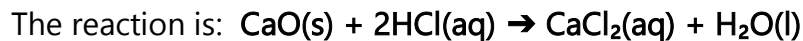
1. Summary

The supplier claims the calcium oxide (CaO) is 99 % pure. However, acid–base back titration results show the actual purity is only approximately 87.0 %. This report explains the proposed titration method and why it works, presents the calculation of the true purity, and advises the farm on the reliability of the supplier and recommended actions.

2. Explanation of the Proposed Method and Why It Works

Calcium oxide is sparingly soluble in water, so a direct titration with NaOH is not possible. The nutritionist’s method is a back titration, which is ideal for sparingly soluble or insoluble bases:

- A known excess of standard hydrochloric acid (1 M, 100 cm³) is added to 1.4 g of CaO.



Any unreacted (excess) HCl is then titrated with standard sodium hydroxide (0.2 M) using phenolphthalein indicator.

This method works because:

- The excess acid ensures complete reaction with the CaO even if it is sparingly soluble.
- The difference between the total acid added and the acid left after reaction gives the exact amount of acid that reacted with the CaO.
- Phenolphthalein gives a sharp endpoint for the strong acid–strong base titration of the excess HCl.

3. Assessment of Supplier's Claim

Titration data:

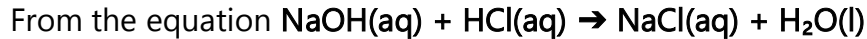
Volume of NaOH used = 20.0 cm³ of 0.2 M solution

Volume of diluted solution titrated = 17.7 cm³

Calculations:

$$\text{Moles of NaOH} = \frac{0.2 \times 20}{1000} = 0.004 \text{ mol}$$

This neutralises the excess HCl in 17.7 cm³ of the 250 cm³ diluted solution.



1 mol NaOH reacts with 1 mol HCl; 17.7 cm³ contains 0.004 mol HCl.

$$\text{Moles of excess HCl in 250 cm}^3 = 0.004 \times \left(\frac{250}{17.7}\right) = 0.0565 \text{ mol}$$

$$\text{Total HCl added} = 100 \text{ cm}^3 \text{ of } 1 \text{ M} = 100 \times \left(\frac{1}{1000}\right) = 0.100 \text{ mol}$$

$$\text{HCl that reacted with CaO} = \text{total HCl} - \text{excess HCl} = 0.100 - 0.0565 = 0.0435 \text{ mol}$$

From the equation, 2 mol HCl react with 1 mol CaO.

$$\text{Moles of CaO} = \frac{0.0435}{2} = 0.02175 \text{ mol}$$

Molar mass of CaO is 40 + 16 = 56 g mol⁻¹

Mass of pure CaO in the sample = 0.02175 × 56 = 1.218 g .

$$\text{Percentage purity} = \frac{1.218}{1.4} \times 100 = 87.0\%$$

Conclusion: The supplier's claim of 99 % purity is inaccurate. The actual purity is only 87.0 %.

4. Recommendations

- Reject the current batch or negotiate a price reduction with the supplier.
- Always perform your own standardisation (back titration) on every new batch of CaO before use in feed formulation.

- Consider sourcing CaO from a more reliable supplier with certified analytical data.

This will ensure the poultry feed additive meets the required calcium content and protects the health of the chickens.

Scoring Guide

Basis	Scoring Criteria
Interpretation of the scenario / task	<p>Score 5 – 4 Fully interprets the poultry farm quality-control crisis and correctly addresses both tasks (explanation of back titration method + purity calculation and advice).</p> <p>Score 3 Interprets the scenario well with only minor gaps in linking to the feed additive context.</p> <p>Score 2 Identifies the main tasks but weak connection to the real-world problem.</p> <p>Score 1 Misinterprets or omits one of the two tasks; No relevant interpretation.</p>
Analysis of data / application	<p>Score 5 – 4 Correctly explains why back titration is necessary, performs accurate calculation (purity = 87.0 %), and clearly states the supplier's claim is inaccurate.</p> <p>Score 3 Calculation and explanation mostly correct; minor arithmetic errors only.</p> <p>Score 2 Some correct steps but significant errors in concentration or purity.</p> <p>Score 1 – 0 Major errors in calculation or explanation of the method; No meaningful analysis.</p>
Logical flow of ideas	<p>Score 5 – 4 Clear, logical sequence: explanation of method → titration data analysis → calculation of purity → conclusion and advice. All steps explained with correct equations and units.</p>

	<p>Score 3 Logical sequence with only minor omissions.</p> <p>Score 2 Basic sequence but some steps out of order.</p> <p>Score 1 – 0 Ideas scattered and illogical; No logical flow.</p>
Scientific Communication	<p>Score 5 – 4 Report is well-organised (clear headings, equations, professional tone), uses precise terminology, and is easy for non-chemists (nutritionist/farm staff) to understand.</p> <p>Score 3 Report well-structured and mostly clear.</p> <p>Score 2 Basic structure; terminology mostly correct but some confusion.</p> <p>Score 1 Poor organisation or inconsistent terminology. Report Incoherent or difficult to follow.</p>
Recommendations	<p>Score 5 – 4 Excellent, practical, evidence-based recommendations for the farm, clearly linked to the quality-control crisis and future prevention.</p> <p>Score 3 Good recommendations with some practical focus.</p> <p>Score 2 Basic recommendations mentioned but superficial.</p> <p>Score 1 – 0 Recommendations weak or unrelated; No recommendations.</p>

Item 8

A truck carrying an industrial radiography source (iridium-192) overturned on the Kampala–Masaka highway near Lukaya town at 10:00 a.m. The container cracked, releasing radioactive material onto the roadside. The National Emergency Coordination Centre (NECC) quickly cordoned off the area and began monitoring activity levels every two hours to determine when the site can be safely accessed for cleanup and when the road can reopen.

The Uganda Atomic Energy Council (UAEC) has set a safe activity threshold for unprotected public access and initial cleanup operations at ≤ 50 counts per minute (cpm) at the accident site. Above this level, workers require full protective gear and limited exposure time; below it, normal traffic and residents can return with minimal risk.

Measured activity readings at the accident location are:

Time after accident occurs (hours)	Activity (counts per minute)
0	1200
2	850
4	600
6	425
8	300

The NECC Director and District Police Commander have urgently contacted you, an independent radiation safety specialist from UAEC, for an expert assessment before the 6:00 p.m. press briefing and public announcement. They need to decide whether the activity will drop below the safe level of 50 cpm soon enough to allow partial reopening overnight or whether full closure must continue.

Task

Prepare a concise technical write up for the NECC Director that clearly shows your scientific treatment of the data and necessary advise.

Expected Learner Response

Assessment of Radioactive Decay at the Kampala–Masaka Highway Accident Site (Iridium-192 Source).

Prepared for :NECC Director and District Police Commander

Date: _____

1. Executive Summary

The released material is iridium-192, undergoing radioactive decay. A graph of $\ln(\text{Activity})$ versus time yields a straight line with gradient = -0.173 h^{-1} , giving a decay constant $\lambda = 0.173 \text{ h}^{-1}$ and a half-life of approximately 4.0 hours.

At 8 hours after the accident, the activity is 300 cpm. Using the integrated rate law, the activity is predicted to fall below the safe threshold of 50 cpm at approximately 18.3 hours after the accident (around 04:20 a.m. tomorrow).

Recommendation: The site must remain fully closed overnight. Protected clean-up operations can begin after midnight, but full public access and normal traffic should only resume after independent verification confirms activity ≤ 50 cpm.

2. Data Analysis and Graph

Radioactive decay follows the integrated rate law:

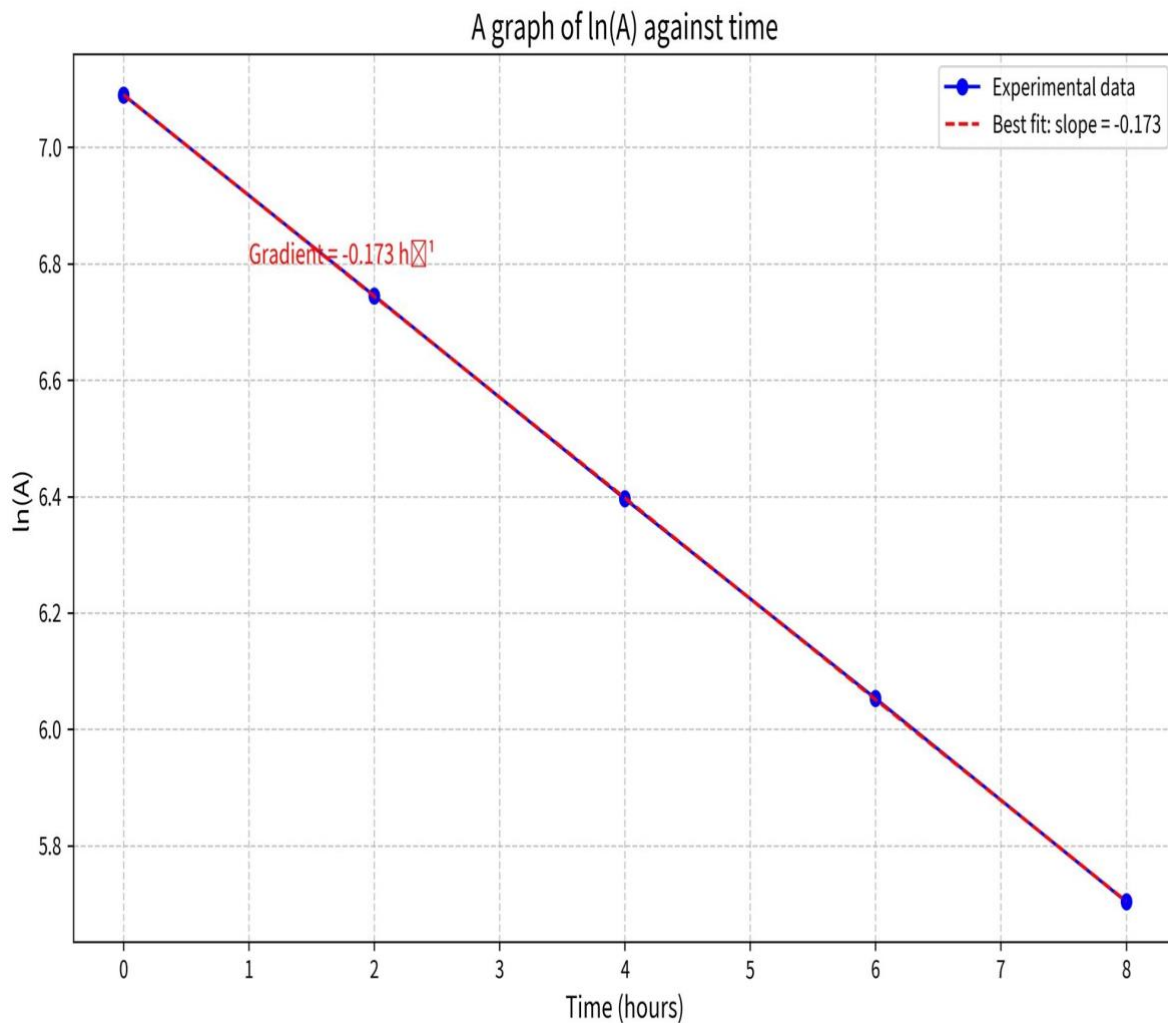
$$\ln(A) = -\lambda t + \ln(A_0)$$

A plot of $\ln(\text{Activity})$ against time is linear with slope = $-\lambda$.

Processed Data

Time (hours)	Activity, A, (cpm)	$\ln(A)$
0	1200	7.090
2	850	6.745
4	600	6.396
6	425	6.053
8	300	5.704

Graph: $\ln(\text{Activity})$ versus time (hours)



The graph is a straight line with negative slope.

Gradient (slope) = -0.173 h^{-1}

Therefore, decay constant $\lambda = 0.173 \text{ h}^{-1}$

Half-life T : $T = \ln 2 / \lambda$

$$T = \frac{\ln 2}{0.173} = 4.0$$

3. Prediction of Time to Safe Level Using Integrated Rate Law

At $t = 8 \text{ h}$, $A = 300 \text{ cpm}$. We need $A \leq 50 \text{ cpm}$.

Using the integrated rate law:

$$\ln\left(\frac{A_0}{A}\right) = \lambda t$$

$$\ln\left(\frac{300}{50}\right) = 0.173t$$

$$t = 10.36 \text{ hours}$$

Total time from accident = $8 + 10.36 = 18.36$ hours.

Clock time: accident at 10:00 a.m. → safe level reached at approximately 04:20 a.m. the following day.

4. Recommendations

- Maintain full road closure and cordon until at least 04:20 a.m.
- Allow protected emergency clean up teams (with full PPE and limited exposure time) to begin work after midnight, provided continuous monitoring confirms the decay trend.
- Perform independent verification measurements at 04:00 a.m. before any public announcement of reopening.
- Issue a public health advisory warning residents not to approach the site and to report any symptoms of radiation exposure.
- In future, ensure all industrial radiography sources are transported in double lead walled, impact-resistant containers.

5. Conclusion

The activity will reach the safe threshold of 50 cpm at approximately 04:20 a.m. tomorrow. Full closure must continue overnight for public safety.

Continuous monitoring remains essential.

Scoring Guide

Basis	Scoring criteria
Interpretation of the scenario / task	<p>Score 5 – 4 Fully interprets the emergency and correctly addresses data analysis (graph of $\ln A$ vs t), half-life from gradient, time prediction using integrated rate law, and safety advice.</p> <p>Score 3 Interprets the scenario well with only minor gaps.</p> <p>Score 2 Identifies the main task but weak connection to the real-world emergency.</p> <p>Score 1 – 0 Misinterprets or omits key requirements (e.g. graph or integrated rate law); No relevant interpretation.</p>
Analysis of data / application	<p>Score 5 – 4 Correctly constructs $\ln(A)$ data, describes the linear graph, calculates gradient = -0.173 h^{-1}, determines λ and $T_{1/2}$, and uses the integrated rate law to predict time to 50 cpm accurately.</p> <p>Score 3</p>

	<p>Analysis mostly correct; minor errors in ln values or gradient only.</p> <p>Score 2 Some correct steps but significant errors in graph treatment or rate-law calculation.</p> <p>Score 1 – 0 Major errors in data processing or fails to use integrated rate law; No meaningful analysis.</p>
Logical flow of ideas.	<p>Score 5 – 4 Clear, logical sequence: data processing → graph description → gradient → λ and half-life → integrated rate-law calculation → recommendations. All steps explained with correct equations.</p> <p>Score 3 Logical sequence with only minor omissions.</p> <p>Score 2 Basic sequence but some steps out of order.</p> <p>Score 1 – 0 Ideas scattered and illogical; No logical flow.</p>
Scientific Communication	<p>Score 5 – 4 Write-up is well-organised (clear headings, data table, graph description), uses precise terminology, and is accessible to emergency officials.</p> <p>Score 3 Write-up well-structured and mostly clear.</p> <p>Score 2 – 1 Basic structure; terminology mostly correct but some confusion.</p> <p>Score 1 – 0 Poor organisation or inconsistent terminology; Write-up incoherent.</p>