Government of Western Australia
School Curriculum and Standards Authority

School Curriculum and Standards Authority

Chemistry

Stage 3 Standards Guide

Exemplification of Standards through the 2011 WACE Examination

2012/2601

CONTENTS

Introductory notes for Chemistry Stage 3 Standards Guide 2011

What are the 'standards' and how were they developed?

Standards describe the kinds of qualities seen in candidate responses in WACE examination conditions. In late 2011, WACE (written) examination scripts for Chemistry Stage 3 were analysed by teacher expert panels who identified the qualities of candidates' scripts at each of five performance bands: 'excellent achievement', 'high achievement', 'satisfactory achievement', 'limited achievement' and 'inadequate achievement'. WACE Course scores were reported against these performance bands.

The band descriptions for Chemistry Stage 3 are provided in Appendix 1.

What do standards tell us?

The standards described through the band descriptions tell us, in general terms, how students need to be performing if they wish to achieve a particular 'standard'. To get a clearer picture of what each standard means, teachers and students can refer to the candidate responses provided. This will help students see what they need to do to improve and help them understand how their work compares with the standards. Standards can also assist teachers in providing students with feedback about their work and see how they might need to modify their teaching.

What is provided in this Standards Guide?

There are five main components in this standards guide:

1. questions from the examination paper
2. the marking key for each question
3. candidate responses and annotated marker notes
4. keywords and examination statistics such as the highest and lowest marks achieved, mean, standard deviation, etc
5. examiner comments.

What standards have been exemplified in this guide?

Sample candidate responses which illustrate 'excellent' and 'satisfactory' performance have been included in this guide, along with marker annotations. In most cases, 'excellent' responses received full marks or close to full marks. If there were no responses judged to be 'excellent', a 'high achievement' response sample may be provided. Judgements about the standard illustrated in a candidate response must also take into account the difficulty of the question. It should also be remembered that overall judgements about standards are best made with reference to a range of performances across a range of assessment types and conditions.

How well did this examination 'target' the ability of candidates?

Rasch analysis of raw examination marks achieved by candidates enables us to provide estimates of question difficulty and student ability, on the same scale. From this relationship, we are able to evaluate how well the questions in this examination were broadly targeted to candidates' abilities.

Table 1 in Appendix 2 provides estimates of the difficulty of each question. Graph 2 (where provided) in Appendix 2 shows the distribution of the student ability and question difficulty. Graph 3 (where provided) shows the distribution of the student ability and item thresholds. Explanatory notes for these graphs are also provided in Appendix 2.

Other points to consider when viewing this guide

Use of half marks

Examination items are marked in whole numbers. Half marks occurring in this guide are a result of averaging the whole number marks from each of two markers.

Section statistics and marks weightings

Section statistics for the highest mark achieved, lowest mark achieved, mean and standard deviation are based on weighted section total marks. Raw mark totals are provided for each section. The raw marks distribution and the weighted total marks distribution is provided on the following page.

Examination standards for 2011 WACE examinations

The analysis of written examination scripts was used to determine performance band descriptions for 2011.

Marks distribution for this examination

Section	Number of questions available	Number of questions to be answered	Suggested working time (minutes)	Marks available	Percentage of exam
Section One: Multiple-choice	25	25	50	25	25
Section Two: Short answer	10	10	60	70	35
Section Three: Extended answer	6	6	70	80	40
				Total	100

Chemistry
Stage 3

Section One: Multiple-choice

25 marks

Note:
Raw section total marks = 25
Weighted section total marks = 25

Weighted section statistics

Statistics ID = CHE3-S01
Number of attempts = 4753
Highest mark achieved = 25.00
Lowest mark achieved = 0.00
Mean = 17.48
Standard deviation = 4.19
Correlation between section and exam = 0.86

This section has **25** questions

Suggested working time: 50 minutes

Examiners' comments for this section

This section was rather easy for candidates, while the questions requiring explanation or mastery of calculations proved more challenging, but were probably pitched at about the right level. Question 5 and Question 8 were the least difficult.

Questions

Questions 1 – 3

Question statistics

1. Consider the ion below.

$$^{115}_{49}\mathrm{In}^{3+}$$

Which one of the following lists the number of protons, neutrons and electrons for this ion correctly?

	Protons	Neutrons	Electrons
(a)	115	49	49
(b)	49	66	49
(c)	49	66	52
(d)	**49**	**66**	**46**

Statistics ID = CHE3-MC-1
Number of attempts = 4753
Correct answer = (d)
(a) = 39 (0.82%)
(b) = 271 (5.70%)
(c) = 243 (5.11%)
(d) = 4197 (88.30%)
Question difficulty = Very easy
Correlation between question and section = 0.34

Refer to the following table to answer Questions 2 and 3.

The table shows the approximate successive molar ionisation energies (in kJ mol^{-1}) of five elements denoted I to V.

Element	Ionisation energy			
	1st	**2nd**	**3rd**	**4th**
I	502	4570	6919	9550
II	580	1820	2750	11600
III	590	1145	4910	6490
IV	744	1460	7740	10550
V	1250	2300	3820	5160

2. Which two elements are most likely to be Group 2 (alkaline earth) metals?

(a) I and III
(b) III and IV
(c) II and V
(d) I and V

Statistics ID = CHE3-MC-2
Number of attempts = 4753
Correct answer = (b)
(a) = 277 (5.83%)
(b) = 4120 (86.68%)
(c) = 159 (3.35%)
(d) = 194 (4.08%)
Question difficulty = Easy
Correlation between question and section = 0.44

3. Which element would react with chlorine to form a compound with the general formula $AC\ell_3$, where A represents one of the five elements (I to V) listed in the table above?

(a) I
(b) II
(c) III
(d) IV

Statistics ID = CHE3-MC-3
Number of attempts = 4753
Correct answer = (b)
(a) = 251 (5.28%)
(b) = 3956 (83.23%)
(c) = 220 (4.63%)
(d) = 322 (6.77%)
Question difficulty = Easy
Correlation between question and section = 0.45

Questions

Questions 4 – 7

Question statistics

4. Which of the following statements about the Group 2 metals are true?

   (i) Their first ionisation energy decreases with increasing atomic number.
   (ii) Two electrons are present in the valence shell of the metal.
   (iii) Their chemical reactivity increases with increasing atomic number.
   (iv) Their +2 (positive) ions have noble gas configurations.
   (v) They are likely to form covalent compounds with Group 17 elements.

(a) (ii) and (iii) only
(b) (iv) and (v) only
(c) (i), (ii), (iii) and (iv)
(d) (i), (ii), (iii), (iv) and (v)

Statistics ID = CHE3-MC-4
Number of attempts = 4753
Correct answer = (c)
(a) = 471 (9.91%)
(b) = 157 (3.30%)
(c) = 3418 (71.91%)
(d) = 700 (14.73%)
Question difficulty = Easy
Correlation between question and section = 0.40

5. Which one of the following best explains the decrease in atomic radius as the atomic number increases across Period 3 of the Periodic Table?

(a) increasing nuclear charge
(b) decreasing number of neutrons
(c) decreasing number of protons
(d) the elements becoming more noble gas-like

Statistics ID = CHE3-MC-5
Number of attempts = 4753
Correct answer = (a)
(a) = 4219 (88.76%)
(b) = 62 (1.30%)
(c) = 145 (3.05%)
(d) = 323 (6.80%)
Question difficulty = Very easy
Correlation between question and section = 0.38

6. Which one of the following trends occurs as the atomic number increases for the Group 17 elements?

(a) atomic radii decrease
(b) melting points decrease
(c) the tendency to gain electrons decreases
(d) the elements become more reactive

Statistics ID = CHE3-MC-6
Number of attempts = 4753
Correct answer = (c)
(a) = 516 (10.86%)
(b) = 514 (10.81%)
(c) = 3009 (63.31%)
(d) = 709 (14.92%)
Question difficulty = Moderate
Correlation between question and section = 0.44

7. What is the formula of an ionic compound consisting of positive ions with a configuration 2,8 and negative ions with the same configuration?

(a) LiF
(b) MgS
(c) NaF
(d) $KC\ell$

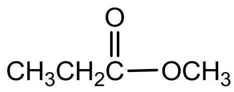
Statistics ID = CHE3-MC-7
Number of attempts = 4753
Correct answer = (c)
(a) = 403 (8.48%)
(b) = 825 (17.36%)
(c) = 3307 (69.58%)
(d) = 209 (4.40%)
Question difficulty = Easy
Correlation between question and section = 0.43

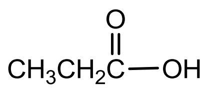
Questions

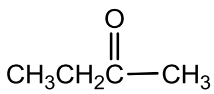
Questions 8 – 9

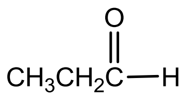
Question statistics

Questions 8 and 9 refer to the compounds shown below.

I 

II 

III 

IV 

8. Which one of the following lists places these compounds in their correct class?

	I	II	III	IV
(a)	Ester	Aldehyde	Ketone	Carboxylic acid
(b)	Carboxylic acid	Ketone	Aldehyde	Ester
(c)	Ketone	Carboxylic acid	Ester	Aldehyde
(d)	**Ester**	**Carboxylic acid**	**Ketone**	**Aldehyde**

Statistics ID = CHE3-MC-8
Number of attempts = 4753
Correct answer = (d)
(a) = 119 (2.50%)
(b) = 65 (1.37%)
(c) = 187 (3.93%)
(d) = 4381 (92.17%)
Question difficulty = Very easy
Correlation between question and section = 0.40

9. Which of these compounds can be prepared by oxidation of 1-propanol, $CH_3CH_2CH_2OH$?

(a) I only
(b) I and II
(c) II and III
(d) II and IV

Statistics ID = CHE3-MC-9
Number of attempts = 4753
Correct answer = (d)
(a) = 162 (3.41%)
(b) = 254 (5.34%)
(c) = 276 (5.81%)
(d) = 4057 (85.36%)
Question difficulty = Easy
Correlation between question and section = 0.41

Questions

Questions 10 – 11

Question statistics

10. An enzyme is a biological catalyst. Esters can be hydrolysed, as represented below by an esterase enzyme.

$$\text{ester} + \text{water} \xrightleftharpoons{\text{esterase}} \text{carboxylic acid} + \text{alcohol}$$

In the presence of esterase which one of the following statements is true for this process?

(a) The position of the equilibrium for this reaction is shifted to the right.
(b) The rate of forward reaction and rate of reverse reaction both increase equally.
(c) The rate of forward reaction increases more than the rate of reverse reaction.
(d) The rate of forward reaction increases and rate of reverse reaction decreases.

Statistics ID = CHE3-MC-10
Number of attempts = 4753
Correct answer = (b)
(a) = 272 (5.72%)
(b) = 3430 (72.16%)
(c) = 858 (18.05%)
(d) = 187 (3.93%)
Question difficulty = Easy
Correlation between question and section = 0.36

11. Hydrogen can be produced by the reaction

$$CH_4(g) + H_2O(g) \rightleftharpoons CO(g) + 3\,H_2(g) \quad \Delta H > 0$$

Which one of the following will increase the equilibrium yield of hydrogen?

(a) increasing the total pressure of the reaction system
(b) decreasing the partial pressure of the water vapour
(c) removing carbon monoxide from the system as it is produced
(d) decreasing the temperature of the system

Statistics ID = CHE3-MC-11
Number of attempts = 4753
Correct answer = (c)
(a) = 437 (9.19%)
(b) = 312 (6.56%)
(c) = 3580 (75.32%)
(d) = 422 (8.88%)
Question difficulty = Easy
Correlation between question and section = 0.49

Questions

Questions 12 – 14

Question statistics

12. Which of the properties listed below are characteristic of a gaseous system in dynamic equilibrium?

    (i) The concentrations of reactants are equal to the concentrations of products.
    (ii) The concentrations of reactants and products are constant.
    (iii) The rate of the forward reaction is equal to the rate of the reverse reaction.
    (iv) The pressure of the system is constant.

(a) (i), (ii) and (iii)
(b) (i), (ii) and (iv)
(c) (ii), (iii) and (iv)
(d) (iii) only

Statistics ID = CHE3-MC-12
Number of attempts = 4753
Correct answer = (c)
(a) = 469 (9.87%)
(b) = 223 (4.69%)
(c) = 3164 (66.57%)
(d) = 893 (18.79%)
Question difficulty = Easy
Correlation between question and section = 0.42

13. In which one of the following will a precipitate be formed when 0.1 mol L^{-1} solutions of the compounds listed are mixed at 25°C?

(a) K_2SO_4, $NiC\ell_2$ and $NaC\ell$
(b) $BaC\ell_2$, H_2SO_4 and HNO_3
(c) $Zn(NO_3)_2$, NaBr and H_2SO_4
(d) K_3PO_4, $(NH_4)_2CO_3$ and CH_3COOH

Statistics ID = CHE3-MC-13
Number of attempts = 4753
Correct answer = (b)
(a) = 175 (3.68%)
(b) = 3966 (83.44%)
(c) = 206 (4.33%)
(d) = 400 (8.42%)
Question difficulty = Easy
Correlation between question and section = 0.47

14. Assuming the substances below dissociate to the same extent, a 500 mL sample of which one of the following 0.01 mol L^{-1} solutions will contain the greatest number of ions?

(a) $(NH_4)_2CO_3$
(b) $K_2Cr_2O_7$
(c) $Ca(OH)_2$
(d) Na_3PO_4

Statistics ID = CHE3-MC-14
Number of attempts = 4753
Correct answer = (d)
(a) = 900 (18.94%)
(b) = 626 (13.17%)
(c) = 367 (7.72%)
(d) = 2852 (60.00%)
Question difficulty = Moderate
Correlation between question and section = 0.55

Questions

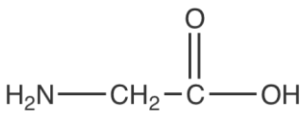
Questions 15 – 17

Question statistics

15. Consider the following substances.

(i) $BaSO_4$ (ii) $CH_3CH_2CH_2CH_2OH$

(iii) $CH_3CH_2COCH_3$ (iv)



Which one of the following lists the substances in order of **decreasing** solubility in water?

(a)	(i)	(iv)	(ii)	(iii)
(b)	(i)	(iii)	(ii)	(iv)
(c)	**(iv)**	**(ii)**	**(iii)**	**(i)**
(d)	(ii)	(iv)	(iii)	(i)

Statistics ID = CHE3-MC-15
Number of attempts = 4753
Correct answer = (c)
(a) = 954 (20.07%)
(b) = 478 (10.06%)
(c) = 2501 (52.62%)
(d) = 816 (17.17%)
Question difficulty = Moderate
Correlation between question and section = 0.32

16. Which one of the following is the strongest electrolyte?

(a) $NH_4C\ell$
(b) H_3PO_4
(c) H_2O
(d) CH_3COOH

Statistics ID = CHE3-MC-16
Number of attempts = 4753
Correct answer = (a)
(a) = 2471 (51.99%)
(b) = 1787 (37.60%)
(c) = 346 (7.28%)
(d) = 143 (3.01%)
Question difficulty = Moderate
Correlation between question and section = 0.33

17. Which one of the following describes the acidity/basicity of a solution of the following compounds when dissolved in distilled water?

	Ammonium chloride	Potassium carbonate	Sodium nitrate	Sodium ethanoate
(a)	**acidic**	**basic**	**neutral**	**basic**
(b)	acidic	basic	acidic	basic
(c)	basic	acidic	neutral	acidic
(d)	basic	basic	basic	acidic

Statistics ID = CHE3-MC-17
Number of attempts = 4753
Correct answer = (a)
(a) = 3284 (69.09%)
(b) = 428 (9.00%)
(c) = 595 (12.52%)
(d) = 435 (9.15%)
Question difficulty = Easy
Correlation between question and section = 0.48

Questions

Questions 18 – 20

Question statistics

18. In which one of the following is the reactant in bold reacting as an acid?

(a) 2**Na**(s) + $2H_2O \rightarrow 2NaOH + H_2$
(b) $\mathbf{NH_3}$ + $H_2O \rightarrow NH_4^+ + OH^-$
(c) $\mathbf{Fe(H_2O)_6^{3+} + H_2O \rightarrow Fe(H_2O)_5(OH)^{2+} + H_3O^+}$
(d) $\mathbf{CO_2}$ + $H_2O \rightarrow H_2CO_3$

Statistics ID = CHE3-MC-18
Number of attempts = 4753
Correct answer = (c)
(a) = 212 (4.46%)
(b) = 422 (8.88%)
(c) = 3955 (83.21%)
(d) = 159 (3.35%)
Question difficulty = Easy
Correlation between question and section = 0.39

19. Which one of the following gives the correct formula for sodium chlorite?

(a) $NaC\ell O$
(b) $\mathbf{NaC\ell O_2}$
(c) $NaC\ell O_3$
(d) $NaC\ell O_4$

Statistics ID = CHE3-MC-19
Number of attempts = 4753
Correct answer = (b)
(a) = 1940 (40.82%)
(b) = 1305 (27.46%)
(c) = 1127 (23.71%)
(d) = 379 (7.97%)
Question difficulty = Difficult
Correlation between question and section = 0.09

20. Four water samples were found to be contaminated with an arsenic chloride compound. The samples were analysed and the arsenic and chloride content of each sample was reported, as shown below.

Sample	As content (g)	Cℓ content (g)
(i)	0.68	0.97
(ii)	0.38	0.55
(iii)	0.48	0.68
(iv)	0.41	0.96

Which one of the samples contains a different arsenic chloride contaminant from that in the other three samples?

(a) (i)
(b) (ii)
(c) (iii)
(d) (iv)

Statistics ID = CHE3-MC-20
Number of attempts = 4753
Correct answer = (d)
(a) = 639 (13.44%)
(b) = 464 (9.76%)
(c) = 107 (2.25%)
(d) = 3532 (74.31%)
Question difficulty = Easy
Correlation between question and section = 0.40

Questions

Questions 21 – 24

Question statistics

21. How many moles of electrons must be exchanged to oxidise 1 mole of hypophosphorous acid, H_3PO_2, to phosphoric acid, H_3PO_4?

(a) 2
(b) 3
(c) 4
(d) 5

Statistics ID = CHE3-MC-21
Number of attempts = 4753
Correct answer = (c)
(a) = 1249 (26.28%)
(b) = 299 (6.29%)
(c) = 3103 (65.29%)
(d) = 88 (1.85%)
Question difficulty = Easy
Correlation between question and section = 0.48

22. In which one of the following compounds is rhenium (Re) in the highest oxidation state?

(a) $NaReO_4$
(b) $ReC\ell O$
(c) Re_2O_3
(d) $ReC\ell_5$

Statistics ID = CHE3-MC-22
Number of attempts = 4753
Correct answer = (a)
(a) = 4006 (84.28%)
(b) = 155 (3.26%)
(c) = 171 (3.60%)
(d) = 416 (8.75%)
Question difficulty = Easy
Correlation between question and section = 0.40

23. Corrosion is a redox process. Which one of the following explains why coating iron with nickel protects the iron from corrosion?

(a) Nickel accepts electrons from iron.
(b) Iron and nickel form an alloy that is particularly resistant to redox processes.
(c) Nickel is a stronger oxidising agent than iron.
(d) The thin coating of nickel prevents iron from reacting.

Statistics ID = CHE3-MC-23
Number of attempts = 4753
Correct answer = (d)
(a) = 186 (3.91%)
(b) = 250 (5.26%)
(c) = 1601 (33.68%)
(d) = 2699 (56.79%)
Question difficulty = Moderate
Correlation between question and section = 0.33

24. Which one of the species below is **not** commonly used as a reducing agent?

(a) $C_2O_4^{2-}$
(b) H_2
(c) $C\ell_2$
(d) C

Statistics ID = CHE3-MC-24
Number of attempts = 4753
Correct answer = (c)
(a) = 552 (11.61%)
(b) = 569 (11.97%)
(c) = 1358 (28.57%)
(d) = 2261 (47.57%)
Question difficulty = Difficult
Correlation between question and section = 0.34

Questions

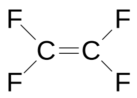
Question 25

Question statistics

25. Which one of the following is a polar molecule?

(a) CO

(b) $BC\ell_3$

(c) 

(d) CF_4

Statistics ID = CHE3-MC-25
Number of attempts = 4753
Correct answer = (a)
(a) = 3194 (67.20%)
(b) = 1217 (25.60%)
(c) = 179 (3.77%)
(d) = 155 (3.26%)
Question difficulty = Easy
Correlation between question and section = 0.42

Keywords

Keywords: Questions 1 – 25

1. Atomic theory
2. Periodic table
3. Ionic bonding
4. Periodic table
5. Periodic table
6. Periodic table
7. Ionic bonding
8. Organic compounds
9. Redox reactions
10. Equilibrium
11. Equilibrium
12. Equilibrium
13. Precipitation (Chemistry), Chemical reactions
14. Chemical reactions
15. Solubility
16. Electrolytes
17. Hydrolysis
18. Acids
19. Chemical formula
20. Chemical formula
21. Stoichiometry, Chemical reactions
22. Redox reactions
23. Corrosion
24. Redox reactions
25. Molecular structure, Chemical formula

Chemistry
Stage 3

Section Two: Short answer

70 marks

Note:
Raw section total marks = 70
Weighted section total marks = 35

Weighted section statistics

Statistics ID = CHE3-S02
Number of attempts = 4751
Highest mark achieved = 35.00
Lowest mark achieved = 0.00
Mean = 20.80
Standard deviation = 6.86
Correlation between section and exam = 0.94

This section has **10** questions. Answer **all** questions.

Suggested working time: 60 minutes

Examiners' comments for this section

Questions 29, 30 and 35 were the most difficult questions, while Question 26 was the least difficult. Although the mean for this section was lower relative to 2010, there was an apparent improvement in the structure and coherence of sentences in questions requiring an explanatory answer.

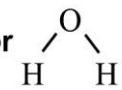
Question

Question 26

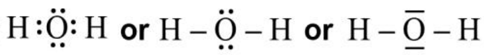
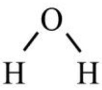
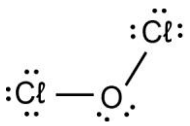
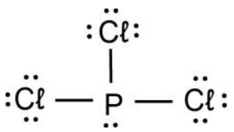
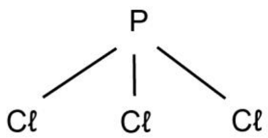
Complete the table below by drawing the Lewis structures of the molecules listed and either drawing or naming the shape of the molecule.

All valence shell electron pairs should be represented either as **:** or as — .

The first row has been completed as an example.
(4 marks)

Molecule	Lewis structure	Sketch or name of shape
H_2O	One of $\mathrm{H:\underset{\cdot\cdot}{\ddot{O}}:H}$ **or** $\mathrm{H-\underset{\cdot\cdot}{\ddot{O}}-H}$ **or** $\mathrm{H-\underline{\overline{O}}-H}$	One of bent, **or** 
$C\ell_2O$		
$PC\ell_3$		

Marking key

Molecule	Lewis structure	Sketch or name of shape
H_2O	One of 	One of bent, **or** 
$C\ell_2O$		V-shaped or bent
$PC\ell_3$		Triangular pyramidal 

Description	Marks
1 mark for each Lewis structure; dashes or dots acceptable for representing electron pairs. Award 1 mark if bonding pairs are correct but lone pairs are missing.	1–2
1 mark for each shape; accept pyramidal	1–2
Question incorrectly answered	0
Question not attempted	–
Total	**4**

NB No follow-through marks. Answers must conform to marking key e.g. each cell must be correct.

Keywords

Molecular structure

Question statistics

Statistics ID = CHE3-26
Number of attempts = 4748
Highest mark achieved = 4.00
Lowest mark achieved = 0.00
Mean = 3.27
Standard deviation = 0.88
Question difficulty = Easy
Correlation between question and section = 0.45

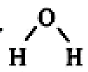
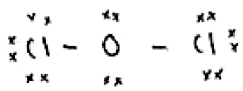
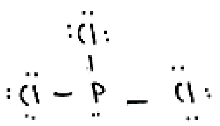
Candidate responses

Question 26

Complete the table below by drawing the Lewis structures of the molecules listed and either drawing or naming the shape of the molecule.

All valence shell electron pairs should be represented either as **:** or as — .

The first row has been completed as an example.
(4 marks)

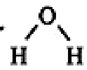
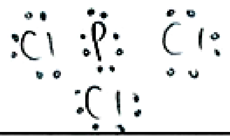
Molecule	Lewis structure	Sketch or name of shape
H_2O	One of $H:\underset{..}{\ddot{O}}:H$ or $H-\underset{..}{\ddot{O}}-H$ or $H-\underline{\overline{O}}-H$	One of bent, or 
$20e^-$ Cl_2O		bent
$26e^-$ PCl_3		pyramidal

Notes

Excellent response
4/4 marks

Completes the table with Lewis structures and names of shapes.

Candidate responses (continued)

Molecule	Lewis structure	Sketch or name of shape
H_2O	One of $H:\ddot{\underset{\cdot\cdot}{O}}:H$ or $H-\ddot{\underset{\cdot\cdot}{O}}-H$ or $H-\overline{\underline{O}}-H$	One of bent, or 
Cl_2O	7 6 7 = 20 	linear
PCl_3	5 7 7 7 = 26 	triangular planar

Notes

Satisfactory response
2/4 marks

Completes the table with correct Lewis structures.

Names of shapes are incorrect.

Examiners' comments

Although this was the least difficult question incorrect responses were disappointing. Candidates must be encouraged to make the connection between number of electron domains (i.e. VSEPR) and molecular shape.

Question

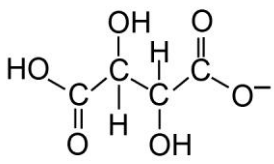
Question 27
(10 marks)

Question statistics

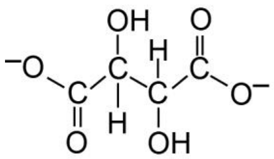
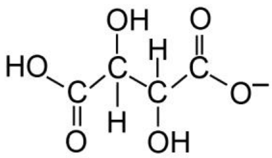
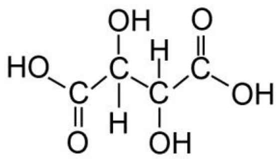
Statistics ID = CHE3-27
Number of attempts = 4735
Highest mark achieved = 10.00
Lowest mark achieved = 0.00
Mean = 5.80
Standard deviation = 3.02
Question difficulty = N/A
Correlation between question and section = 0.80

27(a)

Complete the table by writing the formula or drawing the structure for the conjugate base, species X or conjugate acid in the blank spaces as appropriate. Species X is the species that is able to form both a conjugate base and a conjugate acid.
(6 marks)

Conjugate base	Species X	Conjugate acid
		$CH_3NH_3^+$
$C_2O_4^{2-}$		
		

Marking key

Conjugate base	Species X	Conjugate acid
CH_3NH^-	CH_3NH_2	$CH_3NH_3^+$
$C_2O_4^{2-}$	$HC_2O_4^-$	$H_2C_2O_4$
		

Description	Marks
1 mark for each cell.	1–6
Question incorrectly answered	0
Question not attempted	–
Total	**6**

Keywords

Acids

Question statistics

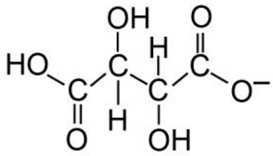
Statistics ID = CHE3-28
Number of attempts = 4517
Highest mark achieved = 6.00
Lowest mark achieved = 0.00
Mean = 3.20
Standard deviation = 2.28
Question difficulty = Moderate
Correlation between question and section = 0.71

Government of **Western Australia**
School Curriculum and Standards Authority

Candidate responses

27(a)

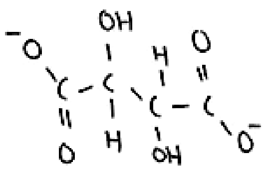
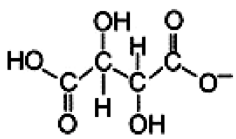
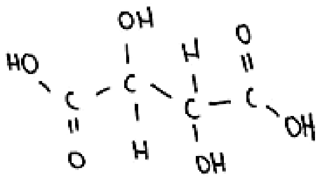
Complete the table by writing the formula or drawing the structure for the conjugate base, species X or conjugate acid in the blank spaces as appropriate. Species X is the species that is able to form both a conjugate base and a conjugate acid.
(6 marks)

Conjugate base	Species X	Conjugate acid
		$CH_3NH_3^+$
$C_2O_4^{2-}$		
		

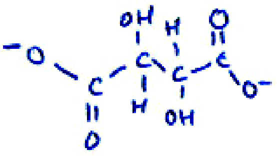
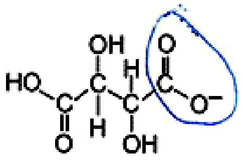
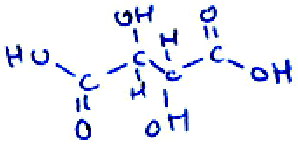
Notes

Excellent response
6/6 marks

Correctly completes the table with conjugate base and conjugate acid.

Conjugate base	Species X	Conjugate acid
$CH_3NH_2^-$	CH_3NH_2	$CH_3NH_3^+$
$C_2O_4^{2-}$	$\cancel{H_2}$ $HC_2O_4^-$	$H_2C_2O_4$
		

Candidate responses (continued)

Conjugate base	Species X	Conjugate acid
CH_3NH^-	CH_3NH_2	$CH_3NH_3^+$
$C_2O_4^{2-}$	$H_2C_2O_4$ [illegible]	$H_3C_2O_4^+$
		

Notes

Satisfactory response
4/6 marks

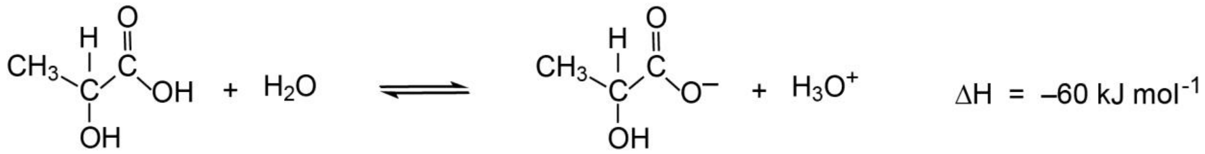
Correctly completes the table for two species of conjugate base and conjugate acid.

The $C_2O_4^{2-}$ examples are incorrect.

Question

Lactic acid produced by muscles during exercise, is found in many milk products and is used in the brewing of beer. It is also added to a number of canned food items as a buffer.

The equation for the reaction of lactic acid with water is shown below.



The value of the equilibrium constant for the above reaction, at 25°C, is approximately
7.9×10^{-5}.

27(b)

State whether the ratio of organic products to organic reactants will be equal to one, less than one (< 1) or greater than one (> 1) for this system at equilibrium at 25°C.
(1 mark)

Marking key

Description	Marks
Ratio of P to R less than one <1; OR there are less P than R	1
Question incorrectly answered	0
Question not attempted	–
Total	**1**

Keywords

Equilibrium

Question statistics

Statistics ID = CHE3-29
Number of attempts = 4624
Highest mark achieved = 1.00
Lowest mark achieved = 0.00
Mean = 0.59
Standard deviation = 0.49
Question difficulty = Moderate
Correlation between question and section = 0.31

Candidate responses

27(b)

State whether the ratio of organic products to organic reactants will be equal to one, less than one (< 1) or greater than one (> 1) for this system at equilibrium at 25°C.
(1 mark)

· <1 (less than one)

Notes

Excellent response
1/1 mark

Correctly states the ratio of organic products to organic reactants.

Question

27(c)

Predict the direction in which the equilibrium will shift immediately after the changes indicated in the table below. Write ‘left’, ‘right’ or ‘no change’.
(3 marks)

Change	Direction of initial equilibrium shift
Decreasing the temperature	
Adding hydrochloric acid	
Adding sodium hydroxide	

Marking key

Change	Direction of initial equilibrium shift
Decreasing the temperature	Right
Adding hydrochloric acid	Left
Adding sodium hydroxide	Right

Description	Marks
1 mark for each cell	1–3
Question incorrectly answered	0
Question not attempted	–
Total	**3**

Keywords

Equilibrium

Question statistics

Statistics ID = CHE3-30
Number of attempts = 4726
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 2.18
Standard deviation = 1.00
Question difficulty = Easy
Correlation between question and section = 0.56

Candidate responses

27(c)

Predict the direction in which the equilibrium will shift immediately after the changes indicated in the table below. Write ‘left’, ‘right’ or ‘no change’.
(3 marks)

Change	Direction of initial equilibrium shift
Decreasing the temperature	
Adding hydrochloric acid	
Adding sodium hydroxide	

Notes

Change	Direction of initial equilibrium shift
Decreasing the temperature	right
Adding hydrochloric acid	left
Adding sodium hydroxide	right

Excellent response
3/3 marks

Predicts the direction of the initial equilibrium shift correctly.

Change	Direction of initial equilibrium shift
Decreasing the temperature	right
Adding hydrochloric acid	~~ti~~ no change
Adding sodium hydroxide	right

Satisfactory response
2/3 marks

Predicts the direction of the initial equilibrium shift correctly, for two of the three changes.

Examiners’ comments

In Part (a), this question was not particularly well done. Candidates had difficulty drawing structures for conjugate acids/bases of what might be considered more ‘complex’ molecules, and identifying the acidic protons (hydrogens) in such structures. Candidates should be encouraged to draw structural diagrams where necessary. Care should also be taken in determining charge. In Part (b), there was some evidence that candidates are not able to interpret the magnitude of the equilibrium constant, in terms of concentration of reactants relative to that of products.

Question

Question 28

Chloromethane can be produced industrially by the reaction of methanol and hydrogen chloride at high temperature in the presence of a catalyst. The equation for this reaction is shown below.

$$CH_3OH + HCℓ \rightleftharpoons CH_3Cℓ + H_2O$$

The boiling points and melting points for each of the species involved in the reaction are shown below.

Species	**Boiling point (°C)**	**Melting point (°C)**
CH_3OH	65	-98
$HCℓ$	-85	-114
$CH_3Cℓ$	-24	-98
H_2O	100	0

Write the phase, i.e., solid (s), liquid (ℓ) or gas (g), of each species in this system at the temperatures shown in the table below, and predict the effect of an increase in total pressure on this equilibrium at each of the temperatures.

Temperature (°C)	**Phase (s, ℓ or g)**				**Shift in equilbrium (right, left or no change)**
	CH_3OH	$HCℓ$	$CH_3Cℓ$	H_2O	
-50					
40					
70					
110					

(8 marks)

Marking key

Temperature (°C)	Phase (s, ℓ or g)				Shift in equilbrium (right, left or no change)
	CH_3OH	HCℓ	$CH_3C\ell$	H_2O	
-50	ℓ	g	ℓ	s	right
40	ℓ	g	g	ℓ	no change
70	g	g	g	ℓ	right
110	g	g	g	g	no change

Description	Marks
1 mark for correctly identifying phases at each temperature for each substance (All four at each temperature must be correct.)	1–4
1 mark for correct shift in equilibrium; award the mark if the phases are incorrect but the shift is correct based on incorrect phases **	1–4
Question incorrectly answered	0
Question not attempted	–
Total	**8**

** Shift in equilibrium must correspond with phases identified.

Keywords

Equilibrium

Question statistics

Statistics ID = CHE3-31
Number of attempts = 4742
Highest mark achieved = 8.00
Lowest mark achieved = 0.00
Mean = 6.04
Standard deviation = 2.10
Question difficulty = Moderate
Correlation between question and section = 0.61

Candidate responses

Question 28

Chloromethane can be produced industrially by the reaction of methanol and hydrogen chloride at high temperature in the presence of a catalyst. The equation for this reaction is shown below.

$$CH_3OH + HC\ell \rightleftharpoons CH_3C\ell + H_2O$$

The boiling points and melting points for each of the species involved in the reaction are shown below.

Species	Boiling point (°C)	Melting point (°C)
CH_3OH	65	-98
$HC\ell$	-85	-114
$CH_3C\ell$	-24	-98
H_2O	100	0

Write the phase, i.e., solid (s), liquid (ℓ) or gas (g), of each species in this system at the temperatures shown in the table below, and predict the effect of an increase in total pressure on this equilibrium at each of the temperatures.
(8 marks)

Notes

Temperature (°C)	Phase (s, ℓ or g)				Shift in equilibrium (right, left or no change)
	CH_3OH	$HC\ell$	$CH_3C\ell$	H_2O	
-50	l	g	l	s	right
40	l	g	g	l	no change
70	g	g	g	l	right
110	g	g	g	g	no change

Excellent response
8/8 marks

Correctly identifies the phase of the species.

Using the equation, predicts the shifts in equilibrium.

Temperature (°C)	Phase (s, ℓ or g)				Shift in equilibrium (right, left or no change).
	CH_3OH	$HC\ell$	$CH_3C\ell$	H_2O	
-50	l	g	l	s	~~no change~~ decrease
40	l	g	g	l	no change
70	g	g	g	l	increase
110	g	g	g	g	increase

Satisfactory response
5/8 marks

Correctly identifies the phase of the species.

Predicts the shifts in equilibrium of one out of four correctly.

Examiners' comments

This question was reasonably well done; most candidates, if they did not identify the phase of each species correctly, nevertheless could predict the direction of the shift in equilibrium (based on the phases they had identified), demonstrating a good understanding of equilibrium concepts. A large number of candidates were unable to identify correctly states/phases from the temperature and other data supplied in the question.

Question

Question 29

Write a relevant equation or equations to explain each of the observations shown in the table below.
(4 marks)

Observation	Explanatory equation/s
The pH of a $NaHSO_4$ solution is 5	
A solution of $Mg(OH)_2$ is basic	
A solution of Na_2HPO_4 is basic, while a solution of KH_2PO_4 is acidic	

Marking key

Observation	Explanatory equation/s
The pH of a $NaHSO_4$ solution is 5	$HSO_4^{-}(aq) + H_2O(l) \rightleftharpoons SO_4^{2-}(aq) + H_3O^{+}(aq)$ or $HSO_4^{-}(aq) \rightleftharpoons H^{+}(aq) + SO_4^{2-}(aq)$
A solution of $Mg(OH)_2$ is basic	$Mg(OH)_2 \rightleftharpoons Mg^{2+}(aq) + 2\ OH^{-}(aq)$ or $2H_2O(l) \rightleftharpoons H_3O^{+}(aq) + OH^{-}(aq)$ $[OH^{-}]>[H^{+}]$ therefore basic
A solution of Na_2HPO_4 is basic, while a solution of KH_2PO_4 is acidic	$HPO_4^{2-}(aq) + H_2O(l) \rightleftharpoons H_2PO_4^{-}(aq) + OH^{-}(aq)$ $H_2PO_4^{-}(aq) + H_2O(l) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^{+}(aq)$ or $H_2PO_4^{-}(aq) \rightleftharpoons HPO_4^{2-}(aq) + H_3O^{+}(aq)$

Description	Marks
1 mark for each equation	1–4
Question incorrectly answered	0
Question not attempted	–
Total	**4**

NB Double arrows not required i.e. no penalty for single arrows.

Keywords

Hydrolysis

Question statistics

Statistics ID = CHE3-32
Number of attempts = 4490
Highest mark achieved = 4.00
Lowest mark achieved = 0.00
Mean = 1.77
Standard deviation = 1.51
Question difficulty = Moderate
Correlation between question and section = 0.67

Candidate responses

Question 29

Write a relevant equation or equations to explain each of the observations shown in the table below.
(4 marks)

Observation	Explanatory equation/s
The pH of a $NaHSO_4$ solution is 5	
A solution of $Mg(OH)_2$ is basic	
A solution of Na_2HPO_4 is basic, while a solution of KH_2PO_4 is acidic	

Notes

Excellent response
4/4 marks

Writes equations to show how solutions become acidic or basic.

Observation	Explanatory equation/s
The pH of a $NaHSO_4$ solution is 5	$HSO_4^-{}_{(aq)} \rightarrow \underline{H^+_{(aq)}} + SO_4^{2-}{}_{(aq)}$
A solution of $Mg(OH)_2$ is basic	$Mg(OH)_{2(s)} \xrightarrow{H_2O} Mg^{2+}_{(aq)} + \underline{2OH^-_{(aq)}}$
A solution of Na_2HPO_4 is basic, while a solution of KH_2PO_4 is acidic	$HPO_4^{2-}{}_{(aq)} + H_2O_{(l)} \rightarrow H_2PO_4^-{}_{(aq)} + \underline{OH^-_{(aq)}}$ $H_2PO_4^-{}_{(aq)} \rightarrow \underline{H^+_{(aq)}} + HPO_4^{2-}{}_{(aq)}$

Satisfactory response
2/4 marks

Writes two out of four correct equations.

HPO_4^- and H_2PO_4 should be HPO_4^{2-} and $H_2PO_4^-$.

Observation	Explanatory equation/s
The pH of a $NaHSO_4$ solution is 5	$NaHSO_{4(aq)} \rightarrow Na^+_{(aq)} + HSO_4^-{}_{(aq)}$ $HSO_4^-{}_{(aq)} + H_2O_{(l)} \rightarrow SO_4^{2-}{}_{(aq)} + H_3O^+$ ← acidic
A solution of $Mg(OH)_2$ is basic	$Mg(OH)_{2(aq)} \rightarrow Mg^{2+}_{(aq)} + \underline{2OH^-_{(aq)}}$ - hydroxide ions formed = basic
A solution of Na_2HPO_4 is basic, while a solution of KH_2PO_4 is acidic	$HPO_4^-{}_{(aq)} + H_2O_{(l)} \rightarrow H_2PO_{4(aq)} + OH^-_{(aq)}$ ← basic $H_2PO_{4(aq)} + H_2O_{(l)} \rightarrow HPO_4^-{}_{(aq)} + H_3O^+_{(aq)}$ ← acidic

Examiners' comments

This question was poorly done. Many candidates did not write a chemical equation, but rather a mathematical equation of some sort. Where chemical equations were given, they were very often not balanced, or were molecular rather than ionic. Although the aim was not to examine directly whether a student can balance an equation, the examiners still expected that the equations be balanced. Full marks were not awarded for incorrectly balanced equations, or equations that were slightly incorrect in some other way. Attention to detail is important.

Question

Question 30
(12 marks)

Complete the table below by giving a brief description of a chemical test that could be used to distinguish between the substances listed. List the observations relating to the test for each of Substance 1 and Substance 2.

Substances to be distinguished		**Description of chemical test**	**Observation with Substance 1**	**Observation with Substance 2**
Substance 1	**Substance 2**			
butan-2-ol	2-methylpropan-2-ol			
zinc nitrate solution	zinc sulfate solution			
solid magnesium hydroxide	solid lead sulfate			
methanol	methanal			

Marking key

Substances to be distinguished		Description of chemical test	Observation with Substance 1	Observation with Substance 2
Substance 1	**Substance 2**			
butan-2-ol	2-methylpropan-2-ol	Shake a small quantity of each substance with acidified $Cr_2O_7^{2-}$ or acidified MnO_4^-	When shaken the $Cr_2O_7^{2-}$ mixture changes from orange to green OR When shaken with MnO_4^- will go from purple to colourless (or pale pink)	When shaken with the $Cr_2O_7^{2-}$ remains orange (no observable change acceptable) OR When shaken with MnO_4^- remains purple (no observable change acceptable)
		Addition of sodium (Na)	Reacts faster	Reacts slower (do not accept no visible reaction)
zinc nitrate solution	zinc sulfate solution	Add a little $Ba(NO_3)_2$ or $Pb(NO_3)_2$ solution to each solution Accept Ba^{2+} or Pb^{2+} Accept anything that gives ppt	No observable reaction	A precipitate forms [white]
solid magnesium hydroxide	solid lead sulfate	Add a little of each solid to dilute HNO_3 or H_2SO_4 or HCl or CH_3COOH	Solid dissolves	Solid does not dissolve
		Addition of $H_2C_2O_4$	No visible reaction	[colourless] gas evolved
methanol	methanal	Shake each with a little acidified acetic acid Any carboxylic acid okay	Fruity smell develops; [(acetic) acid odour goes]	No fruity smell develops; [odour of (acetic) acid persists]
		Addition of sodium (Na)	Gas evolved	No visible reaction

Marking key (continued)

Description	Marks
1 mark for description of each test – must be acidified $Cr_2O_7^{2-}$ or MnO_4^-; any suitable precipitation reaction acceptable for zinc solutions. (Any suitable chemical test – that adequately distinguishes one substance from the other – is acceptable.)	1–4
1 mark for each observation	1–8
Question incorrectly answered	0
Question not attempted	–
Total	**12**

NB (i) If $Cr_2O_7^{2-}$ or MnO_4^- not acidified, correct observations should be awarded (i.e. 2 out of 3 for the row).

(ii) If $Cr_2O_7^{2-}$ or MnO_4^- not acidified, but butan-2-ol solution turns brown, award marks (for test and observation).

(iii) Look out for any acceptable chemical test that is not listed here.

Keywords

Alcohols, Redox reactions, Precipitation (Chemistry)

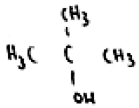
Question statistics

Statistics ID = CHE3-33
Number of attempts = 4526
Highest mark achieved = 12.00
Lowest mark achieved = 0.00
Mean = 5.32
Standard deviation = 3.18
Question difficulty = Moderate
Correlation between question and section = 0.78

Candidate responses

Question 30
(12 marks)

Complete the table below by giving a brief description of a chemical test that could be used to distinguish between the substances listed. List the observations relating to the test for each of Substance 1 and Substance 2.

Substances to be distinguished		Description of chemical test	Observation with Substance 1	Observation with Substance 2
Substance 1	Substance 2			
butan-2-ol	tertiary alcohol 2-methylpropan-2-ol 	Add acidified dichromate solution.	Orange solution added to colourless solution. Solution turns green.	Orange solution added to colourless solution. Solution remains orange.
zinc nitrate solution	zinc sulfate solution	Add barium nitrate solution.	~~Two~~ colourless solution added to colourless solution. No visible reaction.	colourless solution added to colourless solution. White precipitate formed.
solid magnesium hydroxide	solid lead sulfate	Add hydrochloric acid.	Colourless solution added to white solid. White solid dissolves.	Colourless solution added to white solid. No visible reaction.
methanol	methanal	Add sodium metal.	Silver solid added to colourless solution. Solid dissolves. Bubbling - colourless, odourless gas evolved.	Silver solid added to colourless solution. No visible reaction.

Notes

Excellent response
12/12 marks

Describes chemical tests to distinguish between substances.

Candidate responses (continued)

Substances to be distinguished		Description of chemical test	Observation with Substance 1	Observation with Substance 2
Substance 1	Substance 2			
OH on C–C–C–C (second carbon) butan-2-ol secondary	OH, C–C–C with CH_3 on central carbon 2-methylpropan-2-ol Tertiary	addition of acidified potassium permangarate	colour change from purple to colourless	No change (doesn't react)
zinc nitrate solution	zinc sulfate solution	Addition of Pb^{2+}.	No precipitate	silver precipitate
solid magnesium hydroxide $Mg(OH)_2$	solid lead sulfate $PbSO_4$.	addition of an acid (HCl)	corrosion	$SO_{2(g)}$ is formed. colourless pungent gas. + corrosion
OH on C methanol	O=C–H methanal	Add water.	Most soluble → dissolve fastest.	dissolve at a slower rate

Notes

Satisfactory response
7/12 marks

Describes three chemical tests and one physical test.

One chemical test has incorrect observations.

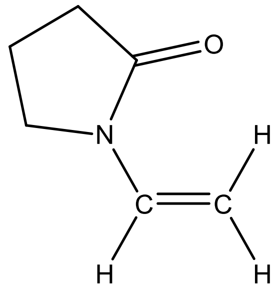
Examiners' comments

This was perhaps the most difficult question in Section Two, and was not well done. A common error was to not include acidified permanganate or dichromate in distinguishing between the two alcohols. In cases where no acidification was noted, marks were awarded if correct associated observations were given. Most candidates were able to describe a test to distinguish between zinc nitrate and zinc sulfate, although it is important to note that candidates must explicitly state addition of ions (e.g. barium ions or lead ions) in such questions (rather than simply 'barium' or 'lead') to be awarded full marks. It is only through the use of such detail that markers can be sure of a candidate's understanding of the chemistry. The second half of the table in this question was, overall, rather poorly completed.

Question

Question 31
(2 marks)

Polyvinylpyrrolidone is a polymer with a wide range of applications including as a binder in tablets and hair styling agents. It is made from the monomer shown below.



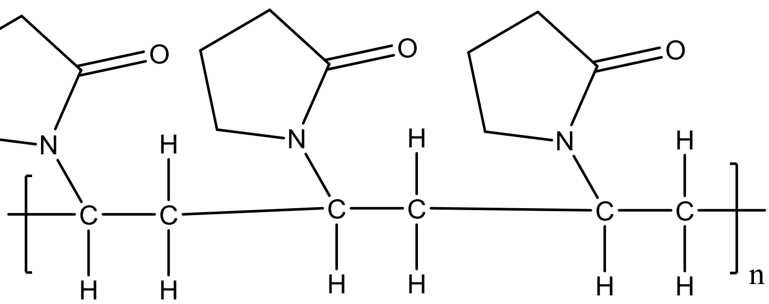
Question statistics

Statistics ID = CHE3-34
Number of attempts = 4468
Highest mark achieved = 2.00
Lowest mark achieved = 0.00
Mean = 1.29
Standard deviation = 0.78
Question difficulty = N/A
Correlation between question and section = 0.58

31(a)

Draw three units in the polymer formed from this monomer.
(1 mark)

Marking key



Description	Marks
3 units correctly combined required to gain mark. (“n” and brackets not needed)	1
Question incorrectly answered e.g. Hs on the ends	0
Question not attempted	–
Total	**1**

Keywords

Polymerisation

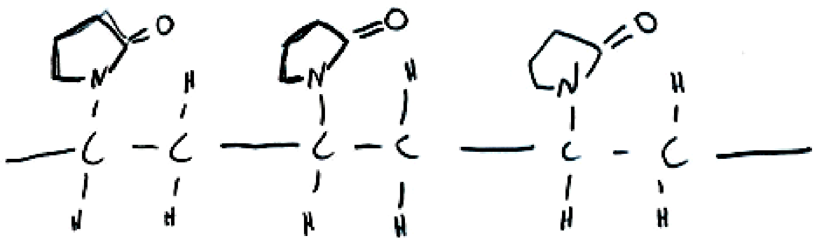
Question statistics

Statistics ID = CHE3-35
Number of attempts = 4240
Highest mark achieved = 1.00
Lowest mark achieved = 0.00
Mean = 0.56
Standard deviation = 0.50
Question difficulty = Moderate
Correlation between question and section = 0.52

Candidate responses

31(a)

Draw three units in the polymer formed from this monomer.
(1 mark)



Notes

Excellent response
1/1 mark

Correctly breaks the double bond to form the polymer.

Question

31(b)

What type of polymerisation reaction occurs to form the polymer from the above monomer?
(1 mark)

Marking key

Description	Marks
Addition	1
Question incorrectly answered	0
Question not attempted	–
Total	**1**

Keywords

Polymerisation

Question statistics

Statistics ID = CHE3-36
Number of attempts = 4266
Highest mark achieved = 1.00
Lowest mark achieved = 0.00
Mean = 0.79
Standard deviation = 0.40
Question difficulty = Easy
Correlation between question and section = 0.38

Candidate responses

31(b)

What type of polymerisation reaction occurs to form the polymer from the above monomer?
(1 mark)

addition polymerisation

Notes

Excellent response
1/1 mark

Recognises that question 31(a) is an example of addition polymerisation.

Question

Question 32
(13 marks)

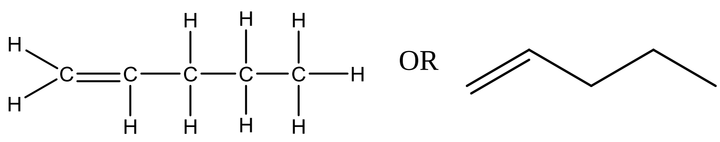
Question statistics

Statistics ID = CHE3-37
Number of attempts = 4734
Highest mark achieved = 13.00
Lowest mark achieved = 0.00
Mean = 8.75
Standard deviation = 3.26
Question difficulty = N/A
Correlation between question and section = 0.79

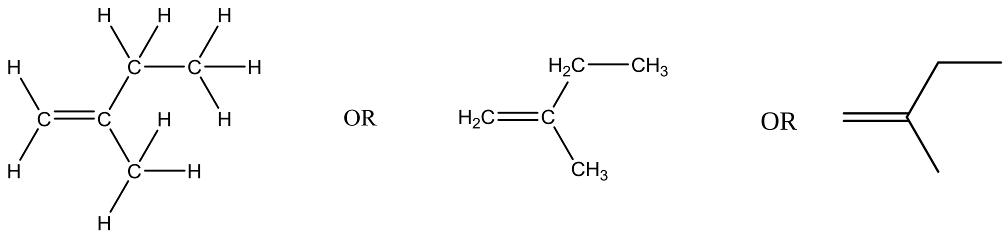
32(a)

Draw the structure for, and write the name of, any five straight chain isomers for the compounds with the molecular formula C_5H_{10}. Show all atoms in the structures.
(10 marks)

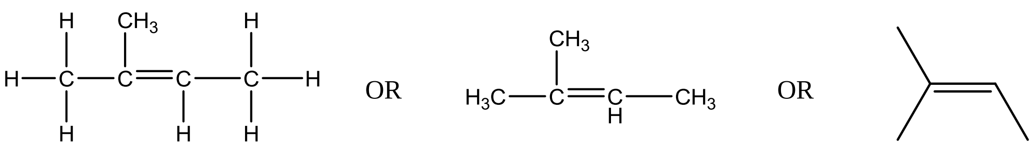
Marking key



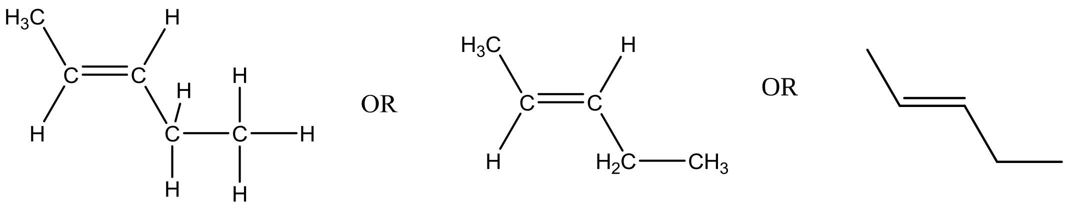
Name: pent-1-ene or 1-pentene



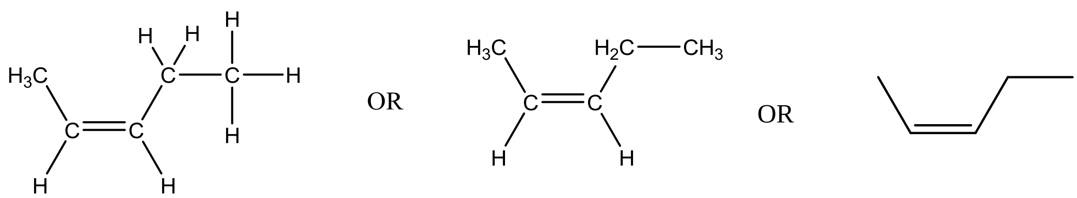
Name: 2-methyl-but-1-ene or 2-methyl-1-butene



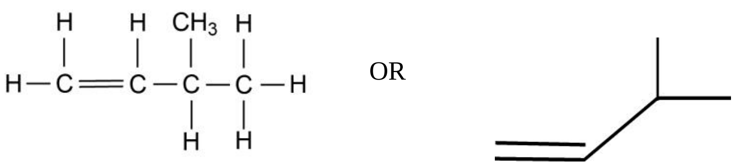
Name: 2-methyl-but-2-ene or 2-methyl-2-butene



Name: *trans*-pent-2-ene OR *trans*-2-pentene



Name: *cis*-pent-2-ene OR *cis*-2-pentene



Name: 3-methyl-but-1-ene

Marking key (continued)

Description	Marks
1 mark for each correct structure. Condensed structures acceptable. Award 4 marks for structures if H atoms consistently left off but structure is otherwise correct.	1–5
1 mark for each correct name	1–5
Question incorrectly answered or not attempted	0
Total	**10**

NB (i) If structure is incorrect (e.g. – cyclic structure), but name is correct, award one mark. Must be C_5H_{10}.

(ii) If there is some systematic error in naming, deduct one mark.

Keywords

Isomerism, Organic compounds

Question statistics

Statistics ID = CHE3-38
Number of attempts = 4730
Highest mark achieved = 10.00
Lowest mark achieved = 0.00
Mean = 6.73
Standard deviation = 2.56
Question difficulty = Moderate
Correlation between question and section = 0.70

Candidate responses

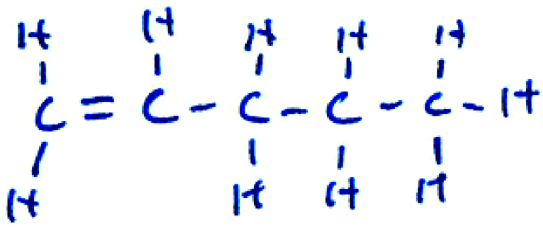
32(a)

Draw the structure for, and write the name of, any five straight chain isomers for the compounds with the molecular formula C_5H_{10}. Show all atoms in the structures.
(10 marks)

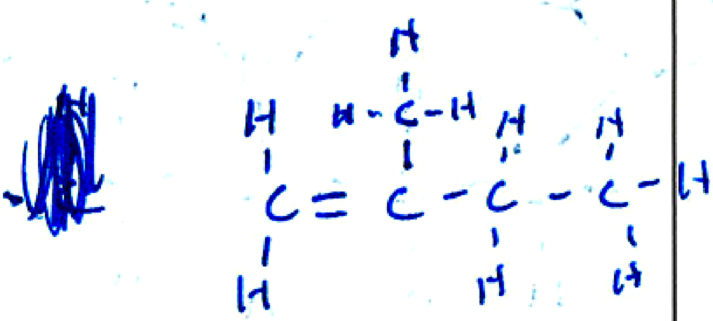
Notes

Excellent response
10/10 marks

Draws and names five straight chained isomers of C_5H_{10}.



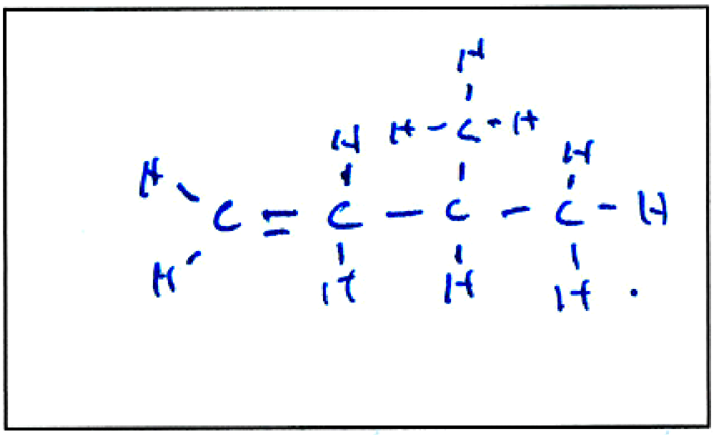
Name: pent-1-ene.



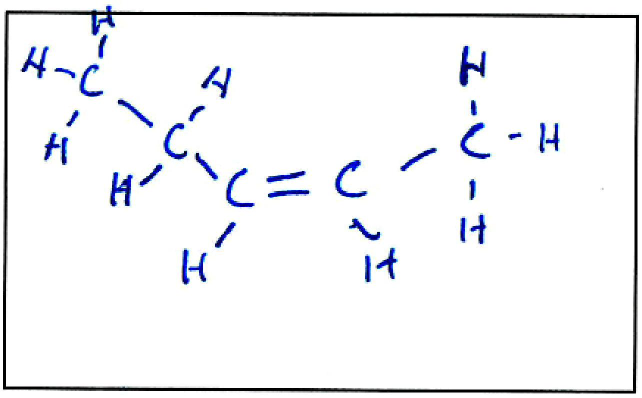
Name: 2-methy but-1-ene.

Candidate responses (continued)

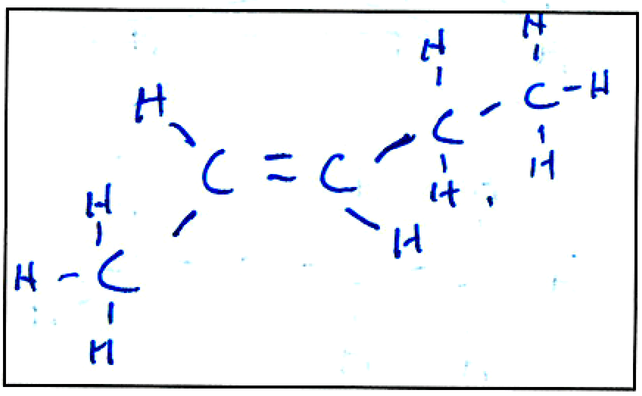
Notes



Name: 3-methy but-1-ene.

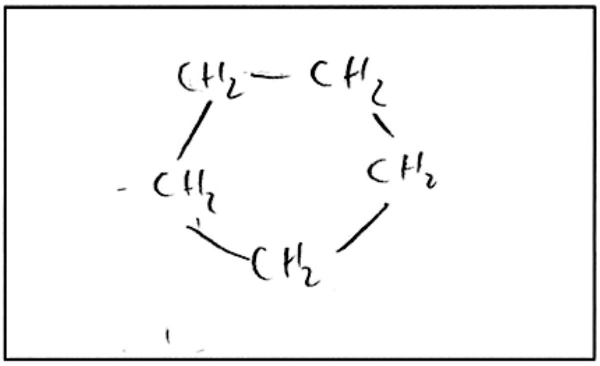


Name: cis-pent-2-ene.

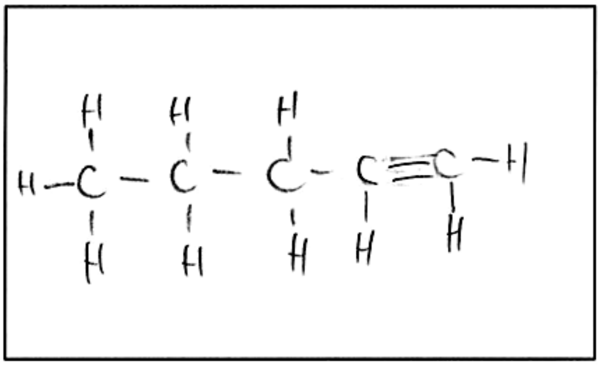


Name: trans-pent-2-ene.

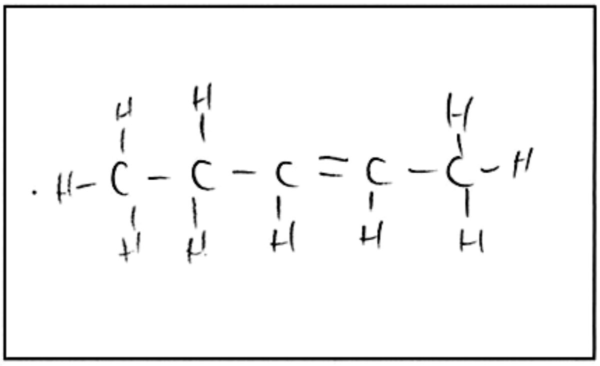
Candidate responses (continued)



Name: cyclopentane.



Name: Pent-1-ene



Name: cis pent-2-ene

Notes

Satisfactory response
7/10 marks

Draws and names three straight chained isomers of C_5H_{10}.

One C_5H_{10} isomer is cyclic, but correctly named. The other is a four carbon chain.

Question

32(b)

An organic compound is known to be an ester. Its molar mass is 74 g mol^{-1}.

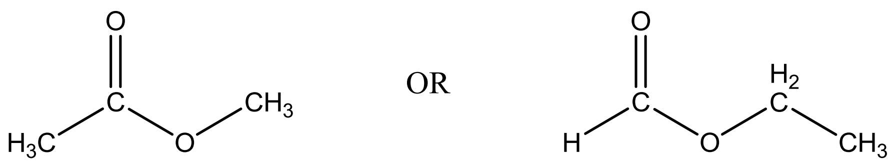
Question statistics

Statistics ID = CHE3-39
Number of attempts = 4426
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 2.17
Standard deviation = 1.06
Question difficulty = N/A
Correlation between question and section = 0.62

32(b)(i)

Draw the structural formula for the compound. Show all atoms in the structure.
(1 mark)

Marking key



Description	Marks
1 mark for a correct structure. Condensed structure acceptable.	1
Question incorrectly answered	0
Question not attempted	–
Total	**1**

Keywords

Molecular structure

Question statistics

Statistics ID = CHE3-40
Number of attempts = 4412
Highest mark achieved = 1.00
Lowest mark achieved = 0.00
Mean = 0.81
Standard deviation = 0.40
Question difficulty = Easy
Correlation between question and section = 0.51

Candidate responses

32(b)(i)

Draw the structural formula for the compound. Show all atoms in the structure.
(1 mark)

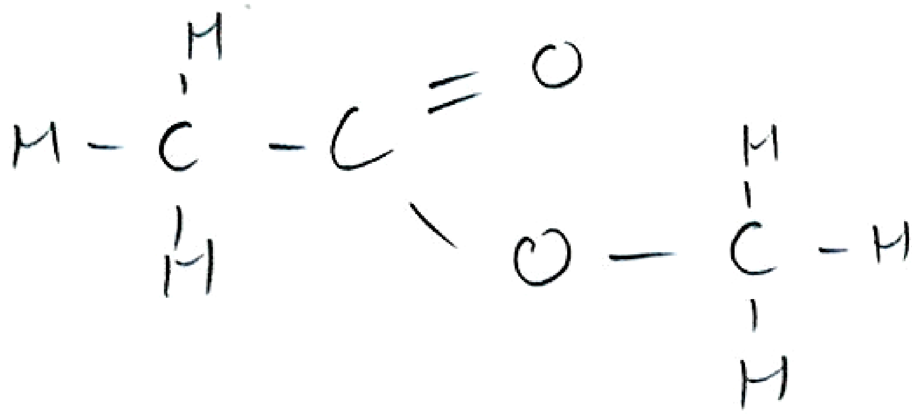
$$74\ g\,mol^{-1} = C_x H_y O_2$$

$$42\ g\,mol^{-1} = C_x H_y$$

If $x = 3$,

$$5.97 = H_y$$

$$y \approx 6$$



Notes

Excellent response
1/1 mark

Uses the molar mass to calculate the number of carbon atoms and draws a three carbon ester.

Question

32(b)(ii)

Write the name for the compound you have drawn.
(1 mark)

Marking key

Description	Marks
methyl ethanoate OR ethyl methanoate	1
Question incorrectly answered	0
Question not attempted	–
Total	**1**

NB Accept methyl acetate

Keywords

Organic compounds

Question statistics

Statistics ID = CHE3-41
Number of attempts = 4203
Highest mark achieved = 1.00
Lowest mark achieved = 0.00
Mean = 0.72
Standard deviation = 0.45
Question difficulty = Moderate
Correlation between question and section = 0.48

Candidate responses

32(b)(ii)

Write the name for the compound you have drawn.
(1 mark)

Methyl ethanoate

Notes

Excellent response
1/1 mark

Correctly names the ester from question 32(b)(i).

Question

32(b)(iii)

What is the IUPAC name for a carboxylic acid that has the same molecular formula as the ester above?
(1 mark)

Marking key

Description	Marks
propanoic acid	1
Question incorrectly answered	0
Question not attempted	–
Total	**1**

Keywords

Organic compounds

Question statistics

Statistics ID = CHE3-42
Number of attempts = 4132
Highest mark achieved = 1.00
Lowest mark achieved = 0.00
Mean = 0.73
Standard deviation = 0.45
Question difficulty = Moderate
Correlation between question and section = 0.39

Candidate responses

32(b)(iii)

What is the IUPAC name for a carboxylic acid that has the same molecular formula as the ester above?
(1 mark)

Propanoic acid

Notes

Excellent response
1/1 mark

Names the carboxylic acid with the same molecular formula ($C_3H_6O_2$) as the ester.

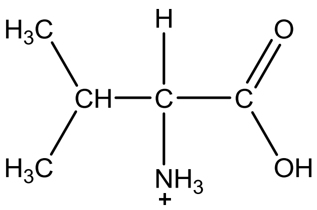
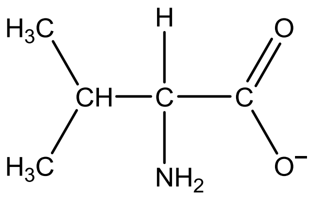
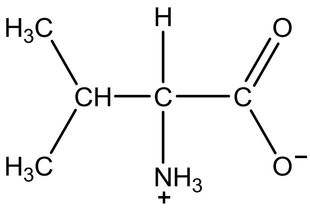
Examiners' comments

A number of candidates presented cyclic structures in Part (a); candidates should be reminded to read the question carefully and thoroughly. Some had difficulty in applying rules of nomenclature to correctly drawn structures.

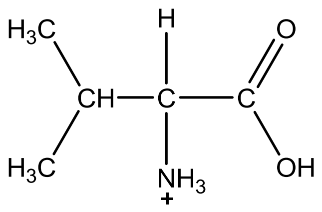
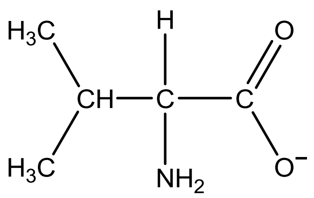
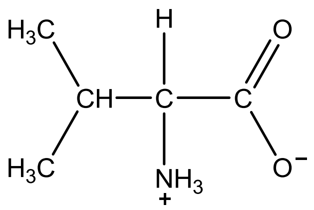
Question

Question 33

Below are the structures for the amino acid valine under different pH conditions. In the spaces provided, give the approximate pH range (acidic, basic or neutral) under which each valine structure would exist.
(3 marks)

Valine structure	pH range
	
	
	

Marking key

Valine structure	pH range
	acidic (pH < 7) Or any range of acidic values
	basic (pH > 7) Or any range of basic values
	neutral (pH ~ 7)

Description	Marks
1 mark each	1–3
Question incorrectly answered	0
Question not attempted	–
Total	**3**

NB Either words or pH range acceptable.

Keywords

Acids

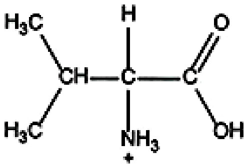
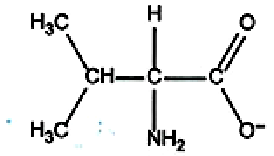
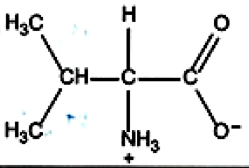
Question statistics

Statistics ID = CHE3-43
Number of attempts = 4667
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 2.13
Standard deviation = 1.11
Question difficulty = Easy
Correlation between question and section = 0.41

Candidate responses

Question 33

Below are the structures for the amino acid valine under different pH conditions. In the spaces provided, give the approximate pH range (acidic, basic or neutral) under which each valine structure would exist.
(3 marks)

Valine structure	pH range
	Acidic ($pH < 7$).
	Basic ($pH > 7$)
	Neutral ($pH = 7$)

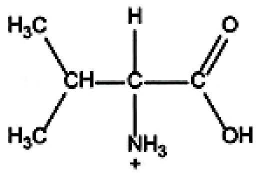
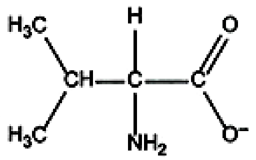
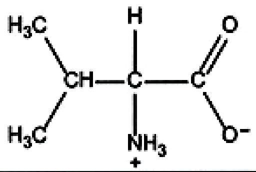
R NH_3

Notes

Excellent response
3/3 marks

Understands that an acidic (lose H^+) solution will give a H^+ to Valine and a basic (gain H^+) solution will take a H^+ from Valine.

Candidate responses (continued)

Valine structure	pH range
	Basic
	Acidic
	Neutral

Notes

Satisfactory response
1/3 marks

Correctly predicts the neutral solution.

Question

Question 34

Examine the following data for some Group 16 hydrides.

Group number	Hydride	Period	Melting point (°C)
16	H_2O	2	0
	H_2S	3	–86
	H_2Se	4	–66
	H_2Te	5	–49

Complete the table below by identifying which one or more of these Group 16 hydrides matches each of the descriptions given.
(7 marks)

Note that all hydrides are assumed to be pure samples.

Description	Hydride/hydrides (formula or name)
Hydride with the strongest intramolecular forces	
Hydride with the strongest intermolecular forces	
Hydride/hydrides with hydrogen bonding	
Hydride/hydrides with dipole-dipole bonding	
Hydride/hydrides with dispersion forces	
Hydride with strongest dispersion forces	
Hydride with weakest dispersion forces	

Marking key

Description	**Hydride/hydrides (formula or name)**
Hydride with the strongest intramolecular forces	H_2O
Hydride with the strongest intermolecular forces	H_2O
Hydride/hydrides with hydrogen bonding	H_2O
Hydride/hydrides with dipole-dipole bonding	H_2O, H_2S, H_2Se, H_2Te or ALL
Hydride/hydrides with dispersion forces	H_2O, H_2S, H_2Se, H_2Te or ALL
Hydride with strongest dispersion forces	H_2Te
Hydride with weakest dispersion forces	H_2O

Description	**Marks**
1 mark for each cell	1–7
Question incorrectly answered	0
Question not attempted	–
Total	**7**

Keywords

Molecular forces

Question statistics

Statistics ID = CHE3-44
Number of attempts = 4720
Highest mark achieved = 7.00
Lowest mark achieved = 0.00
Mean = 4.74
Standard deviation = 1.60
Question difficulty = Easy
Correlation between question and section = 0.62

Candidate responses

Question 34

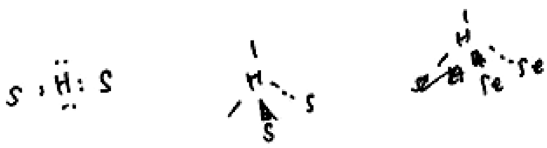
Examine the following data for some Group 16 hydrides.

Group number	Hydride	Period	Melting point (°C)
16	H_2O	2	0
	H_2S	3	–86
	H_2Se	4	–66
	H_2Te	5	–49

Complete the table below by identifying which one or more of these Group 16 hydrides matches each of the descriptions given.
(7 marks)

Note that all hydrides are assumed to be pure samples.

Description	Hydride/hydrides (formula or name)
Hydride with the strongest intramolecular forces EN	H_2O
Hydride with the strongest intermolecular forces	H_2O
Hydride/hydrides with hydrogen bonding	H_2O
Hydride/hydrides with dipole-dipole bonding	H_2O, H_2S, H_2Se, H_2Te
Hydride/hydrides with dispersion forces	H_2O, H_2S, H_2Se, H_2Te
Hydride with strongest dispersion forces	H_2Te
Hydride with weakest dispersion forces	H_2O



Notes

Excellent response
7/7 marks

Gives correct examples of intermolecular forces and their relative strengths.

Candidate responses (continued)

Description	Hydride/hydrides (formula or name)
Hydride with the strongest intramolecular forces	H_2S
Hydride with the strongest intermolecular forces	H_2O
Hydride/hydrides with hydrogen bonding	H_2O
Hydride/hydrides with dipole-dipole bonding	H_2S, H_2O, H_2Se, H_2Te
Hydride/hydrides with dispersion forces	H_2S
Hydride with strongest dispersion forces	H_2Te
Hydride with weakest dispersion forces	H_2S

Notes

Satisfactory response
4/7 marks

Provides four correct examples of intermolecular forces and their relative strengths.

Question

Question 35
(7 marks)

A nickel-cadmium cell consists of a positive nickel(III) oxide-hydroxide, NiO(OH), electrode and a negative metallic cadmium electrode plate. The following processes occur during discharge:

(i) metallic cadmium reacts in the presence of hydroxide ions to produce cadmium(II) hydroxide; and

(ii) nickel(III) oxide-hydroxide reacts in the presence of water to produce nickel(II) hydroxide and hydroxide ions.

Question statistics

Statistics ID = CHE3-45
Number of attempts = 4681
Highest mark achieved = 7.00
Lowest mark achieved = 0.00
Mean = 3.11
Standard deviation = 1.81
Question difficulty = N/A
Correlation between question and section = 0.70

35(a)

Write the half-equations for the reactions occurring at the anode and cathode and the overall redox equation for the Ni-Cd cell.
(3 marks)

Anode half-equation	
Cathode half-equation	
Overall redox equation	

Marking key

Anode half-equation	$Cd + 2\,OH^- \rightarrow Cd(OH)_2 + 2\,e^-$
Cathode half-equation	$NiO(OH) + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$
Overall redox equation	$Cd + 2\,NiO(OH) + 2\,H_2O \rightarrow Cd(OH)_2 + 2\,Ni(OH)_2$

Description	Marks
1 mark for anode reaction	1
1 mark for cathode reaction	1
1 mark for overall equation (i.e. correct with reference to anode and cathode)	1
Question incorrectly answered	0
Question not attempted	–
Total	**3**

If anode and cathode equations are reversed but otherwise correct award 1 mark out of the possible 2 marks for the half- equations.

Keywords

Redox reactions, Electrochemical reactions, Electrolytic cells

Question statistics

Statistics ID = CHE3-46
Number of attempts = 4630
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 1.26
Standard deviation = 0.91
Question difficulty = Moderate
Correlation between question and section = 0.52

Candidate responses

35(a)

Write the half-equations for the reactions occurring at the anode and cathode and the overall redox equation for the Ni-Cd cell.
(3 marks)

Notes

Oxidation	Anode half-equation	$Cd_{(s)} + 2OH^-_{(aq)} \rightarrow Cd(OH)_{2(s)} + 2e^-_{(aq)}$
Reduction	Cathode half-equation	$NiO(OH)_{(s)} + H_2O_{(l)} + e^- \rightarrow Ni(OH)_{2(s)} + OH^-_{(aq)}$
	Overall redox equation	$Cd_{(s)} + 2NiO(OH)_{(s)} + 2H_2O_{(l)} \rightarrow Cd(OH)_{2(s)} + 2Ni(OH)_{2(s)}$

Excellent response
3/3 marks

Constructs half-equations and combines them to give an overall redox equation.

Anode half-equation	$Cd_{(s)} \rightarrow Cd^{2+} + 2e^-$
Cathode half-equation	$NiO(OH) + H_2O + e^- \rightarrow Ni(OH)_2 + OH^-$ ~~$Ni^{2+} + 2e^- \rightarrow Ni_{(s)}$~~
Overall redox equation	$Cd_{(s)} + 2NiO(OH) + 2H_2O \rightarrow Cd^{2+} + 2Ni(OH)_2 + 2OH^-$

Satisfactory response
2/3 marks

Constructs one correct half-equation and combines the half-equations to give an overall redox equation.

Question

35(b)

The electrolyte in the Ni-Cd cell is usually a solution of potassium hydroxide. State the role of an electrolyte in an electrochemical cell.
(1 mark)

Marking key

Description	Marks
To enable flow of ions/complete the cell circuit allowing charge flow	1
Question incorrectly answered	0
Question not attempted	–
Total	**1**

Keywords

Electrolytic cells, Electrolytes

Question statistics

Statistics ID = CHE3-47
Number of attempts = 4474
Highest mark achieved = 1.00
Lowest mark achieved = 0.00
Mean = 0.57
Standard deviation = 0.49
Question difficulty = Moderate
Correlation between question and section = 0.29

Candidate responses

35(b)

The electrolyte in the Ni-Cd cell is usually a solution of potassium hydroxide. State the role of an electrolyte in an electrochemical cell.
(1 mark)

To allow ion transfer between the electrodes.

Notes

Excellent response
1/1 mark

Correctly states the role of the electrolyte in an electrochemical cell.

Question

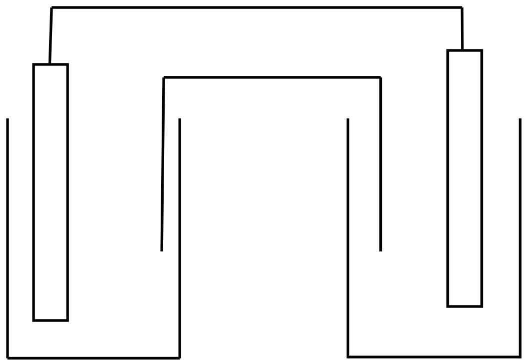
35(c)

The standard reduction potential for cadmium metal is -0.4 V. Explain the role of the hydrogen half-cell in determining this value. Comment on the significance of the negative value. You may use diagrams to aid your explanation.
(3 marks)

Marking key

Description	Marks
1 mark for recognition that the hydrogen half-cell is assigned an E° of 0 V or reference cell (or similar)	1
1 mark for recognition that cadmium half-cell E° is determined relative to the hydrogen half-cell.	1
1 mark for recognition that the negative value means that the cadmium half-cell is anodic relative to the hydrogen half-cell (OR electrons flow from the cadmium to the hydrogen cell or some other version)	1
Question incorrectly answered	0
Question not attempted	–
Total	**3**

An example of a possible diagram



Keywords

Redox reactions

Question statistics

Statistics ID = CHE3-48
Number of attempts = 4036
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 1.53
Standard deviation = 0.99
Question difficulty = Moderate
Correlation between question and section = 0.56

Candidate responses

35(c)

The standard reduction potential for cadmium metal is -0.4 V. Explain the role of the hydrogen half-cell in determining this value. Comment on the significance of the negative value. You may use diagrams to aid your explanation.
(3 marks)

Notes

The hydrogen half cell is the relative benchmark for all standard reduction potentials. We measure the emf of a electrochemical cell with the hydrogen half cell and the other cell we want to find the reduction potential of (in this case the Cd half cell). The negative symbol just means that Cd is a stronger reducing agent than H_2. ~~Also~~ and that ~~in~~ a complete cell with the hydrogen half cell and the Cd half cell, the Cd half cell will be the anode.

Excellent response
3/3 marks

Explains the standard and comparative roles of the hydrogen half-cell and the significance of negative values in the standard reduction potential table.

~~m~~The hydrogen half cell is what all the S.R. potentials are based on. A negative value indicates that hydrogen was giving off electrons (oxidised)

Satisfactory response
2/3 marks

Explains the significance of negative values.

The standard and comparative roles of the hydrogen half-cell require more detail.

Examiners' comments

This question was rather poorly done. Candidates should be encouraged to thoroughly and carefully read the question. The reactants and products for each of the half equations in Part (a) are clearly given in the explanatory information for this question, yet many candidates apparently attempted to find half equations that 'matched' in the Standard Reduction Potential table given in the data sheet.

Government of **Western Australia**
School Curriculum and Standards Authority

Chemistry
Stage 3

Section Three: Extended answer

80 marks

Note:
Raw section total marks = 80
Weighted section total marks = 40

Weighted section statistics

Statistics ID = CHE3-S03
Number of attempts = 4731
Highest mark achieved = 40.00
Lowest mark achieved = 0.00
Mean = 24.46
Standard deviation = 9.05
Correlation between section and exam = 0.95

This section contains **six (6)** questions. You must answer **all** questions.

Where questions require an explanation and/or description, marks are awarded for the relevant chemical content and also for coherence and clarity of expression.

Final answers to calculations should be expressed to **three (3)** significant figures and include appropriate units.

For numerical answers, a 1% tolerance in answers is acceptable.

Suggested working time: 70 minutes

Examiners’ comments for this section

Question 36 was the least difficult, while Question 41 was the most difficult.

Question

Question 36

Sevoflurane is a gaseous compound (at room temperature) used for inducing and maintaining general anaesthesia. It contains carbon, hydrogen, oxygen and fluorine.

Analysis of a 1.6328 g sample of sevoflurane yielded, on combustion, 866.0 mL of carbon dioxide at 50°C and 101.3 kPa and 0.220 g of water. The fluorine was released as hydrogen fluoride and absorbed by alkaline solution, revealing 5.71×10^{-2} mole of hydrogen fluoride. Determine the empirical formula of sevoflurane.
(10 marks)

Marking key

Description	Marks
$n(C) = n(CO_2) = \frac{PV}{RT} = \frac{101.3 \times 0.866}{8.315 \times 323} = 3.266 \times 10^{-2}\,\text{mol}$	1
$m(C) = 12.01 \times 3.266 \times 10^{-2} = 0.3923$ g	1
$n(H) = 2 \times n(H_2O) = 2 \times \frac{0.220}{18.016} = 2.44 \times 10^{-2}\,\text{mol}$	1
$m(H) = 1.008 \times 2.44 \times 10^{-2} = 2.462 \times 10^{-2}$ g	1
$m(F) = 19.00 \times 5.71 \times 10^{-2} = 1.085$ g	1
$m(O) = 1.6328 - (0.3923 + 2.462 \times 10^{-2} + 1.085) = 0.13099$ g	1
$n(O) = \frac{0.13099}{16.00} = 8.187 \times 10^{-3}\,\text{mol}$	1
C, H, O, F: 0.03266, 0.0244, 0.008187, 0.0571 ÷ by smallest: $\frac{0.03266}{0.008187}$, $\frac{0.0244}{0.008187}$, 1, $\frac{0.0571}{0.008187}$ 3.99, 2.98, 1, 6.97 4, 3, 1, 7 1 mark for ÷ by smallest; 1 mark for rounding	1–2
Thus EF is $C_4H_3OF_7$	1
Question incorrectly answered	0
Question not attempted	–
Total	**10**

NB: Any appropriate logic leading to the correct answer is acceptable.
NB: $C_7H_{18}OF_{12}$ = rounding error (9 marks)
If reasonable attempt to produce whole numbers from EF developed from H from water and HF then full marks

Keywords

Chemical formula

Question statistics

Statistics ID = CHE3-49
Number of attempts = 4675
Highest mark achieved = 10.00
Lowest mark achieved = 0.00
Mean = 7.90
Standard deviation = 2.70
Question difficulty = Moderate
Correlation between question and section = 0.64

Candidate responses

Question 36

Sevoflurane is a gaseous compound (at room temperature) used for inducing and maintaining general anaesthesia. It contains carbon, hydrogen, oxygen and fluorine.

Analysis of a 1.6328 g sample of sevoflurane yielded, on combustion, 866.0 mL of carbon dioxide at 50°C and 101.3 kPa and 0.220 g of water. The fluorine was released as hydrogen fluoride and absorbed by alkaline solution, revealing 5.71×10^{-2} mole of hydrogen fluoride. Determine the empirical formula of sevoflurane.
(10 marks)

$n(C) = n(CO_2)$ but since $PV = nRT$,

$= (PV)/(RT)$

$= (101.3 \times 0.866)/(8.315 \times (273.1+50))$

$= 0.03265$

$n = \frac{m}{M} \Rightarrow m(C) = nM$

$= 0.03265 \times 12.01$

$= 0.3922\ g$

$n(H) = 2 \times n(H_2O)$

$= 2 \times \frac{m}{M}$

$= 2 \times \frac{0.22}{2 \times 1.008 + 16}$

Notes

Excellent response
10/10 marks

Determines the empirical formula by calculating moles, masses and mole ratios of carbon, hydrogen, fluorine and oxygen atoms.

Candidate responses (continued)

Notes

$n(H) = 0.02442$

$n = \frac{m}{M} \Rightarrow m(H) = nM$
$= 0.02442 \times 1.008$
$\doteq 0.02462\,g$

$n(F) = n(HF) = 5.71 \times 10^{-2}$

$n = \frac{m}{M} \Rightarrow m(F) = nM = 5.71 \times 10^{-2} \times 19 = 1.085\,g$

$m(O) = m(\text{sample}) - m(C) - m(H) - m(F)$
$= 1.6328 - 0.3922 - 0.02462 - 1.085$
$= 0.1310\,g$
$n(O) = \frac{m}{M} = \frac{0.131}{16} = 0.008186$

	C	H	O	F
moles	0.03265	0.02442	0.008186	0.0571
÷ by 0.008186	3.989	2.983	1.000	6.975
	≈ 4	≈ 3	≈ 1	≈ 7

Empirical formula is $C_4H_3OF_7$.

Candidate responses (continued)

$CHOF + O_2 \rightarrow CO_2 + H_2O + HF$ $\qquad n(O) = \frac{0.22}{18.016}$

1.6328g $\quad$ 866ml @ 50°C $\quad$ 0.22g $\quad$ 0.0571 mol $\qquad = 0.01221$ mol

$n(C) = \frac{PV}{RT}$ $\qquad n(H) = 2 \times \frac{0.22}{18.016}$ $\qquad n(F) = 0.0571$ mol

$= \frac{101.3 \times 0.866}{8.315 \times 323.1}$ $\qquad = 0.02442$ mol

$= 0.03265$ mol

	C	H	O	F
	$\frac{0.03265}{0.01221}$	$\frac{0.02442}{0.01221}$	$\frac{0.01221}{0.01221}$	$\frac{0.05710}{0.01221}$
	= 2.67	= 2	= 1	= 4.67
x3	= 8	= 6	= 3	= 14

Notes

Satisfactory response
6/10 marks

Uses the correct method, but the number of moles of oxygen is incorrect.

Needs to calculate the masses of carbon, hydrogen and fluorine to find the mass of oxygen and then the number of moles of oxygen.

Examiners' comments

Some candidates misinterpreted this question, with a number concluding that the hydrogen component of hydrogen fluoride originated in the sevoflurane. Given that the wording of the question perhaps lent itself to this misinterpretation, candidates were not penalised. The question was generally well done.

Question

Question 37
(13 marks)

The percentage of manganese in steel needs to be monitored carefully. To determine this, a 5.31 g sample of steel was dissolved in concentrated acid and the manganese oxidised to permanganate ion, MnO_4^-. The volume of this solution was made up to 100.0 mL in a volumetric flask.

The concentration of permanganate ion was determined by titration against a standard solution of oxalic acid. The oxalic acid solution was prepared by dissolving 2.42 g of oxalic acid dihydrate ($H_2C_2O_4 . 2H_2O$) in a small volume of water, which was then made up to a final volume of 250.0 mL in a volumetric flask.

A 20.00 mL aliquot of the standard oxalic acid solution was transferred into a conical flask and acidified with some sulfuric acid. The permanganate solution was then titrated against this 20.00 mL aliquot of oxalic acid solution. This was repeated three times. The results are shown in the table below.

The balanced equation for the reaction between oxalic acid and permanganate ion is as below.

$$6\,H^+ \quad + \quad 2\,MnO_4^- \quad + \quad 5\,H_2C_2O_4 \quad \rightarrow \quad 2\,Mn^{2+} \quad + \quad 10\,CO_2 \quad + \quad 8\,H_2O$$

	1	**2**	**3**	**4**
Final reading (mL)	9.54	17.59	25.57	33.64
Initial reading (mL)	0.97	9.54	17.59	25.57
Titre volume (mL)				

Question statistics

Statistics ID = CHE3-50
Number of attempts = 4661
Highest mark achieved = 13.00
Lowest mark achieved = 0.00
Mean = 7.51
Standard deviation = 3.69
Question difficulty = N/A
Correlation between question and section = 0.79

37(a)

Calculate the concentration of the standard oxalic acid solution.
(3 marks)

Marking key

Description	Marks
$M(H_2C_2O_4{\cdot}2H_2O)$ = 126.068 g mol^{-1}	1
$n(H_2C_2O_4) = \dfrac{2.42}{126.068} = 1.9196 \times 10^{-2}\,mol$	1
$c(H_2C_2O_4) = \dfrac{1.9196 \times 10^{-2}}{0.250} = 7.68 \times 10^{-2}\ mol\,L^{-1}$	1
Question incorrectly answered	0
Question not attempted	–
Total	**3**

Keywords

Titration

Question statistics

Statistics ID = CHE3-51
Number of attempts = 4606
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 2.34
Standard deviation = 0.91
Question difficulty = Easy
Correlation between question and section = 0.51

Candidate responses

37(a)

Calculate the concentration of the standard oxalic acid solution.
(3 marks)

$n(H_2C_2O_4 \cdot 2H_2O) = \frac{m}{M}$ $\quad M(H_2C_2O_4 \cdot 2H_2O) = 126.068\ g\ mol^{-1}$

$= \frac{2.42}{126.068}$

$= 0.019196\ mol$

$n(H_2C_2O_4) = n(H_2C_2O_4 \cdot 2H_2O) \times 1$

$= 0.019196\ mol$

$c(H_2C_2O_4) = \frac{n}{V}$

$= \frac{0.019196}{0.25}$

$= 0.0768\ mol\ L^{-1}$ (3 s.f.)

Notes

Excellent response
3/3 marks

Calculates the number of moles and then the concentration, using the correct chemical relationships.

$n(H_2C_2O_4 \cdot 2H_2O) = \frac{2.42}{110.068}$

$n = 0.02198$

$c = \frac{n}{V}$

$c = \frac{0.02198}{0.25}$

$c = 8.79 \times 10^{-2}\ mol/L$

Satisfactory response
2/3 marks

Calculates the number of moles, using the incorrect molar mass.

Uses the correct method to calculate the concentration.

Question

37(b)

Determine the percentage of manganese in the original sample of steel.
(8 marks)

Marking key

Description	Marks
$n(H_2C_2O_4) = 7.68 \times 10^{-2} \times 0.02 = 1.536 \times 10^{-3}$ mol	1
$n(MnO_4^-) = \frac{2}{5} \times n(H_2C_2O_4) = 6.144 \times 10^{-4}$ mol	1
$V_{av}(MnO_4^-) = 8.033$ mL	1
*$n(MnO_4^-)$ in 100 mL = $\frac{6.144 \times 10^{-4}}{8.033 \times 10^{-3}} \times 0.100 = 7.648 \times 10^{-3}$ mol	1–2
Thus n(Mn) in sample = 7.648×10^{-3} mol	1
$m(Mn) = 7.648 \times 10^{-3} \times 54.94 = 0.4202$ g	1
%Mn = $\frac{0.4202}{5.31} \times 100 = 7.91\%$	1
Question incorrectly answered	0
Question not attempted	-
Total	**8**

*Calculation of the concentration of the MnO_4^- solution and then calculation of $n(MnO_4^-)$ in 100 mL is also acceptable.

Keywords

Titration

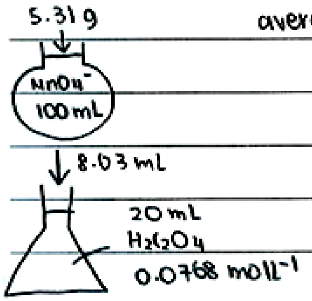
Question statistics

Statistics ID = CHE3-52
Number of attempts = 4380
Highest mark achieved = 8.00
Lowest mark achieved = 0.00
Mean = 5.04
Standard deviation = 2.65
Question difficulty = Moderate
Correlation between question and section = 0.74

Candidate responses

37(b)

Determine the percentage of manganese in the original sample of steel.
(8 marks)



average titre volume $= \frac{8.05 + 7.98 + 8.07}{3}$

$= 8.03$ mL

$n(H_2C_2O_4)$ in 20 mL $= cV$

$= 0.0768\ (20 \times 10^{-3})$

$= 0.001536$ mol

$n(MnO_4^-)$ in 8.03 mL $= \frac{2}{5} \times n(H_2C_2O_4)$

$= 6.144 \times 10^{-4}$ mol

$n(MnO_4^-)$ in 100 mL $= \frac{100}{8.03} \times 6.144 \times 10^{-4}$

$= 7.65 \times 10^{-3}$ mol

$n(Mn) = n(MnO_4^-) \times 1$

$= 7.65 \times 10^{-3}$ mol

$m(Mn) = nM$

$= 7.65 \times 10^{-3}\ (54.94)$

$= 0.420$ g

% Mn $= \frac{0.42}{5.31} \times 100$

$= 7.92$ % (3 s.f.)

Notes

Excellent response
8/8 marks

Correctly completes each step to determine the percentage of manganese.

Candidate responses (continued)

$\frac{n(MnO_4^-)}{2} = \frac{n(H_2C_2O_4)}{5}$

~~2n(~~ $\therefore 2/5 \times 1.92 \times 10^{-2}$ will give $n(MnO_4^-)$

$= 7.68 \times 10^{-3}$ mol

$C(MnO_4^-) = 7.68 \times 10^{-3} / 0.00823 = 0.9332 \text{ mol L}^{-1}$

Conc of MnO_4^-

~~$n(MnO_4^-)$ =~~

n (Oxalic acid) in 20mls =

~~$n(MnO_4^-)$ in 20mls = 7.68×10^{-3}~~

~~$n(Mn^{2+})$ in 20mls = 7.68×10^{-3}~~

~~$n(Mn^{2+})$ in~~

$n(MnO_4^-)$ in 20mls = $n(Mn^{2+})$ in 20mls $= 7.68 \times 10^{-3}$

$n(MnO_4^-)$ in 100mls $= 100/20 \times 7.68 \times 10^{-3}$

$= 0.0384$

$m(Mn) = 0.0384 \times 54.94 = 2.12$ g

$\% = \frac{2.12}{5.31} \times 100 = 39.7\%$

Notes

Satisfactory response
5/8 marks

Uses the equation ratio correctly with an incorrect number of moles of oxalic acid.

Calculates the titre volume, but incorrectly calculates the number of moles of manganese.

Uses the correct method to calculate the mass and percentage of manganese.

Question

37(c)

Suggest the most suitable indicator for this titration and describe the colour change that would be observed during the titration.
(2 marks)

Indicator	
Description of colour change	

Marking key

Indicator	No indicator needs to be added; MnO_4^- acts as indicator
Description of colour change	Solution will turn from colourless to pale pink

Description	Marks
Recognition that no indicator needs to be added	1
Solution will turn from colourless to pale pink (i.e., that is the end point)	1
Question incorrectly answered	0
Question not attempted	-
Total	**2**

NB: “Self indicating” is acceptable

Keywords

Indicator chemicals

Question statistics

Statistics ID = CHE3-53
Number of attempts = 4307
Highest mark achieved = 2.00
Lowest mark achieved = 0.00
Mean = 0.49
Standard deviation = 0.71
Question difficulty = Difficult
Correlation between question and section = 0.36

Candidate responses

37(c)

Suggest the most suitable indicator for this titration and describe the colour change that would be observed during the titration.
(2 marks)

Notes

Indicator	No indicator needed (MnO_4^- is self indicating)
Description of colour change	Colourless solution turns pale pink

Excellent response
2/2 marks

Recognises that no indicator is needed; MnO_4^- will act as the indicator.

Correctly notes the observed colour change in the flask.

Indicator	no indicator necessary
Description of colour change	MnO_4^- (purple) → Mn^{2+} (pale pink)

Satisfactory response
1/2 marks

Recognises that no indicator is needed; MnO_4^- will act as the indicator.

Incorrectly notes the observed colour change in the flask.

Examiners' comments

Errors were commonly made with dilutions, and to use a titration equation involving manganese rather than the one provided involving the permanganate ion. Again, careful reading of the question would have reduced the risk of this error.

Question

Question 38
(20 marks)

The sandy soils of Western Australia are deficient in several elements essential to the growth of plant life. One of these elements is nitrogen, and there are a number of nitrogen-containing fertilisers available on the market. Urea, $CO(NH_2)_2$, is a commonly-used fertiliser that contains nitrogen. Urea is produced as crystals by the reaction of ammonia with carbon dioxide. Water is also produced in the reaction. The equation for this reaction is shown below.

$$2\ NH_3 + CO_2 \rightarrow CO(NH_2)_2 + H_2O$$

A reaction vessel designed for the synthesis of urea is operated at 200°C and 148 atmospheres. It has a total volume capacity of 5000 L, and ammonia and carbon dioxide are fed into it in batches so that ammonia occupies 62.0% of the volume and carbon dioxide occupies the remainder.

Question statistics

Statistics ID = CHE3-54
Number of attempts = 4663
Highest mark achieved = 20.00
Lowest mark achieved = 0.00
Mean = 14.03
Standard deviation = 5.10
Question difficulty = N/A
Correlation between question and section = 0.83

38(a)

Determine the limiting reagent for the reaction under the above operating conditions. Show **all** your workings.
(5 marks)

Marking key

Description	Marks
P = 148 × 101.3 = 1.49924 × 10^4 kPa (conversion of atm to kPa; alternatively students may use R = 0.08206 in the next step and be awarded 1 mark for remembering it)	1
Calculation of total number of moles: $n_{total} = \frac{PV}{RT} = \frac{1.49924 \times 10^4 \times 5000}{8.315 \times 473} = 1.906 \times 10^4$ mol	1
$n(NH_3) = 0.62 \times 1.906 \times 10^4 = 1.182 \times 10^4$ mol	1–3
$n(CO_2)$ = 0.38 × 1.906 × 10^4 = 7.243 × 10^3 mol	
From balanced eq'n: 2 mol NH_3 reacts with 1 mol CO_2 Thus 1.182 × 10^4 mol NH_3 needs 5.909 × 10^3 mol CO_2 Hence NH_3 is the limiting reagent. **Any acceptable method for finding LR may be used as long as it is supported with correct working.**	
Question incorrectly answered	0
Question not attempted	–
Total	**5**

NB: the 62% may be "applied" in any logical way

Students may choose to get the moles of NH_3 and CO_2 by finding the volume occupied by each of these gases and using the Ideal gas law twice. Gay-Lussac's law may also be used. Any valid method should be accepted. Use of a correct method for LR calculation based on incorrectly calculated moles of reagents should be rewarded.

Keywords

Stoichiometry, Chemical reactions

Question statistics

Statistics ID = CHE3-55
Number of attempts = 4644
Highest mark achieved = 5.00
Lowest mark achieved = 0.00
Mean = 4.18
Standard deviation = 1.33
Question difficulty = Easy
Correlation between question and section = 0.59

Candidate responses

38(a)

Determine the limiting reagent for the reaction under the above operating conditions. Show **all** your workings.
(5 marks)

Notes

$T = 200 + 273.1 = 473.1\ K$

$P = 148 \times 101.3 = 14992.4\ kPa$

$V(NH_3) = 0.62 \times 5000 = 3100\ L$

$V(CO_2) = 1900\ L$

$n(NH_3) = \frac{PV}{RT} = \frac{14992.4 \times 3100}{8.315 \times 473.1}$

$= 11814.56\ mol$

$n(CO_2) = \frac{PV}{RT} = \frac{14992.4 \times 1900}{8.315 \times 473.1}$

$= 7241.184\ mol$

Let $n(CO_2)$ be Limiting Reagent.

Thus, $n(NH_3)$ required $= 2 \times n(CO_2)$

$= 14482.4\ mol$

But $n(NH_3)$ provided is $11814.6\ mol$

Thus not enough NH_3.

Thus NH_3 is Limiting Reagent

Excellent response
5/5 marks

Calculates the number of moles of each reactant.

Uses the equation ratio to determine the limiting reagent.

$n = \frac{PV}{RT}$

$V(NH_3) = 5000 \times 0.62$

$V = 3100\ L$

$n(NH_3) = \frac{148 \times 3100}{8.315 \times 473.1}$

$n = 116.63\ mol$

$\therefore n = 58.315\ mol$

$V(CO_2) = 5000 - 3100$

$V = 1900$

$n(CO_2) = \frac{148 \times 1900}{8.315 \times 473.1}$

$n = 71.482\ mol$

$\therefore NH_3$ is the L.R.

Satisfactory response
3/5 marks

Calculates the number of moles of each reactant incorrectly using atmospheres.

Does not show the working of how the limiting reagent was calculated.

Question

38(b)

What mass of urea is theoretically produced in this reaction?
(3 marks)

Marking key

Description	Marks
$n(NH_2CONH_2)$ = ½ × $n(NH_3)$ = 0.5 × 1.182 × 10^4 = 5.909 × 10^3 mol	1
$M(NH_2CONH_2)$ = 60.062 g mol^{-1}	1
$m(NH_2CONH_2)$ = 60.062 × 5.909 × 10^3 = 3.55 × 10^5 g	1
Question incorrectly answered	0
Question not attempted	–
Total	**3**

NB: Award marks for follow through if candidate has used incorrect LR
Award marks for correct method based on incorrect LR

Keywords

Chemical reactions, Stoichiometry

Question statistics

Statistics ID = CHE3-56
Number of attempts = 4567
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 2.55
Standard deviation = 0.81
Question difficulty = Easy
Correlation between question and section = 0.50

Candidate responses

38(b)

What mass of urea is theoretically produced in this reaction?
(3 marks)

Notes

NH_3 is LR.
$\therefore$ n(NH_3) = 11814.56 mol

n(CO(NH$_2$)$_2$) = ½ × n(NH_3) Mr = 12.01 + 16 + 2(16.026)
= 5907.28 mol. = 60.062 g mol^{-1}

m = n × M

m(urea) = 5907.28 × 60.062
= ~~34~~ 354803.05 g
or 355 × 10^3 g

Excellent response
3/3 marks

Starts with the limiting reagent and uses the equation to calculate the number of moles and mass of urea produced.

m = n × mr = 11814.56 × 60.062
m = 709606.10 g
≈ 710 kg

Satisfactory response
2/3 marks

Calculates the molar mass and mass of urea, but did not use the equation ratio of 2 NH_3 produces 1 $CO(NH_2)_2$.

Question

38(c)

Calculate the mass of the excess reactant remaining after reaction.
(3 marks)

Marking key

Description	Marks
$n(CO_2)$ used = ½ × $n(NH_3)$ = 0.5 × 1.182 × 10^4 = 5.909 × 10^3 mol	1
$n(CO_2)$ remaining = 7.243 × 10^3 - 5.909 × 10^3 = 1.334 × 10^3 mol	1
$m(CO_2)$ remaining = 44.01 × 1.334 × 10^3 = 5.87 × 10^4 g	1
Question incorrectly answered	0
Question not attempted	–
Total	**3**

Keywords

Stoichiometry, Chemical reactions

Question statistics

Statistics ID = CHE3-57
Number of attempts = 4434
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 2.33
Standard deviation = 1.03
Question difficulty = Moderate
Correlation between question and section = 0.56

Candidate responses

38(c)

Calculate the mass of the excess reactant remaining after reaction.
(3 marks)

Notes

$n(CO_2)$ req. $= \frac{1}{2} \cdot 1.18 \times 10^4 = 5.91 \times 10^3$ mol.

$\rightarrow n(CO_2)$ left $= 7.24 \times 10^3 - 5.91 \times 10^3$

$= 1.33 \times 10^3$ mol.

$m(CO_2)$ left $= 1.33 \times 10^3 \cdot (12.01 + 2(16.00))$

$= \cancel{5.85}\ 5.87 \times 10^4$ g.

Excellent response
3/3 marks

Subtracts the reacted number of moles of CO_2 from the initial number of moles of CO_2 to find the remaining excess CO_2 reactant.

Calculates the mass of the remaining excess CO_2 reactant.

$n(CO_2) - n(NH_3) = n(CO_2$ remaining$)$

$= 7241.18 - 6288.54$

$= 952.64$ mol remaining

$M = 44.01$

$m = n \times M$

$= 952.64 \times 44.01$

$= 41925.6864$

$\therefore$ mass of CO_2 ~~remaing~~ remaining

$= 41925.64$ g

$= 41.93$ kg

$PV = nRT$

Satisfactory response
2/3 marks

Subtracts the total number of moles of NH_3 from the initial number of moles of CO_2 to incorrectly find the remaining excess CO_2 reactant.

Uses the correct method to calculate the mass of the remaining excess CO_2 reactant.

Question

38(d)

Calculate the pressure of the remaining gas in the reactor after it is allowed to cool to room temperature (25°C).
(The volume occupied by the urea crystals and water formed can be ignored.)
(2 marks)

Marking key

Description	Marks
$P = \frac{nRT}{V} = \frac{1.334 \times 10^3 \times 8.315 \times 298}{5000} = 6.61 \times 10^2\,kPa$ (or 6.53 atm) 1 mark for correct rearrangement of eq'n; 1 mark for final answer	1–2
Question incorrectly answered	0
Question not attempted	–
Total	**2**

Award marks for follow through for correct working when moles of CO_2 from (c) is incorrect.

Keywords

Chemical reactions, Stoichiometry

Question statistics

Statistics ID = CHE3-58
Number of attempts = 4295
Highest mark achieved = 2.00
Lowest mark achieved = 0.00
Mean = 1.35
Standard deviation = 0.69
Question difficulty = Moderate
Correlation between question and section = 0.38

Candidate responses

38(d)

Calculate the pressure of the remaining gas in the reactor after it is allowed to cool to room temperature (25°C). (The volume occupied by the urea crystals and water formed can be ignored.)
(2 marks)

Only excess CO_2 remains.

$n(CO_2) = 1.33 \times 10^3$ mol.

$P(CO_2) = \frac{n.R.T}{V}$

$= \frac{1.33 \times 10^3 . 8.315 . (25.0 + 273.1)}{5000}$

$= 6.61 \times 10^2$ kPa.

~~PV=nRT~~ ~~V~~

$PV = nRT$

$5000P = (11817.06 + 7242.7) \times 8.315 \times (25+273)$

$P = 41,749.2$ kPa

≈ 412.1 atm

Notes

Excellent response
2/2 marks

Uses the number of moles of remaining excess CO_2 reactant from question 38(c) to calculate the pressure of excess CO_2 reactant at 25°C.

Satisfactory response
1/2 mark

Uses the incorrect number of moles of remaining excess CO_2 reactant, which should be the same as for question 38(c).

Uses the correct method to calculate the pressure of excess CO_2 reactant at 25°C.

Question

38(e)

376 kg of impure crystals are formed in the above reaction and found, on analysis, to contain 83.0% urea. Calculate the percentage yield of the above process.
(2 marks)

Marking key

Description	Marks
$m(NH_2CONH_2) = 3.76 \times 10^5 \times 0.83 = 3.1208 \times 10^5$ g	1
$\text{Yield} = \dfrac{3.1208 \times 10^5}{3.55 \times 10^5} \times 100 = 87.9\%$	1
Question incorrectly answered	0
Question not attempted	–
Total	**2**

Keywords

Chemical reactions

Question statistics

Statistics ID = CHE3-59
Number of attempts = 3924
Highest mark achieved = 2.00
Lowest mark achieved = 0.00
Mean = 1.37
Standard deviation = 0.75
Question difficulty = Moderate
Correlation between question and section = 0.50

Candidate responses

38(e)

376 kg of impure crystals are formed in the above reaction and found, on analysis, to contain 83.0% urea. Calculate the percentage yield of the above process.
(2 marks)

Notes

$m(CO(NH_2)_2) = 0.83 . 376 \times 10^3$
$= 3.12 \times 10^5 g.$

$\rightarrow$ % eff. $= \frac{3.12 \times 10^5}{3.55 \times 10^5} \times 100$ from Part (b)

$= (8.79 \times 10^1)$% yield

Excellent response
2/2 marks

Uses the percentage purity and the theoretical yield from question 38(b) to calculate the yield of the process.

$376 \times 0.83 = 312.08$

$\% = \frac{312.08}{376} \times 100$

$\% = 83.0$

Satisfactory response
1/2 marks

Uses the percentage purity and not the theoretical yield from question 38(b) to calculate the yield of the process.

Question

38(f)

Urea is added to fertiliser preparations at about 45.0% by mass. Ammonium sulfate is an alternative source of nitrogen often used in fertilisers.

Question statistics

Statistics ID = CHE3-60
Number of attempts = 4103
Highest mark achieved = 5.00
Lowest mark achieved = 0.00
Mean = 3.14
Standard deviation = 1.77
Question difficulty = N/A
Correlation between question and section = 0.60

38(f)(i)

What mass of nitrogen is contained in 5.00 tonne of fertiliser that is 45.0% by mass urea? (1 tonne = 1×10^6 g)
(2 marks)

Marking key

Description	Marks
m(NH_2CONH_2) in fertiliser batch = $0.45 \times 5 \times 10^6 = 2.25 \times 10^6$ g	1
m(N) in fertiliser = $\frac{28.02}{60.062} \times 2.25 \times 10^6 = 1.05 \times 10^6$ g	1
Question incorrectly answered	0
Question not attempted	–
Total	**2**

Keywords

Chemical reactions

Question statistics

Statistics ID = CHE3-61
Number of attempts = 4100
Highest mark achieved = 2.00
Lowest mark achieved = 0.00
Mean = 1.47
Standard deviation = 0.68
Question difficulty = Moderate
Correlation between question and section = 0.48

Candidate responses

38(f)(i)

What mass of nitrogen is contained in 5.00 tonne of fertiliser that is 45.0% by mass urea? (1 tonne = 1 × 10^6 g) (2 marks)

Notes

Excellent response
2/2 marks

$m(\text{urea}) = 0.45 \times 5 \times 10^6 = 2250000\ g$

$n(\text{urea}) = \frac{m}{M} = \frac{2250000}{12.01+16+2\times(14.01+2\times1.008)} = 37460$

$n(N) = 2\times n(\text{urea}) = 2\times 37460 = 74920$

$n = \frac{m}{M} \Rightarrow m(N) = nM = 74920 \times 14.01 = 1.050\times10^6 g$

$m(N) = \underline{1.05\times10^6 g}$ (3SF)

Uses the percentage purity, when calculating the mass of nitrogen in the fertiliser.

Satisfactory response
1/2 marks

$m(\text{fertilised}) = 5\times10^6\ g$ $CO(NH_2)_2$

$m(\text{urea}) = 2.25\times10^6\ g$.

$n(\text{urea}) = \frac{m}{M} = \frac{2.25\times10^6}{58.046}$

$= 38762.36\ mol.$

$n(N) = 2\times 38762.36$

$= 77524.72$

$m = 77524.72\times 14.01$

$= 1.0861$ tonne

Employs the correct method, but uses an incorrect molar mass for urea.

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Question

38(f)(ii)

What mass of ammonium sulfate, $(NH_4)_2SO_4$, is needed to prepare 5.00 tonne of fertiliser with the same mass of nitrogen as your answer in (i) above?
(3 marks)

Marking key

Description	Marks
n(N) in fertiliser = $\dfrac{1.05 \times 10^6}{14.01} = 7.492 \times 10^4 \text{mol}$	1
$n((NH_4)_2SO_4) = 0.5 \times 7.492 \times 10^4 = 3.746 \times 10^4$ mol	1
$m((NH_4)_2SO_4) = 132.144 \times 3.746 \times 10^4 = 4.95 \times 10^6$ g	1
Question incorrectly answered	0
Question not attempted	–
Total	**3**

Keywords

Chemical reactions

Question statistics

Statistics ID = CHE3-62
Number of attempts = 3485
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 1.96
Standard deviation = 1.19
Question difficulty = Moderate
Correlation between question and section = 0.52

Candidate responses

38(f)(ii)

What mass of ammonium sulfate, $(NH_4)_2SO_4$, is needed to prepare 5.00 tonne of fertiliser with the same mass of nitrogen as your answer in (i) above?
(3 marks)

Notes

Excellent response
3/3 marks

$n(N)$ needed = 74920
$n((NH_4)_2SO_4)$ needed = $n(N) \div 2$ = 37460

$n = \frac{m}{M}$ => $m((NH_4)_2SO_4)$ needed $\cancel{= nM}$
= nM
= $37460 \times (2 \times (14.01 + 4 \times 1.008) + 32.06 + 4 \times 16)$
= 4.950×10^6 g
= 4.95×10^6 g (3SF)

Uses the answer from 38f(i) and the correct chemical relationship to calculate the mass of ammonium sulfate.

Satisfactory response
2/3 marks

$n(N)$ in $CO(NH_2)_2$ = $n(N)$ in $((NH_4)_2SO_4)$
∴ $n(N) = 7492.58$
$m = nM$
$= 7492.58 \times 132.144$
$= 990099.5$ g

Uses the correct method, but fails to calculate the number of moles of ammonium sulfate as half the number of moles of nitrogen.

Examiners' comments

Part (a) was well done overall, but candidates should be strongly encouraged to show adequate reasoning for their choice of limiting reagent.

Question

Question 39
(12 marks)

A student was given three bottles, A, B and C. Each bottle was labelled with its contents as shown in the table below.

Bottle	Contents
A	46.5 mL of 0.010 mol L^{-1} HCℓ
B	65.7 mL of 0.0555 mol L^{-1} HNO_3
C	20.9 mL of 0.4161 mol L^{-1} NaOH

Question statistics

Statistics ID = CHE3-63
Number of attempts = 4576
Highest mark achieved = 12.00
Lowest mark achieved = 0.00
Mean = 6.83
Standard deviation = 4.10
Question difficulty = N/A
Correlation between question and section = 0.79

39(a)

Calculate the pH of the NaOH solution.
(2 marks)

Marking key

Description	Marks
$[H^+] = \frac{1\times10^{-14}}{[OH^-]} = \frac{1\times10^{-14}}{0.4161} = 2.403\times10^{-14}\ \text{mol L}^{-1}$	1
pH = $-\log^{10}[H^+]$ = $-\log 2.403 \times 10^{-14}$ = 13.6 (13.619)	1
Question incorrectly answered	0
Question not attempted	–
Total	**2**

Keywords

Stoichiometry

Question statistics

Statistics ID = CHE3-64
Number of attempts = 4565
Highest mark achieved = 2.00
Lowest mark achieved = 0.00
Mean = 1.55
Standard deviation = 0.76
Question difficulty = Easy
Correlation between question and section = 0.52

Candidate responses

39(a)

Calculate the pH of the NaOH solution.
(2 marks)

$pH = [H^+]$ $[OH^-] = [NaOH] = 0.4161 \text{ mol L}^{-1}$

$[H^+] = 10^{-14} / 0.4161$

$= 2.403 \times 10^{-14}$

$-\log(2.403 \times 10^{-14}) = 13.62$

Notes

Excellent response
2/2 marks

Using K_w, calculates the H^+ concentration in the NaOH solution.

Uses the H^+ concentration of the NaOH solution to calculate the pH.

$n(OH) = n(NaOH) = cV$ $V = 0.0209 L$

$= 0.4161 \times 0.0209$

$= 8.69649 \times 10^{-3} mol$

$14 - (-\log(n(OH)))$

$= 14 - (-\log(8.69649 \times 10^{-3}))$

$PH = 11.94$

Satisfactory response
1/2 marks

Uses the number of moles and not the concentration to calculate the pH from the pOH.

Question

39(b)

The contents of all three bottles are placed in one beaker and mixed thoroughly. Calculate the pH of the final mixture.
(10 marks)

Marking key

Description	Marks
$n(H^+)$ from HCl = c ×V = 0.010 × 0.0465 = 4.65 × 10^{-4} mol	1
$n(H^+)$ from HNO_3 = c ×V = 0.0555 × 0.0657 = 3.646 × 10^{-3} mol	1
$n(H^+)_{total}$ = 4.65 × 10^{-4} + 3.646 × 10^{-3} = 4.111 × 10^{-3} mol	1
$n(OH^-)$ = c ×V = 0.4161 × 0.0209 = 8.696 × 10^{-3} mol	1
Recognition that 1 mole of H^+ reacts with 1 mole of OH^-; this may be by showing the mole relationship $n(H^+) = n(OH^-)$ or giving the balanced equation	1
$n(OH^-)$ reacted = $n(H^+)_{total}$ = 4.111 × 10^{-3} mol	1
$n(OH^-)$ excess = 8.696 × 10^{-3} - 4.111 × 10^{-3} = 4.585 × 10^{-3} mol	1
$c(OH^-) = \frac{n}{V} = \frac{4.585\times10^{-3}}{(0.0465+0.0657+0.0209)} = \frac{4.585\times10^{-3}}{0.1331} = 3.444\times10^{-2}\,\text{mol L}^{-1}$	1
$[H^+] = \frac{1\times10^{-14}}{[OH^-]} = \frac{1\times10^{-14}}{3.444\times10^{-2}} = 2.903\times10^{-13}\,\text{mol L}^{-1}$	1
pH = $-\log_{10}[H^+]$ = -log 2.903 × 10^{-13} = 12.5 (12.537)	1
Question incorrectly answered	0
Question not attempted	–
Total	**10**

NB: Steps may be amalgamated

Students may also calculate pH using:
pOH = $-\log^{10}[OH^-]$ = -log 0.03444 = 1.46 (2 marks)
pH = 14 – 1.46 = 12.54 (1 mark)

Keywords

Stoichiometry

Question statistics

Statistics ID = CHE3-65
Number of attempts = 4227
Highest mark achieved = 10.00
Lowest mark achieved = 0.00
Mean = 5.72
Standard deviation = 3.53
Question difficulty = Moderate
Correlation between question and section = 0.74

Candidate responses

39(b)

The contents of all three bottles are placed in one beaker and mixed thoroughly. Calculate the pH of the final mixture.
(10 marks)

Notes

Excellent response
10/10 marks

Calculates the number of moles and concentration of the excess OH^-. Using K_w calculates the H^+ concentration and then the pH.

$n(HCl) = (0.010)(0.0465) = 0.000465$ mol
$n(HNO_3) = (0.0555)(0.0657) = 0.0036464$ mol
$n(NaOH) = (0.4161)(0.0209) = 0.008696$ mol

Total $n(H^+) = 0.004114$ mol $n(OH^-) = 0.008696$ mol
Result : $n(OH^-) = 0.0045846$ mol
Total volume = 133.1 mL = 0.1331 L

$[OH^-] = \cancel{\frac{0.1331}{0.0045846}}\ \frac{0.0045846}{0.1331} = 0.03444$ molL^{-1}
$[H^+] = 10^{-14}/0.03444 = 2.903 \times 10^{-13}$
$-\log(\text{ans}) = 12.54$

Satisfactory response
5/10 marks

Calculates the number of moles of the H^+, the total volume and a pH value.

Ignores the effect of the OH^- reacting with the H^+.

Total volume is $46.5 + 65.7 + 20.9 = 133.1$ mL
$= 0.1331$ L
[A] $n(H^+) = CV$
$= 0.010(0.0465) = 0.000465$ mol of H^+
[B] $n(H^+) = CV$
$= 0.0555(0.0657) = 0.003646$ mol of H^+
[C] $[H_3O^+] = 2.403 \times 10^{-14}$ mol L^{-1}
we have 0.1331 L ie 3.198×10^{-15} mol of H^+

Total $= 0.000465 + 0.003646 + 3.198 \times 10^{-15}$
$= 0.004111$ mol of H^+
$C = \frac{n}{V} = \frac{0.00411}{0.1331} = 0.3089$
$\therefore pH = -\log(0.3089)$
$= 1.51$

Examiners' comments

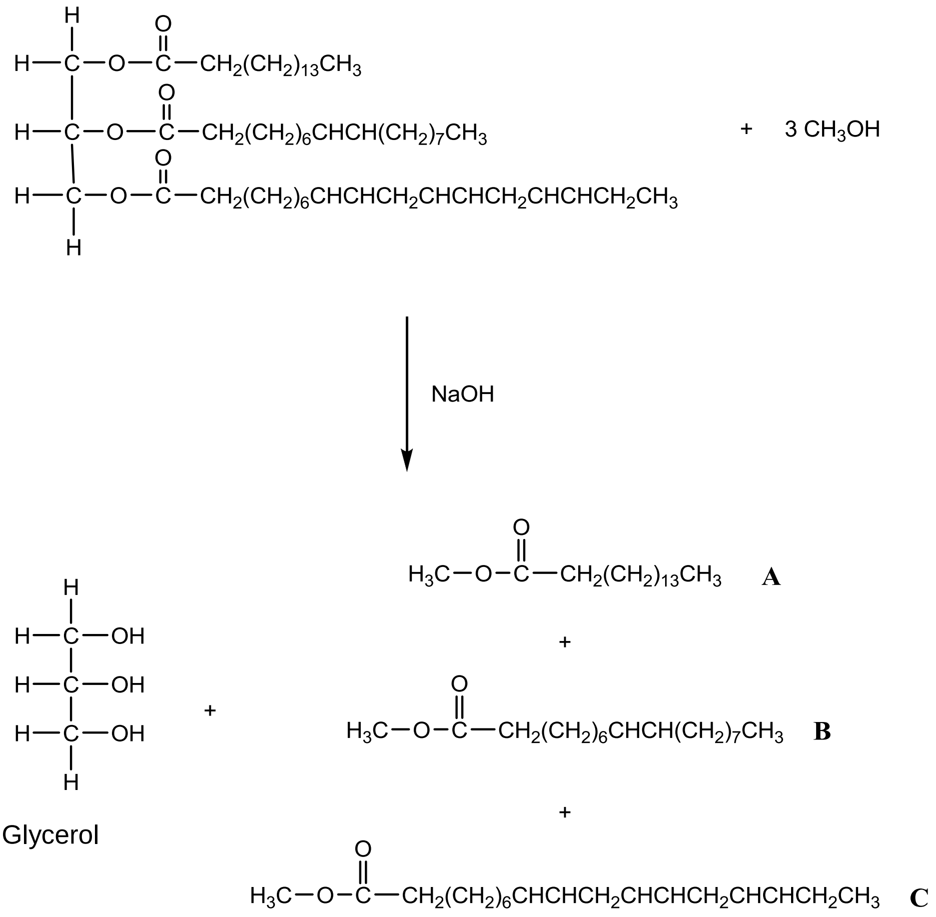
Part (b) presented challenges for a large number of candidates. Many did not recognise the chemical reaction that would take place when the solutions are mixed, and therefore did not pay attention to the stoichiometric aspects of the problem. Those who recognised the neutralisation reaction and the need to calculate excess reactants, performed well in answering the question. A common error was simply to calculate the $[H^+]$ of all solutions (including NaOH) and sum the hydrogen ion concentrations.

Question

Question 40
(15 marks)

Biodiesel can be produced by a trans-esterification reaction between vegetable oil and an alcohol in the presence of sodium hydroxide catalyst. A typical trans-esterification reaction is shown below. The products are glycerol and three methyl esters.

Vegetable oil



Glycerol

Methyl esters

Question statistics

Statistics ID = CHE3-66
Number of attempts = 4548
Highest mark achieved = 15.00
Lowest mark achieved = 0.00
Mean = 9.76
Standard deviation = 3.76
Question difficulty = N/A
Correlation between question and section = 0.82

Question

40(a)

The vegetable oil in the reaction above has a molar mass of 855.334 g mol^{-1}. If 1.50 tonnes of vegetable oil is reacted, what mass of methanol will be required to react with this amount of oil? (1 tonne = 1×10^6 g)
(3 marks)

Marking key

Description	Marks
n(Veg oil) = $\frac{1.5 \times 10^6}{855.334} = 1.754 \times 10^3 \text{mol}$	1
n(CH_3OH) = 3 × n(Veg oil) = 5.261×10^3 mol	1
m(CH_3OH) = $5.261 \times 10^3 \times 32.042 = 1.69 \times 10^5$ g	1
Question incorrectly answered	0
Question not attempted	–
Total	**3**

Keywords

Stoichiometry

Question statistics

Statistics ID = CHE3-67
Number of attempts = 4406
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 2.70
Standard deviation = 0.66
Question difficulty = Easy
Correlation between question and section = 0.44

Candidate responses

40(a)

The vegetable oil in the reaction above has a molar mass of 855.334 g mol^{-1}. If 1.50 tonnes of vegetable oil is reacted, what mass of methanol will be required to react with this amount of oil? (1 tonne = 1 × 10^6 g)
(3 marks)

Notes

$n(\text{oil}) = \frac{m}{M} = \frac{1.5\times10^6}{855.334} = 1754$

$n(CH_3OH)$ needed $= 3\times n(\text{oil}) = 3\times1754 = 5261$

$n = \frac{m}{M} \Rightarrow m(CH_3OH) = nM = 5261\times(12.01+4\times1.008+16) = \underline{1.69\times10^5 g}$ (3SF)

Excellent response
3/3 marks

Uses the equation to find the number of moles of oil and then correctly calculates the mass.

$n(\text{vege oil}) = \frac{1.5\times10^6}{855.334}$
$= 1.75\times10^3$ mol
$n(\text{methanol}) = 1.75\times10^3$ mol
$m(\text{methanol}) = 1.75\times10^3 \times 32.042$
$= 56.07$ Kg

Satisfactory response
2/3 marks

Calculates the number of moles and mass of oil without using the equation ratio.

Question

40(b)

Three different methyl esters, denoted **A**, **B** and **C**, are produced from this reaction. What is the mass of Ester **A** produced in this process if the reaction is 78% efficient in production of this ester?
(4 marks)

Marking key

Description	Marks
For 100% efficient: n(A) = n(Veg oil) = 1.754×10^3 mol	1
78% efficient, thus n(A) = $0.78 \times 1.754 \times 10^3 = 1.368 \times 10^3$ mol	1
MF Ester A is $C_{17}H_{34}O_2$ thus M(A) = 270.442 g mol^{-1}	1
m(A) = $1.368 \times 10^3 \times 270.442 = 3.70 \times 10^5$ g	1
Question incorrectly answered	0
Question not attempted	–
Total	**4**

The 78% efficiency step can be done based on the theoretical 100% efficient mass of A rather than number of moles of A.

Keywords

Chemical reactions

Question statistics

Statistics ID = CHE3-68
Number of attempts = 3995
Highest mark achieved = 4.00
Lowest mark achieved = 0.00
Mean = 3.26
Standard deviation = 1.17
Question difficulty = Moderate
Correlation between question and section = 0.46

Candidate responses

40(b)

Three different methyl esters, denoted **A**, **B** and **C**, are produced from this reaction. What is the mass of Ester **A** produced in this process if the reaction is 78% efficient in production of this ester?
(4 marks)

Notes

n(A) theoretically produced = n(oil) = 1754
n(A) actually produced = 0.78 × n(oil) = 0.78 × 1754 = 1368

n = m / M
m(A) = nM
= 1368 × (17 × 12.01 + 2 × 16 + 34 × 1.008)
= 370000 g
= 3.70×10^5 g (3SF)

Excellent response
4/4 marks

Uses percentage efficiency to correctly calculate the mass of ester produced.

n(A) = n(vegt oil) = 1753.7
m(A) = n × Mr = 1753.7 × 259.442 = 454983.44 g
m(ester A actually produced) =
= 454983.44 × 78%
= 354887.08 g
= 354.89 kg ester A

Satisfactory response
3/4 marks

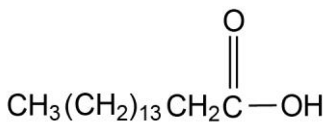
Employs the correct method, but uses an incorrect molar mass.

Question

40(c)

Esters can also be produced by the reaction of a carboxylic acid with an alcohol. Draw the structure of the carboxylic acid that would be needed to produce Ester A in the reaction above. Show H atoms.
(1 mark)

Marking key



Description	Marks
1 mark for structure; condensed or expanded acceptable.	1
Question incorrectly answered	0
Question not attempted	–
Total	**1**

Keywords

Carboxylic acid

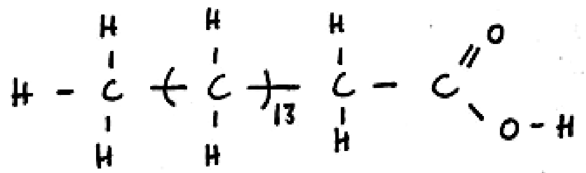
Question statistics

Statistics ID = CHE3-69
Number of attempts = 4090
Highest mark achieved = 1.00
Lowest mark achieved = 0.00
Mean = 0.73
Standard deviation = 0.45
Question difficulty = Moderate
Correlation between question and section = 0.40

Candidate responses

40(c)

Esters can also be produced by the reaction of a carboxylic acid with an alcohol. Draw the structure of the carboxylic acid that would be needed to produce Ester A in the reaction above. Show H atoms.
(1 mark)



or $CH_3 (CH_2)_{13} CH_2 - COOH$

Notes

Excellent response
1/1 mark

Draws the carboxylic acid and shows all H atoms.

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Question

40(d)

The glycerol produced from this process has a wide range of applications, including anti-freeze in the radiators of engines. A factor that contributes to its use as anti-freeze is its high water solubility. Explain, with the aid of a diagram, why glycerol has high water solubility.
(4 marks)

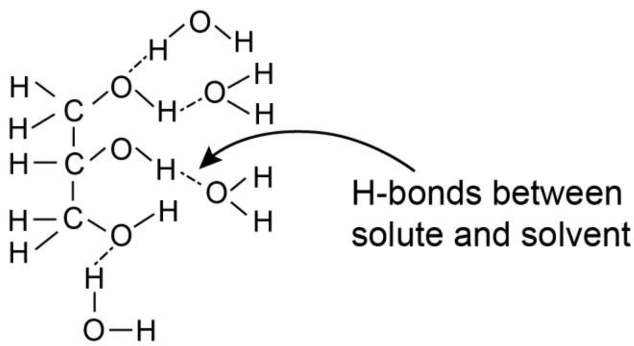
Marking key

Description	Marks
1 mark for recognition that both water and glycerol have H-bonding as their predominant type of IMF.	1
1 mark for showing that their similar IMFs leads to a high degree of interaction between solvent and solute molecules/formation of H-bonding	1
I mark for recognising that solubility arises due to the strength of attraction between solute and solvent molecules being sufficient to overcome attraction between solute-solute and solvent-solvent molecules**	1
1 mark for a suitable labelled diagram representing H-bonding between water and glycerol molecules.	1
Question incorrectly answered	0
Question not attempted.	–
Total	**4**

**An explanation in terms of the competing forces of attraction between solute-solute molecules, solvent-solvent molecules and between solvent-solute molecules is also acceptable. Students may also discuss the energy released when solvent-solute molecules attract being sufficient to overcome the energy to separate solute-solute molecules and solvent-solvent molecules.

'Like dissolves like', contains no chemistry and should not be awarded any marks.

Possible diagram



Keywords

Solubility, Hydrogen bonding

Question statistics

Statistics ID = CHE3-70
Number of attempts = 4120
Highest mark achieved = 4.00
Lowest mark achieved = 0.00
Mean = 2.12
Standard deviation = 1.19
Question difficulty = Moderate
Correlation between question and section = 0.65

Candidate responses

40(d)

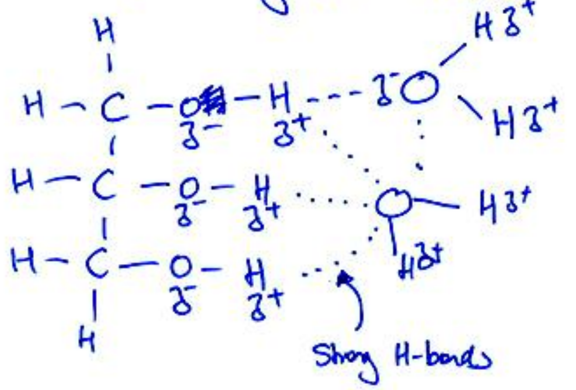
The glycerol produced from this process has a wide range of applications, including anti-freeze in the radiators of engines. A factor that contributes to its use as anti-freeze is its high water solubility. Explain, with the aid of a diagram, why glycerol has high water solubility.
(4 marks)

Notes

Excellent response
4/4 marks

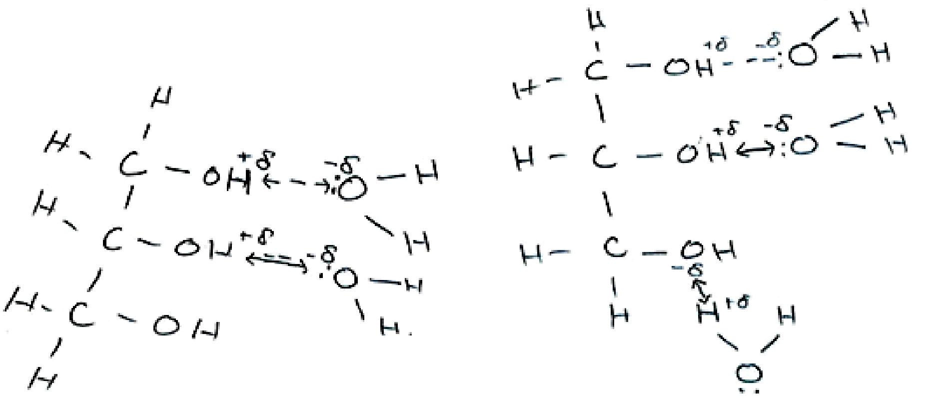
Explains, using a diagram and the hydrogen bonding of each liquid, why glycerol has a high solubility in water.

Solubility depends on whether forces formed between the solute and solvent are of equal strength to those between the solute particles by themselves or the solvents by themselve. Water exhibits hydrogen bonding so solutes that can form H-bonds are highly soluble in water. This is true of glycerol which has 3 alcohol (OH) functional groups that can exhibit H-bonding with water.



Candidate responses (continued)

Glycerol has high water solubility due to the presence of 3 OH groups. These are able to form Hydrogen bonds with the water molecules. This allows glycerol to form dipoles between the H^+ and O^- (lone pairs) of a water molecule to the glycerol. These bonds formed = high solubility.



Notes

Satisfactory response
3/4 marks

Discusses the hydrogen bonding of glycerol and water, but does not mention that solubility arises from the strength of attraction between solute and solvent molecules.

Question

40(e)

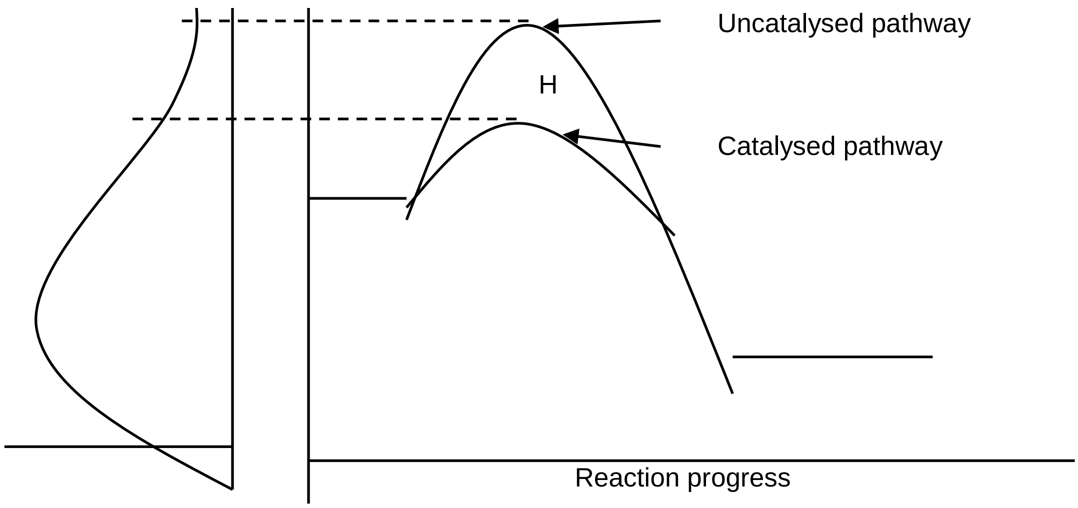
Use your understanding of the collision theory to explain the role of sodium hydroxide in the reaction.
(3 marks)

Marking key

Description	Marks
1 mark for recognising that the NaOH speeds the reaction	1
1 mark for recognising the NaOH provides an alternative reaction pathway that has lower E_a than the uncatalysed pathway	1
1 mark for recognising a higher proportion of collisions will occur with energy above the E_a (cat) and so be successful in forming products	1
Question incorrectly answered	0
Question not attempted	–
Total	**3**

NB: Must show some understanding of catalytic action of NaOH

An appropriately labelled energy profile diagram showing the catalysed and uncatalysed reaction pathways may be drawn to aid explanation. For a correct diagram on its own with no supporting explanation award 2 marks.



Keywords

Catalysis, Kinetic theory

Question statistics

Statistics ID = CHE3-71
Number of attempts = 3971
Highest mark achieved = 3.00
Lowest mark achieved = 0.00
Mean = 1.95
Standard deviation = 1.10
Question difficulty = Moderate
Correlation between question and section = 0.46

Candidate responses

40(e)

Use your understanding of the collision theory to explain the role of sodium hydroxide in the reaction.
(3 marks)

Notes

NaOH acts as a catalyst in the reaction. A catalyst is a substance which provides an alternative reaction pathway with lower activation energy. This increases the proportion of particle collisions in which the reacting molecules collide with the new, necessary activation energy, thereby increasing the rate of the trans-esterification reaction.

Excellent response
3/3 marks

Uses the collision theory to explain the role of a catalyst.

The sodium hydroxide speeds up the rate of reaction by ~~increasing~~ providing an alternate pathway with a lower activation energy

Satisfactory response
2/3 marks

States the role of a catalyst, without referring to collision theory.

Examiners' comments

This question was very well done, although most candidates were unable to adequately describe the processes occurring during dissolution, and were equally unable to draw a diagram that suitably illustrates forces established during dissolution. The relative strength of solute-solvent interactions and solute-solute, solvent-solvent interactions during dissolution should be highlighted to candidates.

Question

Question 41
(10 marks)

Soaps and detergents are common organic substances. Discuss the chemistry of these two classes of organic substances, including their structure, manufacture and how they act as cleaning agents.

Your answer should

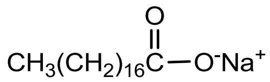
- include relevant chemical content.
(8 marks)

- display coherence and clarity of expression.
(2 marks)

A comprehensive answer should consist of at least three (3) paragraphs and be at least one page in length.

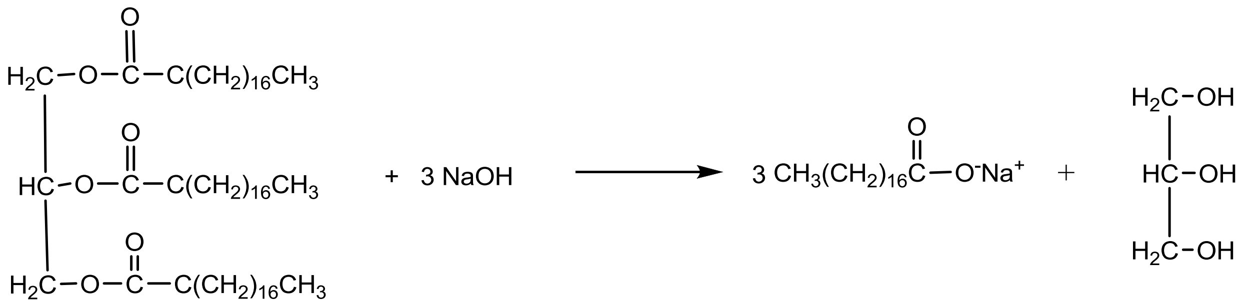
Marking key

- Soaps are sodium (or potassium) salts of long chain fatty acids.

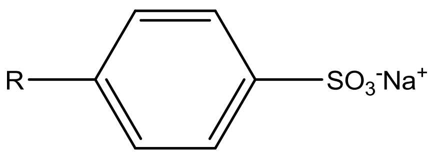


Typical soap molecule

- Soaps are manufactured by reaction of sodium (or potassium) hydroxide with an animal fat or vegetable oil. Fats and oils are esters of glycerol (1,2,3-propantriol). Known as a saponification reaction. The hydroxide hydrolyses the ester to give the sodium salt.
- General equation for saponification

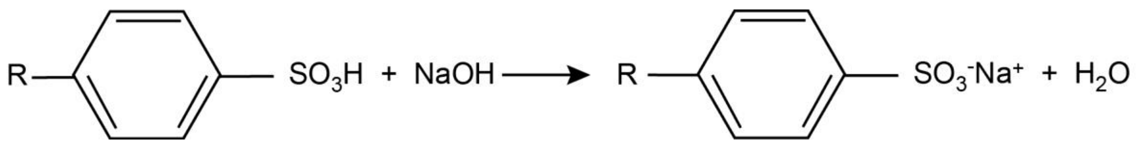


- Detergents are sodium (or potassium) salts of an alkylbenzene sulfonate.



R = long chain alkyl group

- Detergents are manufactured by reaction of alkylbenzenes with concentrated sulfuric acid to give the alkylbenzene sulfonate which is then reacted with sodium hydroxide to give the detergent.
- General equation



- Soaps and detergents are surfactant molecules comprised of a large non-polar part and a small polar part.
- The non-polar section of the soap/detergent molecule will dissolve in the (usually) non-polar dirt or grease with the polar section dissolved in the polar water.
- Agitation can then enable the soap/detergent molecule to lift the dirt/grease from the object to be cleaned.

Marking key (continued)

Description	Marks
Coherent sentences and clarity of expression	1–2
Structure for general soap molecule or specific example (can be part of the saponification equation) (ion or salt)	1
Comparison of effectiveness of detergents vs. soaps **or** manufacture of either (soap or detergent) This would include reference to reaction of soap with Mg^{2+} and Ca^{2+} ions to form scum	1–2
Structure for general detergent molecule or specific example acceptable (can be part of the detergent equation) (ion or salt)	1
Recognition of non-polar and polar nature of soap/detergent molecules	1
Recognition that the non-polar part of the molecule dissolves in the dirt/grease and the polar part of the molecule dissolves in the water	1–3
Question incorrectly answered	0
Question not attempted	–
Total	**10**

Keywords

Soaps, Detergents

Question statistics

Statistics ID = CHE3-72
Number of attempts = 4217
Highest mark achieved = 10.00
Lowest mark achieved = 0.00
Mean = 4.36
Standard deviation = 2.52
Question difficulty = Moderate
Correlation between question and section = 0.68

Candidate responses

Question 41
(10 marks)

Soaps and detergents are common organic substances. Discuss the chemistry of these two classes of organic substances, including their structure, manufacture and how they act as cleaning agents.

Your answer should

- include relevant chemical content.

(8 marks)

- display coherence and clarity of expression.

(2 marks)

A comprehensive answer should consist of at least three (3) paragraphs and be at least one page in length.

STRUCTURE

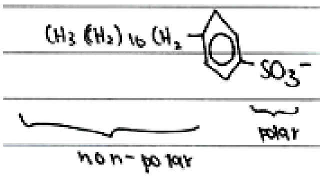
Soap is a salt and contains carboxylic acids while detergents are alkyl benzene sulfonates.

Soap consists of a polar end and a non polar end.

$CH_3(CH_2)_{16}C{=}O\ (O^-Na^+)$ or $\underbrace{CH_3(CH_2)_{16}}_{\text{non-polar end}}\underbrace{C{=}O\ (O^-)}_{\text{polar end}}$

As seen in the diagram above soap has a non-polar end due to the long hydrocarbon chain and a polar end due to the carboxylic acid group.

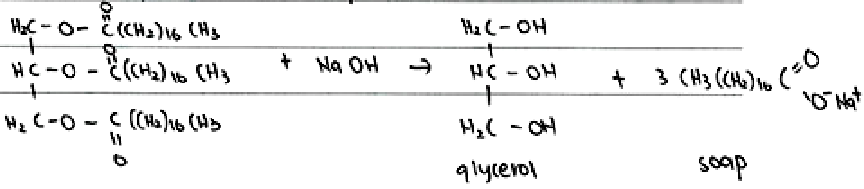
Similarly detergent also has a polar and non-polar end.



the polar end is due to the SO_3^- group and the long hydrocarbon chain is nonpolar.

MANUFACTURE

Soap is made by reacting animal fats or oils with glycerol and then reacting the productwith sodium hydroxide. An example of the reaction with sodium hydroxide:



Notes

Excellent response
10/10 marks

Discusses, with the use of equations and diagrams, the chemistry of soaps and detergents.

The discussion includes the structure, manufacture and how they act as cleaning agents.

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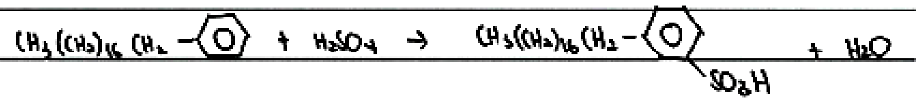
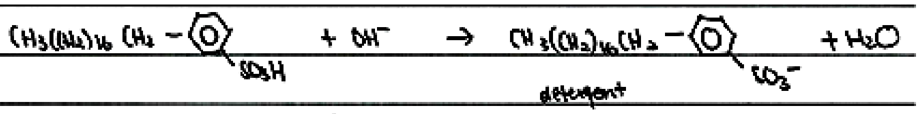
Candidate responses (continued)

Notes

Detergent is made by reacting an alkyl benzene with concentrated sulfuric acid.



The product is then reacted with sodium hydroxide to form detergent.



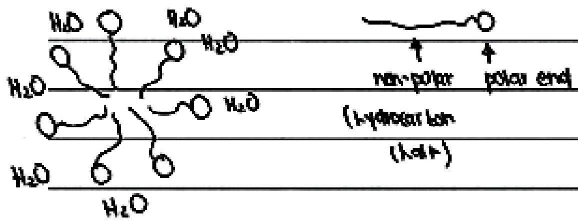
ACTION

Soap and detergent act as cleaning agents in much the same way.

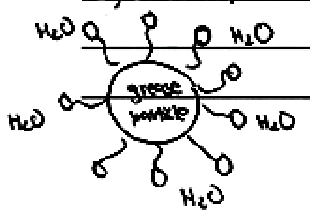
~~Since they both have a polar end, this end will form~~

Since soap has a polar COO^- end, and detergent has a polar SO_3^- end, these ends will form dipole-dipole forces with water molecules (which are polar). Their long hydrocarbon chain is however non-polar and will ~~not~~ only not form any strong bonds with the water molecules ~~and is form~~. These hydrocarbon chains form dispersion forces with the non-polar ends of other molecules, forming a structure called a micelle.

~~When added to water~~



Grease or dirt particles are non-polar and so are unable to dissolve in water. When soaps or detergents are added, the non-polar ends are attracted to the grease particles by dispersion forces. The grease particle is then surrounded by other soap/detergent particles and become captured in the micelle.



This allows the grease particle to act as a polar molecule and dissolve in water to be washed away.

Candidate responses (continued)

Notes

Scrubbing will increase the rate of cleaning process as this will break apart any micelles that has formed and increase interaction between detergent or soap molecules with the dirt or grease particle.

Soaps are biogradeable while detergents are not. However, soap reacts with ions in hard water to form scum (precipitates). For example, reacting with calcium ions.

$CH_3(CH_2)_{14}COO^-(aq) + Ca^{2+}(aq) \rightarrow Ca(CH_3(CH_2)_{14}COO)_2(s)$

Detergents do not form scum in hard water.

Candidate responses (continued)

Soaps are made from the process saponification. It is used in household to clean or remove dirt. However, soaps has its disadvantage that it will form scum in hard water that contains Ca^{2+} or Mg^{2+} ions. Thus requiring more soap to be used. To solve this problem, detergents are being magnifactured. Detergent does not form scum in hard water.

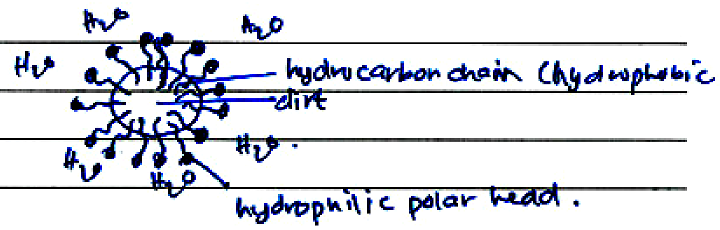
~~Soap~~ Soap contain two main parts, one is the hydrophobic tail of non-polar hydrocarbons and the other is hydrophilic polar head. The structure of soap is as below;

$R - COO^-$

long non-polar hydrocarbon chain — the functional group of soap and also the hydrophilic polar head.

The hydrophobic non-polar hydrocarbon chain can only form dispersion force between them. However the hydrophic head can form ~~hydrogen bond~~ dipole-dipole forces between the soaps. ~~The soap will remove~~ Detergent on the other hand has also two main parts same as ~~the hydrop~~ ~~the~~ soap. The difference is the functional group is not COO^- instead is SO_3^-. ~~Detergent is formed by adding~~ and the hydrocarbon cain contains a benzene ring. Detergent is formed by adding ~~Na~~ acidified H_2SO_4 to the original structure of detergent.

Both soap and detergent remove the dirt by forming micelle on the dirt. The diagram below shows how micelle;



Notes

Satisfactory response 7/10 marks

Discusses, with the use of diagrams, the structure and manufacture of soaps and detergents.

Provides a brief discussion of how soaps and detergents act as cleaning agents.

Examiners' comments

This was the most difficult question of the section. It is not clear whether it is because this part of the syllabus is challenging for candidates, or whether the nature of the question was inherently challenging or the type of question not practiced routinely. The question required a very heavy emphasis on content. Few responses contained diagrams and chemical equations; candidates should be reminded that an explanatory response still requires equations and diagrams, even if the question does not explicitly ask for them.

Appendix 1: Course achievement band descriptions

Excellent achievement (75 - 100)
- Recognises the limiting reagent aspect when determining the pH of a mixture of acids and bases.
- Distinguishes between species by recognising chemical differences.
- Uses logical reasoning and appropriate precision in calculations.
- Transfers chemical concepts to unfamiliar situations.
- Clearly communicates a range of concepts, including intermolecular forces, acid-base theory, catalysis, electrochemical cells and the chemistry of cleaning agents.
- Uses correct terminology, annotated diagrams and relevant equations.

High achievement (65 - 74)
- Completes multi-step calculations with minor errors or omissions.
- Explains the solution process and the role of the hydrogen half-cell using relevant terminology.
- Uses hydrolysis equations in explaining pH data.
- Consistently applies Le Chatelier's Principle.
- Draws and names geometric isomers.

Satisfactory achievement (50 - 64)
- Draws and names structural isomers and constructs an addition polymer.
- Applies VSEPR Theory to determine shapes of simple molecules.
- Represents hydrogen bonding diagrammatically.
- Calculates the pH of a basic solution.
- Applies a stoichiometric ratio to determine a limiting reagent.
- Combines half-equations by balancing electrons.
- Applies solubility rules to distinguish solutions.
- Describes the hydrophobic and hydrophilic properties of surfactant ions.

Limited achievement (35 - 49)
- Draws a Lewis structure and uses it to determine molecular shape without applying theory.
- Converts units and correctly substitutes into the Ideal Gas Equation.
- Inconsistently applies Le Chatelier's Principle.
- Provides simplistic explanation of catalysis.

Inadequate achievement (0 - 34)
- Applies the octet rule to drawing Lewis structures of simple molecules.
- May rearrange expressions, substitute data and calculate molar masses.
- May identify an alkene and draw simple isomers.
- Recalls only that water forms hydrogen bonds.

Cut points:
Excellent/High = 69.61
High/Satisfactory = 59.10
Satisfactory/Limited = 42.56
Limited/Inadequate = 24.88

Appendix 2: Rasch analysis of examinations

Rasch analysis is used to test the reliability and validity of an examination. It produces numerical estimates of the ability of the students who sat the examination and the difficulty of each item in the examination. An ‘item’ is a scoring opportunity. It may be a whole question (e.g. a multiple-choice question) or, in the case of questions that are broken down into discrete elements, a part of a question or a sub-part of a question.

In Rasch analysis, the estimates of student ability and item difficulty are placed on a common measurement scale, like a ruler. Items are clustered into five bands: *Very easy*, *Easy*, *Moderate*, *Difficult* and *Very difficult*. Items that are less difficult to answer correctly are located to the left and items that are more difficult to answer correctly are located to the right. Similarly, using the same scale, less able students are located to the left and more able students are located to the right.

The boundary of the *Moderate* difficulty band is determined by the difficulty of the middle 68% of items, i.e. the difficulty is one standard deviation from the mean student location. The boundaries for the *Very easy–Easy* and the *Difficult–Very difficult* band are determined by reference to student abilities.

Less able students						More able students
Less difficult questions	< - - - - - - - - o - - - - - - - - - o - - - - - - - - - o - - - - - - - - - o - - - - - - - - ->					More difficult questions
	Very easy	Easy	Moderate	Difficult	Very difficult	

Table 1 on the following page provides the item difficulty analysis for the 2011 Stage 3 WACE examination for Chemistry.

Notes

- N/A (in the Difficulty estimates in this Guide) indicates the item was not used in the Rasch analysis. This is because one or more items had too few responses (or no responses).
- As shown in Table 1, when a question consists of a number of items (e.g. in the case of questions 37-40), the difficulty estimate is given for each item, not for the question as a whole.
- In the Rasch model, the higher a student’s ability, relative to the difficulty of an item, the greater the chances are of that student scoring the correct answer. When a student’s *ability location* is equal to the *difficulty location* of an item, there is a 50/50 (or 0.5) probability of that student scoring the correct answer.
- The Rasch model is used in the analysis of data for NAPLAN and PISA and is also used in disciplines such as medicine and the social sciences.
- Location values for student difficulty and item ability are given as *logits* (a contraction of the phrase ‘log-odds units’). Because logit values are based on probability, they are also referred to as *estimates* of item difficulty and *estimates* of student ability.

Table 1: Item difficulty analysis for the 2011 Stage 3 Chemistry examination

Section	Question	Location	Difficulty
S01	1	-1.56	Very easy
S01	2	-1.44	Easy
S01	3	-1.13	Easy
S01	4	-0.36	Easy
S01	5	-1.66	Very easy
S01	6	0.09	Moderate
S01	7	-0.23	Easy
S01	8	-2.23	Very easy
S01	9	-1.34	Easy
S01	10	-0.38	Easy
S01	11	-0.58	Easy
S01	12	-0.08	Easy
S01	13	-1.19	Easy
S01	14	0.26	Moderate
S01	15	0.56	Moderate
S01	16	0.59	Moderate
S01	17	-0.22	Easy
S01	18	-1.13	Easy
S01	19	1.59	Difficult
S01	20	-0.50	Easy
S01	21	-0.02	Easy
S01	22	-1.22	Easy
S01	23	0.37	Moderate
S01	24	1.70	Difficult
S01	25	-0.11	Easy
S02	26	-0.80	Easy
S02	27		N/A
S02	27a	0.66	Moderate
S02	27b	0.37	Moderate
S02	27c	-0.15	Easy
S02	28	0.00	Moderate
S02	29	0.95	Moderate
S02	30	0.94	Moderate
S02	31		N/A
S02	31a	0.77	Moderate
S02	31b	-0.36	Easy
S02	32		N/A
S02	32a	0.24	Moderate

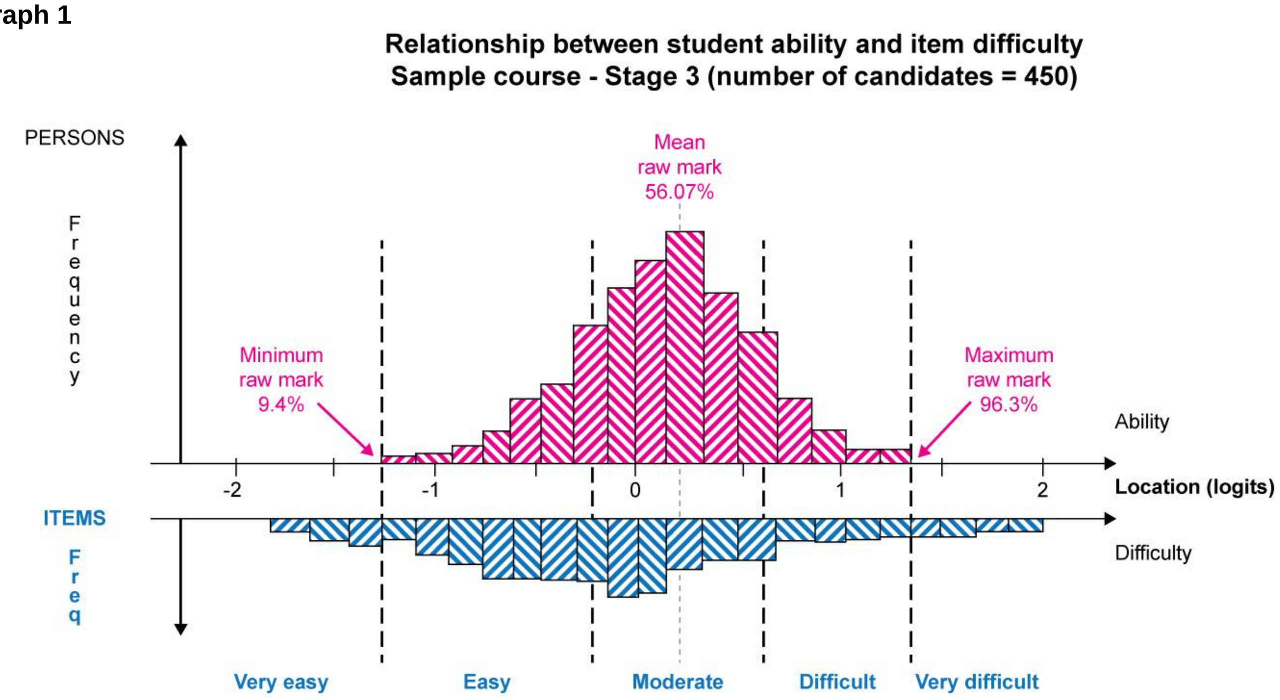
Table 1: Item difficulty analysis for the 2011 Stage 3 Chemistry examination (continued)

Section	Question	Location	Difficulty
S02	32b		N/A
S02	32bi	-0.59	Easy
S02	32bii	0.07	Moderate
S02	32biii	0.10	Moderate
S02	33	-0.06	Easy
S02	34	-0.20	Easy
S02	35		N/A
S02	35a	0.87	Moderate
S02	35b	0.52	Moderate
S02	35c	0.96	Moderate
S03	36	0.02	Moderate
S03	37		N/A
S03	37a	-0.20	Easy
S03	37b	0.47	Moderate
S03	37c	1.79	Difficult
S03	38		N/A
S03	38a	-0.26	Easy
S03	38b	-0.45	Easy
S03	38c	-0.01	Moderate
S03	38d	0.22	Moderate
S03	38e	0.46	Moderate
S03	38f		N/A
S03	38fi	0.16	Moderate
S03	38fii	0.76	Moderate
S03	39		N/A
S03	39a	-0.17	Easy
S03	39b	0.64	Moderate
S03	40		N/A
S03	40a	-0.40	Easy
S03	40b	0.26	Moderate
S03	40c	0.12	Moderate
S03	40d	0.91	Moderate
S03	40e	0.56	Moderate
S03	41	1.05	Moderate

A walk-through of a graph of student ability and item difficulty

Graph 1 (for a sample Stage 3 WACE examination with 450 candidates) provides an example of how data from a Rasch analysis of student ability and item difficulty can be represented.

Graph 1



- The frequency distribution of estimates of student abilities is shown in the top half of the graph.
- The frequency distribution of estimates of item difficulties is shown in the bottom half of the graph.
- These two measures share a common horizontal scale showing locations, expressed as logits.
- Logit values do not relate directly to percentage marks; however, the percentage raw exam scores are represented on the graph, e.g. the maximum raw mark, the minimum raw mark and the mean raw mark of the examination.
- The relationship between the ability of students and the difficulty of items is such that
    - a student with an ability estimate *equal* to the difficulty of an item has a 50% chance of achieving the maximum available mark for the item
    - a student with an ability estimate *greater* than the difficulty of an item has more than a 50% chance of achieving the maximum available mark for the item
    - a student with an ability estimate *less* than the difficulty of an item has less than a 50% chance of achieving the maximum available mark for the item.
- Items of ‘average’ or ‘moderate’ difficulty are placed around the mean person ability; items of increasing difficulty are placed to the right and items of decreasing difficulty are placed to the left.

A good spread of student abilities and item difficulties – and some questions for discussion

Graph 1 presents one example of a good spread of student abilities and question difficulties resulting from a Rasch analysis of a fictional examination:

- the mean raw mark (56.07) is considered appropriate, within general statistical terms and in terms of the expectations for WACE examinations
    - *Discussion question: In terms of raw marks, has this been a difficult or easy examination?*
- the minimum examination mark is close to zero and the maximum is close to 100%.
    - *Discussion questions: What are the implications of having a range of raw marks from 0% to 100%? For example, is this useful for the purposes of discrimination?*
- the range of marks (9.4% to 96.3%) is appropriate.
    - *Discussion question: In terms of raw marks, has this examination efficiently discriminated among students, i.e. were some items too easy or too difficult for this cohort?*
- the distribution of item difficulties is good in relation to the distribution of student abilities.
    - *Discussion question: What implications are suggested when there are items with difficulty estimates greater than the maximum ability estimate and less than the minimum ability estimate?*

Why are two graphs provided for some examinations?

When an item is worth just 1 mark, it is known as a dichotomous item. When an item is worth more than 1 mark, it is known as a polytomous item.

For polytomous items, the item difficulty is the average of the difficulties of achieving each mark allocated to the item. Misleading conclusions can sometimes be drawn from graphs of these data when there are gaps in the item difficulty distribution, e.g. there may appear to be not enough difficult items or not enough easy items.

In these instances, it can be useful to check the distribution of the difficulty estimates for achieving each individual mark (marks category). A Rasch analysis allows for graphing the difficulty in scoring each mark, or the *threshold* for moving from one mark to the next.

Where possible, therefore, *two* graphs are provided in the Standards Guides 2011: Examples are Graphs 2 and 3 below for the 2011 Stage 3 Chemistry examination.

Graph 2 shows the item difficulty and the student abilities frequency distribution.

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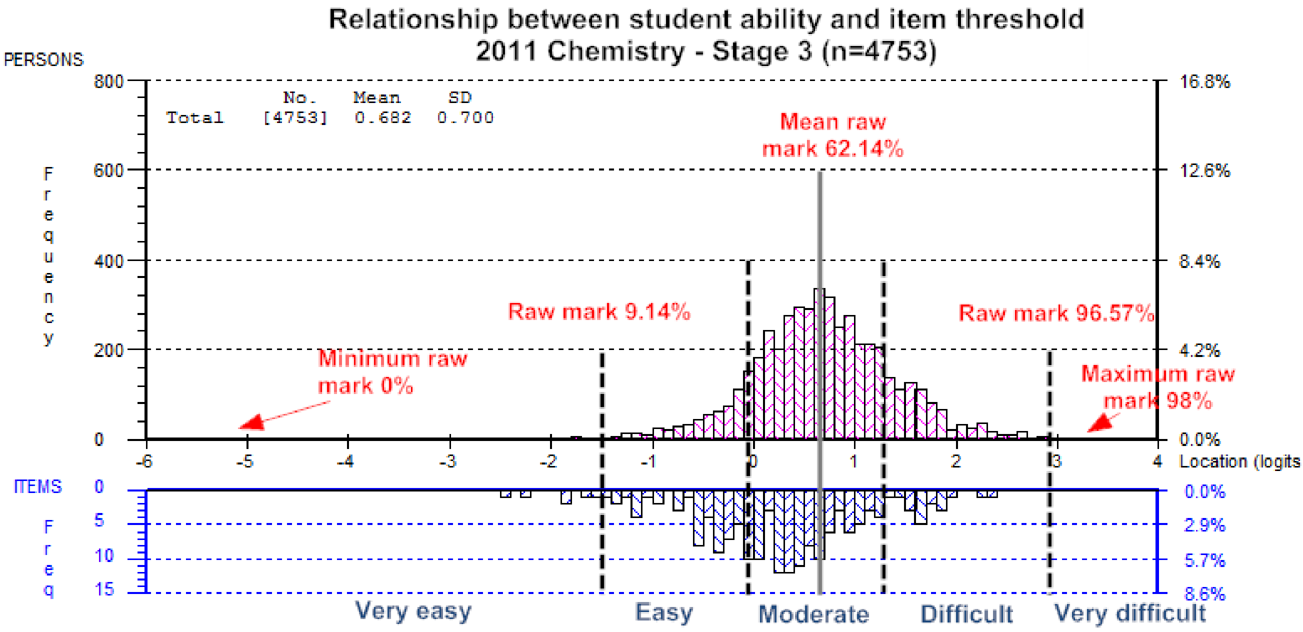
Graph 2 - Distribution between student ability and item difficulty

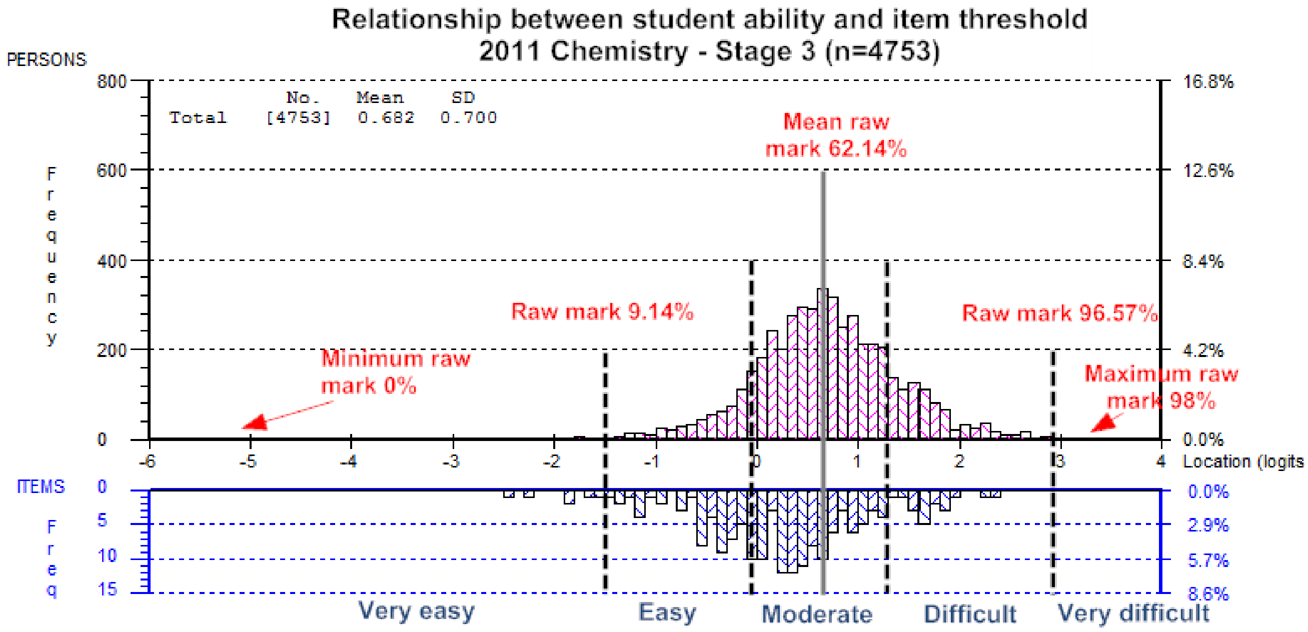


Notes

As the graph shows, there were not enough ‘difficult’ and ‘very difficult’ items. However, although an item might not be ‘difficult’ or ‘very difficult’, it is possible that it was difficult to achieve the higher marks for that item. The difficulty of achieving each mark is called a ‘threshold’. Therefore, for a better understanding of item difficulty, we need to analyse the distribution of person abilities and thresholds, as shown in Graph 3.

Graph 3 *(opposite)* shows the difficulty of achieving each category and the student abilities frequency distribution

Graph 3 - Distribution between student ability and item thresholds difficulty



Notes

From the spread of item thresholds in this graph, we can see that there were no items that had marks that were ‘very difficult’ to achieve. This indicates that to challenge and differentiate better among the best students there would need to be more items with thresholds that were ‘difficult’ or ‘very difficult’ to achieve.

Some points to bear in mind for understanding examination analysis

- When evaluating the **range** (spread) of examination marks, consider the size of the cohort sitting the examination. A small cohort may involve a narrow range of student abilities.
- When evaluating the **mean** examination mark, consider the nature of the cohort sitting the examination. The examination difficulty may be appropriate for the cohort for which the course was designed, but the actual cohort may be weaker or stronger than expected.
- In these notes, the **difficulty** of the item refers to the *average* of the difficulties of acquiring each marks category for the item. For example, it may be very difficult to obtain a high mark for an item rated as being of ‘moderate difficulty’, if that item is worth a large number of marks. Conversely it may be very easy to obtain a low mark.
- Recommendations to remove items of a certain level of difficulty or easiness do not imply that these are poor items, but simply that there are too many items at the same level of difficulty.
- Recommendations to add more difficult items may result in a better discrimination among students.