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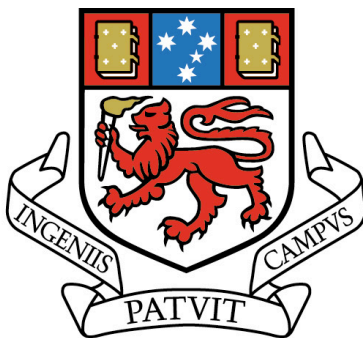
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Appendices to accompany the thesis:

**An Evaluation and Redevelopment of Current
Laboratory Practices: An in-depth Study into the
Differences Between Learning and Teaching Styles**

by

Reyne Pullen, BSc(Hons)

School of Physical Sciences - Chemistry

University of Tasmania

March 2016

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Appendix I - Supporting Information

I.1 Ethics Information

I.2 Systematic Review Marking Scheme

I.3 Sample Sizes of Various Comparisons

I.4 Validation Criteria for Laboratory Performance Rubric

Appendix I - Supporting Information

I.1 Ethics Information

I.1 Ethics Information

PARTICIPANT INFORMATION SHEET (PROFORMA)

**SOCIAL SCIENCE/ HUMANITITES
RESEARCH**

An analysis and redevelopment of first year laboratories.

Invitation

You are invited to participate in a research study into alternative teaching methods used in teaching first year laboratories. The aim for this study is to increase student involvement within a laboratory environment as well as improving independent thinking and problem solving skills.

The study is being conducted by...

Student Investigator: Reyne Pullen. PhD Candidate at School of Chemistry

Chief Investigator: Prof. Brian Yates. Lecturer at School of Chemistry

Co-Investigator: A/Prof. Greg Dicinoski. Head at School of Chemistry

Co-Investigator: Dr. Natalie Brown. Senior Lecturer, Learning and Teaching

Reyne is completing this study in partial fulfillment of the requirements for a PhD degree under the supervision of Professor Yates, A/Professor Dicinoski, and Dr Brown.

1. 'What is the purpose of this study?'

The purpose is to investigate whether using alternative teaching methods have a significant impact on the understanding, enjoyment, and problem solving skills gained from completing the laboratory.

2. 'Why have I been invited to participate in this study?'

You are eligible to participate in this study because you are a student undertaking KRA001.

4. 'What does this study involve?'

This study will involve students undertaking an alternative teaching method laboratories in place of their standard teaching laboratory. The laboratory will progress as per the normal routine with the same time slot, lab space and demonstrators to oversee each group. The alternate experiments being investigated include three versions, Expository, Guided Inquiry, and Problem Solving. On completion of the experiment, students will complete a multiple-choice quiz for understanding and a survey about the experiment. The researchers would also like to compare you grades on these exercises with the quiz and survey answers.

It is important that you understand that your participation in this study is voluntary. While we would be pleased to have you participate in the study, we respect your right to decline. There will be no consequences to you if you decide not to consent to the use of your results or grades, and this will not affect your treatment / service. All information will be treated in a confidential manner, and

your name will not be used in any publication arising out of the research. All of the research will be kept in a locked cabinet in the office of Prof. Brian Yates, the Chief Investigator and will be securely destroyed five years after publication of the study. Your consent to participate in this study and for the researchers to use all your results and grades is implied by your completion of the provided survey. Completion of the quiz is part of your normal laboratory studies. If you do not wish to participate in the study, then you should not complete the survey.

5. Are there any possible benefits from participation in this study?

The completion of these laboratories may give you a better understanding of the processes undertaken. In addition to this, students may feel that they had a greater engagement in the experiment.

6. Are there any possible risks from participation in this study?

There are no specific risks anticipated from this study. Due to the nature of this study being similar to a pilot study, some problems may need to be improved or overcome but they shall be dealt with as they arise.

7. What if I have questions about this research?

If you would like to discuss any aspect of this study please feel free to contact either Reyne Pullen on ph 6226 1744 or Brian Yates on ph 6226 2167. Either of us would be happy to discuss any aspect of the research with you. Once we have analysed the information we will be mailing / emailing you a summary of our findings. You are welcome to contact us at that time to discuss any issue relating to the research study.

This study has been approved by the Tasmanian Social Science Human Research Ethics Committee. If you have concerns or complaints about the conduct of this study should contact the Executive Officer of the HREC (Tasmania) Network on (03) 6226 7479 or email human.ethics@utas.edu.au. The Executive Officer is the person nominated to receive complaints from research participants. You will need to quote [H0011923].

Thank you for taking the time to consider this study.

If you wish to take part in it, please complete the survey form attached.

This information sheet is for you to keep.

I.2 Systematic Review Marking Scheme

Appendix I - Supporting Information
I.2 Systematic Review Marking Scheme

Systematic Review Marking Review

Guidelines to Evaluate the Quality and Evidence of Qualitative/Quantitative/Mixed method Studies (Adapted from Kennelly 2010 (8))

Question	Yes	Partially	No	U/D*
Research Design				
The study's purpose and research aims are clearly stated.	2	1	0	0
Methods of inquiry are appropriate for the study aims. (The research sought to understand, illuminate, or explain the subjective experience or views of those being researched in a defined context or setting.)	2	1	0	0
The authors discussed why they decided to use the chosen methods.	2	1	0	0
Total research design score				
Sampling				
Participant selection is clearly described and appropriate.	2	1	0	0
The sample size is discussed and justified.	2	1	0	0
Total sampling score				
Data collection				
Data collection methods are clearly described and justified.	2	1	0	0
The methods are appropriate given the study aims and research questions.	2	1	0	0
Total data collection score				

Appendix I - Supporting Information
I.2 Systematic Review Marking Scheme

Data analysis				
The analytic process is clearly described.	2	1	0	0
All relevant data were taken into account.	2	1	0	0
The authors considered/discussed contradictory evidence and data.	2	1	0	0
The study included triangulation (namely, comparison of different sources of data re: the same issue).	2	1	0	0
If "yes", Triangulation produced convergent conclusions (or if divergent, they were discussed and justified).	2	1	0	0
If "no", was this adequately explained?	2	1	0	0
Study findings were generated by more than one analyst and/or were analysed with reference to work in similar published studies.	2	1	0	0
Total data analysis score				
Findings/Results				
There is a clear statement of the findings.	2	1	0	0
The study findings are discussed in terms of their relation to the research questions posed.	2	1	0	0
The findings appear credible.	2	1	0	0
Sufficient data are presented to support findings.	2	1	0	0

Appendix I - Supporting Information
I.2 Systematic Review Marking Scheme

Potential researcher biases are taken into account (for example participation of author in study).	2	1	0	0
Conclusions are explicitly linked with exhibits of data.	2	1	0	0
Total findings/results score				
<i>Research value</i>				
Study findings contributed to the current knowledge base.	2	1	0	0
Findings can reasonably be expected to inform current practices or policies.	2	1	0	0
These contributions are discussed by the authors.	2	1	0	0
The authors identified new research questions or directions to be investigated	2	1	0	0
The authors discussed how the research findings could be used and for what populations.	2	1	0	0
Enough descriptive detail was included to allow readers to make their own judgements about potential transferability to other settings.	2	1	0	0
Total findings/results score				
Overall score				

*U/D represents Unable to be Determined

I.3 Sample Sizes of Various Comparisons

Appendix I - Supporting Information
I.3 Sample Sizes of Various Comparisons

The sample sizes compiled below are to accompany those comparisons discussed within the main body of this dissemination. Specifically the comparisons below correspond to the Figures and Tables within Chapter 5 - Results: Foundation Chemistry.

Experiment	Comparison	Sample Size		
		EX	GI	PS
<i>The Analysis of a Solution by Measurement of its Density</i>	Figure 5. Total distribution of survey comments	108	35	19
	Figure 9. Comparison of grades	97	80	93
	Figure 10. Comparison of quiz responses	86	38	56
<i>Distillation as a Separation Technique</i>	Figure 11. Total distribution of survey comments	56	49	58
	Figure 15. Comparison of grades	97	77	94
	Figure 16. Comparison of quiz responses	79	29	68
<i>Identification of a Carboxylic Acid</i>	Figure 17. Comparison of grades	95	76	87
	Figure 18. Comparison of quiz responses	80	21	33
<i>Properties of Solutions of Acids and Bases</i>	Figure 19. Total distribution of survey comments	39	28	23
	Figure 23. Comparison of grades	96	71	84
	Figure 24. Comparison of quiz responses	78	27	50

Appendix I - Supporting Information
I.3 Sample Sizes of Various Comparisons

The sample sizes compiled below are to accompany those comparisons discussed within the main body of this dissemination. Specifically the comparisons below correspond to the Figures and Tables within Chapter 6 - Results: First Year Chemistry.

Experiment	Comparison	Sample Size		
		EX	GI	PS
<i>Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid</i>	Table 24. Comparison of survey responses	98	190	154
	Figure 25. Total distribution of survey comments	215	211	131
	Figure 29. Comparison of grades	104	238	226
	Figure 30. Comparison of quiz responses	130	220	104
<i>Organic Functional Groups</i>	Table 29. Comparison of survey responses	117	166	75
	Figure 31. Total distribution of survey comments	144	141	96
	Figure 35. Comparison of grades	199	233	109
	Figure 36. Comparison of quiz responses	118	210	74
<i>Thermochemistry: Enthalpy of Neutralisation</i>	Table 34. Comparison of survey responses	86	119	53
	Figure 37. Total distribution of survey comments	71	65	69
	Figure 41. Comparison of grades	188	230	79
	Figure 42. Comparison of quiz responses	87	185	52
<i>Determination of the Freezing-Point Depression Constant for Cyclohexane</i>	Table 39. Comparison of survey responses	94	133	47
	Figure 43. Total distribution of survey comments	114	76	78
	Figure 47. Comparison of Grades	196	225	47
	Figure 48. Comparison of quiz responses	99	206	73

Appendix I - Supporting Information
I.4 Validation Criteria for Laboratory Performance Rubric

I.4 Validation Criteria for Laboratory Performance Rubric

Appendix I - Supporting Information
I.4 Validation Criteria for Laboratory Performance Rubric

Assessment task 2: Design, implement and evaluate the effectiveness of a criteria sheet				weighting 50%
criteria	HD	DN	CR	PP
1. Design a criteria sheet • structure and layout • criteria • descriptors Weighting 50 %	You:	You:	You:	You:
	• <i>skilfully</i> designed a criteria sheet that:	• <i>effectively</i> designed a criteria sheet that:	• designed criteria sheet that:	• designed a criteria sheet that:
	– was structured around five standards or levels of achievement			
	– had a clear and readable layout with no less than 8point font			
	– used a <i>manageable</i> number of criteria that were <i>explicitly derived</i> from the unit learning outcomes	– used a <i>manageable</i> number of criteria that were <i>derived</i> from the unit learning outcomes	– used criteria that were <i>related</i> to the unit learning outcomes	– used criteria that were <i>loosely connected</i> to the unit learning outcomes
	– used criteria:		– used criteria:	
	• with <i>no</i> quantifiers or qualifiers		• with <i>an occasional</i> quantifier or qualifier	
	• that were about the <i>key qualities</i> required in students' responses		• <i>that were mostly</i> about the key qualities required in students' responses	• <i>that were partially</i> about the key qualities required in students' responses
	• <i>consistently</i> formulated descriptors that:	• <i>predominantly</i> formulated descriptors that:	• formulated descriptors that:	• formulated descriptors that:
	– were task-specific rather than generic and reflected <i>reasonable</i> expectations for the year level and task requirements	– were <i>mostly</i> task-specific rather than generic and reflected <i>reasonable</i> expectations for the year level and task requirements	– were <i>partially</i> task-specific and, <i>mostly</i> reflected <i>reasonable</i> expectations for the year level and task requirements	
	– described the <i>main</i> aspects of <i>evidence</i> the students must demonstrate at each level	– described <i>evidence</i> the students must demonstrate at each level	– <i>partially</i> described <i>evidence</i> the students must demonstrate at each level	– <i>partially</i> described <i>evidence</i> the students must demonstrate
	– described standards in <i>plain English</i> that were <i>clear, concise, unambiguous and student-friendly</i>		– <i>described standards in plain English</i> that were <i>clear and student friendly but that, at times</i> , contained jargon or difficult-to-understand English	
	– were framed <i>positively</i> with qualifiers that <i>minimised</i> subjective interpretation		– were <i>mostly</i> framed <i>positively</i> with qualifiers that <i>reduced</i> subjective interpretation	
	– reflected <i>clear</i> and <i>discriminating</i>	– reflected <i>clear</i> progression in	– reflected progression in achievement	– reflected <i>some</i> progression in

Appendix I - Supporting Information
I.4 Validation Criteria for Laboratory Performance Rubric

Assessment task 2: Design, implement and evaluate the effectiveness of a criteria sheet					weighting 50%
criteria	HD	DN	CR	PP	
2. Implement and evaluate the effectiveness of the criteria sheet <ul style="list-style-type: none"> • benefits and challenges • students' self evaluation • future practice Weighting 40%	<ul style="list-style-type: none"> • <i>thoroughly</i> implemented and evaluated the effectiveness of the criteria sheet by: 	<ul style="list-style-type: none"> • implemented and evaluated the effectiveness of the criteria sheet by: 	<ul style="list-style-type: none"> • implemented and evaluated the effectiveness of the criteria sheet by: 	<ul style="list-style-type: none"> • implemented and evaluated the effectiveness of the criteria sheet by: 	
	<ul style="list-style-type: none"> – <i>explicitly and perceptively</i> identifying benefits and challenges in the design and your use of the sheet – <i>providing convincing data</i> about whether or not students found the criteria sheet useful in <i>evaluating their responses</i> to the task 	<ul style="list-style-type: none"> – <i>explicitly</i> identifying benefits and challenges in the design process – <i>providing data</i> about whether or not students found the criteria sheet useful in <i>evaluating their responses</i> to the task 	<ul style="list-style-type: none"> – identifying <i>some</i> benefits and challenges in the design process – <i>providing data</i> about whether or not students used the criteria sheet 	<ul style="list-style-type: none"> – making <i>generalised statements</i> about some benefits and challenges in the design process – stating whether or not students used the sheet 	
	<ul style="list-style-type: none"> – <i>described</i> and <i>thoroughly justified</i> future refinements to your criteria sheet based on: <ul style="list-style-type: none"> • your own reflections/experience • <i>evidence</i> of student achievement of intended learning outcomes • discussion with peers • current literature 	<ul style="list-style-type: none"> – <i>described</i> and <i>justified</i> future refinements to your criteria sheet based on: <ul style="list-style-type: none"> • your own reflections/experience • <i>evidence</i> of student achievement of intended learning outcomes • discussion with peers • current literature 	<ul style="list-style-type: none"> – <i>described some</i> future refinements to your criteria sheet based on: <ul style="list-style-type: none"> • your own reflections/experience • your <i>assumptions</i> about student achievement of intended learning outcomes • discussion with peers • some literature 	<ul style="list-style-type: none"> – <i>made some suggestions</i> for future refinements to your criteria sheet based on: <ul style="list-style-type: none"> • your own reflections/experience 	
3. Communicate in academic writing: <ul style="list-style-type: none"> – expression and English conventions (spelling, punctuation, grammar) – use of literature – APA referencing of literature sources Weighting 10%	<ul style="list-style-type: none"> • <i>consistently</i> communicated in <i>fluent</i> academic writing by: 	<ul style="list-style-type: none"> • <i>predominantly</i> communicated in <i>fluent</i> academic writing by: 	<ul style="list-style-type: none"> • communicated in <i>fluent</i> academic writing by: 	<ul style="list-style-type: none"> • communicated in academic writing by: 	
	<ul style="list-style-type: none"> – using <i>coherent, concise and cohesive</i> expression by adhering to English conventions 			<ul style="list-style-type: none"> – using <i>coherent and partly cohesive</i> expression by adhering to English conventions 	
	<ul style="list-style-type: none"> – <i>integrating a range of relevant, scholarly literature</i> (generic and discipline-specific) to support justification of your views 	<ul style="list-style-type: none"> – <i>integrating a range of relevant, scholarly literature</i> to support justification of your views 	<ul style="list-style-type: none"> – <i>integrating relevant</i> scholarly literature to support justification of your views 	<ul style="list-style-type: none"> – <i>used some</i> scholarly literature to support justification of your views 	
	<ul style="list-style-type: none"> – <i>accurately</i> referencing <i>all</i> sources using the APA convention 		<ul style="list-style-type: none"> – <i>accurately</i> referencing <i>most</i> sources using the APA convention 	<ul style="list-style-type: none"> – <i>accurately</i> referencing <i>most</i> sources using the APA convention 	

Appendix II - Data Collection Instruments

II.1 Global instruments

II.1.1 Foundation and First Year Student Perceptions Survey

II.1.2 Rubric for Assessment of Laboratory Performance

II.1.3 Second Year and Third Year Student Perceptions Survey

II.2 Experiment Specific Instruments

II.2.1 Foundation Chemistry

II.2.1.1 The Analysis of a Solution by Measurement of its Density Post-Quiz

II.2.1.2 Distillation as a Separation Technique Post-Quiz

II.2.1.3 Identification of a Carboxylic Acid Post-Quiz

II.2.1.4 Properties of Solutions of Acids and Bases Post-Quiz

II.2.2 First Year Chemistry

II.2.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid Post-Quiz

II.2.2.2 Organic Functional Groups Post-Quiz

II.2.2.3 Thermochemistry: Enthalpy of Neutralisation Post-Quiz

II.2.2.4 Determination of the Freezing Point Depression Constant for Cyclohex

Appendix II - Data Collection Instruments
II.1.1 Foundation and First Year Student Perceptions Survey

II.1 Global Instruments

II.1.1 Foundation and First Year Student Perceptions Survey

Appendix II - Data Collection Instruments
II.1.1 Foundation and First Year Student Perceptions Survey

By giving your ID number you give consent for the results of this survey to be used for research and publication. Please note that no personal information will be kept or published.

Student ID : _____

Response answers range from 1 = Strongly disagree to 10 = Strongly agree. Please **CIRCLE** the chosen response.

Question	Response									
	(1) Strongly disagree					Strongly agree (10)				
This learning format was an engaging experience.	1	2	3	4	5	6	7	8	9	10
The learning objectives were clearly defined.	1	2	3	4	5	6	7	8	9	10
The learning objectives were fulfilled through completion of this experiment.	1	2	3	4	5	6	7	8	9	10
I further developed my practical skills in the laboratory by completing the experiment in this format.	1	2	3	4	5	6	7	8	9	10
The workload expected was acceptable.	1	2	3	4	5	6	7	8	9	10
I deepened my understanding of chemistry through completion of the experiment in this format.	1	2	3	4	5	6	7	8	9	10
I put effort into completing this learning procedure.	1	2	3	4	5	6	7	8	9	10
I found the experiment in this format to be both interesting and enjoyable.	1	2	3	4	5	6	7	8	9	10
Overall rating for experiment in this format.	1	2	3	4	5	6	7	8	9	10
	(1) Failure					Success (10)				

Appendix II - Data Collection Instruments
II.1.1 Foundation and First Year Student Perceptions Survey

Were there any specific elements of this learning procedure that worked well?
Were there any specific elements that did not work well?
Are there any areas that could be improved?
Any additional comments?

Appendix II - Data Collection Instruments
II.1.2 Rubric for Assessment of Laboratory Performance

II.1.2 Rubric for Assessment of Laboratory Performance

Appendix II - Data Collection Instruments
II.1.2 Rubric for Assessment of Laboratory Performance

School of Chemistry – Chemistry 1 Laboratory Report Marking Rubric

Student Name: _____			Student Number: _____		
Experiment Number and Title: _____					
Criteria	HD	DN	CR	PP	NN
	In your laboratory, you:	In your laboratory, you:	In your laboratory, you:	In your laboratory, you:	In your laboratory, you:
Completion of pre-laboratory requirements (5%) Work safely and efficiently within a laboratory (5%) Weighting 20% (10%)	• Correctly answered all prelab questions including the required calculations		• Correctly answered the majority of prelab questions including the required calculations	• Correctly answered at least half of the prelab questions including performing the required calculations.	• Failed to answer at least half of the prelab questions including performing the required calculations.
	• <i>Successfully</i> completed the laboratory with <i>no</i> incidents of safety concerning students or demonstrators.		• <i>Successfully</i> completed the laboratory with at most <i>minor</i> safety incidents.		• Demonstrated insufficient effort to meet the minimum safety requirements as detailed within the laboratory manual.
	• Completed the experiment and associated questions and calculations in a planned and <i>timely</i> manner.		• Completed the experiment and the majority of the associated questions and calculations in a <i>planned</i> manner within the allotted time frame.	• Completed the experiment, but not the associated questions and calculations, within the allotted time frame	• Did not complete the experiment within the time frame allotted.
Use of the correct techniques and calculations	• Produced an <i>expected</i> outcome using the <i>correct</i> techniques and/or calculations with minimal guidance. <i>Applied</i> these to the concepts and principles	• Produced an expected outcome using the <i>correct</i> techniques and/or calculations necessary for completion of the laboratory.	• Produced an expected outcome using the techniques and/or calculations necessary for the laboratory with some <i>minor errors</i> . <i>Moderate</i> guidance was required.	• Produced an expected outcome. The techniques and calculations used were <i>partially</i> correct. <i>Significant</i> guidance was required.	• Achieved an unsatisfactory result with little understanding of the techniques and/or calculations used within the laboratory. <i>Significant</i> guidance was required.

Appendix II - Data Collection Instruments
II.1.2 Rubric for Assessment of Laboratory Performance

Understanding of the concepts and principles Weighting 40% (H); 20% (L)	• Demonstrated a <i>complete</i> understanding of the concepts and principles utilised within the laboratory.	• Demonstrated a <i>near complete</i> understanding of the concepts and principles utilised within the laboratory.	• Demonstrated a <i>partial</i> understanding of the concepts and principles utilised within the laboratory.	• Demonstrated a <i>basic</i> understanding of the concepts and principles utilised within the laboratory.	• Showed insufficient understanding of the concepts and principles utilised within the laboratory.
	• Used the <i>correct</i> number of significant figures and correct units in <i>all</i> calculations and recorded quantities		• Mostly used the <i>correct</i> number of significant figures and correct units in <i>all</i> calculations and recorded quantities		• Did not use the <i>correct</i> number of significant figures and correct units in calculations and recorded quantities
Comments:			Grade:		

- Each grade within the criteria will be divided into 3 zones – high, medium and low (for example the CR grade will have marks of 61, 65 and 69) – for the purposes of deriving a mark from the Rubric.
- The Laboratory Report will receive an overall mark out 100 based upon the above Rubric, calculated from the performance in each of the Criteria.
- The total mark for each laboratory will be 130 being comprised from 30 for the Quiz and 100 for the report. This mark will then be scaled to 100.

Appendix II - Data Collection Instruments
II.1.3 Second and Third Year Student Perceptions Survey

II.1.3 Second and Third Year Student Perceptions Survey

Appendix II - Data Collection Instruments
II.1.3 Second and Third Year Student Perceptions Survey

This survey is designed for students to provide feedback on the effectiveness of the teaching method used for the experiment undertaken.

Response answers range from 1 = Strongly disagree to 10 = Strongly agree. Please **CIRCLE** the chosen response.

This learning format was an engaging experience.	1	2	3	4	5	6	7	8	9	10
What did you find particularly engaging?										
The learning objectives were clearly defined.	1	2	3	4	5	6	7	8	9	10
The learning objectives were fulfilled through completion of this experiment.	1	2	3	4	5	6	7	8	9	10
What changes could be made to improve the learning objectives?										
I further developed my practical skills in the laboratory by completing the experiment in this format.	1	2	3	4	5	6	7	8	9	10
Justify your response.										

Appendix II - Data Collection Instruments
II.1.3 Second and Third Year Student Perceptions Survey

The workload expected was acceptable.	1	2	3	4	5	6	7	8	9	10
If the workload was not acceptable, how might this be improved? For example, pre-laboratory preparation, post-laboratory discussion, research elements, relevance to real world chemistry, etc.										
I deepened my understanding of chemistry through completion of the experiment in this format.	1	2	3	4	5	6	7	8	9	10
How confident would you be in repeating the experiment?	1	2	3	4	5	6	7	8	9	10
Justify your response.										
I found the experiment in this format to be both interesting and enjoyable.	1	2	3	4	5	6	7	8	9	10
Which parts of this experiment were particularly interesting or enjoyable?										
Overall rating for experiment in this format.	1	2	3	4	5	6	7	8	9	10
	(1) Failure							Success (10)		

Appendix II - Data Collection Instruments
II.1.3 Second and Third Year Student Perceptions Survey

What questions or ideas did you have after the experiment? Did you feel these should have been covered as part of the experiment?

What were you unsure about when you began the laboratory?

Were you still unsure upon completion of the laboratory?

Were there any specific elements of this learning procedure that worked well?

Appendix II - Data Collection Instruments
II.1.3 Second and Third Year Student Perceptions Survey

Were there any specific elements that did not work well?

Are there any areas that could be improved?

Any additional comments?

Thank you for your participation in this study.

Appendix II - Data Collection Instruments

II.2.1.1 The Analysis of a Solution by Measurement of its Density Post-Quiz

II.2 Experiment Specific Instruments

II.2.1.1 The Analysis of a Solution by Measurement of its Density Post-Quiz

KRA 001 Laboratory Quiz

Student No.:

Experiment 2: The Analysis of a Solution by Measurement of its Density

During an experiment a student needs to calculate the **amount** (in mols) of a compound.

Given a molar mass for the compound of 245.376 g/mol and a measured compound mass of 1.8020g:

- a) Indicate the number of significant figures in the above values.

- b) Calculate the amount of compound to the correct number of significant figures.

Briefly describe the difference between an **analytical** and **top-pan** balance and when it would be appropriate to use each balance.

Appendix II - Data Collection Instruments

II.2.1.1 The Analysis of a Solution by Measurement of its Density Post-Quiz

A student transfers **20.00** mL of a solution accurately (using a 20.00 mL pipette) into a 50 mL beaker, which has been pre-weighed accurately and found to have a mass of **24.0034** g. The combined mass of the beaker and solution was found to be **63.8251** g. Using the provided information calculate the density of this solution to the correct number of significant figures.

The solution in the previous question was found to have a composition of 3.7 % w/v. Using the determined density, convert the composition to % w/w.

Appendix II - Data Collection Instruments

II.2.1.2 Distillation as a Separation Technique Post-Quiz

II.2.1.2 Distillation as a Separation Technique Post-Quiz

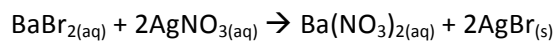
KRA 001 Laboratory Quiz

Student No.:

Experiment 3: Distillation as a Separation Technique

Briefly describe the process of distillation and detail how this technique can be utilized to achieve a separation.

Given the chemical reaction below, provide the **total** ionic and **net** ionic equations.



Appendix II - Data Collection Instruments
II.2.1.3 Identification of a Carboxylic Acid Post-Quiz

II.2.1.3 Identification of a Carboxylic Acid Post-Quiz

KRA 001 Laboratory Quiz

Student No.:

Experiment 5: Identification of a Carboxylic acid

At least how many properties must be measured to identify an unknown compound?

Provide an example of each property.

What volume of 0.1422 M NaOH is required for the titration of 0.8362 g of Malonic acid.

Show all working.

What does it mean if an acid is described as being diprotic?

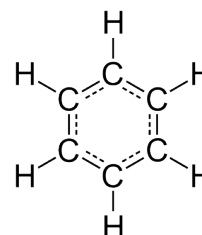
Give the empirical formula for the following compounds:

i. Octane

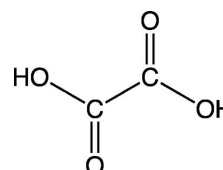
ii. $\text{CH}_3\text{CH}_2\text{CHCH}_3\text{CH}_3$

iii. Acetic Acid

iv.



v.



Appendix II - Data Collection Instruments
II.2.1.4 Properties of Solutions of Acids and Bases Post-Quiz

II.2.1.4 Properties of Solutions of Acids and Bases Post-Quiz

KRA 001 Laboratory Quiz

Student No.:

Experiment 6: Properties of Solutions of Acids and Bases

What is pH a measure of?

What is conductivity a measure of?

Give the ionic equations of the dissociation in water of the following compounds (ensure both sides of the equation are balanced with both charge and molecules):

a) HNO_3

b) LiOH

Detail the neutralisation reaction between the two compounds listed above.

A solution of sodium hydroxide was measured to have a $[\text{OH}^-]$ concentration of 2.5 mol/L.
Calculate the pH of this solution.

First Year

II.2.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid Post-Quiz

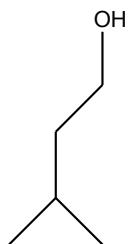
KRA 113 Laboratory Quiz

Student No.:

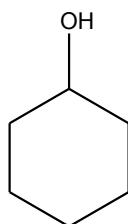
Experiment 4A: Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Given the following starting materials (A – D), draw the end product after they have undergone oxidation using the method detailed in your experiment.

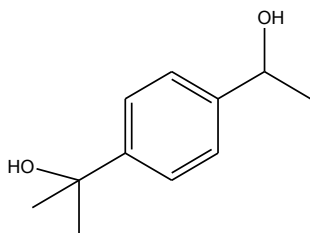
A)



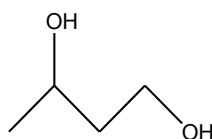
B)



C)



D)



Appendix II - Data Collection Instruments
II.2.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid Post-Quiz

During crystal formation the procedure specifies to cool slowly with no stirring or agitation. Give a brief description of why this is an important step.

A student in a chemistry course completed a benzoic acid synthesis using benzyl alcohol and calculated a final yield of 135%. If they began with a starting benzyl alcohol volume of 2.3 mL (1.046 g/mL) and achieved a final benzoic acid mass of 2.076 g, identify how the student came to this conclusion and provide the correct yield.

Show all working.

Appendix II - Data Collection Instruments
II.2.2.2 Organic Functional Groups Post-Quiz

II.2.2.2 Organic Functional Groups Post-Quiz

KRA 113 Laboratory Quiz

Student No.:

Experiment 5A: Organic Functional Groups

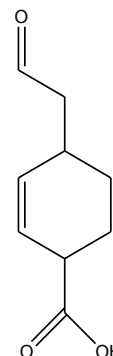
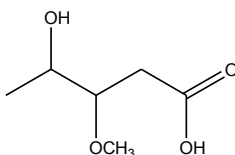
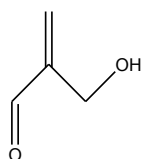
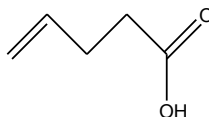
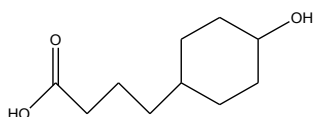
When performing tests for the presence of functional groups, observable changes are required to note a positive or negative result. Give four examples of observable changes.

A student performs a number of functional group tests on organic compound X. The observations from these tests are as follows.

1. Upon addition of red/brown bromine solution, the solution mixed with the bromine solution to produce a red/brown solution.
2. Upon addition of potassium permanganate, the solution became transparent with a fine black precipitate forming.
3. Upon addition of 2,4-dinitrophenylhydrazine, no precipitation was observed. NOTE: during this test a drop of 2,4-DNP fell into the potassium permanganate test tube in step 2 immediately forming an orange/red precipitate.
4. Finally, upon addition of 5% sodium bicarbonate, bubbles were observed.

From these observations, what conclusions can be drawn?

Identify (circle your choice) organic compound X from the options below:



Appendix II - Data Collection Instruments
II.2.2.3 Thermochemistry: Enthalpy of Neutralisation Post-Quiz

II.2.2.3 Thermochemistry: Enthalpy of Neutralisation Post-Quiz

KRA 113 Laboratory Quiz

Student No.:

Experiment 7A: Thermochemistry

During this experiment a rudimentary calorimeter was used to measure the enthalpies of three reactions. Give a brief explanation of the purpose of a calorimeter and the flaws, if any, associated with the calorimeters used in the experiment today.

We have observed that energy is being released during these reactions; it is well known energy must be conserved. Therefore, from what source/s is the energy derived from?

Discuss Hess' Law and how this was used in the experiment completed.

Appendix II - Data Collection Instruments

II.2.2.4 Determination of the Freezing Point Depression Constant for Cyclohexane Post-Quiz

II.2.2.4 Determination of the Freezing Point Depression Constant for Cyclohexane Post-Quiz

KRA 113 Laboratory Quiz

Student No.:

Experiment 8A: Freezing Point Depression

Define the difference between molarity and molality.

Given a freezing point depression of 14 K.kg.mol^{-1} for a solution containing 12.56 g of cyclohexane and an unknown amount of naphthalene, find the mass of naphthalene added to observe a freezing point depression of 0.7°C .

Show all working.

How would the freezing point of cyclohexane change if an insoluble ionic compound were added?

Appendix III - Alternative Teaching Approaches Procedures

Within this appendix, each the three versions of each experiment will be presented. To avoid repetition of information, only the first version of each experiment will contain those components common amongst each version.

III.1 Foundation Chemistry

III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

III.1.2 Guided Inquiry - The Analysis of a Solution by Measurement of its Density

III.1.3 Problem Solving - The Analysis of a Solution by Measurement of its Density

III.1.4 Expository - Distillation as a Separation Technique

III.1.5 Guided Inquiry - Distillation as a Separation Technique

III.1.6 Problem Solving - Distillation as a Separation Technique

III.1.7 Expository - Identification of a Carboxylic Acid

III.1.8 Guided Inquiry - Identification of a Carboxylic Acid

III.1.9 Problem Solving - Identification of a Carboxylic Acid

III.1.10 Expository - Properties of Solutions of Acids and Bases

III.1.11 Guided Inquiry - Properties of Solutions of Acids and Bases

III.1.12 Problem Solving - Properties of Solutions of Acids and Bases

III.2 First Year Chemistry

III.2.1 Expository - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

III.2.2 Guided Inquiry - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

III.2.3 Problem Solving - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

III.2.4 Expository - Organic Functional Groups

III.2.5 Guided Inquiry - Organic Functional Groups

III.2.6 Problem Solving - Organic Functional Groups

III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

III.2.8 Guided Inquiry - Thermochemistry: Enthalpy of Neutralisation

III.2.9 Problem Solving - Thermochemistry: Enthalpy of Neutralisation

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

*III.2.11 Guided Inquiry - Determination of the Freezing Point Depression Constant for
Cyclohexane*

*III.2.12 Problem Solving - Determination of the Freezing Point Depression Constant for
Cyclohexane*

III.3 Second Year Chemistry

*III.3.1 Determination of Copper and Arsenic in Treated Wood by Atomic Absorption
Spectroscopy*

III.3.2 EDTA Titration of Calcium and Magnesium in Natural Waters

III.3.3 Spectrophotometric Determination of Phosphate in Natural Waters

III.4 Third Year Chemistry

III.4.1 Palladium Cross Coupling Reactions

III.1 Foundation Chemistry

III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

Experiment 2: The Analysis of a Solution by Measurement of its Density.

This experiment relates to the material you have covered in Chapter 1 of Seager and Slabaugh and explores the fundamental concept of Density.

Learning Objectives

- *to become familiar with a variety of equipment for the measurement of volume and mass.*
- *to understand and be able to make basic calculations with appropriate significant figures.*

Introduction

The concentration of a solution can be determined by chemical or instrumental analysis. In cases where the solution is a simple binary mixture (ie contains only two components) a measurement of a physical property such as freezing point, refractive index, viscosity or density is a quick and direct way to determine the composition. In this project the composition of a sugar solution is determined by measuring its density.

Pre-Laboratory Exercise

- 1) To measure the density of a liquid what two measurements do you need to make on the liquid?
- 2) If a chemist takes two volume measurements, 25.00 mL and 25 mL, what is the uncertainty of each measurement?

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

- 3) To how many decimal places can each of the following glassware be recorded to:
- a. Volumetric flask

 - b. Pipette

 - c. Measuring cylinder

Uncertainty in Measurement

The number associated with a measurement is obtained using some measuring device. We customarily report a measurement by recording all of the certain digits plus the first uncertain digit. These numbers are called the **significant figures** of a measurement.

It is very important to realise that a **measurement always has some degree of uncertainty**. The uncertainty of a measurement depends on the precision of the measuring device.

The convention of significant figures automatically indicates the uncertainty in a measurement. The uncertainty in the last number (the estimated number) is usually assumed to be ± 1 unless otherwise indicated.

For example, the measurement of 1.86 kilograms really means 1.86 ± 0.01 kilograms.

Weighing

Which balance should be used?

There are two types of balances available, a top pan balance and an analytical balance. The top pan balance gives the mass to ± 0.01 g while the analytical balance weighs to ± 0.0001 g (ie. 0.0001g). We do not use an analytical balance for all our weighings because the capacity of the analytical balance is only 50 g while the top pan balance can manage 300 g.

Weighing Rules

The balances are by far the most expensive pieces of equipment in the first year laboratories, and we would like them to last for many years. The most serious potential problem that we have is one of corrosion that would occur if chemicals are spilt or corrosive vapours are given off from the chemicals that are weighed. Thus the following rules are designed to keep the balances clean.

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

- * The outside of the container used for weighing must be clean and dry.
- * There shall be no transfer of chemical from one container to another on or near the balance.
- * All spills must be cleaned up immediately

Note: In this manual the word *weight* is used to also mean *mass*.

The Measurement of Volume

Introduction

The volume of a liquid may be accurately measured with three pieces of volumetric apparatus: the volumetric flask, the pipette and the burette, or approximately determined with a graduated pipette, a measuring cylinder or the marks on the side of a beaker.

The most important way to reduce error is to make sure your glassware is clean. Volumetric measurement depends upon the fact that on a clean glass surface a constant film of moisture remains, whereas droplets of an unknown volume adhere to a contaminated surface. Also, contamination leads to a decrease in the surface tension and a consequent change in the shape and volume of the meniscus. Glassware may be cleaned with soapy water. Do not use an excess of detergent or a brush, since the latter disturbs the film on the glass surface. Ensure that the glass is thoroughly rinsed with tap water to remove the detergent.

Since the capacity of a glass vessel varies with temperature, any given vessel can be correct at only one temperature. We don't need to take this into account, however as the cubic expansion of water is much more significant at about 0.2 ppt per 1°C change at 20°C.

The precise measurement of a liquid volume involves the matching of a liquid level in a glass container with an accurately etched line on the container wall. This matching procedure must be used in a consistent manner. The surface of an aqueous solution in a clean glass container has a concave meniscus, which appears as a dark crescent when viewed from the side. In all cases the meniscus must be viewed with the eye of the observer in the horizontal plane of the etched mark causing the circular etched mark to appear as a straight line, otherwise it will appear as an ellipse.

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

The Volumetric Flask

A standard solution (one whose concentration is accurately known) cannot be prepared by the addition of a known mass of solute to a known volume of water because the dissolution of a solute in water invariably leads to a change in the liquid volume. Hence the mass of solute and volume of solution (not solvent) must both be accurately known. Consequently for this purpose volumetric flasks are calibrated to contain a specified volume of liquid.

To use a volumetric flask:

- * Dissolve any solid solute in a small volume of solvent in a beaker
- * Transfer to the volumetric flask and rinse in with enough solvent to rise to the base of the neck of the flask
- * Gently swirl solution to mix
- * Add more solvent until the **bottom of the meniscus** rises to the etched mark
- * Mix the solution thoroughly by inverting several times, do not add more solvent



A volumetric flask is capable of measuring volumes with an accuracy of:

25 mL \pm 0.06 mL

100 mL \pm 0.16 mL

200 mL \pm 0.24 mL

All volumetric flask volumes should be reported with 2 decimal places.

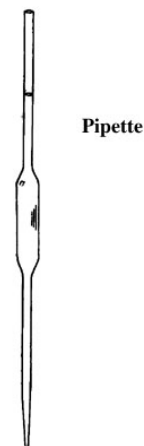
The Pipette

Volumetric transfer pipettes are used to deliver a precise volume of liquid. The tip must meet stringent requirements because the delivery time is controlled by the tip diameter. A precision of 1 part in 1000 can be readily attained but only if the pipette is used in a reproducible manner. All pipette readings should be expressed with 2 decimal places.

To use a pipette:

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

- * Rinse the pipette with several **small amounts** of the stock solution (at most 5 mL).
- * Fill the pipette using a rubber bulb to above the graduation mark.
- * Lower the level of the solution until the **bottom of the meniscus** is precisely on the mark.
- * Discharge the liquid into the chosen container with the tip of the pipette touching the side of the container. The remaining liquid in the pipette tip is accounted for and therefore **should not** be blown out.



A pipette is capable of measuring volumes with an accuracy of:

5 mL \pm 0.02 mL

10 mL \pm 0.04 mL

20 mL \pm 0.06 mL

All pipette volumes should be reported with 2 decimal places.

The Measuring Cylinder

Measuring cylinders are useful as a tool for measuring a volume that does not need to be precise. An additional benefit to this is the ease of transferring larger volumes. Measuring cylinders should never be used when an accurate volume is required.

To use a measuring cylinder:

- Rinse the measuring cylinder with several small amounts of the stock solution.
- Fill the measuring cylinder to just below the required volume.
- Using a disposable pipette, add small amounts of the stock solution until the bottom of the meniscus is near the mark.
- Transfer the solution from the measuring cylinder to your chosen container.



Summary

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

Uncertainty

If no uncertainty is given the uncertainty is assumed as ± 1 of the last significant digit. Eg 1.86 really means 1.86 ± 0.01 .

Balances

Different balances have different levels of accuracy. To know the number of significant figures to use for a balance, record all the information displayed on the balance screen.

Measurement of volumes

All **volumetric flasks** should be reported with **2 decimal places**.

All **pipette** volumes should be reported with **2 decimal places**.

All **measuring cylinder** volumes should be reported with **0 decimal places**.

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

Method:

Part 1: Determination of the Density of water

1. Collect a 50 mL **measuring cylinder**, a **sample vial** (with lid), and a 25 mL **volumetric flask** (with stopper).
2. Ensure all equipment is clean and dry.
3. Weigh the 50 mL **measuring cylinder** on a **top pan balance**, remove the **measuring cylinder** from the balance and fill to the 50 mL mark with deionized water (ensuring the bottom of the meniscus is at the 50 mL mark).
4. Reweigh the now filled **measuring cylinder** on the **top pan balance**.
5. Weigh the sample vial (with lid) on the analytical balance. Pipette 20 mL of deionized water into the sample vial.
6. Reweigh the now filled sample vial (with lid) on the analytical balance.
7. Weigh the 25 mL volumetric flask (with stopper) on the top pan balance, remove the volumetric flask from the balance and fill to the mark with deionized water.
8. Reweigh the now filled volumetric flask (with stopper) on the top pan balance.
9. Calculate the density of water for all three measurement methods.

Part 2: Determination of the Density of a Sodium Chloride Solution

1. Clean and dry a sample vial (with lid) and weigh on an analytical balance.
2. Pipette 20 mL of Sodium Chloride solution into the sample vial.
3. Reweigh the now filled sample vial (with lid) on an analytical balance.
4. Empty and thoroughly clean the sample vial (with lid). Collect a new sample vial (with lid).
5. Repeat steps 1 to 4 two more times.

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

6. Calculate the density of the Sodium Chloride solution.
7. If one of the densities is too different from the others, repeat steps 1 to 4 for additional data.

Density of water at varying temperatures

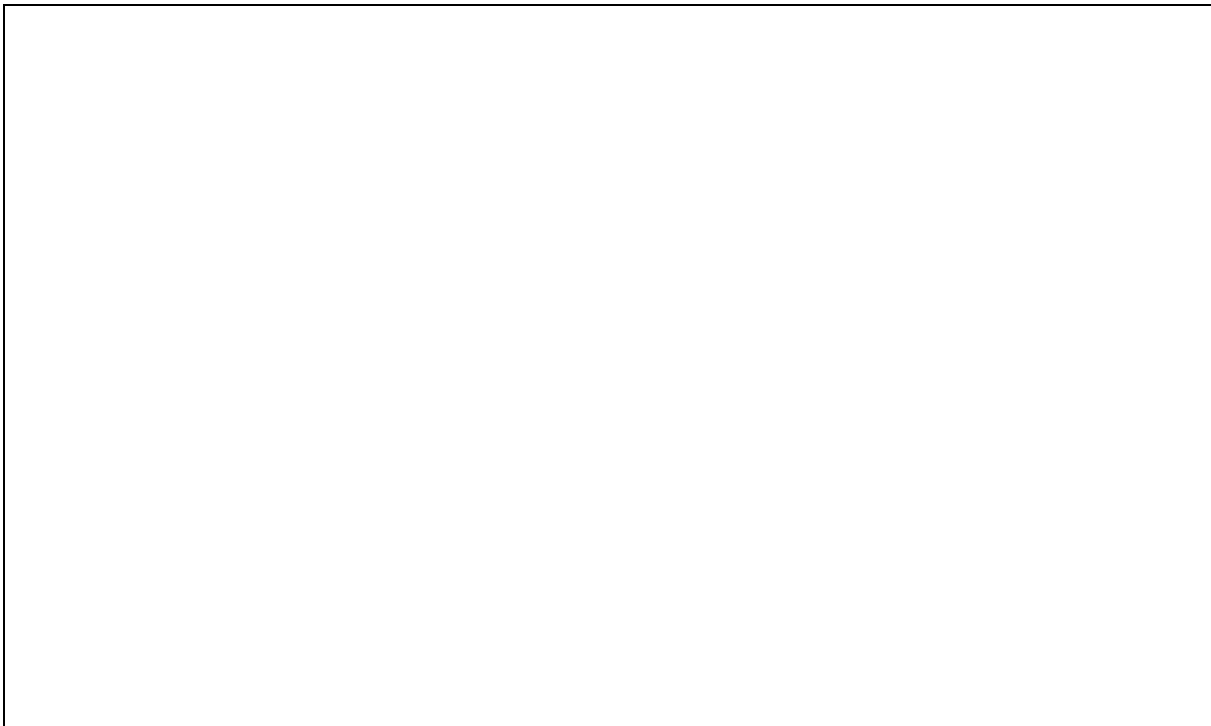
Temp. (°C)	Density (g mL ⁻¹)	Temp. (°C)	Density (g mL ⁻¹)	Temp. (°C)	Density (g mL ⁻¹)
10.0	0.9997026	17.0	0.9987779	24.0	0.9972995
11.0	0.9996084	18.0	0.9985986	25.0	0.9970479
12.0	0.9995004	19.0	0.9984082	26.0	0.9967867
13.0	0.9993801	20.0	0.9982071	27.0	0.9965162
14.0	0.9992474	21.0	0.9979955	28.0	0.9962365
15.0	0.9991026	22.0	0.9977735	29.0	0.9959478
16.0	0.9989460	23.0	0.9975415	30.0	0.9956502

Compare your results with the density values provided in the table above. Which is the most accurate apparatus to use for the measurement of the density of water?

=g/mL

Experimental Details (What did you do? Write in the past tense, using third person, e.g. The water was pipetted)

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density



Calculation of the Composition of the Sodium Chloride Solution

The Table below gives the density of sodium chloride solutions as a function of composition.

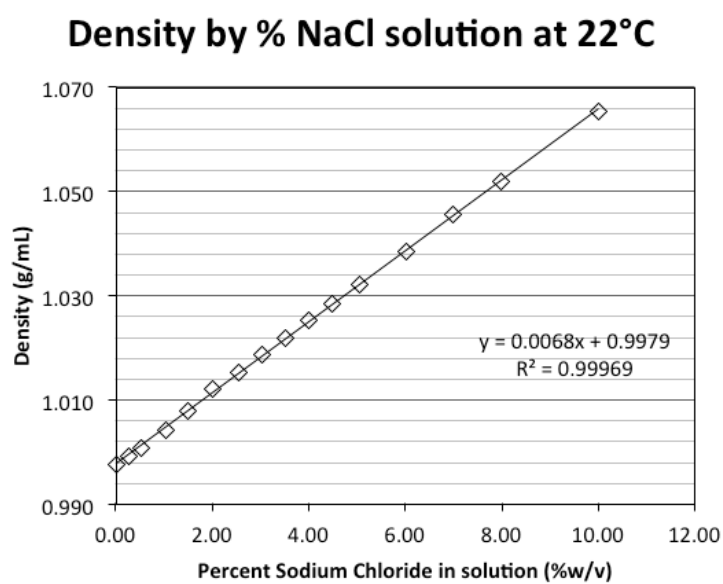
Use this Table to determine the composition of your sodium chloride solution. For the purpose of this experiment we will assume that the density of water and of the sodium chloride solution has been obtained at 22°C.

A% by wt = mass of sodium chloride (g) in 100 (g) of solution.

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

Variation of Density With Sodium Chloride Concentration

A% by wt	20 D 20
0.00	0.998
0.25	0.999
0.51	1.001
1.02	1.004
1.50	1.008
2.00	1.012
2.53	1.015
3.01	1.019
3.51	1.022
3.98	1.026
4.49	1.029
5.03	1.032
6.01	1.039
6.97	1.046
7.97	1.052
10.00	1.065



Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

Example Calculation:

Let's assume the density of the solution was determined to be 1.015 g/mL

Therefore, composition of the sodium chloride sample

$$= (1.015 - 0.9979) / 0.0068 = 2.5\% \text{ w/v}$$

To convert to %w/w use the density of the solution.

Your Calculation

Composition of your sodium chloride solution:

=

= %w/v

= %w/w

Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

What other methods could be used to analyse the contents of a solution?

What are the advantages of measuring solution density to analyse a solution?

What are the disadvantages?

Comment on the accuracy of the method (list sources of error and possible solutions)



Appendix III - Alternative Teaching Approaches Procedures
III.1.1 Expository - The Analysis of a Solution by Measurement of its Density

Comment on the number of significant figures appropriate in your result (Indicate the number of significant figures required in your answer based upon the accuracy of the various experimental measurements and the calculations you made. Indicate how you arrived at your answer)

Appendix III - Alternative Teaching Approaches Procedures
III.1.2 Guided Inquiry - The Analysis of a Solution by Measurement of its Density

III.1.2 Guided Inquiry Method for the Analysis of a Solution by Measurement of its Density

Experiment

Method

Part I: Determination of the Density of water

1. Collect a 50 mL **measuring cylinder**, a **sample vial** (with lid), and a 25.00 mL **volumetric flask** (with stopper).
2. Ensure all equipment is clean and dry.

QUESTION: Why might dirty or wet equipment not be suitable?

3. Weigh the 50 mL **measuring cylinder** on a **top pan balance**, remove the **measuring cylinder** from the balance and fill to the 50 mL mark with deionized water.

QUESTION: Does the top of the liquid form a straight line in the cylinder? Where would you read the volume measurement in relation to the liquid?

QUESTION: To what degree of accuracy can a measuring cylinder be read?

4. Reweigh the now filled **measuring cylinder** on the **top pan balance**.
5. Weigh the sample vial (with lid) on the analytical balance. Pipette 20.00 mL of deionized water into the sample vial.
6. Reweigh the now filled sample vial (with lid) on the analytical balance.
7. Weigh the 25.00 mL volumetric flask (with stopper) on the top pan balance, remove the volumetric flask from the balance and fill to the mark with deionized water.
8. Reweigh the now filled volumetric flask (with stopper) on the top pan balance.
9. Calculate the density of water for all three measurement methods.

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 III.1.2 Guided Inquiry - The Analysis of a Solution by Measurement of its Density

	Top Loading Balance		Analytical Balance
	50 mL Measuring Cylinder	25 mL Volumetric Flask	Pipette, with sample vial
Mass of Vessel + Water			
Mass of Vessel			
Mass of Water			
Volume of Water			
Density of Water			

Temperature = °C

QUESTION: To how many significant figures should the density for each method be calculated?

If differences between your calculated densities are apparent, discuss briefly where these differences could come from.

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III.1.2 Guided Inquiry - The Analysis of a Solution by Measurement of its Density

Part 2: Determination of the Density of a Sodium Chloride Solution

1. Clean and dry a sample vial (with lid) and weigh on an analytical balance.
2. Pipette 20.00 mL of Sodium Chloride solution into the sample vial.
3. Reweigh the now filled sample vial (with lid) on an analytical balance.
4. Empty and thoroughly clean the sample vial (with lid). Collect a new sample vial (with lid).
5. Repeat steps 1 to 4 two more times.

QUESTION: Why would we collect multiple results of the same method?

.....C

calculate the average density of the Sodium Chloride solution.

6. If one of the densities is too different from the others, repeat steps 1 to 4 for additional data.

Temperature = °C

	1	2	3	4
Mass of Vessel + Sodium Chloride Solution				
Mass of Vessel				
Mass of Sodium Chloride Solution				
Volume of Sodium Chloride Solution				
Density of Solution				

Average Density of the Sodium Chloride solution =

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III.1.3 Problem Solving - The Analysis of a Solution by Measurement of its Density

III.1.3 Problem Solving Method for the Analysis of a Solution by Measurement of its Density

Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.1.3 Problem Solving - The Analysis of a Solution by Measurement of its Density

Method:

Available equipment

Measurement of Volume	Measurement of Mass	Additional equipment
20.00 mL Pipette	Top loading balance	Sample vial (with lid)
25.00 mL Volumetric flask (with stopper)	Analytical balance	Thermometer ($^{\circ}\text{C}$)
50 mL Measuring cylinder		

Available reagents

Deionised water

Sodium Chloride solution

Part 1: Determination of the Density of water

Within a laboratory, a range of different equipment and measuring techniques are available.

One of the purposes of this experiment is to compare three different methods for calculating the density of water and then compare this to a reference value for the density of water at room temperature at that time.

Using the list of available equipment, design three methods for calculating the density of water.

Some questions to consider during the preparation of your methods:

- Why might dirty or wet equipment not be suitable?
- Does the top of the liquid form a straight line in the vessel? Where would you read the volume measurement in relation to the liquid?
- To what degree of accuracy can a measuring cylinder be read?

Appendix III - Alternative Teaching Approaches Procedures

III.1.3 Problem Solving - The Analysis of a Solution by Measurement of its Density

- To how many significant figures should each density be calculated?
- If differences between your calculated densities are apparent, where could these differences come from?

Once your methods have been developed, confirm with your demonstrator before performing the experiment and determining the density of water using each method.

Part 2: Determination of the Density of a Sodium Chloride Solution

After consulting with your demonstrator and choosing an appropriate method, determine the density of the Sodium Chloride solution provided. Previously, we only collected data once for each method, what would be the benefit of multiple data collections for this step?

Appendix III - Alternative Teaching Approaches Procedures

III.1.4 Expository - Distillation as a Separation Technique

III.1.4 Expository Method for the Distillation as a Separation Technique

Experiment 3: Distillation as a Separation Technique.

Learning Objectives:

- *to become familiar with the equipment and techniques associated with completing a distillation.*
- *to be able to describe the interactions between multiple molecules using ionic equations.*

Distillation

This experiment relates to the material you have covered in Chapter 2 and 5 of Seager and Slabaugh and explores the fundamental concepts of the formation of chemical species along with the important tool of Distillation. You should review this material prior to undertaking this laboratory.

Introduction

The separation of mixtures by distillation is one of the **oldest and most important** operations of chemistry. Distillation requires that one or more components of a mixture be volatile, that is, have the ability to evaporate. Distillation can be used to remove nonvolatile substances (dissolved minerals, for example) from liquids. Sea water contains dissolved minerals that must be removed to make it suitable for human consumption. As sea water is boiled in a distillation apparatus, only the water vaporizes, and the salts remain behind. When the vapors are condensed and collected, the water is free of these salts and safe for drinking.

The process of boiling a liquid and condensing the resultant vapour into a separate container is called **distillation**. The components of a mixture may be separated by distillation, provided that their **boiling points are sufficiently different**.

The boiling point, the temperature at which the vapour pressure of the liquid is equal to atmospheric pressure, is a characteristic physical property of the compound which may be

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III.1.4 Expository - Distillation as a Separation Technique

used to identify the compound. In the separation of a mixture however, a small range of temperature is usually observed in the collection of a volume of distillate and this is called the boiling point range.

Water that contains dissolved minerals which provide significant levels of calcium ion, Ca^{2+} , iron(II) and iron(III) ions, Fe^{2+} , Fe^{3+} , and/or magnesium ion, Mg^{2+} , is commonly classed as "**hard water**." These ions combine with soap to form soap scum, an insoluble, curdy material that is responsible for the common "bathtub ring." In this experiment you will distill some homemade hard water to remove the minerals responsible for hardness. The hard water you will use will not contain magnesium ion, but it will contain calcium ion and iron(III) ion, and also chloride ion, Cl^- , and sulfate ion, SO_4^{2-} .

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III.1.4 Expository - Distillation as a Separation Technique

Care and Use of Ground Glass Joints in the Distillation Equipment

Points to watch, in addition to the usual fragility of glass:

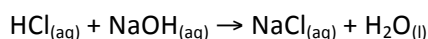
- * **Do not scratch** the ground surfaces. Be careful, if using a brush, not to scratch metal wire against them. Ground glass surfaces must be **CLEAN**; therefore **always use a funnel** when loading material into a flask which has a ground glass joint.
- * **Do not strain** the joints. The cone will rest comfortably in the socket, so do not thrust it in nor grind it in. Avoid misalignment. Each piece of apparatus should be supported against gravity by a clamp *without putting a stress* on the neighbouring joints. *Only one of the jaws of a clamp moves when it is being tightened*;
- * Never expect ground glass apparatus to hold together by friction in the cone and socket.
- * Never leave alkali in contact with ground glass joints. It tends to glue them together.

Hot glass expands slightly and shrinks again on cooling; disassembly should not need force.

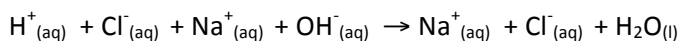
Therefore, take your apparatus to pieces **as soon as it has cooled**. If any of the ground glass joints are stuck, **ask for help**.

Ionic Equations

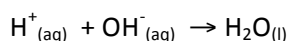
The equations used for ionic reactions can take various forms. For example the reaction of hydrochloric acid and sodium hydroxide can be written as a molecular equation:



A total ionic equation:



Or a net ionic equation:



We learn in Seager and Slabaugh that a molecular equation shows each compound as its molecular formula and a total ionic equation shows each ionic compound dissociated into ions. Some of the ions in a total ionic equation do not undergo any changes in the reaction and we

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III.1.4 Expository - Distillation as a Separation Technique

call them spectator ions (in this case $\text{Na}^+ + \text{Cl}^-$ are the spectators). An ionic equation that doesn't include spectator ions is called a net ionic equation.

In this report you should report the net ionic equations for each reaction.

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III.1.4 Expository - Distillation as a Separation Technique

Pre-Laboratory Questions:

1. What is the boiling point/condensation temperature of water?
2. What substances are commonly found in hard water?
3. What is the role of the condenser in a distillation apparatus?
4. Write down the formula for the oxalate ion and the thiocyanate ion.

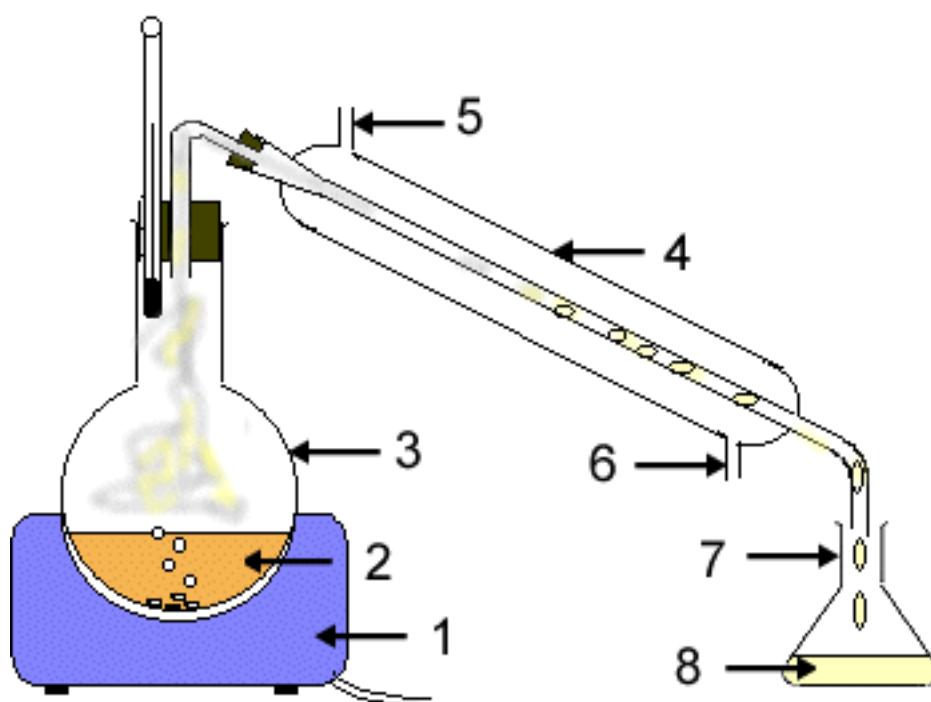
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III.1.4 Expository - Distillation as a Separation Technique

Experimental Procedure – Set up the distillation in pairs

NOTE: All results and observations are to be recorded within the template provided on the following pages.

I. Distillation of an Impure Water Sample (**Completed in pairs**)

1. Collect the required equipment and set up a distillation apparatus as shown in Figure 1.



2. Ensure all glassware has been cleaned thoroughly. Obtain 50 mL of hard water from the supply in the lab.
3. Transfer 45 mL of the hard water with 2 to 3 boiling chips into the distillation flask.
4. Begin distillation and record the temperature at which the first drop has been distilled.
5. Leave distillation to continue running and proceed to part II.
6. Once approximately 10 mL have been distilled, record the temperature and switch the distillation off.

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III.1.4 Expository - Distillation as a Separation Technique

Part II. Tests for Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- in water. **(Completed individually)**

7. Thoroughly clean four small test tubes with deionized water and transfer 5 drops of the remaining hard water into each.
8. To test for the presence of Ca^{2+} , add 3 drops of ammonium oxalate solution, $(\text{NH}_4)_2\text{C}_2\text{O}_4$, to the water in one test tube. Record your observations.
9. To test for the presence of Fe^{3+} , add 2 or 3 crystals of ammonium thiocyanate, NH_4SCN , to the water in a second test tube. Record your observations.
10. To test for the presence of SO_4^{2-} , add 3 drops of barium chloride solution, BaCl_2 , to the water in a third test tube. Record your observations.
11. To test for the presence of Cl^- , add 3 drops of AgNO_3 , to the water in a fourth test tube. Record your observations.

Part III. Tests for Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- in the distilled water **(Completed individually)**

12. The distillation should have completed by this time. Thoroughly clean the four test tubes with deionized water to prevent contamination.
13. Transfer 5 drops of the distilled water to each test tube.
14. Using the procedure outlined in steps 7 through to 10, test for the presence of Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- ions.

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III.1.4 Expository - Distillation as a Separation Technique

Part I.

Temperature at which distillation commences =°C

Temperature after 10 mL distillate collected =°C

Part II.

Ca²⁺ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Fe³⁺ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Appendix III - Alternative Teaching Approaches Procedures
III.1.4 Expository - Distillation as a Separation Technique

SO₄²⁻ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Cl⁻ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Appendix III - Alternative Teaching Approaches Procedures
III.1.4 Expository - Distillation as a Separation Technique

Part III.

Ca²⁺ Test

Observations:

Fe³⁺ Test

Observations:

SO₄²⁻ Test

Observations:

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III.1.4 Expository - Distillation as a Separation Technique

Cl⁻ Test

Observations:

Conclusions about Distillate:

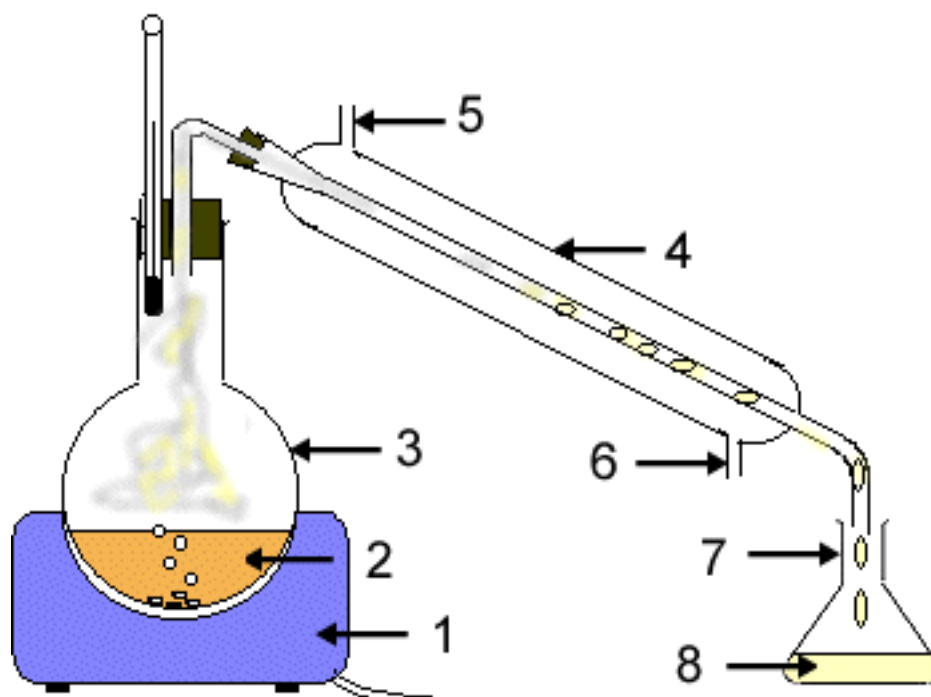
Appendix III - Alternative Teaching Approaches Procedures
III.1.5 Guided Inquiry - Distillation as a Separation Technique

III.1.5 Guided Inquiry Method for the Distillation as a Separation Technique Experiment

NOTE: All results and observations are to be recorded within the template provided on the following pages.

I. Distillation of an Impure Water Sample (**Completed in pairs**)

1. Collect the required equipment and set up a distillation apparatus as shown in Figure 1.



2. Ensure all glassware has been cleaned thoroughly. Obtain 50 mL of hard water from the supply in the lab.
3. Transfer 45 mL of the hard water with 1 or 2 boiling chips into the distillation flask.
The remaining 5 mL will be used in Part II to test for the presence of known ions.
4. Begin distillation and record the temperature at which the first drop has been distilled.
5. Leave distillation to continue running and proceed to Part II.
6. Once approximately 10 mL have been distilled, record the temperature and switch the distillation off.

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III.1.5 Guided Inquiry - Distillation as a Separation Technique

Part II. Tests for Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- in water. **(Completed individually)**

A number of tests are available for testing the presence of ions or compounds within a solution. One example of the use of these tests is the rigorous quality control for drinking water.

For this experiment, we are trying to remove the ions from an impure water sample containing Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- ions.

7. Thoroughly clean four small test tubes with deionized water and transfer 5 drops of the remaining hard water into each.
8. To test for the presence of Ca^{2+} , add 3 drops of ammonium oxalate solution, $(\text{NH}_4)_2\text{C}_2\text{O}_4$, to the water in one test tube.

Record your observations of the reaction occurring:

What compound is being formed during this process? Give the reaction equation.

9. To test for the presence of Fe^{3+} , add 2 or 3 crystals of ammonium thiocyanate, NH_4SCN , to the water in a second test tube.

Record your observations of the reaction occurring:

What compound is being formed during this process? Give the reaction equation.

Appendix III - Alternative Teaching Approaches Procedures
III.1.5 Guided Inquiry - Distillation as a Separation Technique

10. To test for the presence of SO_4^{2-} , add 3 drops of barium chloride solution, BaCl_2 , to the water in a third test tube.

Record your observations of the reaction occurring:

What compound is being formed during this process? Give the reaction equation.

11. To test for the presence of Cl^- , add 3 drops of AgNO_3 , to the water in a fourth test tube.

Record your observations of the reaction occurring:

What compound is being formed during this process? Give the reaction equation.

Would these four tests be suitable for use within any water sample? What are some other considerations to take into account?

Appendix III - Alternative Teaching Approaches Procedures
III.1.5 Guided Inquiry - Distillation as a Separation Technique

Part III. Tests for Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- in the distilled water (**Completed individually**)

By this point of time enough of the impure water sample should have distilled to proceed. By using 5 drops of your distilled water product, test for the presence of Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- ions.

Record your observations for these tests:

What can we conclude from the process and data collected?

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III.1.5 Guided Inquiry - Distillation as a Separation Technique

Part I.

Temperature at which distillation commences =°C

Temperature after 10 mL distillate collected =°C

Part II.

Ca²⁺ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Fe³⁺ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

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III.1.5 Guided Inquiry - Distillation as a Separation Technique

SO₄²⁻ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Cl⁻ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

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III.1.5 Guided Inquiry - Distillation as a Separation Technique

Part III.

Ca²⁺ Test

Observations:

Fe³⁺ Test

Observations:

SO₄²⁻ Test

Observations:

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III.1.5 Guided Inquiry - Distillation as a Separation Technique

Cl⁻ Test

Observations:

Conclusions about Distillate:

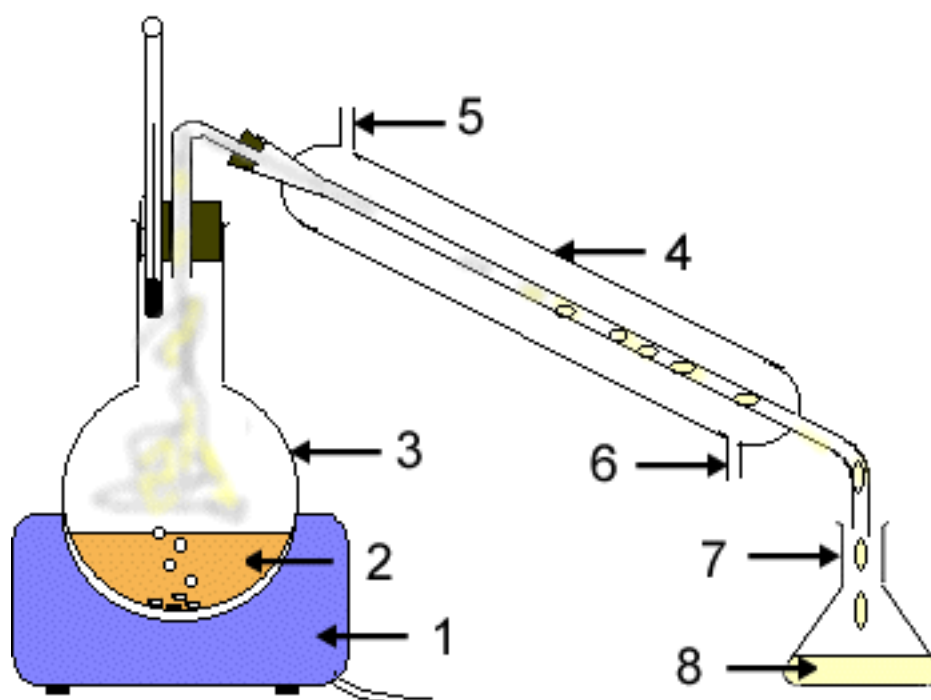
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III.1.6 Problem Solving - Distillation as a Separation Technique

III.1.6 Problem Solving Method for the Distillation as a Separation Technique Experiment

NOTE: All results and observations are to be recorded within the template provided on the following pages.

I. Distillation of an Impure Water Sample (**Completed in pairs**)

1. Collect the required equipment and set up a distillation apparatus as shown in Figure 1.



2. Ensure all glassware has been cleaned thoroughly. Obtain 50 mL of hard water from the supply in the lab.
3. Transfer 45 mL of the hard water with 2 to 3 boiling chips into the distillation flask.
4. Begin distillation and record the temperature at which the first drop has been distilled.
5. Leave distillation to continue running and proceed to part II.
6. Once approximately 10 mL have been distilled, record the temperature and switch the distillation off.

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III.1.6 Problem Solving - Distillation as a Separation Technique

Part II. Tests for Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- in water. (**Completed individually**)

Many tests exist to detect the presence of ions within a solution. The important feature of these tests is the need for a physical or recordable change to the solution to indicate the presence of the ion. What are some types of changes that could be easily measured?

Available reagents:

- Ammonium oxalate
- Ammonium thiocyanate
- Barium chloride
- Silver nitrate

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III.1.6 Problem Solving - Distillation as a Separation Technique

Using the information provided in the tables below, determine which reagents would be most appropriate to test for the presence of the ions Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- in an impure water sample.

Substance	Formula	Solubility (mol/L)*	Solution Colour
Calcium oxalate	CaC_2O_4	1.5×10^{-8}	Colourless
Calcium thiocyanate	$\text{Ca}(\text{SCN})_2$	Very soluble	Colourless
Calcium chloride	CaCl_2	1210	Colourless
Calcium nitrate	$\text{Ca}(\text{NO}_3)_2$	121.2	Colourless
Iron(III) chloride	FeCl_3	91.8	Colourless
Iron(III) nitrate	$\text{Fe}(\text{NO}_3)_3 \cdot 9\text{H}_2\text{O}$	138	Colourless
Iron(III) oxalate	$\text{Fe}_3(\text{C}_2\text{O}_4)_3$	Very soluble	Colourless
Iron(III) thiocyanate	$\text{Fe}(\text{SCN})_3$	2×10^{-6}	Deep red
Barium sulfate	BaSO_4	1.1×10^{-10}	Colourless
Silver sulfate	Ag_2SO_4	1.2×10^{-5}	Colourless
Ammonium sulfate	NH_4SO_4	75.4	Colourless
Barium chloride	BaCl_2	1.72	Colourless
Silver chloride	AgCl	1.8×10^{-10}	Colourless
Ammonium chloride	NH_4Cl	37.2	Colourless

* The **smaller** a solubility constant, the more **insoluble** that compound is.

Before proceeding with your tests, confirm with a demonstrator to justify your choices.

For each test, transfer five drops of the remaining hard water sample into a **clean** small test tube before adding the test reagents.

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III.1.6 Problem Solving - Distillation as a Separation Technique

Part III. Tests for Ca^{2+} , Fe^{3+} , SO_4^{2-} , and Cl^- in the distilled water (**Completed individually**)

7. The distillation should have completed by this time. Thoroughly clean the four test tubes with deionized water to prevent contamination.
8. Transfer 5 drops of the distilled water to each test tube.
9. Using the tests determined from Part II, test whether the distillation of your hard water sample was successful.

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III.1.6 Problem Solving - Distillation as a Separation Technique

Part I.

Temperature at which distillation commences =°C

Temperature after 10 mL distillate collected =°C

Part II.

Ca²⁺ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Fe³⁺ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Appendix III - Alternative Teaching Approaches Procedures
III.1.6 Problem Solving - Distillation as a Separation Technique

SO₄²⁻ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Cl⁻ Test

What ions are present in Ammonium oxalate?

Observations:

Net Ionic Equation:

Appendix III - Alternative Teaching Approaches Procedures
III.1.6 Problem Solving - Distillation as a Separation Technique

Part III.

Ca²⁺ Test

Observations:

Fe³⁺ Test

Observations:

SO₄²⁻ Test

Observations:

Appendix III - Alternative Teaching Approaches Procedures
III.1.6 Problem Solving - Distillation as a Separation Technique

Cl⁻ Test

Observations:

Conclusions about Distillate:

Appendix III - Alternative Teaching Approaches Procedures

III.1.7 Expository - Identification of a Carboxylic Acid

III.1.7 Expository Method for the Identification of a Carboxylic Acid Experiment

Experiment 5: Identification of a Carboxylic Acid.

This experiment relates to the material you have covered in Chapters 1 and 9 of Seager and Slabaugh and explores the extremely important concept of acid-base chemistry. In particular this experiment studies and identifies biochemically important carboxylic acids.

Learning Objectives

- * *to understand the concept of equivalent mass*
- * *to undertake simple titrations with appropriate precision*

Introduction

Physical properties such as melting and boiling points, crystalline shapes and colour are unique to every compound and are often the simplest way to characterise a pure compound. However the measurement of one of these properties is usually insufficient for a complete identification because several compounds may have similar properties that cannot be distinguished within the accuracy of the measurement. Usually **at least two properties** must be measured to confirm the identification of a compound.

In this experiment you will identify an acid by determining the equivalent mass and its melting point. The acid may also contain water of crystallisation which you will need to determine.

The equivalent mass is that mass of the acid that will provide one mole of hydrogen ions. This is a useful concept when the molar mass of the acid is unknown.

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III.1.7 Expository - Identification of a Carboxylic Acid

Pre-Laboratory Questions:

If 0.1159 g of a solid unknown carboxylic acid required 21.32 mL of 0.1199 M NaOH, what is the:

1. equivalent weight (molecular weight if monoprotic) of the carboxylic acid?
2. empirical formula (simplest ratio of atoms) of the carboxylic acid?
3. if the carboxylic acid is diprotic, what is the molecular formula of the carboxylic acid?

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III.1.7 Expository - Identification of a Carboxylic Acid

Sample Calculation

Acid	Formula	Molecular Mass (g.mol ⁻¹)	Equivalent Mass (g.equiv ⁻¹)	M.Pt °C	Phase at 20 °C
Formic	HCOOH	46	46	8	Liquid
Acetic	CH ₃ COOH	60	60	16	Liquid
Benzoic	C ₆ H ₅ COOH	122	122	122	Solid
Oxalic	(COOH) ₂	90	45	189	Solid
Malonic	CH ₂ (COOH) ₂	104	52	135	Solid
Succinic	(CH ₂ COOH) ₂	118	59	188	Solid

. If 0.1642g of a solid unknown carboxylic acid required 20.64mL of 0.1342M NaOH

(a) what is the equivalent mass?

mol of OH ⁻ in 20.64 mL of 0.1342 M NaOH	= 20.64 mL x 1 L / 1000 mL x 0.1342 mol/L
	= 2.770 x 10 ⁻³ mol
mol H ⁺ in 0.1642 g acid	= 2.770 x 10 ⁻³ mol
mass acid for 1 mol H ⁺	= 0.1642 g / 2.770 x 10 ⁻³ mol
	= 59.28 g mol ⁻¹
equivalent mass	= 59.28 g.equiv ⁻¹

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III.1.7 Expository - Identification of a Carboxylic Acid

(b) what is the empirical formula?

from the table an equivalent mass = 59 g mol^{-1} corresponds to an empirical formula of CH_2COOH

(c) what is the molecular formula?

$(\text{CH}_2\text{COOH}) \times n$, where $n = 2$ at least since the acid is a solid

Appendix III - Alternative Teaching Approaches Procedures

III.1.7 Expository - Identification of a Carboxylic Acid

Procedure

Wear gloves when handling the unknown acid

Unknown acid: (circle one) α / β

Oven position: _____

During the process of crystallization, it is normal for the crystal structure to incorporate water molecules. This can lead to errors when measuring the mass or other properties of crystals, as the additional water molecules will inflate the mass. In this experiment, we will be determining the identity of an unknown acid. As part of this we will need to first determine how much mass has been contributed by the water of crystallization as a percentage of the total initial mass.

Part 1: Water of Crystallisation

1. Collect your chosen unknown acid and identify the location of the oven within your laboratory space.
2. Collect a dry sample vial (with lid) and weigh on an analytical balance to four decimal places. Add enough of the sample of the compound to cover the base of the sample vial.
3. Reweigh the sample vial (with lid) before placing the sample vial into the oven tray.
The laboratory technician will place the tray into the oven for an hour to dry the compound. Ensure you have recorded the numbered position of your sample vial.
4. During this time move onto Part 2.
5. Once an hour has passed, collect your sample vial from the oven and immediately recap with your lid.
6. Reweigh the sample vial (with lid) on an analytical balance.
7. Calculate the mass lost through evaporation of water and therefore the percentage of water that was present within the compound initially.

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III.1.7 Expository - Identification of a Carboxylic Acid

Part 2: Equivalent mass

1. Weigh 0.18 g \pm 10 % of the unknown acid using an analytical balance. Write down the mass of acid to four decimal places.
2. Add 50 mL deionized water to the acid in each of three conical beakers.
3. Prepare a 50 mL burette with the appropriate stand and clamps. Ensure the burette is clean and has been rinsed with NaOH.
4. Fill the burette with NaOH ensuring the meniscus is not past the graduated measuring scale on the burette
5. Read and record the initial volume of the NaOH solution
6. Add two drops of phenolphthalein to the unknown acid solution.
7. Titrate to the first faint steady pink colour visible using a white tile as a background.
8. Record the final volume of the NaOH solution
9. Repeat steps 4 through to 6 for the other two conical beakers.
10. Calculate the equivalent mass.

Part 3: Identification

1. Given the mass determined by titration, correct for the water content using the results calculated in Part 1.
2. Calculate the empirical formula for the acid.
3. Using the table in the Introduction section, determine the identity of the acid.
4. Determine the number of water molecules in the molecular formula

Appendix III - Alternative Teaching Approaches Procedures

III.1.8 Guided Inquiry - Identification of a Carboxylic Acid

III.1.8 Guided Inquiry Method for the Identification of a Carboxylic Acid Experiment

Part 1: Water of Crystallisation

1. Collect your chosen unknown acid and identify the location of the oven within your laboratory space.
2. Collect a dry sample vial (with lid) and weigh on an analytical balance. Add enough of the unknown acid to just cover the base of the sample vial.

Estimate what the percentage of your acid will be water.

.....

3. Reweigh the sample vial (with lid) before placing the sample vial into the oven tray.

The laboratory technician will place the tray into the oven for an hour to dry the compound. Ensure you have recorded the numbered position of your sample vial.
4. During this time move onto Part 2.
5. Once an hour has passed, collect your sample vial from the oven and immediately recap with your lid.

What would be a concern if the cap was left off for some amount of time after drying?

.....

6. Reweigh the sample vial (with lid) on an analytical balance.

Appendix III - Alternative Teaching Approaches Procedures

III.1.8 Guided Inquiry - Identification of a Carboxylic Acid

7. Calculate the mass lost through evaporation of water and therefore the percentage of water that was present within the compound initially.

Was your estimate near the calculated percentage?

.....

Mass of sample tube (g) =

Mass sample tube and compound before heating (g) =

Mass sample tube and compound after heating (g) =

Mass compound before heating (g) =

Mass loss on heating (g) =

% water (as a % of the original mass)
=

(mass lost / original mass x 100)

Part 2: Equivalent mass

1. Weigh 0.18 g \pm 10 % of the unknown acid into three conical beakers using an analytical balance. Write down the mass of acid for each beaker to four decimal places.

Using the same techniques taught in Experiment 4 – Preparation and Standardisation of Sodium Hydroxide Solution, titrate your unknown acid against the standardized Sodium Hydroxide using phenolphthalein indicator.

What is the known value in this titration? What is the unknown that you are trying to find out? What do you need to calculate to work out this unknown value?

.....

Appendix III - Alternative Teaching Approaches Procedures
III.1.8 Guided Inquiry - Identification of a Carboxylic Acid

Dissolve your first sample of solid acid in approximately 50 mL of water

2. Read and record the initial volume of the NaOH solution
3. Add two drops of phenolphthalein to the unknown acid solution.
4. Titrate to the first faint steady pink colour visible using a white tile as a background.
5. Record the final volume of the NaOH solution
6. Repeat steps 2 through to 6 for two other acid samples
7. Calculate the equivalent mass.

	1	2	3
Mass unknown acid (g)			
Final burette reading (mL)			
Initial burette reading (mL)			
Titre-----M NaOH (mL)			
Moles of NaOH (mol)			
Moles of H ⁺ (mol)			
Equivalent mass (g)			
Average equivalent mass (g)			
Deviation from average (g)			

Average equivalent mass of the hydrated acid = g

Average deviation = g Precision =

Appendix III - Alternative Teaching Approaches Procedures

III.1.8 Guided Inquiry - Identification of a Carboxylic Acid

Mass water in an equivalent mass = g

Moles water per equivalent = mol

Mass anhydrous acid in an equivalent mass = g

Part 3: Identification

1. We have now experimentally determined the equivalent mass of the unknown acid.

Before proceeding to identify what acid you have, what is one factor that must be accounted for?

.....

- After accounting for the factor above, calculate the empirical formula for the acid.
- Using the table in the Introduction section, determine the identity of the acid.
- Determine the number of water molecules in the molecular formula.

Empirical formula of the hydrated acid =

Molecular formula of the hydrated acid =

Appendix III - Alternative Teaching Approaches Procedures

III.1.9 Problem Solving - Identification of a Carboxylic Acid

III.1.9 Problem Solving Method for the Identification of a Carboxylic Acid Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.1.9 Problem Solving - Identification of a Carboxylic Acid

Part 1: Water of Crystallisation

1. Collect your chosen unknown acid and identify the location of the oven within your laboratory space.
2. Collect a dry sample vial (with lid) and weigh on an analytical balance. Add enough of the unknown acid to cover the base of the sample vial.

Estimate what the percentage of your acid will be water.

3. Reweigh the sample vial (with lid) before placing the sample vial into the oven tray.
The laboratory technician will place the tray into the oven for an hour to dry the compound. Ensure you have recorded the numbered position of your sample vial.
4. During this time move onto Part 2.
5. Once an hour has passed, collect your sample vial from the oven and immediately recap with your lid.

What would be a concern if the cap was left off for some amount of time after drying?

6. Reweigh the sample vial (with lid) on an analytical balance.
7. Calculate the mass lost through evaporation of water and therefore the percentage of water that was present within the compound initially.

Was your estimate near the calculated percentage?

Appendix III - Alternative Teaching Approaches Procedures
III.1.9 Problem Solving - Identification of a Carboxylic Acid

Part 2: Equivalent mass

1. Weigh 0.18 g \pm 10 % of the unknown acid into three conical beakers using an analytical balance. Write down the mass of acid for each beaker to four decimal places.
2. Using the same techniques taught in Experiment 4 – Preparation and Standardisation of Sodium Hydroxide Solution, titrate your unknown acid against the standardized Sodium Hydroxide using phenolphthalein indicator.

What does the pink colour represent for a titration? (Hint: Pink does not mean the end point)

3. Calculate the equivalent mass.

Part 3: Identification

1. We have now experimentally determined the equivalent mass of the unknown acid.
Before proceeding to identify what acid you have, what is one factor that must be accounted for?
2. After accounting for the factor above, calculate the empirical formula for the acid.
3. Using the table in the Introduction section, determine the identity of the acid.
4. Determine the number of water molecules in the molecular formula.

Appendix III - Alternative Teaching Approaches Procedures
III.1.10 Expository - Properties of Solutions of Acids and Bases

III.1.10 Expository Method for the Properties of Solutions of Acids and Bases Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.1.10 Expository - Properties of Solutions of Acids and Bases

Experiment 6: Properties of Solutions of Acids and Bases.

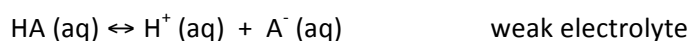
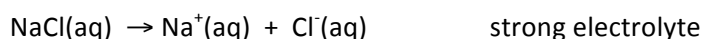
This experiment relates to the material you have covered in Chapters 1, 7 and 9 of Seager and Slabaugh and explores the extremely important concept of strong and weak acid-base chemistry and the concept of strong and weak electrolyte solutions.

Learning Objectives

- * *to become familiar with the correct measurement of pH using a pH meter*
- * *to measure the approximate pH and resistance of solutions strong acids and bases and their salts*
- * *interpret your observations.*

Introduction

When a compound dissolves in water it can either dissociate fully or partially into ions. In the first case the compound is called a strong electrolyte in the second a weak electrolyte. Sodium chloride is an example of a strong electrolyte, most organic acids are examples of weak electrolytes.



In the case of the strong electrolyte there will be few undissociated molecules and the solution will contain mainly ions and hence will be able to conduct electricity, ie: have a low resistance.

In the case of a weak electrolyte there will be few ions present, and the compound will exist as mainly undissociated molecules, and hence the solution will have a high resistance (or low conductivity).

Appendix III - Alternative Teaching Approaches Procedures
III.1.10 Expository - Properties of Solutions of Acids and Bases

Acids and bases are also classified as strong or weak, depending on the degree of ionisation.

Solutions of strong acids therefore should have few undissociated acid molecules present and a relatively high concentration of hydrogen ions (as indicated by a low pH). The solution of a weak base on the other hand should contain a relatively low concentration of hydroxyl ions and a much higher concentration of undissociated base.

In this experiment you will measure the resistance and the pH of several solutions and draw conclusions about whether they are weak or strong electrolytes (acids/bases) and estimate the approximate concentration of the various species, ions and undissociated molecules present in solution.

Appendix III - Alternative Teaching Approaches Procedures
III.1.10 Expository - Properties of Solutions of Acids and Bases

Pre-Laboratory Questions:

1. What is the difference between a strong and weak acid?
2. What is the difference between a strong and weak electrolyte?
3. How is conductivity related to resistance?
4. Would a solution with low conductivity measurement indicate a high or low concentration of ions? Explain your answer.
5. What is the main advantage of a pH meter over pH paper?

Appendix III - Alternative Teaching Approaches Procedures
III.1.10 Expository - Properties of Solutions of Acids and Bases

Experimental – work in bench groups

Preparation:

1. Collect 50 mL of each of the following solutions into 100 mL beakers:
 - a. Deionized water
 - b. 0.1 M HCl
 - c. 0.1 M NaOH
 - d. 0.1 M NH_3
 - e. 0.1 M CH_3COOH
 - f. 0.1 M CH_3COONa
 - g. 0.1 M NH_4Cl
2. Prepare a larger beaker for rinsing probes with deionized water.

Part 1: Measurement of Conductivity

1. Completely immerse the electrodes of the conductivity cell in the beaker of deionized water and record the conductivity.
2. Completely immerse the electrodes of the conductivity cell in the beaker of 0.1 M HCl solution and record the conductivity. (A reading of 1 means that the conductivity is too high for the meter to measure)
3. Rinse the electrodes in the beaker of deionized water.
4. Repeat steps 2 and 3 with the remaining prepared solutions.

Appendix III - Alternative Teaching Approaches Procedures
III.1.10 Expository - Properties of Solutions of Acids and Bases

Part 2: Measurement of pH

1. Measurement of pH using Universal Indicator paper:
 - a. Place one drop of your 0.1 M HCl solution onto Universal Indicator paper.
 - b. Using the colour wheel provided, record the colour and estimate the pH of the solution.
 - c. Repeat steps 1a and 1b with the remaining solutions.
2. Measurement of pH using pH meters
 - a. Using the pH meter, fully immerse the electrodes of the pH meter in each solution and record the pH.

Part 3: Interpretation

Using the data collected on the conductivities and pH values for each solution and your knowledge of acids and bases, fill out the tables below.

Solution	Conductivity	Strong Electrolyte	Weak Electrolyte
0.1 M HCl			
0.1 M NaOH			
0.1 M NH ₃			
0.1 M CH ₃ COOH			
0.1 M CH ₃ COONa			
0.1 M NH ₄ Cl			

Appendix III - Alternative Teaching Approaches Procedures
 III.1.10 Expository - Properties of Solutions of Acids and Bases

Solution	Indicator colour	pH	[H ₃ O ⁺]	[OH ⁻]
0.1 M HCl				
0.1 M NaOH				
0.1 M NH ₃				
0.1 M CH ₃ COOH				
0.1 M CH ₃ COONa				
0.1 M NH ₄ Cl				

$$\text{pH} = -\log [\text{H}_3\text{O}^+], \quad [\text{H}_3\text{O}^+] = 10^{-\text{pH}}, \quad [\text{OH}^-] = \frac{1.0 \times 10^{-14}}{[\text{H}_3\text{O}^+]}$$

Solution	Strong Acid	Strong Base	Weak Acid	Weak Base	Salt
0.1 M HCl					
0.1 M NaOH					
0.1 M NH ₃					
0.1 M CH ₃ COOH					
0.1 M CH ₃ COONa					
0.1 M NH ₄ Cl					

Appendix III - Alternative Teaching Approaches Procedures
 III.1.10 Expository - Properties of Solutions of Acids and Bases

Solution	Reaction Equations and Relative Strengths
0.1 M HCl	
0.1 M NaOH	
0.1 M NH ₃	
0.1 M CH ₃ COOH	
0.1 M CH ₃ COONa	
0.1 M NH ₄ Cl	

Appendix III - Alternative Teaching Approaches Procedures
III.1.11 Guided Inquiry - Properties of Solutions of Acids and Bases

III.1.11 Guided Inquiry Method for the Properties of Solutions of Acids and Bases Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.1.11 Guided Inquiry - Properties of Solutions of Acids and Bases

Experimental – work in bench groups

Preparation:

1. Collect 50 mL of each of the following solutions into 100 mL beakers:
 - a. Deionized water
 - b. 0.1 M HCl
 - c. 0.1 M NaOH
 - d. 0.1 M NH_3
 - e. 0.1 M CH_3COOH
 - f. 0.1 M CH_3COONa
 - g. 0.1 M NH_4Cl
2. Prepare a larger beaker for rinsing probes with deionized water.

Some basic technique pointers:

- The electrodes for both the conductivity and pH meters must be fully immersed to gain a correct reading.
- A conductivity reading of 1 indicates that the solution has conductivity too high for the meter to measure.
- The electrodes should be rinsed after each reading in deionized water.
- A drop of solution is placed on Universal Indicator paper. Universal Indicator paper should NEVER be dipped into a solution. This will lead to incorrect readings and is wasteful.

Appendix III - Alternative Teaching Approaches Procedures
III.1.11 Guided Inquiry - Properties of Solutions of Acids and Bases

Part 1: Measurement of Conductivity

Conductivity is the ease of conducting electrons through a medium. In this case we are considering a series of solutions. From your lecture material it is known that some compounds will fully dissociate while others will only partially dissociate.

Based on your knowledge, would a highly conductive solution be fully or partially dissociated?

Measure and record the conductance of each of the prepared solutions.

From the conductivity measurements decide which of the solutions is a strong or weak electrolyte

Solution	Conductivity	Strong Electrolyte	Weak Electrolyte
0.1 M HCl			
0.1 M NaOH			
0.1 M NH ₃			
0.1 M CH ₃ COOH			
0.1 M CH ₃ COONa			
0.1 M NH ₄ Cl			

Part 2: Measurement of pH

From your lecture material we know that pH can indicate whether a solution is acidic, basic, or neutral. In addition to this, pH can give an indication as to how much dissociation has occurred.

Given a solution with a measured pH of 11, and a conductivity of 0.5 indicate whether this is a strong/weak acid, base, or neutral?

For this experiment, we will be measuring the pH with two methods:

1. Measurement of pH using Universal Indicator paper and a colour wheel;
2. Measurement of pH using pH meters.

Measure and record the pH of each of your prepared solutions using both methods.

Appendix III - Alternative Teaching Approaches Procedures
III.1.11 Guided Inquiry - Properties of Solutions of Acids and Bases

Results

Remember $K_w = 1 \times 10^{-14} = [H^+][OH^-]$

$$pH = -\log[H_3O^+], \quad [H_3O^+] = 10^{-pH}, \quad [OH^-] = \frac{1.0 \times 10^{-14}}{[H_3O^+]}$$

Solution	Indicator colour	pH	$[H_3O^+]$	$[OH^-]$
0.1 M HCl				
0.1 M NaOH				
0.1 M NH_3				
0.1 M CH_3COOH				
0.1 M CH_3COONa				
0.1 M NH_4Cl				

Appendix III - Alternative Teaching Approaches Procedures
III.1.11 Guided Inquiry - Properties of Solutions of Acids and Bases

Part 3: Interpretation

Using the data collected on the conductivities and pH values for each solution and your knowledge of acids and bases, fill out the tables below.

For each solution, using the information from the previous two tables, determine which are weak acids/bases, strong acids/bases or salts.

Solution	Strong Acid	Strong Base	Weak Acid	Weak Base	Salt
0.1 M HCl					
0.1 M NaOH					
0.1 M NH ₃					
0.1 M CH ₃ COOH					
0.1 M CH ₃ COONa					
0.1 M NH ₄ Cl					

After confirming with your demonstrator on your classifications, give your conclusions for each solution and write the appropriate reaction equations. For some solutions there is a primary reaction and then a secondary hydrolysis reaction. Write equations for both reactions. (Table is on the next page)

Appendix III - Alternative Teaching Approaches Procedures
III.1.11 Guided Inquiry - Properties of Solutions of Acids and Bases

Solution	Reaction Equations and Relative Strengths
0.1 M HCl	
0.1 M NaOH	
0.1 M NH ₃	
0.1 M CH ₃ COOH	
0.1 M CH ₃ COONa	
0.1 M NH ₄ Cl	

Appendix III - Alternative Teaching Approaches Procedures
III.1.12 Problem Solving - Properties of Solutions of Acids and Bases

III.1.12 Problem Solving Method for the Properties of Solutions of Acids and Bases Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.1.12 Problem Solving - Properties of Solutions of Acids and Bases

Experimental – work in bench groups

Preparation:

Collect 50 mL of each of the following solutions into 100 mL beakers:

- a. Deionized water
- b. 0.1 M HCl
- c. 0.1 M NaOH
- d. 0.1 M NH_3
- e. 0.1 M CH_3COOH
- f. 0.1 M CH_3COONa
- g. 0.1 M NH_4Cl

Prepare a larger beaker for rinsing probes with deionized water.

Some basic technique pointers:

- The electrodes for both the conductivity and pH meters must be fully immersed to gain a correct reading.
- A conductivity reading of 1 indicates that the solution has conductivity too high for the meter to measure.
- The electrodes should be rinsed after each reading in deionized water.
- A drop of solution is placed on Universal Indicator paper. Universal Indicator paper should NEVER be dipped into a solution. This will lead to incorrect readings and is wasteful.

Appendix III - Alternative Teaching Approaches Procedures
III.1.12 Problem Solving - Properties of Solutions of Acids and Bases

For each of the seven solutions provided, classify whether they are strong/weak acids, bases or salts based on their conductivity and pH.

Solution	Strong Acid	Strong Base	Weak Acid	Weak Base	Salt
0.1 M HCl					
0.1 M NaOH					
0.1 M NH ₃					
0.1 M CH ₃ COOH					
0.1 M CH ₃ COONa					
0.1 M NH ₄ Cl					

After confirming with your demonstrator on your classifications, give your conclusions for each solution and write the appropriate reaction equations. For some of these reactions, a secondary reaction will take place with water to form a conjugate of your initial solution.

III.2 First Year Chemistry

III.2.1 Expository Method for the Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Experiment

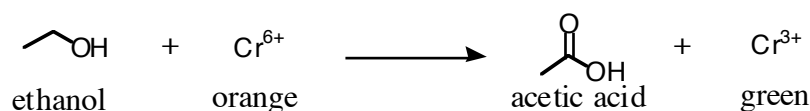
Week 7: Experiment 4A

**Oxidation of Benzyl Alcohol: Synthesis of
Benzoic Acid**

Concepts and Principles:

- *to understand the fundamentals of an oxidation reaction in organic synthesis*
- *to perform recrystallization and isolation of an organic compound*

In nature oxidation is one of the most common chemical reactions and involves increasing the oxidation state of a species. This is often carried out by molecular oxygen or by enzymes such as peroxidases that contain a metal ion at the reactive centre. In the laboratory high valent metal substrates are often employed to carry out oxidations of organic molecules. Two of the most common are sodium dichromate (Cr^{VI}) and potassium permanganate (Mn^{VII}). As in all oxidations something must be reduced (red-ox) and with permanganate the manganese is reduced from Mn^{VII} (purple) to Mn^{IV} (brown). These principles were used for many years in the breathalyser. The subject blows over crystals of sodium dichromate (Cr^{VI}) and if alcohol (ethanol is a 1° alcohol) is present it is oxidised to acetic acid and the chromium is reduced from +VII (orange) to +III (green).



In this experiment you will use potassium permanganate to oxidise a primary alcohol to a carboxylic acid. An aldehyde is an intermediate in the reaction.

Appendix III - Alternative Teaching Approaches Procedures
III.2.1 Expository - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

A generic synthesis of benzoic acid:

Prepare a solution of your oxidant in 30 mL of deionised water in a 100 mL conical flask. The next step is to add the benzyl alcohol to be oxidised. There is one problem however, if we simply combined the reagents, the reaction would not be completed. We therefore need to warm the oxidant solution to 30°C before adding the benzyl alcohol. Note that this reaction is exothermic and a temperature change of solution will occur which should be **observed and recorded in addition to any other observed changes**. Initially, the odour of benzaldehyde will become apparent but over time should dissipate after approximately 5 minutes. In unusual circumstances additional heating to 60°C for 5 minutes may be necessary to drive the reaction to completion.

After the reaction is complete we need to add some solutions to “work up” the crude product. The following steps require the addition of substances in excess and may differ from reaction to reaction. Therefore, the amounts listed are approximate and upon no further change to the solution, no more substance need be added. Add each individually and observe carefully for any changes.

- 10 mL of deionized water
- 6 mL of 50% sulfuric acid
- 12 mL of sodium sulfite solution

If the solution is not colourless, check the pH of the solution to determine if the solution is acidic. If the solution is not acidic, add a small volume of sulfuric acid. If the solution is acidic but not colourless, add further small amounts of sodium sulfite solution.

Appendix III - Alternative Teaching Approaches Procedures
III.2.1 Expository - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Once this has been achieved, the process of recrystallisation is used to produce a purified product. This process includes dissolving the crude product by warming gently until all precipitate has dissolved. The solution is then cooled slowly to room temperature before cooling in an ice-water bath. The final product, benzoic acid crystals, must then be collected by a method that can separate solids from a solution.

AIM

With any scientific investigation it is important to have an understanding of the aim of the experiment before proceeding. Use the box space below to briefly summarise your aim for this experiment.

Procedure

Part 1: Synthesis of benzoic acid

1. Collect a sample vial containing 2.1 g of potassium permanganate and add this to a 100 mL conical flask containing 30 mL of deionized water.
2. Warm the purple solution in a water bath until the temperature reaches 30 °C. At that temperature, add 1.0 mL of benzyl alcohol from the dispenser provided.
3. Replace the thermometer and swirl the mixture and note the highest temperature reached by the solution. Allow the solution to cool to room temperature.
4. Add each of the following to the conical flask:
 - a. 10 mL of deionized water
 - b. 6 mL of 50% sulfuric acid
 - c. 12 mL of 20% sodium sulfite solution
5. Swirl the solution. A colourless solution and white precipitate should have formed. If this is not the case, test the pH with indicator paper and try the following:
 - a. If pH is not acidic, add a small amount of sulfuric acid
 - b. If solution is acidic but not colourless, add a **small** amount of sulfite solution
6. Warm the solution gently on a hot plate until all precipitate has redissolved.
7. Allow the solution to cool gently to room temperature without disturbing the crystallization process.
8. Once solution has reached room temperature, cool the flask within an ice – water bath.

Appendix III - Alternative Teaching Approaches Procedures
III.2.1 Expository - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

9. Collect the crystals by vacuum filtration and transfer to a pre-weighed watch glass.

10. Calculate the yield of the sample.

11. Test for the presence of a carboxyl functional group by addition of a small amount of your crystals to dilute sodium hydrogen carbonate solution in a sample vial. Record your observations.

12. Show your crystal product to your demonstrator.

13. Dispose of your crystal product in the container provided.

Pre-laboratory preparation: Oxidation of Benzyl Alcohol: Synthesis of Benzoic

Acid

This section must be completed before arrival at the laboratory.

- Suggest an alternative oxidizing agent that could be used in the experiment.
- True or false- the best crystals are obtained by allowing the solution to cool slowly.
- What are the potential hazards associated with this experiment?
- What product would you obtain if you substituted benzaldehyde for benzyl alcohol in the experiment?
- Calculate the yield of the reaction if 0.76 g of benzoic acid were formed.
(**note**: density of benzyl alcohol = 1.046 g/mL and quote the yield to the nearest whole number).

Demonstrator's initials

Appendix III - Alternative Teaching Approaches Procedures
III.2.1 Expository - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

School of Physical Sciences (Chemistry) Materials Hazard Sheet
University of Tasmania

Expt 4A: Synthesis of Benzoic acid

Chemical Hazards:			
Name	Amount	Signal Word	Hazard statements
Benzyl alcohol	1 mL	Warning	H302, 312, 332: Harmful if swallowed, in contact with skin, or inhaled H312: Harmful in contact with skin
Benzaldehyde	<i>in situ</i>	Warning	H302: Harmful if swallowed
Benzoic acid	<5 g	Danger	H318: Causes serious eye damage H335: May cause respiratory irritation
Sulfuric acid 50%	6 mL	Danger	H290: May be corrosive to metals H314: Causes severe skin burns and eye damage
Potassium permanganate	2.1 g	Danger	H272: May intensify fire; Oxidiser H302: Harmful if swallowed H314: Causes severe skin burns and eye damage H410: Very toxic to aquatic life, long lasting effects
Sodium sulfite 20% solution	12 mL	None	Contact with strong acids may liberate toxic gas
Manganese dioxide	<i>in situ</i>	Warning	H302, 332: Harmful if swallowed, or inhaled
Sodium bicarbonate 5% solution	10 mL	None	None
Manganese sulfate	<i>in situ</i>	Warning	H373: May cause damage to organs through prolonged or repeated exposure

Experimental Procedure:

Dissolve potassium permanganate in water and add benzyl alcohol. On completion of the reaction add sulfuric acid and sodium sulfite to reduce the brown manganese dioxide and give a colourless solution. Heat the solution to dissolve the benzoic acid and allow to cool. Collect the resultant crystalline mass by vacuum filtration.

Precautionary statements:

P210: Keep away from heat and flames
P221: Take any precaution to avoid mixing with flammable/ combustible material
P261: Avoid breathing dust/ fume/ gas/ vapours/ spray
P264: Wash hands thoroughly after handling
P271: Use only in a well ventilated area
P280: Wear protective gloves/ protective clothing/ eye protection

Extra Precautions:

Take care with hotplates and hot glassware, potential for burns. Gloves may melt in contact with hotplate. Hotplates are to be left out at end of class if they are still hot.
Sodium sulfite in contact with sulfuric acid may liberate toxic gas.

Gloves:	Polyethylene	Open Bench:	Yes	Fume cupboard:	No
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Spill Instructions:

ALWAYS ADVISE DEMONSTRATOR IMMEDIATELY
Acid spills: Neutralise acid before cleaning spill. Wipe up with a cloth and wash at the sink.
Organic spills: For spills <50 mL apply sand and sweep into solid waste container.
For large spills, surround spill with sand to contain the spread

Disposal Instructions:

Organic waste: Decant into waste containers provided in fume cupboards
Aqueous waste: Decant into waste containers provided in fume cupboards

Staff / Supervisor

Student

Name _____

Name _____

Signature _____

Signature _____

Expt 4A: Oxidation of Benzyl alcohol: Synthesis of Benzoic Acid.

Mass of watch glass =

Mass of watch glass and product =

Mass of benzoic acid =

Highest Temperature reached by solution = °C

Moles of benzyl alcohol =

Moles of benzoic acid =

Yield of benzoic acid = _____% (show calculations)

Question 1. What was observed upon addition of substances during the work up of your product? Explain these observations.

Question 2. What reasons can you give to account for the fact that the yield of benzoic acid is less than 100%?

Question 3. What method was chosen to identify the product formed was benzoic acid?

Complete the reaction equation to account for this.



Appendix III - Alternative Teaching Approaches Procedures
III.2.2 Guided Inquiry - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

III.2.2 Guided Inquiry Method for the Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.2.2 Guided Inquiry - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Procedure

1. Collect a sample vial containing 2.1 g of potassium permanganate and add this to a 100 mL conical flask containing 30 mL of deionized water.

Potassium permanganate is a well-known oxidant, what are some examples of other oxidants?

2. Warm the purple solution in a water bath until temperature reaches 30 °C. At that temperature, add 1.0 mL of benzyl alcohol from the dispenser provided.
3. Replace the thermometer and swirl the mixture and note the highest temperature reached by the solution. Allow the solution to cool to room temperature. **NOTE: If the highest temperature does not reach above 60° C, you may need to heat to complete reaction.**

The oxidation occurs in two steps. What is the intermediate? How could you tell if the reaction had gone to completion?

4. Add each of the following to the conical flask:
 - a. 10 mL of deionized water
 - b. 6 mL of 50% sulfuric acid
 - c. 12 mL of 20% sodium sulfite solution
5. Swirl the solution. A colourless solution and white precipitate should have formed.

At this point we have produced a crude product. Would this be suitable to present as a final result? Justify what some potential problems with a crude product are.

Appendix III - Alternative Teaching Approaches Procedures
III.2.2 Guided Inquiry - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

6. If this is not the case, test the pH with indicator paper and try the following:
 - a. If pH is not acidic, add a small amount of sulfuric acid
 - b. If solution is acidic but not colourless, add a small amount of sulfite solution
7. Warm the solution gently on a hot plate until all precipitate has redissolved.
8. Allow the solution to cool gently to room temperature without disturbing the crystallization process.

What would happen if the solution were agitated whilst cooling?

9. Once solution has reached room temperature, cool the flask within an ice – water bath.

Why do we cool gently to room temperature before placing the flask into an ice bath? (Hint: Crystal formation is involved)

10. Collect the crystals by vacuum filtration and transfer to a pre-weighed watch glass.
11. Calculate the yield of the sample.

For this experiment, it is common to calculate a yield greater than 100%. How would this be possible?

12. Test for the presence of a carboxylic acid functional group by addition of a small amount of your crystals to dilute sodium hydrogencarbonate solution in a sample vial.
Record your observations.
13. Show your crystal product to your demonstrator.
14. Dispose of your crystal product in the container provided

Appendix III - Alternative Teaching Approaches Procedures
III.2.3 Problem Solving - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

III.2.3 Problem Solving Method for the Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.2.3 Problem Solving - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Introduction:

A generic synthesis of benzoic acid:

Prepare a solution of your oxidant in 30 mL of deionised water within a 100 mL conical flask.

The next step is to add the benzyl alcohol to be oxidised. There is one problem however, if we simply combined the reagents, the reaction would not be completed. We therefore need to warm the oxidant solution to 30°C before adding the benzyl alcohol. Note that this reaction is exothermic and a temperature change of solution will occur which should be observed and recorded. Initially, the odour of benzaldehyde will become apparent but over time should dissipate after approximately 5 minutes. In unusual circumstances additional heating to 60°C for 5 minutes may be necessary to drive the reaction to completion.

After the reaction is complete we need to add some solutions to “work up” the crude product.

The following steps require the calculation of the amounts (mol) to be added based on these molar ratios:

- **57.4** (water) : **1** (benzyl alcohol)
- **5.6** (50% sulfuric solution) : **1** (benzyl alcohol)
- **17.6** (20% sodium sulfite solution) : **1** (benzyl alcohol)

HINT: Assume the density of water is 1 g/mL and the density of 20% sodium sulfite solution is 1.48 g/mL. 100% sulfuric acid has a concentration of 18 mol/L.

Add the calculated volumes of these solutions to the reaction solution. After some swirling, a colourless solution with a white precipitate should be seen to form. If the solution is not colourless, check the pH of the solution to determine if the solution is acidic. If the solution is

Appendix III - Alternative Teaching Approaches Procedures
III.2.3 Problem Solving - Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

not acidic, add a small volume of sulfuric acid. If the solution is acidic but not colourless, add further small amounts of sodium sulfite solution.

Once this has been achieved, the process of recrystallisation is used to produce a purified product. This process includes dissolving the crude product by warming gently until all precipitate has dissolved. The solution is then cooled slowly to room temperature before cooling in an ice-water bath. The final product, benzoic acid crystals, must then be collected by a method that can separate solids from a solution.

Procedure

Part 1: Synthesis of Benzoic acid

Using the information provided from the introduction, design a procedure for the synthesis of benzoic acid from 1 mL of benzyl alcohol (density of 1.046 g/mL). This will involve the calculation of volumes and amounts in addition to identifying a method for the separation of the benzoic acid crystals from solution.

Part 2: Identification of end product

There are multiple methods for the identification of a compound. One useful technique is the various reactions that can occur with functional groups. For benzoic acid, identify the functional group and a method to test for the presence of this functional group. (Hint: One of the experiments completed throughout the semester centres around testing for the presence of functional groups.)

Appendix III - Alternative Teaching Approaches Procedures

III.2.4 Expository - Organic Functional Groups

III.2.4 Expository Method for the Organic Functional Groups Experiment

Week 9: Experiment 5A Organic Functional Group Tests.

Concepts and Principles:

- *to understand the chemical reactivity of certain functional groups*
- *to apply knowledge of chemical reactivity to determine the presence of a functional group*
- *development of scientific observational skills*

Introduction

In modern organic chemistry there is a large dependence on spectroscopy to determine the structure and functional groups present within a compound. These can include infra-red spectroscopy (IR) for functional groups, nuclear magnetic resonance spectroscopy (NMR) for proton and carbon environments, ultra violet spectroscopy (UV-Vis) for conjugation and mass spectrometry (MS) for mass of a compound. Historically these methods were not available therefore many simple laboratory tests were developed to allow the detection of various functional groups within an organic molecule. Most of these tests are simply carried out in a test tube and rely on observations such as a change of colour, formation of a gas or the formation of a precipitate so it is clear if the test is positive or negative. This experiment will involve some of the most characteristic tests for the common functional groups.

Common functional group tests:

Alkenes:

Alkenes possess a double bond as the functional group. The characteristic reaction of the double bond is electrophilic addition, but it is also susceptible to oxidation.

Bromine test (electrophilic addition):

This test involves reaction between bromine solution and your chosen compound (colourless).

The bromine will undergo electrophilic addition onto the double bond. During this the bromine solution is consumed leaving a colourless solution (reaction is rapid).

To perform this test, in a small test tube add 1 to 2 drops of bromine solution to a few drops of your compound, shake and observe immediately.

Potassium permanganate test (oxidation):

Potassium permanganate is a well-known oxidant; during oxidation the potassium permanganate reduces itself to manganese dioxide, a fine black/brown precipitate. During this process, the purple colour from the potassium permanganate solution will disappear and a fine black/brown precipitate will form (manganese dioxide).

To perform this test, in a small test tube add 1 to 2 drops of potassium permanganate solution to a few drops of your compound and shake.

Phenols:

A phenol is both a particular compound and a class of compounds possessing a hydroxyl group attached to an aromatic ring. Phenol as a compound is the most simple of these compounds otherwise known as hydroxybenzene. The chemical properties of these compounds differ greatly from those of hydroxyl groups on aliphatic chains such as alcohols.

NaOH test

Phenols are stronger acids than alcohols and will form water soluble salts with 5% NaOH solution.

To perform this test, add a small crystal of your phenol to 3 mL of 5% NaOH solution in a test tube and shake. Dissolution of the crystal indicates a positive result.

FeCl₃ test

Most phenols form violet coloured complexes with Fe³⁺ solutions.

To perform this test, add 1 mL of 1% aqueous ferric chloride solution to a few small crystals of your chosen phenol in a couple of drops of ethanol and shake. Formation of a violet coloured solution indicates a positive result.

Aldehydes and Ketones:

Both of these classes of compounds contain a carbonyl group (C = O) as their functional group and hence share some similarities in properties and reactions. Both aldehydes and ketones can undergo nucleophilic addition with, for example, 2,4-dinitrophenylhydrazine (2,4-DNP). The 2,4-DNP test is a common test for aldehydes and ketones and upon a positive result will produce a red/orange solid (hydrazone). The downside to this test is that it cannot distinguish between a ketone and an aldehyde. One method to distinguish between aldehydes and ketones is to take advantage that an aldehyde will undergo oxidation to a carboxylic acid. The most spectacular demonstration of this is the Tollens silver mirror test, which, if positive, indicates an aldehyde. Using these tests in conjunction will allow the detection of both aldehydes and ketones and the ability to distinguish between them.

2,4-DNP test

Upon reaction, nucleophilic addition occurs to the aldehydes and ketones forms, after elimination of water, a 2,4-dinitrophenylhydrazone. These hydrazone compounds are typically orange/red and will precipitate from solution.

To perform this test, add 1 drop of the carbonyl compound to 0.5 mL of 2,4-dinitrophenylhydrazine solution in a small test tube and shake. An orange/red precipitate forming indicates a positive result. Dispose of the waste solution in the container provided and wash the tube with acetone.

NOTE: 2,4 – DNP is a CARCINOGEN and should be used in the fumehood at all times. Gloves should be used whenever handling.

Tollens' silver mirror test

Ag^+ is a mild oxidant and as such will oxidise an aldehyde through to a carboxylic acid. In this process, the Ag^+ is reduced to metallic silver, which is deposited onto the surface of the test tube to produce a silver mirror coating. Ketones are not oxidised and therefore will not produce a positive test result.

To perform this test, place 1 mL of 0.1 M AgNO_3 in a **thoroughly clean** test tube and add 2 – 3 drops of 2 M NaOH solution with shaking. Add 2 M ammonia solution drop wise until the precipitate **just** dissolves (adding too much will compromise the test). Add 2 drops of the compound to be tested with shaking. At this point a silver mirror should start to deposit on the test tube. It may be necessary to warm the test tube for a short period of time (40 – 50°C for 10 minutes).

Carboxylic Acids:

Carboxylic acids have the functional group $\text{R-CO}_2\text{H}$.

NaHCO_3 test

Carboxylic acids are slightly acidic and therefore will react with weak bases such as 5% NaHCO_3 forming a water-soluble salt and **liberating CO_2 (g)**. The reaction is relatively slow for water insoluble acids and requires close and careful observation of the solid-liquid interface.

To perform this test, add one drop (or the solid equivalent) of your compound to 1 mL of 5% sodium bicarbonate in a test tube and **observe carefully**.

AIM

With any scientific investigation it is important to have an understanding of the aim of the experiment before proceeding. Use the box space below to briefly summarise your aim for this experiment.

Appendix III - Alternative Teaching Approaches Procedures
III.2.4 Expository - Organic Functional Groups

School of Physical Sciences (Chemistry) Materials Hazard Sheet
University of Tasmania

Expt 5A: Organic functional group testing

<u>Chemical Hazards:</u>			
Name	Amount	Signal Word	Hazard statements
Cyclohexane	0.25 mL	Danger	H225: Highly flammable liquid and vapour H304: May be fatal if swallowed or enters airway H315: Causes skin irritation H336: May cause dizziness or drowsiness H400: Very toxic to aquatic life
Cyclohexene	0.25 mL	Danger	H225: Highly flammable liquid and vapour H301, 311: Toxic if swallowed or in contact with skin H304: May be fatal if swallowed or enters airway
Toluene	0.25 mL	Danger	H225: Highly flammable liquid and vapour H304: May be fatal if swallowed or enters airway H315: Causes skin irritation H336: May cause dizziness or drowsiness H361: Suspected of damaging fertility or the unborn child H373: May cause damage to organs through prolonged or repeated exposure
Bromine (10% in dichloromethane)	0.25 mL	Danger	H314: Causes severe skin burns and eye damage H331: Toxic if inhaled H335: May cause respiratory irritation H336: May cause dizziness or drowsiness H351: Suspected of causing cancer H373: May cause damage to Liver, Blood and CNS through prolonged or repeated exposure H400: Very toxic to aquatic life
Potassium permanganate (0.02M)	0.25 mL	None	None
2-Naphthol	10 mg	Danger	H302, 332: Harmful if swallowed or inhaled H400: Very toxic to aquatic life
Sodium Hydroxide 2M	10 mL	Danger	H290: May be corrosive to metals H314: Causes severe skin burns and eye damage
Ferric chloride 1%	0.25 mL	Warning	H302: Harmful if swallowed H315: Causes skin irritation
Phenol	10 mg	Danger	H301, 311: Toxic if swallowed, by skin contact, or inhaled H314: Causes severe skin burns and eye damage H341: Suspected of causing genetic defects H373: May cause damage to organs through prolonged or repeated exposure
Ethanol	2 mL	Danger	H225: Highly flammable liquid and vapour H341: Suspected of causing genetic defects H336: May cause dizziness or drowsiness H350: May cause cancer H361: Suspected of damaging fertility or the unborn child H373: May cause damage to organs through prolonged or repeated exposure
2,4-dinitrophenylhydrazine solution in sulfuric acid and ethanol	0.25 mL	Danger	H225: Highly flammable liquid and vapour H290: May be corrosive to metals H302: Harmful if swallowed H341: Suspected of causing genetic defects H350: May cause cancer H361: Suspected of damaging fertility or the unborn child H373: May cause damage to organs through prolonged or repeated exposure

III.2.4 Expository - Organic Functional Groups

Experimental Procedure:

1. Alkenes: Test cyclohexane, cyclohexene and toluene by adding a few drops of each of the compounds into a test tube and adding 1-2 drops of bromine solution. Test the same compounds except adding 1-2-drops of potassium permanganate solution and shake.
2. Phenols: Add a small crystal of 2-naphthol to water and 5 % sodium hydroxide to test the solubility. Add 1 ml of 1 % ferric chloride solution to phenol in couple of drops of ethanol.
3. Aldehydes and ketones: 2,4-DNP test (carry this out in the fume cupboard)- Add 0.5 mL of the 2,4-DNP reagent to a test tube and add 1 drop of the carbonyl compound to be tested and shake. Wash the contents into the container provided. Tollen's silver mirror test- add 1 mL of silver nitrate solution to a test tube and add 3 drops of sodium hydroxide. Add ammonia solution until the precipitate just dissolves. Add 2-3 drops of the carbonyl and shake. Clean the test tube into the bottle provided.
4. Carboxylic acids: Add a drop or small crystal of the acid to be tested into a test tube with 1 mL of sodium bicarbonate solution.
5. Unknown n: Obtain your unknown n and carry out the tests above to determine its identity.

P210: Keep flammables away from heat and flames
P261: Avoid breathing dust/ fume/ gas/ vapours/ spray
P264: Wash hands thoroughly after handling
P271: Use only in a well ventilated area
P273: Avoid release into the environment
P280: Wear protective gloves/ protective clothing/ eye protection

Gloves:	Polyethylene	Open Bench:	Yes - varies	Fume cupboard:	Yes - varies
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ALWAYS ADVISE DEMONSTRATOR IMMEDIATELY

Acid spills: Neutralise acid before cleaning spill. Wipe up with a cloth and wash at the sink.

Alkali spills

Organic spills: For spills <50 mL apply sand and sweep into solid waste container.

For large spills, surround spill with sand to contain the spread

Organic waste: Decant into waste containers provided in fume cupboards
Aqueous waste: Decant into waste containers provided in fume cupboards

Student

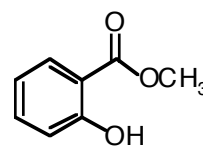
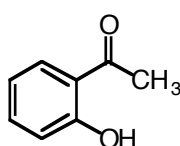
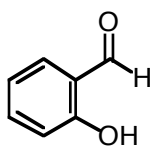
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Signature _____

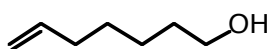
Pre-laboratory preparation: Organic Functional Group Tests.

This section must be completed before arrival at the laboratory

- What test(s) would you recommend to differentiate between the three following compounds? Briefly explain your answer.



- KMnO₄ gives a positive test for a C=C in the following molecule but is not the best test for this compound. Why?



Suggest an alternative test.

- What are the hazards associated with this experiment?

Demonstrator's initials

Expt 5A: Organic Functional Group Tests.

Labtech Note:

Many of these chemicals are dangerous. Please wear gloves when handling them.

The main cause of error in this experiment is unclean glassware. Make sure your glassware is clean before you begin.

Part 1: Alkenes

Bromine test

1. Collect 3 test tubes and clean thoroughly.
2. To each test tube, add a few drops of one of the following hydrocarbons:
 - a. Cyclohexane
 - b. Cyclohexene
 - c. Toluene
3. To each test tube add 1 to 2 drops of bromine solution.
4. Shake each test tube thoroughly and record your observations and the conclusions drawn from these below.

Hydrocarbon	Observations	Conclusions
Cyclohexane		
Cyclohexene		
Toluene		

Appendix III - Alternative Teaching Approaches Procedures
III.2.4 Expository - Organic Functional Groups

Potassium permanganate test

1. Collect 3 test tubes and clean thoroughly.
2. To each test tube, add a few drops of the following hydrocarbons:
 - a. Cyclohexane
 - b. Cyclohexene
 - c. Toluene
3. To each test tube, add 1 to 2 drops of potassium permanganate solution.
4. Shake each test tube thoroughly and record your observations and the conclusions drawn from these below.

Hydrocarbon	Observations	Conclusions
Cyclohexane		
Cyclohexene		
Toluene		

Part 2: Phenols

NaOH and FeCl₃ test

1. Collect 2 test tubes and clean thoroughly.
2. To each test tube, add 3 mL of one of the following solvents:
 - a. Water
 - b. 5% NaOH solution
3. Add a small crystal of 2-naphthol to each of the test tubes.
4. Shake each test tube thoroughly and record your observations and the conclusions drawn from these below.
5. Collect 1 test tube and clean thoroughly.
6. Add a few small crystals of 2-naphthol and 2 drops of ethanol to the test tube.
7. Add 1 mL of 1% aqueous ferric chloride (FeCl₃) solution to the test tube.
8. Shake thoroughly and record your observations and the conclusions drawn from these below.

Appendix III - Alternative Teaching Approaches Procedures
III.2.4 Expository - Organic Functional Groups

Mixture	Observations	Conclusions
2-naphthol in H ₂ O		
2-naphthol in 5% aq. NaOH		
2-naphthol + EtOH in 1% aqueous ferric chloride		

Part 3: Aldehydes and Ketones

2,4-Dinitrophenylhydrazine (2,4-DNP) test

1. Collect 2 test tubes and clean thoroughly.
2. To each test tube, add a few drops of one of the following:
 - a. Acetone (propanone)
 - b. Benzaldehyde
3. To each test tube add 0.5 mL of the 2,4-dinitrophenylhydrazine reagent.
4. Shake each test tube thoroughly and record your observations and the conclusions drawn from these below.
5. Dispose test tube contents into the waste container provided and wash tubes with acetone.

Appendix III - Alternative Teaching Approaches Procedures
III.2.4 Expository - Organic Functional Groups

Compound	Observations	Conclusions
Acetone		
Benzaldehyde		

Tollens Silver Mirror test

1. Collect 2 test tubes and clean thoroughly.
2. To each test tube, prepare as follows:
 - a. Place 1 mL of 0.1 M AgNO_3
 - b. Add 2 to 3 drops of 2 M NaOH solution with shaking
 - c. Add 2 M ammonia solution dropwise until precipitate just begins to form
 - d. To each test tube, add a 2 drops of one of the following:
 - i. Benzaldehyde
 - ii. Acetone (propanone)
3. If no deposition occurs, warm the test tube in a water bath gently.

Appendix III - Alternative Teaching Approaches Procedures
III.2.4 Expository - Organic Functional Groups

- Record your observations and the conclusions drawn from these below.

Compound	Observations	Conclusions
Acetone		
Benzaldehyde		

Part 4: Carboxylic Acids

Sodium bicarbonate test

- Collect 2 test tubes and clean thoroughly.
- To each test tube add 1 mL of 5% sodium bicarbonate.
- To each test tube add 1 drop of one of the following:
 - Acetic acid (ethanoic acid)
 - Benzoic acid

Appendix III - Alternative Teaching Approaches Procedures
III.2.4 Expository - Organic Functional Groups

5. Record your observations and the conclusions drawn from these below.

Carboxylic Acid	Observations	Conclusions
Acetic acid		
Benzoic acid		

Part 5: Unknown analysis

1. Collect an unknown from your demonstrator.

2. Perform each of the following tests:
 - a. Bromine test
 - b. Phenol test
 - c. 2,4-DNP test
 - d. Tollens test
 - e. Carboxylic acid test

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III.2.4 Expository - Organic Functional Groups

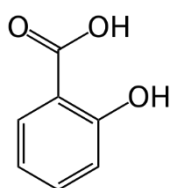
3. Record each of your observations and identify your unknown.

Test	Observations
Bromine test	
Phenol test	
2,4-DNP test	
Tollens test	
Carboxylic acid test	

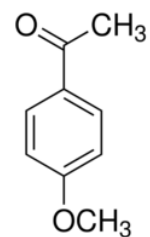
NOTE: All solid unknown substances should be dissolved in a SMALL amount of DCM when completing the Br₂ test for alkenes. Dissolve the unknown solid in a small amount of ethanol for the Tollens test.

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III.2.4 Expository - Organic Functional Groups

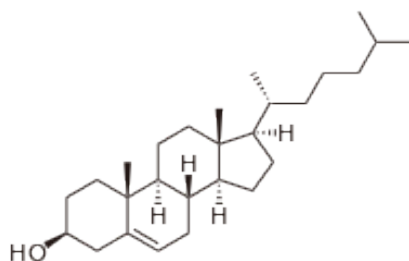
Available reagents (unknowns)



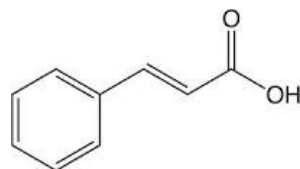
Salicylic acid



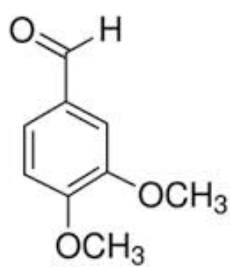
p-methoxyacetophenone



Cholesterol



Cinnamic acid



3,4 – dimethoxybenzaldehyde

Appendix III - Alternative Teaching Approaches Procedures

III.2.5 Guided Inquiry - Organic Functional Groups

III.2.5 Guided Inquiry Method for the Organic Functional Groups Experiment

Procedure

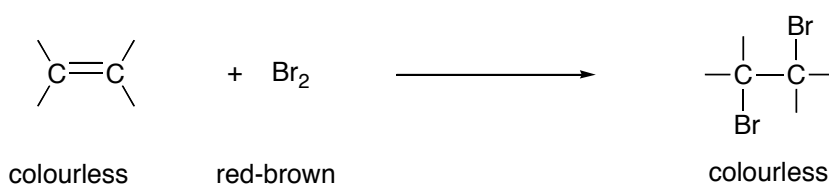
ALKENES

Alkenes possess a double bond as the functional group. The characteristic reaction of the double bond is electrophilic addition, but it is also susceptible to oxidation. Note that aromatic compounds do not undergo rapid reaction with bromine indicating that they are not simple alkenes (i.e. aromaticity).

If the test tubes are not clean and contain other compounds, how would this effect the tests?

Before proceeding to step 3, predict whether the tests will be positive or negative.

- i) Bromine test: The addition reaction can be demonstrated by reacting bromine (reddish) with an alkene. As the bromine reacts with the alkene its characteristic colour rapidly disappears, showing that a reaction has occurred.



Conduct the following test on :

- (a) cyclohexane,
- (b) cyclohexene, and
- (c) toluene.

Appendix III - Alternative Teaching Approaches Procedures

III.2.5 Guided Inquiry - Organic Functional Groups

To a few drops of the hydrocarbon to be tested, add 1 to 2 drops of a solution of bromine (10 % in dichloromethane) and shake. If a double bond is present the colour will vanish rapidly.

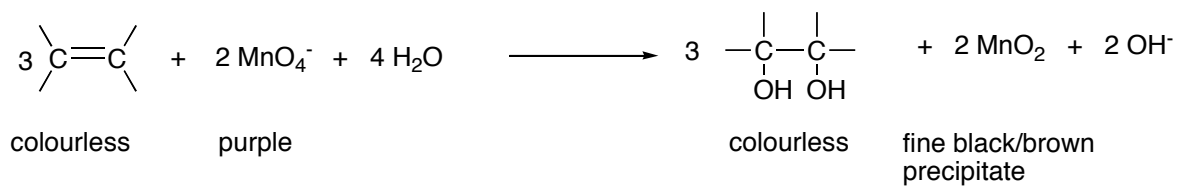
Bromine test results

compound	observations	result
cyclohexane		
cyclohexene		
toluene		
Equations		

(ii) Potassium permanganate test: This intensely purple coloured reagent oxidises the double bond and is itself reduced to manganese dioxide, a very fine black/brown precipitate. (**Note**: KMnO_4 can also react with other oxidisable groups such as alcohols, see Expt. 7A, so might not always be the best test for alkenes)

Appendix III - Alternative Teaching Approaches Procedures

III.2.5 Guided Inquiry - Organic Functional Groups



Give some examples of other oxidants commonly used.

If we used permanganate on CH_2CHOH , what would be the outcome of this?

Carry out the test below on :

- (a) cyclohexane,
- (b) cyclohexene, and
- (c) toluene.

To a few drops of the hydrocarbon to be tested add 1 to 2 drops of potassium permanganate solution and shake. If a double bond is present the purple colour will vanish rapidly and form a black/ brown precipitate.

Appendix III - Alternative Teaching Approaches Procedures
III.2.5 Guided Inquiry - Organic Functional Groups

Potassium permanganate test

compound	observations	result
cyclohexane		
cyclohexene		
toluene		
Equations		

2. PHENOLS : **(caution:** phenols cause burns to skin!)

The term "phenol" is a general name for the class of compounds possessing an hydroxyl group attached to an aromatic ring. Phenol itself ("hydroxybenzene") is the simplest compound of this class. The chemical properties of the hydroxyl group in phenols differ in many respects from the properties of the hydroxyl group of alcohols.

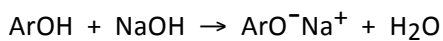
Draw the structure of Phenol.

What is an alternative to using NaOH? (Hint: consider the components of NaOH)

Appendix III - Alternative Teaching Approaches Procedures

III.2.5 Guided Inquiry - Organic Functional Groups

- (i) NaOH : Phenols are stronger acids than alcohols and react with 5 % NaOH solution forming water soluble salts.



Test the solubility of 2-naphthol in :

(a) *water, and*

(b) *5 % NaOH*

by adding a small crystal of naphthol to 3 mL of the solvent in a test tube and shake. Observe whether or not the phenol dissolves.

- (ii) FeCl₃ : Most phenols form violet coloured complexes with Fe³⁺ solutions.

Add 1 mL of a 1 % aqueous ferric chloride solution to a solution of a few small crystals of phenol in a couple of drops of ethanol and shake. Observe the colour produced.

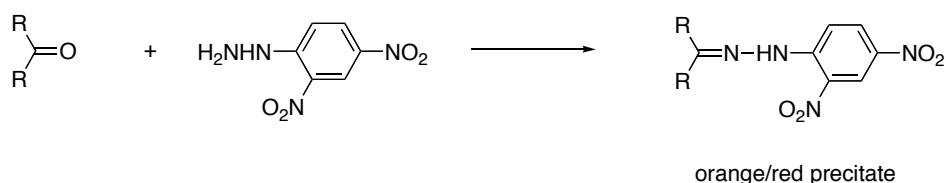
Phenol test results

test	observations	result
(i) solubility of 2-naphthol		
(ii) FeCl ₃ and phenol		
Equation for solubility test		

3. ALDEHYDES AND KETONES: (caution: 2,4-dinitrophenylhydrazine is a carcinogen)

Aldehydes and ketones both possess a carbonyl group ($C=O$) as their functional group and hence some reactions are common. For example this group undergoes nucleophilic addition with a variety of reagents including 2,4-dinitrophenylhydrazine (2,4-DNP). This is the classic test for aldehydes and ketones as a hydrazone forms which is deposited as an orange/red solid. To distinguish between an aldehyde and a ketone we take advantage that an aldehyde can be oxidised to a carboxylic acid. The most spectacular demonstration of this is the Tollen's silver mirror test which, if positive, indicates an aldehyde. But just as important if the 2,4-DNP test is positive but the silver mirror test is negative then this indicates the presence of a ketone.

- (i) 2,4-dinitrophenylhydrazine (2,4-DNP): This reagent adds to aldehydes and ketones and forms, after elimination of water, a 2,4-dinitrophenylhydrazone.



These are orange or reddish compounds which usually precipitate from solution.

Perform the test below on :

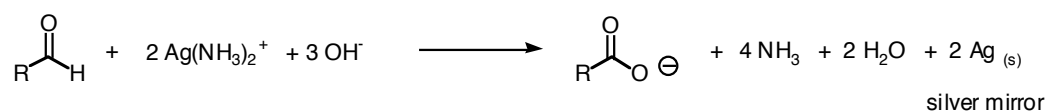
- (a) acetone (propanone), and
- (b) benzaldehyde.

To 0.5 mL of the 2,4 dinitrophenylhydrazine reagent in a test tube add one drop of the carbonyl compound and shake until a precipitate is observed. Dispose of the waste solution in the container provided and wash the tube with acetone.

2,4-dinitrophenylhydrazine test results

compound	observations	result
acetone (propanone)		
benzaldehyde		
Equations		

- (ii) Tollen's Silver Mirror test : Aldehydes are easily oxidised by a variety of reagents, including Ag^+ which is a very mild oxidant. In the reaction this is reduced to metallic silver which forms a mirror on the inside of the test tube. As ketones are not easily oxidised, this test enables aldehydes to be distinguished from ketones.



Perform the test below on :

- (a) benzaldehyde, and
- (b) propanone (acetone).

Appendix III - Alternative Teaching Approaches Procedures

III.2.5 Guided Inquiry - Organic Functional Groups

*Place about 1 mL of 0.1 M AgNO₃ solution in a **thoroughly clean test tube** and add 2 - 3 drops of 2 M NaOH solution with shaking. Add 2 M ammonia solution dropwise until the precipitate **just** dissolves. Add 2 - 3 drops of the substance (aldehyde or ketone) with shaking. Under ideal conditions a silver mirror will gradually deposit. Under less than ideal conditions a black deposit of metallic silver is formed (it may be necessary to warm the mixture gently in a water bath at 40 – 50 °C for 10 minutes).*

When the test is complete add rinse into heavy metal waste container and place test tube in container provided.

Tollen's silver mirror test results

compound	observations	result
benzaldehyde		
propanone (acetone)		
Equations		

4. CARBOXYLIC ACIDS

Carboxylic acids have the functional group $\text{-CO}_2\text{H}$.

- (i) NaHCO_3 : Carboxylic acids are strong enough acids to react with the relatively weak base 5 % NaHCO_3 forming a water soluble salt and liberating CO_2 . The reaction is relatively slow for water insoluble acids and requires close and careful observation of the solid-liquid interface (note: You have already used this test in Expt. 7A to test for the formation of benzoic acid).



Perform the following test on :

- (a) acetic acid (ethanoic acid), and
- (b) benzoic acid.

Place 1 mL of 5 % sodium bicarbonate in a test tube and add one drop of the liquid (or the equivalent of a solid). Observe the evolution of CO_2 .

(i) Sodium bicarbonate test

compound	observations	result
acetic acid (ethanoic acid)		
benzoic acid		
Equations		

Appendix III - Alternative Teaching Approaches Procedures
III.2.6 Problem Solving - Organic Functional Groups

III.2.6 Problem Solving Method for the Organic Functional Groups Experiment

Common functional group tests:

Alkenes:

Alkenes possess a double bond as the functional group. The characteristic reaction of the double bond is electrophilic addition, but it is also susceptible to oxidation.

Bromine test (electrophilic addition):

This test involves reaction between bromine solution and your chosen compound (colourless). The bromine will undergo electrophilic addition onto the double bond. During this the bromine solution is consumed leaving a colourless solution (reaction is rapid).

To perform this test, in a small test tube add 1 to 2 drops of bromine solution to a few drops of your compound, shake and observe immediately.

Potassium permanganate test (oxidation):

Potassium permanganate is a well-known oxidant; during oxidation the potassium permanganate reduces itself to manganese dioxide, a fine black/brown precipitate. During this process, the purple colour from the potassium permanganate solution will disappear and a fine black/brown precipitate will form (manganese dioxide).

To perform this test, in a small test tube add 1 to 2 drops of potassium permanganate solution to a few drops of your compound and shake.

Phenols:

A phenol is both a particular compound and a class of compounds possessing a hydroxyl group attached to an aromatic ring. Phenol as a compound is the most simple of these compounds otherwise known as hydroxybenzene. The chemical properties of these compounds differ greatly from those of hydroxyl groups on aliphatic chains such as alcohols.

NaOH test

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III.2.6 Problem Solving - Organic Functional Groups

Phenols are stronger acids than alcohols and will form water soluble salts with 5% NaOH solution.

To perform this test, add a small crystal of your phenol to 3 mL of 5% NaOH solution in a test tube and shake. Dissolution of the crystal indicates a positive result.

FeCl₃ test

Most phenols form violet coloured complexes with Fe³⁺ solutions.

To perform this test, add 1 mL of 1% aqueous ferric chloride solution to a few small crystals of your chosen phenol in a couple of drops of ethanol and shake. Formation of a violet coloured solution indicates a positive result.

Aldehydes and Ketones:

Both of these classes of compounds contain a carbonyl group (C = O) as their functional group and hence share some similarities in properties and reactions. Both aldehydes and ketones can undergo nucleophilic addition with, for example, 2,4-dinitrophenylhydrazine (2,4-DNP). The 2,4-DNP test is a common test for aldehydes and ketones and upon a positive result will produce a red/orange solid (hydrazone). The downside to this test is that it cannot distinguish between a ketone and an aldehyde. One method to distinguish between aldehydes and ketones is to take advantage that an aldehyde will undergo oxidation to a carboxylic acid. The most spectacular demonstration of this is the Tollens silver mirror test, which, if positive, indicates an aldehyde. Using these tests in conjunction will allow the detection of both aldehydes and ketones and the ability to distinguish between them.

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III.2.6 Problem Solving - Organic Functional Groups

2,4-DNP test

Upon reaction, nucleophilic addition occurs to the aldehydes and ketones forms, after elimination of water, a 2,4-dinitrophenylhydrazone. These hydrazone compounds are typically orange/red and will precipitate from solution.

To perform this test, add 1 drop of the carbonyl compound to 0.5 mL of 2,4-dinitrophenylhydrazine solution in a small test tube and shake. An orange/red precipitate forming indicates a positive result. Dispose of the waste solution in the container provided and wash the tube with acetone.

NOTE: 2,4 – DNP is a CARCINOGEN and should be used in the fumehood at all times. Gloves should be used whenever handling.

Tollens' silver mirror test

Ag^+ is a mild oxidant and as such will oxidise an aldehyde through to a carboxylic acid. In this process, the Ag^+ is reduced to metallic silver, which is deposited onto the surface of the test tube to produce a silver mirror coating. Ketones are not oxidised and therefore will not produce a positive test result.

To perform this test, place 1 mL of 0.1 M AgNO_3 in a **thoroughly clean** test tube and add 2 – 3 drops of 2 M NaOH solution with shaking. Add 2 M ammonia solution drop wise until the precipitate **just** dissolves (adding too much will compromise the test). Add 2 drops of the compound to be tested with shaking. At this point a silver mirror should start to deposit on the test tube. It may be necessary to warm the test tube for a short period of time (40 – 50°C for 10 minutes).

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III.2.6 Problem Solving - Organic Functional Groups

Carboxylic Acids:

Carboxylic acids have the functional group $\text{R-CO}_2\text{H}$.

NaHCO_3 test

Carboxylic acids are slightly acidic and therefore will react with weak bases such as 5% NaHCO_3 forming a water-soluble salt and **liberating** $\text{CO}_2(\text{g})$. The reaction is relatively slow for water insoluble acids and requires close and careful observation of the solid-liquid interface.

To perform this test, add one drop (or the solid equivalent) of your compound to 1 mL of 5% sodium bicarbonate in a test tube and **observe carefully**.

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III.2.6 Problem Solving - Organic Functional Groups

Procedure

Available reagents (necessary for the functional group tests):

Cyclohexane	Cyclohexene
Toluene	2-Naphthol
Phenol	Benzaldehyde
Acetone	Acetic acid
Benzoic acid	

Available reagents (for use in Part 1):

Bromine (10% in dichloromethane)	Potassium permanganate
Water	5% NaOH
1% aqueous ferric chloride	2,4-dinitrophenylhydrazine
Ethanol	0.1 M AgNO ₃
2 M NaOH	2 M Ammonia
5 % Sodium bicarbonate	

Part 1: Confirmation of functional group tests

Using the information provided from the introduction with the available reagents, confirm the validity of the functional group tests. Ensure to record all your observations and the corresponding results (positive or negative). For all positive test results, provide the molecular equation.

Report your observations for the Functional Group tests below:

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

III.2.7 Expository Method for the Thermochemistry Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

Week 11: Experiment 7A Thermochemistry: Enthalpy of Neutralisation

Concepts and Principles:

- *to investigate and apply the technique of calorimetry*
- *to investigate and measure enthalpies of neutralisation*

This experiment centres around a law called Hess' Law. This law states that *"The heat from a given process can be expressed as the sum of the heats of several processes that, when added, yield the process of interest"*.

For this experiment, we will first be measuring the enthalpy of reacting two reagents (HCl and NaOH solutions) to form a product. Secondly, we will measure the enthalpy of one of the reagents (solid NaOH) when dissolving. Finally, we will measure the enthalpy of reacting solid NaOH with HCl solution.

According to Hess' Law we should find that the sum of the heats of the first two processes should equal the heat of the final process.

Tips:

- Be careful with the amount of stirring, we want consistent gentle stirring to minimise heat exchange from the system, ie. excessive stirring can cause a vortex which introduces air into the solution therefore cooling the system. This applies for all of the steps requiring stirring throughout the experiment.
- When adding solid pellets to the system, add them quickly and record as soon as the max temperature is reached.
- Ensure all equipment used is cleaned before proceeding with an experiment.

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

- The calorimeters used should not exceed a volume of 100 mL.
- THE SODIUM HYDROXIDE PELLETS ARE HIGHLY CORROSIVE. DO NOT HANDLE WITHOUT GLOVES AND WIPE UP SPILLS IMMEDIATELY. ALERT A DEMONSTRATOR OF ANY SPILLS.

AIM

With any scientific investigation it is important to have an understanding of the aim of the experiment before proceeding. Use the box space below to briefly summarise your aim for this experiment.



Part 1: Enthalpy of Neutralisation of HCl (aq) and NaOH (aq)

1. Using a clean measuring cylinder, transfer 50 mL of 1.0 M HCl to the calorimeter.
2. Insert the thermometer and stirrer, stir the solution and record the temperature.
3. Thoroughly clean the measuring cylinder.
4. Measure 50 mL of 1.0 M NaOH into the measuring cylinder and record the temperature.
5. Immediately add this to the calorimeter and record the temperature at 30 second intervals for ~ 3 minutes.
6. Rinse the calorimeter thoroughly and invert to allow draining.
7. Repeat the above procedure for a second set of data.

Calculate the enthalpy of neutralization for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Part 2: Enthalpy of Solution of NaOH Solid

1. Place 100 mL of deionized water in the calorimeter and record its temperature.
2. Weigh out approximately 1.50 g of sodium hydroxide pellets (**THESE PELLETS ARE HIGHLY CORROSIVE. DO NOT TOUCH AND WIPE UP SPILLS IMMEDIATELY**)
3. Record the precise mass and quickly add the sodium hydroxide pellets into the calorimeter.
4. Immediately record the temperature.
5. Stir for 30 seconds and record the temperature at 30 second intervals.
6. Continue recording the temperature until the reaction has steadied.

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

7. Rinse the calorimeter with deionized water, drain and repeat the above procedure for a second set of data.

Calculate the enthalpy of solution for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Part 3: Combined Enthalpy of both Neutralisation (Part 1) and Solution (Part 2)

1. Place 40 mL of 1.0 M HCl and 60 mL of deionized water in the calorimeter.
2. Swirl and record the temperature of solution.
3. Accurately weigh out approximately 1.50 g of NaOH pellets (**THESE PELLETS ARE HIGHLY CORROSIVE. DO NOT TOUCH AND WIPE UP SPILLS IMMEDIATELY**) and record their precise mass.
4. Quickly transfer the weighed out pellets into the calorimeter, record the temperature and stir for 30 seconds.
5. Record the temperature at 30 second intervals until the reaction has steadied.
6. Rinse the calorimeter with deionized water, drain and repeat the above procedure for a second set of data.

Calculate the enthalpy of neutralization for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

School of Physical Sciences (Chemistry) Materials Hazard Sheet
University of Tasmania

Expt 7A: Thermochemistry: Enthalpy of neutralisation

<u>Chemical Hazards:</u>			
Name	Amount	Signal Word	Hazard statements
Sodium Hydroxide (1M)	100 mL	Danger	<i>H314: Causes severe skin burns and eye damage</i>
Hydrochloric acid (1M)	200 mL	Warning	<i>H315, 319: Causes skin and serious eye irritation</i> <i>H335: May cause respiratory irritation</i>
Sodium Hydroxide	6 g	Danger	<i>H290: May be corrosive to metals</i> <i>H302: Harmful if swallowed</i> <i>H314: Causes severe skin burns and eye damage</i> <i>H332: Harmful if inhaled</i> <i>H373: May cause damage to organs through prolonged or repeated exposure</i>

Experimental Procedure:

Add 50 mL of 1 M NaOH to the calorimeter (a polystyrene cup) and then add 50 mL of 1 M HCl, stir and record the maximum temperature reached. Repeat the process.

Weigh out 1.5 g of solid NaOH into a weighboat and transfer to the calorimeter and add 100 mL of water, stir the solution and record the temperature every 30 seconds. Repeat.

Add 1.5 g of NaOH to the calorimeter, add 50 mL of 1 M HCl, stir and record the temperature every 30 seconds. Repeat.

Precautionary statements:

P261: Avoid breathing dust/ vapour

P264: Wash hands thoroughly after handling

P280: Wear protective gloves/ protective clothing/ eye protection

Extra Precautions:

Gloves:	Polyethylene	Open Bench:	Yes	Fume cupboard:	No
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Spill Instructions:

ALWAYS ADVISE DEMONSTRATOR IMMEDIATELY

Wipe up with a cloth and dispose of in solid waste

For large spills, surround spill with sand to contain the spread

Disposal Instructions:

Solid waste: Dissolve with water and rinse at sink

Aqueous waste: Dilute with water and rinse at sink

Staff / Supervisor

Name _____

Signature _____

Student

Name _____

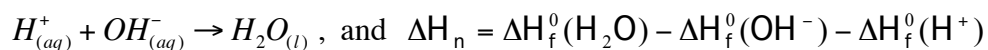
Signature _____

Pre-laboratory preparation: Thermochemistry: Enthalpy of Neutralisation

This section must be completed before arrival at the laboratory

- What do the terms exothermic and endothermic mean?
- When solid sodium hydroxide is added to water is the reaction exothermic or endothermic?
- What does the term 'heat capacity of the calorimeter' mean?
- How many moles of NaOH are there in 50 mL of a 1 M solution?
- Calculate the molar heat of neutralisation using the following.

Since (from the first law)



$$\Delta H_f^0(H_2O) = -285.53 \text{ kJ/mol}$$

$$\Delta H_f^0(OH^{-}) = -229.99 \text{ kJ/mol}$$

$$\Delta H_f^0(H^{+}) = 0 \text{ kJ/mol}$$

Demonstrator's initials

Expt 7A: Thermochemistry: Enthalpy of Neutralisation.

PART 1: HEAT OF NEUTRALISATION PLUS HEAT OF SOLUTION (ΔH_3)

Results and Calculations

	Run 1	Run 2	Run 3
Mass NaOH (g)			
Volume water in soln (density 1.00 g mL^{-1})			
Mass of water in soln (g)			
Volume 1 M $\text{HCl}_{(\text{aq})}$ (density 1.02 g mL^{-1})			
Mass 1 M $\text{HCl}_{(\text{aq})}$ in soln			
Total mass of NaCl soln			
Specific Heat NaCl soln	$4.017 \text{ J g}^{-1} \text{ K}^{-1}$	$4.017 \text{ J g}^{-1} \text{ K}^{-1}$	$4.017 \text{ J g}^{-1} \text{ K}^{-1}$
Temp before mixing ($^{\circ}\text{C}$)			
Soln temp after mixing ($^{\circ}\text{C}$)	Reading 1:	Reading 1:	Reading 1:
	Reading 2:	Reading 2:	Reading 2:
	Reading 3:	Reading 3:	Reading 3:
	Reading 4:	Reading 4:	Reading 4:
	etc:	etc:	etc:
Record Time and Temperature			
Temp change ΔT ($^{\circ}\text{C}$)			
Heat change for soln. (J)			
Calorimeter Const (J K^{-1}) C_2	37.5	37.5	37.5
Heat change for calorimeter (J)			
Total heat change (J)			
As above (kJ)			
Moles of NaOH neutralised			
Total heat change (kJ mol^{-1})			
Heat of rxn (ie enthalpy of rxn, ΔH) (kJ mol^{-1} NaOH) <u>Include the sign.</u>			

Summary

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

Mean ΔH_3 (kJ mol⁻¹)	
Absolute Error (kJ mol⁻¹)	
% Error	

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

PART 2: HEAT OF NEUTRALISATION (ΔH_1)

Results and Calculations

	Run 1	Run 2	Run 3
Vol 1 M HCl _(aq) (mL)			
Temp HCl _(aq) ($^{\circ}\text{C}$) = T_1			
Vol 1 M NaOH _(aq) (mL)			
Temp NaOH _(aq) ($^{\circ}\text{C}$) = T_2			
Temp NaCl _(aq) ($^{\circ}\text{C}$) Record Time and Temperature	Reading 1: Reading 2: Reading 3: Reading 4: etc:	Reading 1: Reading 2: Reading 3: Reading 4: etc:	Reading 1: Reading 2: Reading 3: Reading 4: etc:
Max NaCl temp ($^{\circ}\text{C}$) = T_3			
Density 1 M HCl _(aq) (g mL^{-1})	1.02	1.02	1.02
Mass 1 M HCl _(aq) (g)			
Density 1 M NaOH _(aq) (g mL^{-1})	1.04	1.04	1.04
Mass 1 M NaOH _(aq) (g)			
Mass of sol ⁿ (g) = (Mass 1 M HCl _(aq) + Mass 1 M NaOH _(aq)) (W)			
Specific Heat 0.5 M NaCl ($\text{J g}^{-1}\text{K}^{-1}$) C_1	4.017	4.017	4.017
Calorimeter constant (J K^{-1}) C_2	37.5	37.5	37.5
Mean Initial Temp ($^{\circ}\text{C}$) = $(T_1 + T_2)/2$			
Temp change, ΔT ($^{\circ}\text{C}$)			
Heat change of soln, ($=\Delta T \cdot W \cdot C_1$) (J)			

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

Heat change of calorimeter (J) = $(T_3 - T_1) \times \text{cal. Const.}$			
Total heat for reaction (J)			
Total heat for reaction (kJ)			
Mole NaOH taken			
Heat of neutralisation (kJ mol^{-1}) (ΔH) <u>Include sign</u>			

Summary

Mean ΔH_1 (kJ mol^{-1})	
Absolute Error (kJ mol^{-1})	
% Error	

Appendix III - Alternative Teaching Approaches Procedures
III.2.7 Expository - Thermochemistry: Enthalpy of Neutralisation

PART 2: HEAT OF SOLUTION (ΔH_2)

Results and Calculations

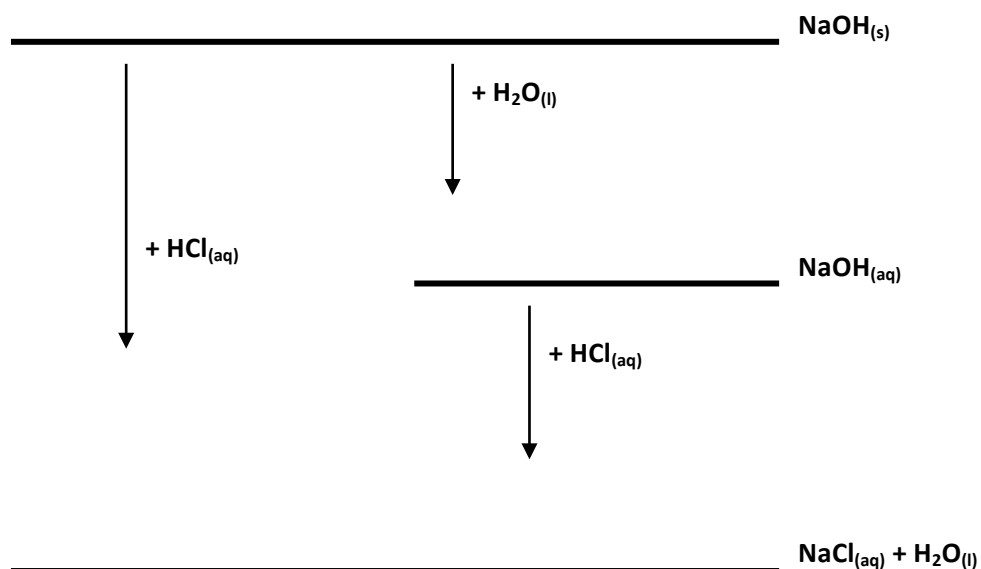
	Run 1	Run 2	Run 3
Volume water (mL)			
Mass NaOH (g)			
Initial water temp. ($^{\circ}\text{C}$)			
Temp NaOH _(aq) ($^{\circ}\text{C}$)	Reading 1:	Reading 1:	Reading 1:
	Reading 2:	Reading 2:	Reading 2:
Record Time and Temperature	Reading 3:	Reading 3:	Reading 3:
	Reading 4:	Reading 4:	Reading 4:
	etc:	etc:	etc:
Max temp. NaOH _(aq) ($^{\circ}\text{C}$)			
Density water (g mL^{-1})	1.00	1.00	1.00
Mass water (g)			
Mass solution (g)			
Temp change ΔT ($^{\circ}\text{C}$)			
Calorimeter Const (J K^{-1}) C_2	37.5	37.5	37.5
Heat change for solution (J)			
Heat change for calorimeter (J)			
Total heat change (J)			
Total heat change (kJ)			
Moles of NaOH dissolved			
Heat of soln. (kJ mol^{-1}) (i.e. enthalpy of solution ΔH). <u>Include sign.</u>			

Summary

Mean ΔH_2 (kJ mol^{-1})	
Absolute Error (kJ mol^{-1})	
% Error	

HESS'S LAW

Complete the equalities on the following energy diagram:



Within your range of errors are your values in accordance with Hess's Law?

Conclusion

Comment briefly on the areas in the experiment that may cause your value of ΔH_n to be in error from the known value.

Were the contributions from each component in Part 2 equal? What percentage of the combined enthalpy did each contribute?

Appendix III - Alternative Teaching Approaches Procedures
III.2.8 Guided Inquiry - Thermochemistry: Enthalpy of Neutralisation

III.2.8 Guided Inquiry Method for the Thermochemistry Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.2.8 Guided Inquiry - Thermochemistry: Enthalpy of Neutralisation

Procedure:

Part 1: Enthalpy of Neutralisation of HCl (aq) and NaOH (aq)

This process is simply the neutralization that occurs between an acid and a base. Give the reaction equation:

8. Using a clean measuring cylinder, transfer 50 mL of 1.0 M HCl to the calorimeter.
9. Insert the thermometer and stirrer, stir the solution and record the temperature.

Be careful with the amount of stirring as stirring will put more energy into the system. This applies for all of the steps requiring stirring throughout the experiment.

10. Thoroughly clean the measuring cylinder. If any HCl is present when the NaOH is added, reaction between the residues and the NaOH will occur, which will influence your experiment.
11. Measure 50 mL of 1.0 M NaOH into the measuring cylinder and record temperature.
12. Immediately add this to the calorimeter and record the temperature at 30 second intervals for ~ 3 minutes.
13. Rinse the calorimeter thoroughly and invert to allow draining.
14. Repeat the above procedure for a second set of data.

Calculate the enthalpy of neutralization for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Appendix III - Alternative Teaching Approaches Procedures
III.2.8 Guided Inquiry - Thermochemistry: Enthalpy of Neutralisation

Part 2: Enthalpy of Solution of NaOH Solid

For this process, we are measuring the heat that is evolved in the process of a compound changing state or more simply, dissolving.

1. Place 100 mL of deionized water in the calorimeter and record its temperature.
2. Weigh out approximately 1.50 g of sodium hydroxide pellets (**THESE PELLETS ARE HIGHLY CORROSIVE. DO NOT TOUCH AND WIPE OUT SPILLS IMMEDIATELY**)
3. Record the precise mass and quickly add the sodium hydroxide pellets into the calorimeter.

What would be a concern if you added the sodium hydroxide pellets gradually?

4. Immediately record the temperature.
5. Stir for 30 seconds and record the temperature at 30 second intervals.

Ensure stirring is steady but not vigorous.

6. Continue recording temperature until the reaction has steadied.
7. Rinse the calorimeter with deionized water, drain and repeat the above procedure for a second set of data.

Calculate the enthalpy of solution for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Appendix III - Alternative Teaching Approaches Procedures
III.2.8 Guided Inquiry - Thermochemistry: Enthalpy of Neutralisation

Part 3: Combined Enthalpy of both Neutralisation (Part 1) and Solution (Part 2)

This process is the combined heat of dissolution and neutralization. By measuring this we can find the combined heats of these processes. We are however, unable to identify the individual heats evolved from each component process.

1. Place 40 mL of 1.0 M HCl and 60 mL of deionized water in the calorimeter.

What could be a possible concern if we used 100 mL of HCl?

2. Swirl and record the temperature of solution.
3. Accurately weigh out approximately 1.50 g of NaOH pellets and record their precise mass.
4. Quickly transfer the weighed out pellets into the calorimeter, record the temperature and stir for 30 seconds.
5. Record the temperature at 30 second intervals until the reaction has steadied.

Compared to the previous two parts of the experiment, what can we expect from the temperature measurements?

6. Rinse the calorimeter with deionized water, drain and repeat the above procedure for a second set of data.

Calculate the enthalpy of neutralization for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Appendix III - Alternative Teaching Approaches Procedures
III.2.9 Problem Solving - Thermochemistry: Enthalpy of Neutralisation

III.2.9 Problem Solving Method for the Thermochemistry Experiment

Appendix III - Alternative Teaching Approaches Procedures
III.2.9 Problem Solving - Thermochemistry: Enthalpy of Neutralisation

Procedure:

Tips:

Be careful with the amount of stirring (we want consistent gentle stirring) as stirring will put more energy into the system. This applies for all of the steps requiring stirring throughout the experiment.

When adding solid pellets to the system, add them quickly and record as soon as possible.

Ensure all equipment used is cleaned before proceeding with an experiment.

The calorimeters used should not exceed a volume of 100 mL.

THE SODIUM HYDROXIDE PELLETS ARE HIGHLY CORROSIVE. DO NOT TOUCH AND WIPE UP SPILLS IMMEDIATELY.

Part 1: Enthalpy of Neutralisation of HCl (aq) and NaOH (aq)

This process is simply the neutralization that occurs between an acid and a base. Give the reaction equation:

Collect two sets of data for the neutralization of HCl (aq) and NaOH (aq).

Calculate the enthalpy of neutralization for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Appendix III - Alternative Teaching Approaches Procedures
III.2.9 Problem Solving - Thermochemistry: Enthalpy of Neutralisation

Part 2: Enthalpy of Solution of NaOH Solid

For this process, we are measuring the heat that is evolved in the process of a compound changing state or more simply, dissolving.

Collect two sets of data for the dissolution of NaOH solid.

Calculate the enthalpy of solution for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Part 3: Enthalpy of Neutralisation and plus Enthalpy of Solution

This process is the combined heat of dissolution and neutralization. By measuring this we can find the combined heats of these processes. We are however, unable to identify the individual heats evolved from each component process.

Collect two sets of data for the combined processes.

Calculate the enthalpy of neutralization for each run, convert to kJ mol^{-1} and calculate the mean value.

Ensure to provide the mean value with the correct number of significant figures and give the absolute and percentage errors.

Appendix III - Alternative Teaching Approaches Procedures

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

III.2.10 Expository Method for the Freezing Point Depression Experiment

Week 12: Experiment 8A Determination of the freezing-point depression
constant for cyclohexane.

Concepts and Principles:

- *to understand the difference between molarity and molality*
- *to be able to experimentally construct cooling curves*
- *to learn methods for determination of molecular mass from experimental techniques*

Theory

The **normal freezing point of a liquid** (or the **melting point of a solid**) is the temperature at which the vapour pressure of the solid and liquid are equal, measured at one atmosphere pressure.

When two components are present in an ideal solution, Raoult's Law states that the vapour pressure (P_A) due to each substance is directly proportional to the **mole fraction** (X_A) of the substance in the solution.

$$P_A = X_A \cdot P_A^* \text{ , where } P_A^* \text{ is vapour pressure of the pure compound}$$

Therefore, if a small quantity of a non-volatile substance (solute) is added to some solvent, the mole fraction of the solvent will be less than unity and, therefore, the vapour pressure of the solvent over the solution will be less than it is over the pure solvent.

The results may be shown on a phase diagram such as that in Figure 8A-1, where the vapour pressure versus temperature behaviour for the pure solvent is shown as the solid black line while the vapour pressure versus temperature behaviour for the solution is shown as a faint grey line.

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

When the solution freezes, the solid which first forms is the pure solvent. Again, freezing occurs when the vapour pressure of the solid phase equals the vapour pressure of the liquid phase. In this case the liquid phase is the solution. Since the vapour pressure of the solution is lower than the vapour pressure of the pure solvent, the freezing point is correspondingly lower.

The depression in freezing point, ΔT_f , is defined as

$$\Delta T_f = T_f^0 - T_f$$

where T_f^0 is freezing point of pure solvent and T_f is the freezing point of the solution.

The depression, ΔT_f , depends on the solvent and on the concentration of the solute.

These factors are related by the equation

$$\Delta T_f = K_f m \quad (\text{EQN 8A-1})$$

where K_f the molal freezing point depression constant (which is characteristic of the solvent)

and m the molality of the solution (mole of solute per kg of solvent).

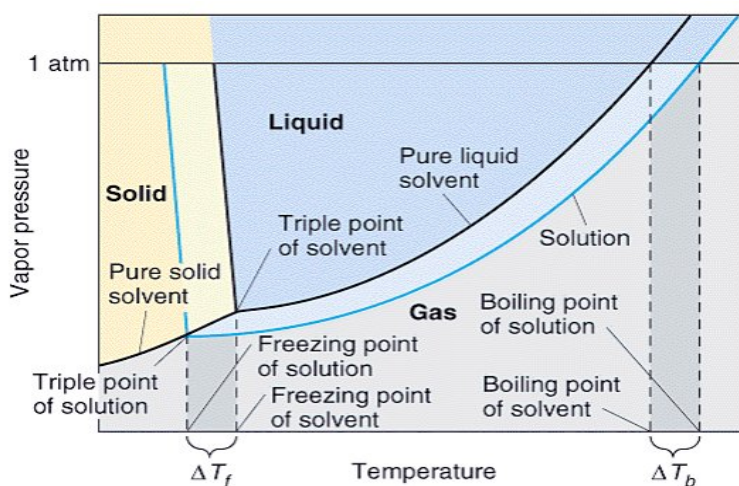


Figure 8A-1

Appendix III - Alternative Teaching Approaches Procedures

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

Freezing point depression measurements are useful for the determination of the molecular mass of a dissolved substance (solute). In this experiment, the freezing point depression constant for cyclohexane will be determined from a known mass of biphenyl in a known mass of cyclohexane.

The value of ΔT_f is found experimentally by measuring:

1. the freezing point of pure cyclohexane, T_f°
2. the freezing point of the solution of the solute (biphenyl) in cyclohexane, T_f and calculating the difference between this and T_f°

The molality of the solution m , is found by using Equation 8A-2.

$$\text{Now } m = \frac{\text{number of mole of solute (n)}}{\text{mass of solvent in kg}} \quad (\text{EQN 8A-2})$$

$$\text{and } n = \frac{\text{mass of solute in g}}{\text{molar mass of solute in g. mol}^{-1}} \quad (\text{EQN 8A-3})$$

Hence the molecular mass of the solute may be calculated since it is the only unknown in equations 8A-2 and 8A-3.

$$\text{i.e. molar mass of solute} = \frac{K_f (\text{mass of solute (g)})}{(\text{mass of solvent (kg)} \Delta T_f)} \quad (\text{EQN 8A-4})$$

A convenient method to chart the progress of a freezing solvent or solution is by means of a cooling curve. To obtain a **cooling curve** for a pure solvent, for example, one cools the solvent

Appendix III - Alternative Teaching Approaches Procedures

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

(by removing heat from the solvent) and plots temperature **versus** time. A cooling curve for pure cyclohexane should appear as follows:

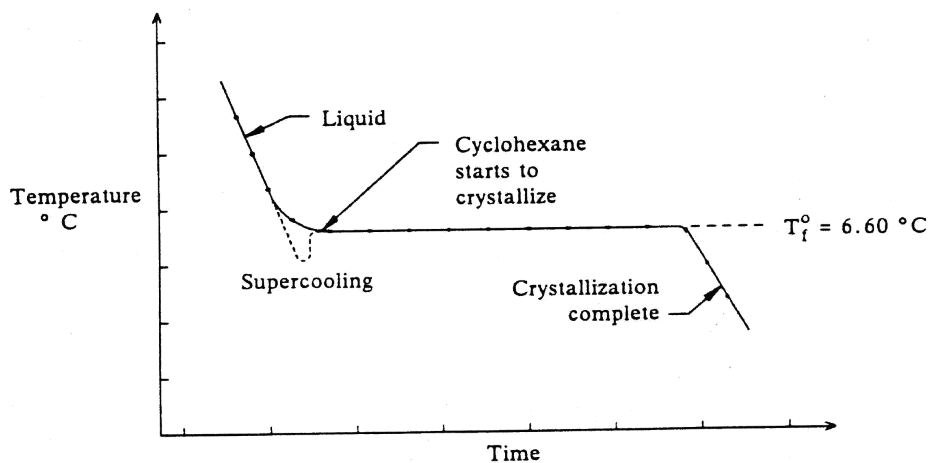


Figure 8A-2

The solution of cyclohexane with some biphenyl added behaves slightly differently. When the pure solvent starts to solidify at the freezing point, the remaining solution becomes more concentrated, so the freezing point is lowered still further. The temperature of the solution therefore continues to fall as shown in the cooling curve in Figure 5A-3.

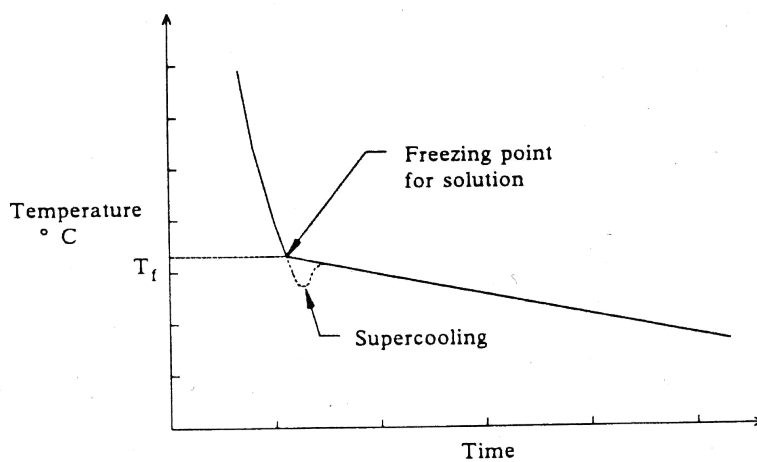


Figure 8A-3

Appendix III - Alternative Teaching Approaches Procedures

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

The lowering of the freezing point of the solvent is proportional to the concentration of the dissolved species and the constant of proportionality is the same for any dissolved substance in that solvent. That is, the constant is a property of the solvent and not of the solute. Thus every solvent has a unique freezing point constant which is the difference between the freezing point of the pure solvent and that of a solution containing one mole of solute in 1000 g of the solvent (a one molal solution).

Concentrations are expressed as moles per 1000 g of solvent (i.e. molality) because this is temperature-independent rather than as moles per litre (i.e. molarity) which will alter if the temperature is changed.

For this experiment we will be using an apparatus specifically designed to measure freezing points. From the diagram seen to the right, we can see that the apparatus consists of an outer tube (insulation) and an inner tube (container for your solution). Within the inner tube, a thermometer (to measure the temperature of the solution) and a stirrer (consistent stirring must occur to avoid the solution freezing unevenly).

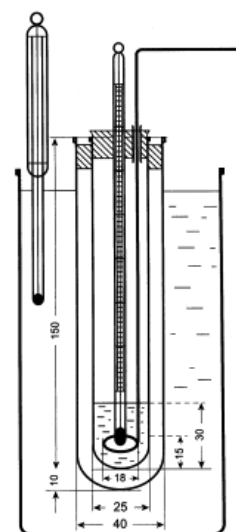


Figure 2.2.18-1. - Apparatus for the determination of freezing point
Dimensions in millimetres

To use this apparatus, first we must know the dry weight of the inner tube, which must be **clean and dry**. This allows a known mass of compound to be used. The inner tube can then be cooled directly in an ice bath to a reasonable temperature to save time. The outer test tube is then used to insulate the inner tube and slow the cooling process. With continual stirring, the temperature is then regularly recorded to observe the cooling process. The recorded temperatures are best to be directly recorded onto a prepared graph.

AIM

With any scientific investigation it is important to have an understanding of the aim of the experiment before proceeding. Use the box space below to briefly summarise your aim for this experiment.

--

Procedure

1. Collect the required equipment.
2. Disassemble the apparatus, ensure the corked inner test tube is clean and dry.
3. Stand the inner tube in a styrofoam test tube holder and weigh to 0.01 g.
4. Fill the inner tube with cyclohexane to a depth of 5 cm and reweigh.
5. Cool the cyclohexane within the inner test tube to 10 °C in an ice water mixture.
6. Prepare your graph paper to plot temperature vs time.
7. Once the temperature has reached 10 °C, place the inner test tube into the outer test tube for some insulation. Clamp the tubes into place in the ice water mixture.
8. Read the temperature at 30 second intervals and record these directly onto your graph.

Ensure you continue stirring throughout the process otherwise the cyclohexane will freeze unevenly.
9. Ensure you have 3 or 4 points both before and after the break in the cooling curve.
10. Draw lines of best fit through the two sections of the curve and identify the melting point.
11. Unfreeze the cyclohexane by warming the solution. Once the solution has been unfrozen, add approximately 0.05 – 0.10 g of naphthalene (ensure you record the mass of naphthalene). Determine the melting point once the naphthalene has fully dissolved.
12. Add another 0.05 – 0.10 g of naphthalene to the solution and determine the melting point.
13. Add another 0.05 – 0.10 g of naphthalene to the solution and determine the melting point.
14. Place the unfrozen cyclohexane solution into the “recovered cyclohexane” bottle for recycling.

Appendix III - Alternative Teaching Approaches Procedures

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

15. Calculate the molal freezing point constant for cyclohexane.
16. Calculate the molar mass of the unknown in the results section at the end of the experiment, using the information given in your laboratory manual and the K_f for cyclohexane.

Appendix III - Alternative Teaching Approaches Procedures
 III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

School of Physical Sciences (Chemistry) Materials Hazard Sheet
 University of Tasmania

Expt 8A: Determination of the Freezing Point Depression Constant for Cyclohexane.

<u>Chemical Hazards:</u>			
Name	Amount	Signal Word	Hazard statements
Cyclohexane	~ 20 mL	Danger	<i>H225: Highly flammable liquid and vapour</i> <i>H304: May be fatal if swallowed and enters airway</i> <i>H315: Causes skin irritation</i> <i>H336: May cause dizziness or drowsiness</i> <i>H400: Very toxic to aquatic life</i>
Biphenyl	~ 0.3 g	Warning	<i>H315: Causes skin irritation</i> <i>H319: Causes serious eye irritation</i> <i>H335: May cause respiratory irritation</i> <i>H400: Very toxic to aquatic life</i>

Experimental Procedure:

Add cyclohexane to a test tube and cool in an ice-water bath to ~ 10°C
 Place that test tube into a larger test tube to slow the rate of cooling. Plot the temperature versus time.
 Remove the test tube and weigh accurately 5-100 mg biphenyl into the test tube and repeat the
 Add a further portion of biphenyl and repeat
 When finished place the waste in the container provided.

Precautionary statements:

P210: Keep flammables away from heat and flames
P261: Avoid breathing dust/ fume/ gas/ vapours/ spray
P264: Wash hands thoroughly after handling
P271: Use only in a well ventilated area
P273: Avoid release into the environment
P280: Wear protective gloves/ protective clothing/ eye protection

Extra Precautions:

Gloves:	Polyethylene	Open Bench:	Yes	Fume cupboard:	No
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Spill Instructions:

ALWAYS ADVISE DEMONSTRATOR IMMEDIATELY
 Wipe up with a cloth and dispose of in solid waste
 Organic spills < 50 mL cover with sand and sweep into solid waste.
 For large spills, surround spill with sand to contain the spread and apply vermiculite

Disposal Instructions:

Solid waste: Dispose of in in solid waste containers
 Organic waste: Decant into non-halogenated organic waste containers in the fume cupboard

Staff / Supervisor

Student

Name _____

Name _____

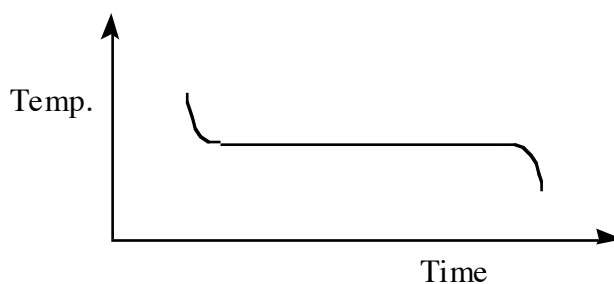
Signature _____

Signature _____

**Pre-laboratory preparation: Determination of the freezing-point depression
constant for cyclohexane.**

This section must be completed before arrival at the laboratory

- Question 1. What is the freezing point of a pure liquid?
- Explain the terms 'molarity' and 'molality'.
- Label the areas of the cooling curve below showing where:
 - A. liquid only exists
 - B. solid only exists.
 - C. liquid and solid are present.



- The addition of 0.24 g of sulfur to 100 g of carbontetrachloride lowers the latter's freezing point by 0.28°C. What is the molar mass of sulfur (S_x), where x is the number of atoms in the molecule. K_f for carbontetrachloride = 29.8 K.kg.mol⁻¹

Demonstrator's initials

Appendix III - Alternative Teaching Approaches Procedures

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

Expt 8A: Determination of the Freezing Point Depression Constant for Cyclohexane.

mass of test tube, beaker + _____ =

cyclohexane

mass of test tube and beaker _____ =

mass of cyclohexane _____ =

Freezing point of cyclohexane = _____ °C

	<i>1st addition of biphenyl</i>	<i>2nd addition of biphenyl</i>	<i>3rd addition of biphenyl</i>
mass of biphenyl added (g)			
mass of biphenyl already added (g)	0		
total mass of biphenyl (g)			
total moles of biphenyl (mol)			
molality of the biphenyl solution (m mol.kg ⁻¹)			
freezing point of pure cyclohexane (T_f°)			
freezing point of the biphenyl solution (T_f)			
freezing point depression ($\Delta T_f = T_f^\circ - T_f$)			
freezing point depression for a 1 molal solution of biphenyl i.e. the molal freezing point constant (K_f for cyclohexane)			

∴ Average molal freezing point constant for cyclohexane = _____ ±

Appendix III - Alternative Teaching Approaches Procedures

III.2.10 Expository - Determination of the Freezing Point Depression Constant for Cyclohexane

Molar mass calculation

If 53.6 mg of an unknown organic liquid dissolved in 11.62 g of cyclohexane depressed the freezing point by 1.2 °C, calculate the molar mass.

Molar mass of unknown =

Appendix III - Alternative Teaching Approaches Procedures
III.2.11 Guided Inquiry - Determination of the Freezing Point Depression Constant for
Cyclohexane

*III.2.11 Guided Inquiry Method for the Determination of the Freezing Point Depression Constant
for Cyclohexane Experiment*

Appendix III - Alternative Teaching Approaches Procedures
III.2.11 Guided Inquiry - Determination of the Freezing Point Depression Constant for
Cyclohexane

Procedure

1. Collect the required equipment.
2. Disassemble the apparatus, ensure the corked inner test tube is clean and dry,
3. Stand the inner tube in a styrofoam test tube holder and weight to 0.01 g.
4. Fill the inner tube with cyclohexane to a depth of 5 cm and reweigh.

We know that the freezing point for cyclohexane is at least below 10 °C. Therefore cool the inner tube to an appropriate temperature in an ice bath to prepare for measurements.

5. Prepare your graph paper to plot temperature vs time.
6. Once the temperature has reached your chosen temperature, place the inner test tube into the outer test tube for some insulation. Clamp the tubes into place in the ice water mixture and continue to cool.

Choosing timing intervals can be a difficult choice, as intervals too short will give a large amount of data to process. In comparison, choosing an interval too large may mean that important gradient changes will be missed. After consideration, choose a time interval that seems appropriate and discuss with your demonstrator.

7. Read the temperature at your chosen time intervals and record these directly onto your graph. **Ensure you continue stirring throughout the process otherwise the cyclohexane will freeze unevenly.**

Graphs with no context are meaningless. Ensure you have several points both before and after any significant changes in your cooling curve.

8. Draw lines of best fit through the two sections of the curve and identify the melting point.
9. Unfreeze the cyclohexane by warming the solution. Once solution has been unfrozen, add approximately 0.05 – 0.10 g of biphenyl (ensure you record the mass of biphenyl).

Predict how this will alter the freezing point (if it does at all).

Appendix III - Alternative Teaching Approaches Procedures

III.2.11 Guided Inquiry - Determination of the Freezing Point Depression Constant for Cyclohexane

10. Redetermine the melting point once the biphenyl has fully dissolved.
11. Repeat this addition of biphenyl and calculation for another two measurements of biphenyl.
12. Place the unfrozen cyclohexane solution into the "recovered cyclohexane" bottle for recycling.
13. Calculate the molal freezing point constant for cyclohexane.

Why do we use molal instead of molarity for this experiment?

14. Calculate the molar mass of the unknown using the information given in your laboratory manual and the K_f for cyclohexane.

Appendix III - Alternative Teaching Approaches Procedures
III.2.12 Problem Solving - Determination of the Freezing Point Depression Constant for
Cyclohexane

III.2.12 Problem Solving Method of the Freezing Point Depression

Appendix III - Alternative Teaching Approaches Procedures
III.2.12 Problem Solving - Determination of the Freezing Point Depression Constant for
Cyclohexane

Introduction

For this experiment we will be using an apparatus specifically designed to measure freezing points. From the diagram seen to the right, we can see that the apparatus consists of an outer tube (insulation) and an inner tube (container for your solution). Within the inner tube, a thermometer (to measure the temperature of the solution) and a stirrer (consistent stirring must occur to avoid the solution freezing unevenly).

To use this apparatus, first we must know the dry weight of the inner tube, which must be **clean and dry**. This allows a known mass of compound to be used. The inner tube can then be quickly cooled directly in an ice bath to a reasonable temperature to save time. The outer test tube is then used to insulate the inner tube and slow the cooling process. With continual stirring, the temperature is then regularly recorded to observe the cooling process. The recorded temperatures are best to be directly recorded onto a prepared graph.

Appendix III - Alternative Teaching Approaches Procedures
III.2.12 Problem Solving - Determination of the Freezing Point Depression Constant for
Cyclohexane

Procedure

Part 1: Freezing point of cyclohexane

Using the information provided in the introduction, design an experiment and determine the freezing point of cyclohexane.

Part 2: The effect on freezing points with addition of naphthalene

We wish to test how the freezing point of cyclohexane is affected by addition of **three** small incremental amounts of naphthalene (no more than 0.10 g of naphthalene per increment).

Tips:

- Ensure all compounds used/added are weighed on an analytical balance and recorded.
- Used cyclohexane solution should be placed into the “recovered cyclohexane” container provided.
- A single set of data is not adequate for determining a freezing point.
- The freezing point of cyclohexane is at least below 10 °C.
- Graphs with no context are meaningless. Ensure you have several points both before and after any significant changes in your cooling curve.
- Molality must be used instead of molarity.

Appendix III - Alternative Teaching Approaches Procedures
III.3.1 Determination of Copper and Arsenic in Treated Wood by Atomic Absorption
Spectroscopy

III.3 Second Year Chemistry

*III.3.1 Determination of Copper and Arsenic in Treated Wood by Atomic Absorption
Spectroscopy*

Experiment 10 – Determination of copper and arsenic in treated wood by atomic absorption spectrophotometry

Procedure

This experiment should be completed with **TWO** duplicate samples to allow averaging of obtained results. Give a justification as to why this is important.

Part 1: Extraction with nitric acid

1. Weigh accurately into a suitable flask (to the nearest milligram) approximately 1 g of small particles (or saw dust) from a sample of CCA pressure treated wood.
2. With the assistance of the demonstrator add 50 mL of 6 M nitric acid and bring to the boil on a hot plate in an acid scrubbing fumehood (rm 309).
3. Boil gently for 10 minutes replacing any volume lost to evaporation with deionized water.

What would further boiling of the sample achieve?

4. Remove boiled samples from the heat and allow to cool. Collect the filtrate
Filter using a sintered glass vacuum filtration apparatus. Rinse the Erlenmeyer flask three times with 10 mL of deionized water and collect the filtrate and washings into a 250 mL volumetric flask. Dilute to the marked volume with deionized water and mix thoroughly.

All glassware for this experiment must be thoroughly cleaned with deionized water. Give a justification for this:

Appendix III - Alternative Teaching Approaches Procedures
III.3.1 Determination of Copper and Arsenic in Treated Wood by Atomic Absorption Spectroscopy

Part 2: Preparation and analysis of standards

1. Using the two provided stock solutions, prepare 6 mixed metal solutions in the following concentration ranges:
 - a. 0 – 25.0 mg/L for arsenic
 - b. 0 – 15.0 mg/L for copper

What aspect/s of the AAS technique allows analysis of multiple elements in the sample?

2. These standards should be prepared in 0.1 % nitric acid. For the preparation of the standards an auto-pipette capable of delivering volumes between 0.10 and 1.00 mL will be supplied.

Why prepare the standards in 0.1% nitric acid as opposed to deionised water?

3. With the aid of a demonstrator, analyse each of the samples and standards for both copper and arsenic using the atomic absorption spectrophotometer.
4. Collect data in triplicate and construct a calibration curve from the standards to determine the concentration of copper and arsenic present in the original samples.

Why do we collect data in triplicate?

Does Beer's Law apply to this analysis?

Appendix III - Alternative Teaching Approaches Procedures
III.3.1 Determination of Copper and Arsenic in Treated Wood by Atomic Absorption Spectroscopy

Given a sample that does not fit within the calibration series, what can be done to achieve a valid analysis?

Discussion

- The above experiment used a standard calibration curve technique to determine each metal. How does this method differ from a standard addition calibration?
- Compare your results with those of two or more fellow students. How do they compare? Give possible causes for any differences noticed and possible causes of any errors in the above technique.

Appendix III - Alternative Teaching Approaches Procedures
III.3.2 EDTA Titration of Calcium and Magnesium in Natural Waters

III.3.2 EDTA Titration of Calcium and Magnesium in Natural Waters

Experiment 7 – EDTA determination of calcium and magnesium in natural waters

Procedure:

This procedure should be completed for both a tap water and sea water sample.

1. Accurately weigh out ~0.6 g of dry (heated at 80°C for 1 hr then cooled and stored in a desiccator) $\text{Na}_2\text{H}_2\text{EDTA} \cdot 2\text{H}_2\text{O}$ (MW 372.24). Prepare 500.00 mL of EDTA solution with deionized water, heating under running hot water to dissolve. Cool to room temperature, dilute to the mark, and mix well.

What is the accurate concentration of your prepared EDTA solution?

2. Pipette a series of samples of the unknown water sample into a 250 mL flask. A 50.00 mL sample of tap water is usually reasonable.
3. To each sample, add 3 mL of pH 10 buffer and ~6 drops of Eriochrome Black T indicator. Titrate with the EDTA solution from a 50.00 mL burette and note the volume when the colour changes from wine red to blue. Practice finding the end point several times by adding a little tap water and titrating with more EDTA. Save a solution at the end point to use as a colour comparison for other titrations.

Why is Eriochrome Black T used as an indicator? Give the pH range and the complex

Eriochrome Black T forms with $\text{Ca}^{2+}/\text{Mg}^{2+}$. Ensure you cite the source this information is collected from.

4. Repeat the titration with three further samples to find an accurate value of the total $\text{Ca}^{2+} + \text{Mg}^{2+}$ concentration.
5. Perform a blank titration with 50.00 mL of deionized water and subtract the value of the blank from each result.

Appendix III - Alternative Teaching Approaches Procedures
III.3.2 EDTA Titration of Calcium and Magnesium in Natural Waters

Justify the use of multiple titrations and the a blank titration.

6. Now that the combined concentration of Mg^{2+} and Ca^{2+} ions has been determined, a method for the determination of the individual concentrations is needed. Prepare four samples of the unknown water sample into clean flasks. To separate the metal ions, we can take advantage of the solubilities of each ion. Using the provided base, 50 wt % NaOH, add 30 drops to each solution and swirl for 2 minutes.

Based on the solubilities of $\text{Mg}(\text{OH})_2$ and $\text{Ca}(\text{OH})_2$, which compound will precipitate completely?

Ensure you cite the source the information is collected from.

7. For these next titrations, we will be using solid hydroxynaphthol blue. Add enough hydroxynaphthol blue to cover the end of your spatula to each flask (the indicator may be collected from the store). Complete a single rapid titration to practice observing the end point.

Why would we use hydroxynaphthol as an alternative indicator? Give the pH range and complex hydroxynaphthol blue forms with the metal ion. Ensure you cite the source this information is collected from.

8. Since both ions may potentially form a precipitate, allow each sample to sit for 5 min with occasional swirling so that any unwanted precipitate may redissolve. Continue titrating until a final end point has been achieved.
9. Perform a blank titration with 50 mL of deionized water.
10. Calculate the total concentration of Ca^{2+} and Mg^{2+} , as well as the individual concentrations of each ion. Calculate the relative standard deviation of replicate titrations.

Appendix III - Alternative Teaching Approaches Procedures
III.3.2 EDTA Titration of Calcium and Magnesium in Natural Waters

11. Repeat the experiment using a sea water sample. Dilute 1.000 mL of sea water in 50.00 mL of deionized water.

Give a justification as to why this dilution is necessary.

Discussion:

- What interferences might we expect with this type of analysis?
- What sources of error are there in this method?
- Provide a brief explanation of how Eriochrome black T functions as an indicator for this titration.
- Provide some indication for the expected levels of Ca^{2+} and Mg^{2+} in tap water and sea water and relate these to your results.

Appendix III - Alternative Teaching Approaches Procedures
III.3.3 Spectrophotometric Determination of Phosphate in Natural Waters

III.3.3 Spectrophotometric Determination of Phosphate in Natural Waters

Experiment 8 – Spectrophotometric Determination of Phosphate in Natural Waters

NOTE: Ensure all solutions are clearly labeled to avoid confusion.

Part 1: Preparation of stock 200 mg/L phosphate solution and subsequent series of standards

1. Calculate the required mass of KH_2PO_4 needed to prepare 1 L of 200.00 mg/L phosphate stock solution using distilled water.

Explain the purpose of preparing a large volume of phosphate stock solution. What is the benefit of preparation in this manner?

2. Using the prepared phosphate stock solution, prepare 100 mL of 20.00 mg/L working standard. From this working standard then prepare a series of phosphate standards ranging from 1.0 to 5.0 mg/L in distilled water. 100 mL of each standard should be sufficient.

Briefly discuss the importance of carefully prepared, accurate standards when constructing a calibration series:

3. Label all solutions with the correct concentration.
4. Prepare 100.00 mL of a control and waste-water samples by performing a 1 in 10 dilution of the provided solutions.
5. Consult the demonstrator before proceeding to Part 2.

Appendix III - Alternative Teaching Approaches Procedures
III.3.3 Spectrophotometric Determination of Phosphate in Natural Waters

Part 2: Colour development

1. Add 25.00 mL of the five standard solutions, and two sample solutions to the 7 suitable flasks.
2. To each flask add 1.00 mL of ammonium molybdate solution and swirl to mix.
3. Before adding the stannous chloride solution, ensure the analysis equipment is prepared and ready for use.

Briefly discuss the process occurring in the colour development. What is the role of the ammonium molybdate and stannous chloride?

4. Add to each flask 2 drops of stannous chloride solution and swirl gently to mix.
5. If phosphate is present, a blue colour will develop to a maximum after approximately 5 minutes.

Explain the errors that could occur with measurements being taken early/late:

6. Using the spectrophotometer available:
 - a. determine the wavelength of maximum
 - b. measure the absorbance of each sample and standard at this wavelength

If an absorbance is observed outside of the calibration series, what measures can be taken to fix this? Why is extrapolation not an option?

Appendix III - Alternative Teaching Approaches Procedures
III.3.3 Spectrophotometric Determination of Phosphate in Natural Waters

Report:

Within your report you should include the following sections:

- Abstract
- Introduction
- Method
- Discussion
- Conclusions

Within your discussion you should include the following:

- Write out the reactions involved in the formation of the above coloured molybdenum blue complex
- Identify those aspects of the above procedure which may have introduced some error into the final results
- Compare your results for each of the samples provided with those of two or more fellow students and comment on the degree of deviation obtained.

III.4 Third Year Chemistry

III.4.1 Palladium Cross-Coupling Experiment

Appendix III - Alternative Teaching Approaches Procedures

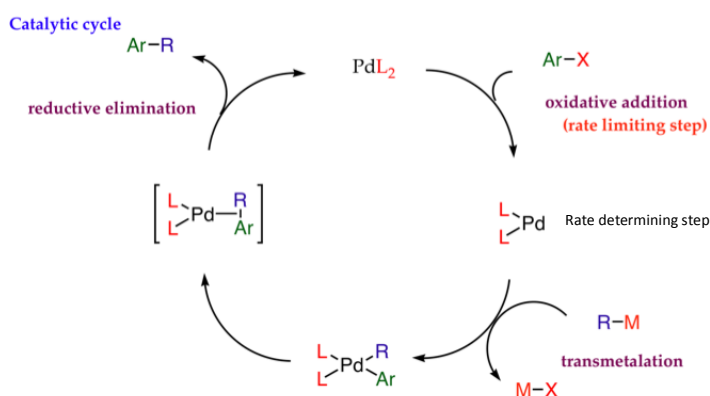
Palladium Cross Coupling Experiment

Concepts:

- Establish the order of reactivity of a variety of aryl halides including steric effects
- Investigate the formation of byproducts and account for these mechanistically
- Investigate the effects of electron donating/withdrawing substituents during the rate determining step, oxidative addition, as detailed below
- Analysis by GC-FID and using this information to estimate % yield formation of a target compound

Introduction:

Transition metal catalysed reactions have become increasingly important by facilitating processes that do not normally occur. Further into the lecture materials, palladium is discussed as a commonly used transition metal in catalysis and when present facilitates the reaction of an organometallic reagent with an electrophilic partner (for this experiment we are considering aryl halides only) to undergo cross coupling reactions.



The catalytic cycle above describes a general mechanism for cross-coupling reactions with different organometallic reagents, each corresponding to a well-known reaction. The variation that will be investigated in this experiment is the Suzuki – Miyaura cross-coupling reaction. The Suzuki – Miyaura reaction, in its simplest form, is commonly associated with the use of aryl

Appendix III - Alternative Teaching Approaches Procedures
Palladium Cross Coupling Experiment

halides and boronic acids in the formation of diaryl products. Within this catalytic cycle, the oxidative addition with the aryl halide is the rate-determining step. The type of substrate (electrophilic partner) used influences this process. Several substrate variables will be investigated to determine their effects including:

- The halide leaving group present in the aryl halide. Eg Cl, I, Br, etc
- The electronic effect of substituents on the aryl halide
- Any steric considerations that could influence product formation

This experiment will be completed in small groups with each student in that group investigating the reactivity of 2-3 different aryl halides. Prior to the laboratory, you should discuss with the other students who are completing the experiment, which aryl halides to analyse in order to produce a meaningful comparison. A meaningful comparison will require the analysis of 6-8 reactions across a broad range of aryl halides. Before beginning the experiment, justify your choices to the demonstrator. On completion of the laboratory work, results will be shared amongst the group to give further insight.

Appendix III - Alternative Teaching Approaches Procedures
Palladium Cross Coupling Experiment

First Week Procedure:

Before beginning the experiment, complete a table of predictions for the reactivity of the available aryl halides. Using the table, select appropriate aryl halides to enable a meaningful study.

Perform the reactions in the parallel reactor. For each reaction you are undertaking, add the following reagents to a reactor tube that has been flushed with N₂:

- 0.5 mmol of one chosen aryl halide
- 0.5 molar equivalents of *o*-nitrobiphenyl (added as an unreactive internal standard for GC analysis to avoid interference from homo-coupling)
- 1.05 molar equivalence of phenylboronic acid
- 4 mL of 1-propanol
- 5 mg of palladium(II) acetate
- 17 mg of triphenylphosphine
- 0.5 mL of 2 M sodium carbonate solution
- 1 mL of deionised water

Connect each reactor tube to the N₂ outlet system and thoroughly flush the tube with N₂. As an additional precaution, degas each reactor tube's contents with N₂. Run reactions at 80 °C for 60 minutes.

Whilst the reaction is occurring, draw a full catalytic cycle specific for **ONE** of your chosen aryl halides. Indicate the oxidation state of palladium in each step of the cycle.

How does the Pd source (palladium(II) acetate) relate to the active catalyst in this reaction?

What is the oxidation state of palladium in the active catalyst?

Appendix III - Alternative Teaching Approaches Procedures
Palladium Cross Coupling Experiment

After 60 minutes of reaction, quench the reactions and prepare a sample of each for GC analysis by the following procedure:

- Disassemble the reaction tube arrangement from the parallel reactor and cool in an ice bath
- Pipette approximately 1 mL from your cooled reaction mixture to a sample vial
- Add approximately 1 mL of ether to this reaction mixture. Stir the mixture well (add extra H₂O if two phases do not form)
- Allow the mixture to settle/separate and pipette the majority of the ether layer (avoid taking any aqueous layer) into a vial by filtering through a pipette of MgSO₄ to dry the solution
- Prepare a second GC vial containing equimolar amounts of the starting aryl halide, internal standard and product
- Submit appropriately labelled samples to the laboratory technician for GC analysis.

Appendix III - Alternative Teaching Approaches Procedures
Palladium Cross Coupling Experiment

Second Week Procedure:

From the results obtained during week 1, choose 1 example and carry a preparative reaction with 5 mmol of starting aryl halide.

Report:

This experiment is to be written as a short report and the focus of the report should be the chemistry concepts covered. The formalities of a full report are not required therefore the inclusion of an abstract, introduction, and conclusions is not necessary. A cover sheet, full procedure, references, and appendices are still required.

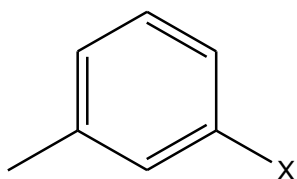
Within the discussion of results, the following areas should be covered:

- 1) A brief justification of your choices for aryl halides and what the comparison is aimed to show.
- 2) GC analysis with FID detection means that compounds with the same number of carbon atoms will give very similar peak areas. As such, the % yield of the target product formed can be estimated by comparison with the internal standard. Using the peak areas obtained from your analyses, estimate the %yield of target product.
- 3) It may be observed that while all of the starting materials have been consumed, the % yield of the target product is low. Discuss this possibility giving examples from your reactions and account for what products have formed instead. (Searching available literature may give assistance in discussing this point)

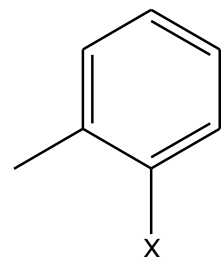
Appendix III - Alternative Teaching Approaches Procedures
Palladium Cross Coupling Experiment

4) During this experiment we have used aryl halides as the electrophilic partner. Give an example of a substrate that is not an aryl halide that would also be appropriate for a coupling reaction.

Available Compounds to test:

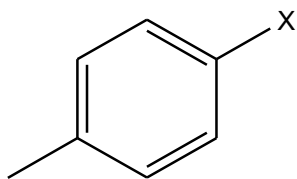


Xtoluene (X = Cl, Br, I)

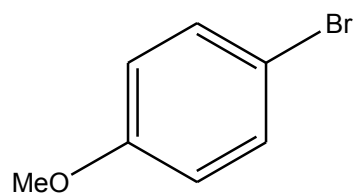


o-Xtoluene

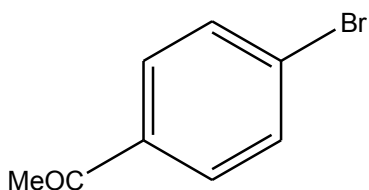
m-



p-Xtoluene



p-bromoanisole



p-bromoacetophenone

Appendix IV - Statistical Analysis Output

The data presented within this Appendix is the raw output provided by SPSS.

Key:

Variable 1.00 = Expository

Variable 2.00 = Guided Inquiry

Variable 3.00 = Problem Solving

Appendix III - Statistical Analysis Output
IV.1.1 The Analysis of a Solution by Measurement of its Density

IV.1 KRA001

IV.1.1 The Analysis of a Solution by Measurement of its Density

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	1.00	88	7.5057	1.48071	.15784	7.1919	7.8194	3.00	10.00
	2.00	43	7.6279	1.67649	.25566	7.1120	8.1439	4.00	10.00
	3.00	62	7.8790	1.59066	.20201	7.4751	8.2830	3.00	10.00
	Total	193	7.6528	1.56165	.11241	7.4311	7.8746	3.00	10.00
Q2	1.00	88	7.8864	1.65002	.17589	7.5368	8.2360	2.00	10.00
	2.00	42	7.8333	1.44689	.22326	7.3825	8.2842	4.00	10.00
	3.00	62	7.8065	1.80017	.22862	7.3493	8.2636	2.00	10.00
	Total	192	7.8490	1.65099	.11915	7.6139	8.0840	2.00	10.00
Q3	1.00	88	8.1875	1.30056	.13864	7.9119	8.4631	5.00	10.00
	2.00	42	7.7857	1.42342	.21964	7.3421	8.2293	4.00	10.00
	3.00	62	8.0806	1.56077	.19822	7.6843	8.4770	3.00	10.00
	Total	192	8.0651	1.41687	.10225	7.8634	8.2668	3.00	10.00
Q4	1.00	86	8.5349	1.37796	.14859	8.2394	8.8303	2.00	10.00
	2.00	42	8.3810	1.48081	.22849	7.9195	8.8424	3.00	10.00
	3.00	62	8.6774	1.39993	.17779	8.3219	9.0329	5.00	10.00
	Total	190	8.5474	1.40497	.10193	8.3463	8.7484	2.00	10.00
Q5	1.00	88	8.7045	1.40736	.15003	8.4064	9.0027	4.00	10.00
	2.00	43	8.2093	1.88425	.28735	7.6294	8.7892	3.00	10.00
	3.00	62	8.7581	1.27634	.16209	8.4339	9.0822	4.00	10.00
	Total	193	8.6114	1.49627	.10770	8.3990	8.8238	3.00	10.00
Q6	1.00	86	7.2849	1.85114	.19961	6.8880	7.6818	1.00	10.00
	2.00	41	7.6098	1.75895	.27470	7.0546	8.1649	3.00	10.00
	3.00	62	7.7742	1.85251	.23527	7.3037	8.2446	2.00	10.00
	Total	189	7.5159	1.83560	.13352	7.2525	7.7793	1.00	10.00
Q7	1.00	87	8.7241	1.26390	.13550	8.4548	8.9935	4.00	10.00
	2.00	42	8.4762	1.19426	.18428	8.1040	8.8483	6.00	10.00
	3.00	62	8.5968	1.53334	.19473	8.2074	8.9862	4.00	10.00
	Total	191	8.6283	1.33989	.09695	8.4370	8.8195	4.00	10.00
Q8	1.00	88	7.6477	1.71565	.18289	7.2842	8.0112	2.00	10.00
	2.00	42	8.0000	1.60791	.24811	7.4989	8.5011	4.00	10.00

Appendix III - Statistical Analysis Output

IV.1.1 The Analysis of a Solution by Measurement of its Density

	3.00	62	7.9516	1.87676	.23835	7.4750	8.4282	2.00	10.00
	Total	192	7.8229	1.74557	.12598	7.5744	8.0714	2.00	10.00
QTotal	1.00	87	8.0172	1.37977	.14793	7.7232	8.3113	3.00	10.00
	2.00	42	7.9524	1.32890	.20505	7.5383	8.3665	4.50	10.00
	3.00	62	8.0726	1.45941	.18535	7.7020	8.4432	3.00	10.00
	Total	191	8.0209	1.38871	.10048	7.8227	8.2191	3.00	10.00
C1	1.00	97	16.8866	2.37993	.24165	16.4069	17.3663	10.00	20.00
	2.00	72	14.8750	4.27221	.50348	13.8711	15.8789	4.00	20.00
	3.00	79	16.5570	3.02870	.34075	15.8786	17.2354	8.00	20.00
	Total	248	16.1976	3.32900	.21139	15.7812	16.6139	4.00	20.00
C2	1.00	97	31.1649	4.22956	.42945	30.3125	32.0174	20.00	40.00
	2.00	72	27.0417	5.24455	.61808	25.8093	28.2741	10.00	40.00
	3.00	79	29.6835	4.56448	.51354	28.6612	30.7059	19.00	40.00
	Total	248	29.4960	4.92946	.31302	28.8794	30.1125	10.00	40.00
C3	1.00	97	29.3814	4.61077	.46815	28.4522	30.3107	10.00	40.00
	2.00	72	26.1250	5.50528	.64880	24.8313	27.4187	10.00	40.00
	3.00	79	27.5570	4.60141	.51770	26.5263	28.5876	19.00	40.00
	Total	248	27.8548	5.04746	.32051	27.2235	28.4861	10.00	40.00
Grade	1.00	97	77.5258	8.94089	.90781	75.7238	79.3278	50.00	100.00
	2.00	80	69.0625	13.64778	1.52587	66.0253	72.0997	25.00	100.00
	3.00	93	74.6022	10.65684	1.10506	72.4074	76.7969	51.00	96.00
	Total	270	74.0111	11.57278	.70430	72.6245	75.3977	25.00	100.00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Q1	.539	2	190	.584
Q2	.262	2	189	.770
Q3	.100	2	189	.905
Q4	.127	2	187	.881
Q5	4.235	2	190	.016
Q6	.103	2	186	.902
Q7	1.523	2	188	.221
Q8	.320	2	189	.727
QTotal	.041	2	188	.960
C1	16.544	2	245	.000
C2	.847	2	245	.430
C3	1.370	2	245	.256
Grade	6.916	2	267	.001

Appendix III - Statistical Analysis Output
IV.1.1 The Analysis of a Solution by Measurement of its Density

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Q1	Between Groups	5.105	2	2.552	1.047	.353
	Within Groups	463.136	190	2.438		
	Total	468.241	192			
Q2	Between Groups	.245	2	.123	.045	.956
	Within Groups	520.374	189	2.753		
	Total	520.620	191			
Q3	Between Groups	4.612	2	2.306	1.150	.319
	Within Groups	378.824	189	2.004		
	Total	383.436	191			
Q4	Between Groups	2.225	2	1.113	.561	.572
	Within Groups	370.848	187	1.983		
	Total	373.074	189			
Q5	Between Groups	9.049	2	4.525	2.043	.132
	Within Groups	420.805	190	2.215		
	Total	429.855	192			
Q6	Between Groups	9.087	2	4.544	1.354	.261
	Within Groups	624.365	186	3.357		
	Total	633.452	188			
Q7	Between Groups	1.832	2	.916	.508	.603
	Within Groups	339.275	188	1.805		
	Total	341.107	190			
Q8	Between Groups	5.045	2	2.522	.826	.439
	Within Groups	576.934	189	3.053		
	Total	581.979	191			
QTotal	Between Groups	.364	2	.182	.093	.911
	Within Groups	366.052	188	1.947		
	Total	366.416	190			
C1	Between Groups	182.197	2	91.099	8.735	.000
	Within Groups	2555.121	245	10.429		
	Total	2737.319	247			
C2	Between Groups	706.672	2	353.336	16.348	.000
	Within Groups	5295.324	245	21.614		
	Total	6001.996	247			
C3	Between Groups	448.519	2	224.259	9.401	.000
	Within Groups	5844.255	245	23.854		
	Total	6292.774	247			
Grade	Between Groups	3189.814	2	1594.907	12.968	.000

Appendix III - Statistical Analysis Output
IV.1.1 The Analysis of a Solution by Measurement of its Density

Within Groups	32837.153	267	122.986		
Total	36026.967	269			

Multiple Comparisons

		(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Q1	Tukey HSD	1.00	2.00	-.12223	.29049	.907	-.8084	.5640
			3.00	-.37335	.25887	.321	-.9849	.2382
		2.00	1.00	.12223	.29049	.907	-.5640	.8084
			3.00	-.25113	.30984	.697	-.9830	.4808
		3.00	1.00	.37335	.25887	.321	-.2382	.9849
			2.00	.25113	.30984	.697	-.4808	.9830
	Games- Howell	1.00	2.00	-.12223	.30046	.913	-.8407	.5962
			3.00	-.37335	.25637	.316	-.9814	.2347
		2.00	1.00	.12223	.30046	.913	-.5962	.8407
			3.00	-.25113	.32584	.722	-1.0280	.5258
Q2	Tukey HSD	1.00	2.00	.05303	.31120	.984	-.6821	.7882
			3.00	.07991	.27513	.955	-.5700	.7299
		2.00	1.00	-.05303	.31120	.984	-.7882	.6821
			3.00	.02688	.33161	.996	-.7565	.8102
		3.00	1.00	-.07991	.27513	.955	-.7299	.5700
			2.00	-.02688	.33161	.996	-.8102	.7565
	Games- Howell	1.00	2.00	.05303	.28422	.981	-.6242	.7302
			3.00	.07991	.28845	.959	-.6044	.7642
		2.00	1.00	-.05303	.28422	.981	-.7302	.6242
			3.00	.02688	.31955	.996	-.7335	.7873
Q3	Tukey HSD	1.00	2.00	.40179	.26552	.287	-.2255	1.0290
			3.00	.10685	.23475	.892	-.4477	.6614
		2.00	1.00	-.40179	.26552	.287	-1.0290	.2255
			3.00	-.29493	.28293	.551	-.9633	.3735
		3.00	1.00	-.10685	.23475	.892	-.6614	.4477
			2.00	.29493	.28293	.551	-.3735	.9633
	Games-	1.00	2.00	.40179	.25974	.275	-.2193	1.0229

Appendix III - Statistical Analysis Output
IV.1.1 The Analysis of a Solution by Measurement of its Density

Q4	Howell		3.00	.10685	.24189	.898	-.4674	.6812
		2.00	1.00	-.40179	.25974	.275	-1.0229	.2193
			3.00	-.29493	.29586	.581	-.9996	.4097
		3.00	1.00	-.10685	.24189	.898	-.6812	.4674
			2.00	.29493	.29586	.581	-.4097	.9996
	Tukey HSD	1.00	2.00	.15393	.26510	.831	-.4724	.7802
			3.00	-.14254	.23462	.816	-.6968	.4118
		2.00	1.00	-.15393	.26510	.831	-.7802	.4724
			3.00	-.29647	.28143	.544	-.9614	.3684
		3.00	1.00	.14254	.23462	.816	-.4118	.6968
Q5	Games- Howell		2.00	.29647	.28143	.544	-.3684	.9614
		1.00	2.00	.15393	.27256	.839	-.4975	.8054
			3.00	-.14254	.23171	.812	-.6919	.4068
		2.00	1.00	-.15393	.27256	.839	-.8054	.4975
			3.00	-.29647	.28952	.564	-.9871	.3942
	Tukey HSD	3.00	1.00	.14254	.23171	.812	-.4068	.6919
			2.00	.29647	.28952	.564	-.3942	.9871
		1.00	2.00	.49524	.27690	.176	-.1589	1.1493
			3.00	-.05352	.24676	.974	-.6364	.5294
		2.00	1.00	-.49524	.27690	.176	-1.1493	.1589
Q6	Games- Howell		3.00	-.54876	.29534	.154	-1.2464	.1489
		3.00	1.00	.05352	.24676	.974	-.5294	.6364
			2.00	.54876	.29534	.154	-.1489	1.2464
		1.00	2.00	.49524	.32415	.285	-.2821	1.2726
			3.00	-.05352	.22087	.968	-.5768	.4697
	Tukey HSD	2.00	1.00	-.49524	.32415	.285	-1.2726	.2821
			3.00	-.54876	.32991	.227	-1.3392	.2417
		3.00	1.00	.05352	.22087	.968	-.4697	.5768
			2.00	.54876	.32991	.227	-.2417	1.3392
		1.00	2.00	-.32487	.34772	.619	-1.1464	.4966
Q6	Games- Howell		3.00	-.48931	.30525	.247	-1.2105	.2319
		2.00	1.00	.32487	.34772	.619	-.4966	1.1464
			3.00	-.16444	.36880	.896	-1.0358	.7069
		3.00	1.00	.48931	.30525	.247	-.2319	1.2105
			2.00	.16444	.36880	.896	-.7069	1.0358
	Tukey HSD	1.00	2.00	-.32487	.33957	.606	-1.1353	.4856
			3.00	-.48931	.30854	.255	-1.2207	.2421
		2.00	1.00	.32487	.33957	.606	-.4856	1.1353
			3.00	-.16444	.36168	.892	-1.0265	.6977
		3.00	1.00	.48931	.30854	.255	-.2421	1.2207
Q6	Games- Howell		2.00	.16444	.36168	.892	-.6977	1.0265
		1.00	2.00	-.32487	.33957	.606	-1.1353	.4856
			3.00	-.48931	.30854	.255	-1.2207	.2421
		2.00	1.00	.32487	.33957	.606	-.4856	1.1353
			3.00	-.16444	.36168	.892	-1.0265	.6977
	Tukey HSD	3.00	1.00	.48931	.30854	.255	-.2421	1.2207
			2.00	.16444	.36168	.892	-.6977	1.0265
		1.00	2.00	-.32487	.33957	.606	-1.1353	.4856
			3.00	-.48931	.30854	.255	-1.2207	.2421
		2.00	1.00	.32487	.33957	.606	-.4856	1.1353

Appendix III - Statistical Analysis Output

IV.1.1 The Analysis of a Solution by Measurement of its Density

Q7	Tukey HSD	1.00	2.00	.24795	.25241	.589	-.3484	.8442
			3.00	.12736	.22327	.836	-.4001	.6548
		2.00	1.00	-.24795	.25241	.589	-.8442	.3484
			3.00	-.12058	.26847	.895	-.7548	.5137
		3.00	1.00	-.12736	.22327	.836	-.6548	.4001
			2.00	.12058	.26847	.895	-.5137	.7548
	Games- Howell	1.00	2.00	.24795	.22873	.527	-.2976	.7935
			3.00	.12736	.23724	.853	-.4359	.6907
		2.00	1.00	-.24795	.22873	.527	-.7935	.2976
			3.00	-.12058	.26810	.895	-.7584	.5173
		3.00	1.00	-.12736	.23724	.853	-.6907	.4359
			2.00	.12058	.26810	.895	-.5173	.7584
Q8	Tukey HSD	1.00	2.00	-.35227	.32767	.531	-1.1263	.4218
			3.00	-.30389	.28969	.547	-.9882	.3805
		2.00	1.00	.35227	.32767	.531	-.4218	1.1263
			3.00	.04839	.34916	.989	-.7765	.8732
		3.00	1.00	.30389	.28969	.547	-.3805	.9882
			2.00	-.04839	.34916	.989	-.8732	.7765
	Games- Howell	1.00	2.00	-.35227	.30823	.491	-1.0874	.3829
			3.00	-.30389	.30043	.571	-1.0166	.4088
		2.00	1.00	.35227	.30823	.491	-.3829	1.0874
			3.00	.04839	.34404	.989	-.7706	.8674
		3.00	1.00	.30389	.30043	.571	-.4088	1.0166
			2.00	-.04839	.34404	.989	-.8674	.7706
QTotal	Tukey HSD	1.00	2.00	.06486	.26218	.967	-.5545	.6842
			3.00	-.05534	.23192	.969	-.6032	.4925
		2.00	1.00	-.06486	.26218	.967	-.6842	.5545
			3.00	-.12020	.27886	.903	-.7790	.5386
		3.00	1.00	.05534	.23192	.969	-.4925	.6032
			2.00	.12020	.27886	.903	-.5386	.7790
	Games- Howell	1.00	2.00	.06486	.25284	.964	-.5384	.6681
			3.00	-.05534	.23714	.970	-.6177	.5070
		2.00	1.00	-.06486	.25284	.964	-.6681	.5384
			3.00	-.12020	.27641	.901	-.7785	.5381
		3.00	1.00	.05534	.23714	.970	-.5070	.6177
			2.00	.12020	.27641	.901	-.5381	.7785
C1	Tukey HSD	1.00	2.00	2.01160*	.50236	.000	.8270	3.1962
			3.00	.32964	.48942	.779	-.8244	1.4837
		2.00	1.00	-2.01160*	.50236	.000	-3.1962	-.8270
			3.00	-1.68196*	.52618	.004	-2.9227	-.4412
		3.00	1.00	-.32964	.48942	.779	-1.4837	.8244

Appendix III - Statistical Analysis Output
IV.1.1 The Analysis of a Solution by Measurement of its Density

			2.00	1.68196 *	.52618	.004	.4412	2.9227
	Games- Howell	1.00	2.00	2.01160 *	.55847	.001	.6836	3.3396
			3.00	.32964	.41774	.710	-.6595	1.3188
		2.00	1.00	-2.01160 *	.55847	.001	-3.3396	-.6836
			3.00	-1.68196 *	.60796	.018	-3.1238	-.2402
		3.00	1.00	-.32964	.41774	.710	-1.3188	.6595
			2.00	1.68196 *	.60796	.018	.2402	3.1238
C2	Tukey HSD	1.00	2.00	4.12328 *	.72319	.000	2.4180	5.8286
			3.00	1.48140	.70456	.091	-.1800	3.1428
		2.00	1.00	-4.12328 *	.72319	.000	-5.8286	-2.4180
			3.00	-2.64188 *	.75748	.002	-4.4281	-.8557
		3.00	1.00	-1.48140	.70456	.091	-3.1428	.1800
			2.00	2.64188 *	.75748	.002	.8557	4.4281
	Games- Howell	1.00	2.00	4.12328 *	.75262	.000	2.3394	5.9072
			3.00	1.48140	.66944	.072	-.1022	3.0650
		2.00	1.00	-4.12328 *	.75262	.000	-5.9072	-2.3394
			3.00	-2.64188 *	.80358	.004	-4.5453	-.7385
		3.00	1.00	-1.48140	.66944	.072	-3.0650	.1022
			2.00	2.64188 *	.80358	.004	.7385	4.5453
C3	Tukey HSD	1.00	2.00	3.25644 *	.75975	.000	1.4649	5.0480
			3.00	1.82448 *	.74018	.038	.0791	3.5699
		2.00	1.00	-3.25644 *	.75975	.000	-5.0480	-1.4649
			3.00	-1.43196	.79577	.172	-3.3084	.4445
		3.00	1.00	-1.82448 *	.74018	.038	-3.5699	-.0791
			2.00	1.43196	.79577	.172	-.4445	3.3084
	Games- Howell	1.00	2.00	3.25644 *	.80007	.000	1.3607	5.1522
			3.00	1.82448 *	.69798	.026	.1739	3.4751
		2.00	1.00	-3.25644 *	.80007	.000	-5.1522	-1.3607
			3.00	-1.43196	.83004	.199	-3.3984	.5345
		3.00	1.00	-1.82448 *	.69798	.026	-3.4751	-.1739
			2.00	1.43196	.83004	.199	-.5345	3.3984
Grade	Tukey HSD	1.00	2.00	8.46327 *	1.67488	.000	4.5158	12.4107
			3.00	2.92362	1.60945	.166	-.8696	6.7169
		2.00	1.00	-8.46327 *	1.67488	.000	-12.4107	-4.5158
			3.00	-5.53965 *	1.69108	.003	-9.5253	-1.5540
		3.00	1.00	-2.92362	1.60945	.166	-6.7169	.8696
			2.00	5.53965 *	1.69108	.003	1.5540	9.5253
	Games- Howell	1.00	2.00	8.46327 *	1.77550	.000	4.2543	12.6723
			3.00	2.92362	1.43013	.105	-.4562	6.3035
		2.00	1.00	-8.46327 *	1.77550	.000	-12.6723	-4.2543

Appendix III - Statistical Analysis Output

IV.1.1 The Analysis of a Solution by Measurement of its Density

	3.00	-5.53965 *	1.88400	.011	-9.9999	-1.0794
3.00	1.00	-2.92362	1.43013	.105	-6.3035	.4562
	2.00	5.53965 *	1.88400	.011	1.0794	9.9999

*. The mean difference is significant at the 0.05 level.

Appendix III - Statistical Analysis Output
IV.1.2 Distillation as a Separation Technique

IV.1.2 Distillation as a Separation Technique

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	1.00	76	8.2237	1.65408	.18974	7.8457	8.6017	2.00	10.00
	2.00	46	8.2391	1.50827	.22238	7.7912	8.6870	3.00	10.00
	3.00	75	8.0800	1.44035	.16632	7.7486	8.4114	5.00	10.00
	Total	197	8.1726	1.53552	.10940	7.9568	8.3883	2.00	10.00
Q2	1.00	76	8.1579	1.72087	.19740	7.7647	8.5511	3.00	10.00
	2.00	46	8.4239	1.41409	.20850	8.0040	8.8438	5.00	10.00
	3.00	75	8.1600	1.49811	.17299	7.8153	8.5047	4.00	10.00
	Total	197	8.2208	1.56597	.11157	8.0008	8.4408	3.00	10.00
Q3	1.00	76	8.3026	1.65747	.19012	7.9239	8.6814	3.00	10.00
	2.00	46	8.5543	1.36719	.20158	8.1483	8.9604	5.00	10.00
	3.00	75	8.7333	1.18929	.13733	8.4597	9.0070	5.00	10.00
	Total	197	8.5254	1.43191	.10202	8.3242	8.7266	3.00	10.00
Q4	1.00	76	8.7368	1.58635	.18197	8.3743	9.0993	2.00	10.00
	2.00	45	8.9333	1.21356	.18091	8.5687	9.2979	5.00	10.00
	3.00	74	8.7230	1.28517	.14940	8.4252	9.0207	5.00	10.00
	Total	195	8.7769	1.39133	.09964	8.5804	8.9734	2.00	10.00
Q5	1.00	75	8.8267	1.29837	.14992	8.5279	9.1254	3.00	10.00
	2.00	46	8.8913	1.52357	.22464	8.4389	9.3437	3.00	10.00
	3.00	75	9.2467	1.05065	.12132	9.0049	9.4884	7.00	10.00
	Total	196	9.0026	1.27752	.09125	8.8226	9.1825	3.00	10.00
Q6	1.00	76	8.3158	1.77547	.20366	7.9101	8.7215	2.00	10.00
	2.00	45	8.3333	1.36515	.20350	7.9232	8.7435	5.00	10.00
	3.00	74	8.3581	1.57793	.18343	7.9925	8.7237	3.00	10.00
	Total	195	8.3359	1.60580	.11499	8.1091	8.5627	2.00	10.00
Q7	1.00	76	8.9868	1.11347	.12772	8.7324	9.2413	5.00	10.00
	2.00	45	8.9333	.98627	.14702	8.6370	9.2296	7.00	10.00
	3.00	74	8.8514	1.37175	.15946	8.5335	9.1692	2.00	10.00
	Total	195	8.9231	1.18810	.08508	8.7553	9.0909	2.00	10.00
Q8	1.00	76	8.5461	1.61075	.18477	8.1780	8.9141	1.00	10.00
	2.00	45	8.5556	1.54560	.23040	8.0912	9.0199	4.00	10.00
	3.00	73	8.5068	1.52865	.17891	8.1502	8.8635	4.00	10.00
	Total	194	8.5335	1.55725	.11180	8.3130	8.7540	1.00	10.00

Appendix III - Statistical Analysis Output
IV.1.2 Distillation as a Separation Technique

QTotal	1.00	73	8.6164	1.16226	.13603	8.3453	8.8876	6.00	10.00
	2.00	45	8.6111	1.24722	.18592	8.2364	8.9858	5.00	10.00
	3.00	73	8.7055	1.02685	.12018	8.4659	8.9451	6.00	10.00
	Total	191	8.6492	1.12857	.08166	8.4881	8.8103	5.00	10.00
C1	1.00	96	16.7708	2.85613	.29150	16.1921	17.3495	10.00	20.00
	2.00	69	17.0870	2.71022	.32627	16.4359	17.7380	8.00	20.00
	3.00	78	18.3077	1.99550	.22595	17.8578	18.7576	10.00	20.00
	Total	243	17.3539	2.64228	.16950	17.0200	17.6878	8.00	20.00
C2	1.00	96	31.0938	4.95257	.50547	30.0903	32.0972	15.00	40.00
	2.00	69	29.5652	3.61565	.43527	28.6966	30.4338	20.00	36.00
	3.00	78	33.1282	3.64445	.41265	32.3065	33.9499	25.00	40.00
	Total	243	31.3128	4.41365	.28314	30.7550	31.8705	15.00	40.00
C3	1.00	96	29.4479	4.62685	.47223	28.5104	30.3854	15.00	39.00
	2.00	69	27.8696	4.53390	.54582	26.7804	28.9587	16.00	38.00
	3.00	78	30.8974	4.86597	.55096	29.8003	31.9945	15.00	40.00
	Total	243	29.4650	4.80635	.30833	28.8577	30.0724	15.00	40.00
Grade	1.00	97	77.4742	10.69179	1.08559	75.3194	79.6291	40.00	98.00
	2.00	77	75.2987	9.18675	1.04693	73.2136	77.3838	48.00	94.00
	3.00	94	81.9362	9.08716	.93727	80.0749	83.7974	50.00	98.00
	Total	268	78.4142	10.06850	.61503	77.2033	79.6251	40.00	98.00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Q1	.341	2	194	.712
Q2	1.148	2	194	.319
Q3	4.648	2	194	.011
Q4	.988	2	192	.374
Q5	1.262	2	193	.285
Q6	1.130	2	192	.325
Q7	.428	2	192	.653
Q8	.200	2	191	.819
QTotal	.664	2	188	.516
C1	9.503	2	240	.000
C2	5.982	2	240	.003
C3	.031	2	240	.969
Grade	.733	2	265	.481

Appendix III - Statistical Analysis Output
IV.1.2 Distillation as a Separation Technique

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Q1	Between Groups	1.045	2	.523	.220	.803
	Within Groups	461.087	194	2.377		
	Total	462.132	196			
Q2	Between Groups	2.476	2	1.238	.502	.606
	Within Groups	478.169	194	2.465		
	Total	480.645	196			
Q3	Between Groups	7.053	2	3.526	1.733	.180
	Within Groups	394.820	194	2.035		
	Total	401.873	196			
Q4	Between Groups	1.438	2	.719	.369	.692
	Within Groups	374.108	192	1.948		
	Total	375.546	194			
Q5	Between Groups	7.359	2	3.679	2.284	.105
	Within Groups	310.890	193	1.611		
	Total	318.249	195			
Q6	Between Groups	.068	2	.034	.013	.987
	Within Groups	500.181	192	2.605		
	Total	500.249	194			
Q7	Between Groups	.694	2	.347	.244	.784
	Within Groups	273.152	192	1.423		
	Total	273.846	194			
Q8	Between Groups	.086	2	.043	.017	.983
	Within Groups	467.947	191	2.450		
	Total	468.032	193			
QTotal	Between Groups	.375	2	.187	.146	.864
	Within Groups	241.623	188	1.285		
	Total	241.997	190			
C1	Between Groups	108.512	2	54.256	8.236	.000
	Within Groups	1581.052	240	6.588		
	Total	1689.564	242			
C2	Between Groups	472.400	2	236.200	13.364	.000
	Within Groups	4241.831	240	17.674		
	Total	4714.230	242			
C3	Between Groups	335.708	2	167.854	7.666	.001
	Within Groups	5254.745	240	21.895		
	Total	5590.453	242			

Appendix III - Statistical Analysis Output
IV.1.2 Distillation as a Separation Technique

Grade	Between Groups	1999.094	2	999.547	10.566	.000
	Within Groups	25067.932	265	94.596		
	Total	27067.026	267			

Multiple Comparisons

		(I) (J)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Q1	Tukey HSD	1.00	2.00	-.01545	.28799	.998	-.6956	.6648
			3.00	.14368	.25092	.835	-.4490	.7363
		2.00	1.00	.01545	.28799	.998	-.6648	.6956
			3.00	.15913	.28872	.846	-.5228	.8410
		3.00	1.00	-.14368	.25092	.835	-.7363	.4490
			2.00	-.15913	.28872	.846	-.8410	.5228
	Games- Howell	1.00	2.00	-.01545	.29232	.998	-.7107	.6798
			3.00	.14368	.25231	.837	-.4537	.7411
		2.00	1.00	.01545	.29232	.998	-.6798	.7107
			3.00	.15913	.27770	.835	-.5024	.8207
		3.00	1.00	-.14368	.25231	.837	-.7411	.4537
			2.00	-.15913	.27770	.835	-.8207	.5024
Q2	Tukey HSD	1.00	2.00	-.26602	.29328	.637	-.9587	.4267
			3.00	-.00211	.25553	1.000	-.6056	.6014
		2.00	1.00	.26602	.29328	.637	-.4267	.9587
			3.00	.26391	.29402	.642	-.4305	.9583
		3.00	1.00	.00211	.25553	1.000	-.6014	.6056
			2.00	-.26391	.29402	.642	-.9583	.4305
	Games- Howell	1.00	2.00	-.26602	.28712	.625	-.9482	.4162
			3.00	-.00211	.26247	1.000	-.6236	.6194
		2.00	1.00	.26602	.28712	.625	-.4162	.9482
			3.00	.26391	.27091	.595	-.3807	.9085
		3.00	1.00	.00211	.26247	1.000	-.6194	.6236
			2.00	-.26391	.27091	.595	-.9085	.3807
Q3	Tukey HSD	1.00	2.00	-.25172	.26650	.613	-.8811	.3777
			3.00	-.43070	.23219	.155	-.9791	.1177
		2.00	1.00	.25172	.26650	.613	-.3777	.8811
			3.00	-.17899	.26717	.781	-.8100	.4520
		3.00	1.00	.43070	.23219	.155	-.1177	.9791
			2.00	.17899	.26717	.781	-.4520	.8100

Appendix III - Statistical Analysis Output
IV.1.2 Distillation as a Separation Technique

	Games- Howell	1.00	2.00	-.25172	.27710	.636	-.9101	.4067
			3.00	-.43070	.23453	.162	-.9865	.1251
		2.00	1.00	.25172	.27710	.636	-.4067	.9101
			3.00	-.17899	.24391	.744	-.7608	.4028
		3.00	1.00	.43070	.23453	.162	-.1251	.9865
			2.00	.17899	.24391	.744	-.4028	.7608
		1.00	2.00	-.19649	.26256	.735	-.8167	.4237
			3.00	.01387	.22797	.998	-.5246	.5523
		2.00	1.00	.19649	.26256	.735	-.4237	.8167
			3.00	.21036	.26388	.705	-.4129	.8336
Q4	Tukey HSD	3.00	1.00	-.01387	.22797	.998	-.5523	.5246
			2.00	-.21036	.26388	.705	-.8336	.4129
		1.00	2.00	-.19649	.25659	.725	-.8060	.4130
			3.00	.01387	.23544	.998	-.5437	.5715
		2.00	1.00	.19649	.25659	.725	-.4130	.8060
			3.00	.21036	.23462	.644	-.3481	.7688
		3.00	1.00	-.01387	.23544	.998	-.5715	.5437
			2.00	-.21036	.23462	.644	-.7688	.3481
		1.00	2.00	-.06464	.23769	.960	-.6260	.4968
			3.00	-.42000	.20726	.109	-.9095	.0695
Q5	Tukey HSD	2.00	1.00	.06464	.23769	.960	-.4968	.6260
			3.00	-.35536	.23769	.296	-.9168	.2060
		3.00	1.00	.42000	.20726	.109	-.0695	.9095
			2.00	.35536	.23769	.296	-.2060	.9168
		1.00	2.00	-.06464	.27007	.969	-.7090	.5798
			3.00	-.42000	.19286	.079	-.8768	.0368
		2.00	1.00	.06464	.27007	.969	-.5798	.7090
			3.00	-.35536	.25530	.351	-.9664	.2557
		3.00	1.00	.42000	.19286	.079	-.0368	.8768
			2.00	.35536	.25530	.351	-.2557	.9664
Q6	Tukey HSD	1.00	2.00	-.01754	.30359	.998	-.7346	.6996
			3.00	-.04232	.26359	.986	-.6649	.5803
		2.00	1.00	.01754	.30359	.998	-.6996	.7346
			3.00	-.02477	.30512	.996	-.7455	.6959
		3.00	1.00	.04232	.26359	.986	-.5803	.6649
			2.00	.02477	.30512	.996	-.6959	.7455
		1.00	2.00	-.01754	.28791	.998	-.7015	.6664
			3.00	-.04232	.27409	.987	-.6913	.6066
		2.00	1.00	.01754	.28791	.998	-.6664	.7015
			3.00	-.02477	.27397	.996	-.6763	.6267
		3.00	1.00	.04232	.27409	.987	-.6066	.6913

Appendix III - Statistical Analysis Output
IV.1.2 Distillation as a Separation Technique

			2.00	.02477	.27397	.996	-.6267	.6763
Q7	Tukey HSD	1.00	2.00	.05351	.22435	.969	-.4764	.5834
			3.00	.13549	.19479	.766	-.3246	.5956
		2.00	1.00	-.05351	.22435	.969	-.5834	.4764
			3.00	.08198	.22548	.930	-.4506	.6146
		3.00	1.00	-.13549	.19479	.766	-.5956	.3246
			2.00	-.08198	.22548	.930	-.6146	.4506
	Games- Howell	1.00	2.00	.05351	.19476	.959	-.4097	.5167
			3.00	.13549	.20431	.785	-.3485	.6195
		2.00	1.00	-.05351	.19476	.959	-.5167	.4097
			3.00	.08198	.21690	.924	-.4331	.5971
		3.00	1.00	-.13549	.20431	.785	-.6195	.3485
			2.00	-.08198	.21690	.924	-.5971	.4331
Q8	Tukey HSD	1.00	2.00	-.00950	.29442	.999	-.7050	.6859
			3.00	.03920	.25651	.987	-.5667	.6451
		2.00	1.00	.00950	.29442	.999	-.6859	.7050
			3.00	.04871	.29666	.985	-.6520	.7494
		3.00	1.00	-.03920	.25651	.987	-.6451	.5667
			2.00	-.04871	.29666	.985	-.7494	.6520
	Games- Howell	1.00	2.00	-.00950	.29534	.999	-.7126	.6936
			3.00	.03920	.25719	.987	-.5698	.6482
		2.00	1.00	.00950	.29534	.999	-.6936	.7126
			3.00	.04871	.29171	.985	-.6462	.7436
		3.00	1.00	-.03920	.25719	.987	-.6482	.5698
			2.00	-.04871	.29171	.985	-.7436	.6462
QTotal	Tukey HSD	1.00	2.00	.00533	.21486	1.000	-.5023	.5129
			3.00	-.08904	.18765	.883	-.5323	.3543
		2.00	1.00	-.00533	.21486	1.000	-.5129	.5023
			3.00	-.09437	.21486	.899	-.6020	.4132
		3.00	1.00	.08904	.18765	.883	-.3543	.5323
			2.00	.09437	.21486	.899	-.4132	.6020
	Games- Howell	1.00	2.00	.00533	.23037	1.000	-.5439	.5545
			3.00	-.08904	.18152	.876	-.5190	.3409
		2.00	1.00	-.00533	.23037	1.000	-.5545	.5439
			3.00	-.09437	.22139	.905	-.6231	.4343
		3.00	1.00	.08904	.18152	.876	-.3409	.5190
			2.00	.09437	.22139	.905	-.4343	.6231
C1	Tukey HSD	1.00	2.00	-.31612	.40509	.715	-1.2715	.6392
			3.00	-1.53686*	.39125	.000	-2.4596	-.6141
		2.00	1.00	.31612	.40509	.715	-.6392	1.2715
			3.00	-1.22074*	.42418	.012	-2.2211	-.2204

Appendix III - Statistical Analysis Output
IV.1.2 Distillation as a Separation Technique

		3.00	1.00	1.53686*	.39125	.000	.6141	2.4596
			2.00	1.22074*	.42418	.012	.2204	2.2211
	Games- Howell	1.00	2.00	-.31612	.43752	.751	-1.3518	.7195
			3.00	-1.53686*	.36882	.000	-2.4090	-.6648
		2.00	1.00	.31612	.43752	.751	-.7195	1.3518
			3.00	-1.22074*	.39687	.007	-2.1622	-.2793
		3.00	1.00	1.53686*	.36882	.000	.6648	2.4090
			2.00	1.22074*	.39687	.007	.2793	2.1622
C2	Tukey HSD	1.00	2.00	1.52853	.66352	.057	-.0363	3.0933
			3.00	-2.03446*	.64086	.005	-3.5458	-.5231
		2.00	1.00	-1.52853	.66352	.057	-3.0933	.0363
			3.00	-3.56299*	.69480	.000	-5.2016	-1.9244
		3.00	1.00	2.03446*	.64086	.005	.5231	3.5458
			2.00	3.56299*	.69480	.000	1.9244	5.2016
	Games- Howell	1.00	2.00	1.52853	.66705	.060	-.0493	3.1063
			3.00	-2.03446*	.65252	.006	-3.5773	-.4917
		2.00	1.00	-1.52853	.66705	.060	-3.1063	.0493
			3.00	-3.56299*	.59979	.000	-4.9835	-2.1425
		3.00	1.00	2.03446*	.65252	.006	.4917	3.5773
			2.00	3.56299*	.59979	.000	2.1425	4.9835
C3	Tukey HSD	1.00	2.00	1.57835	.73850	.085	-.1633	3.3200
			3.00	-1.44952	.71328	.107	-3.1317	.2327
		2.00	1.00	-1.57835	.73850	.085	-3.3200	.1633
			3.00	-3.02787*	.77332	.000	-4.8516	-1.2041
		3.00	1.00	1.44952	.71328	.107	-.2327	3.1317
			2.00	3.02787*	.77332	.000	1.2041	4.8516
	Games- Howell	1.00	2.00	1.57835	.72174	.077	-.1304	3.2871
			3.00	-1.44952	.72564	.116	-3.1661	.2670
		2.00	1.00	-1.57835	.72174	.077	-3.2871	.1304
			3.00	-3.02787*	.77555	.000	-4.8644	-1.1913
		3.00	1.00	1.44952	.72564	.116	-.2670	3.1661
			2.00	3.02787*	.77555	.000	1.1913	4.8644
Grade	Tukey HSD	1.00	2.00	2.17553	1.48450	.309	-1.3234	5.6744
			3.00	-4.46194*	1.40768	.005	-7.7798	-1.1441
		2.00	1.00	-2.17553	1.48450	.309	-5.6744	1.3234
			3.00	-6.63747*	1.49494	.000	-10.1610	-3.1139
		3.00	1.00	4.46194*	1.40768	.005	1.1441	7.7798
			2.00	6.63747*	1.49494	.000	3.1139	10.1610
	Games- Howell	1.00	2.00	2.17553	1.50816	.322	-1.3902	5.7413
			3.00	-4.46194*	1.43422	.006	-7.8505	-1.0734

Appendix III - Statistical Analysis Output
IV.1.2 Distillation as a Separation Technique

2.00	1.00	-2.17553	1.50816	.322	-5.7413	1.3902
	3.00	-6.63747 *	1.40518	.000	-9.9614	-3.3135
3.00	1.00	4.46194 *	1.43422	.006	1.0734	7.8505
	2.00	6.63747 *	1.40518	.000	3.3135	9.9614

*. The mean difference is significant at the 0.05 level.

Appendix III - Statistical Analysis Output
IV.1.3 Identification of a Carboxylic Acid

IV.1.3 Identification of a Carboxylic Acid

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	1.00	74	7.7838	1.79245	.20837	7.3685	8.1991	1.00	10.00
	2.00	30	7.4333	1.61210	.29433	6.8314	8.0353	4.00	10.00
	3.00	40	7.9250	1.57525	.24907	7.4212	8.4288	3.00	10.00
	Total	144	7.7500	1.69532	.14128	7.4707	8.0293	1.00	10.00
Q2	1.00	74	7.4459	2.16537	.25172	6.9443	7.9476	1.00	10.00
	2.00	30	7.2667	1.50707	.27515	6.7039	7.8294	5.00	10.00
	3.00	40	7.7000	2.12675	.33627	7.0198	8.3802	1.00	10.00
	Total	144	7.4792	2.02767	.16897	7.1452	7.8132	1.00	10.00
Q3	1.00	73	7.5890	1.89176	.22141	7.1477	8.0304	1.00	10.00
	2.00	30	7.4000	1.71404	.31294	6.7600	8.0400	3.00	10.00
	3.00	40	8.0000	1.35873	.21483	7.5655	8.4345	5.00	10.00
	Total	143	7.6643	1.72367	.14414	7.3794	7.9493	1.00	10.00
Q4	1.00	73	8.2877	1.57656	.18452	7.9198	8.6555	1.00	10.00
	2.00	29	8.0345	1.29512	.24050	7.5418	8.5271	5.00	10.00
	3.00	40	8.0500	1.83904	.29078	7.4618	8.6382	4.00	10.00
	Total	142	8.1690	1.59775	.13408	7.9039	8.4341	1.00	10.00
Q5	1.00	74	8.2095	1.47120	.17102	7.8686	8.5503	3.00	10.00
	2.00	30	7.7000	1.84110	.33614	7.0125	8.3875	4.00	10.00
	3.00	39	8.5128	1.63630	.26202	7.9824	9.0432	3.00	10.00
	Total	143	8.1853	1.61276	.13487	7.9187	8.4519	3.00	10.00
Q6	1.00	74	8.0270	1.80352	.20965	7.6092	8.4449	1.00	10.00
	2.00	29	7.8276	1.25553	.23315	7.3500	8.3052	5.00	10.00
	3.00	40	7.6500	2.00704	.31734	7.0081	8.2919	1.00	10.00
	Total	143	7.8811	1.76523	.14762	7.5893	8.1729	1.00	10.00
Q7	1.00	74	8.7297	1.27190	.14786	8.4351	9.0244	5.00	10.00
	2.00	29	8.4483	1.27016	.23586	7.9651	8.9314	6.00	10.00
	3.00	40	8.4000	1.49872	.23697	7.9207	8.8793	4.00	10.00
	Total	143	8.5804	1.33829	.11191	8.3592	8.8017	4.00	10.00
Q8	1.00	74	8.0068	1.81790	.21133	7.5856	8.4279	1.00	10.00
	2.00	30	7.8667	1.35782	.24790	7.3596	8.3737	5.00	10.00
	3.00	40	8.0000	1.85362	.29308	7.4072	8.5928	1.00	10.00
	Total	144	7.9757	1.73238	.14437	7.6903	8.2611	1.00	10.00

Appendix III - Statistical Analysis Output

IV.1.3 Identification of a Carboxylic Acid

QTotal	1.00	71	8.0563	1.58238	.18779	7.6818	8.4309	3.00	10.00
	2.00	30	7.6833	1.11791	.20410	7.2659	8.1008	6.00	10.00
	3.00	40	8.0750	1.45686	.23035	7.6091	8.5409	2.00	10.00
	Total	141	7.9823	1.45824	.12281	7.7395	8.2251	2.00	10.00
C1	1.00	95	15.8947	3.56243	.36550	15.1690	16.6204	5.00	20.00
	2.00	68	15.5882	3.71859	.45095	14.6881	16.4883	7.00	20.00
	3.00	85	17.3412	2.67952	.29063	16.7632	17.9191	10.00	20.00
	Total	248	16.3065	3.40559	.21625	15.8805	16.7324	5.00	20.00
C2	1.00	95	29.9053	4.71997	.48426	28.9438	30.8668	12.00	38.00
	2.00	68	28.2647	4.65406	.56439	27.1382	29.3912	15.00	36.00
	3.00	85	30.5176	4.18504	.45393	29.6150	31.4203	22.00	40.00
	Total	248	29.6653	4.59591	.29184	29.0905	30.2401	12.00	40.00
C3	1.00	95	29.0316	4.36000	.44733	28.1434	29.9198	16.00	38.00
	2.00	68	27.9853	4.91872	.59648	26.7947	29.1759	15.00	37.00
	3.00	85	29.7647	3.76275	.40813	28.9531	30.5763	22.00	40.00
	Total	248	28.9960	4.37003	.27750	28.4494	29.5425	15.00	40.00
Grade	1.00	95	74.7263	11.01589	1.13021	72.4823	76.9704	36.00	96.00
	2.00	76	72.6053	11.77690	1.35090	69.9141	75.2964	37.00	92.00
	3.00	87	77.7701	8.86685	.95063	75.8803	79.6599	54.00	100.00
	Total	258	75.1279	10.74588	.66901	73.8105	76.4453	36.00	100.00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Q1	.873	2	141	.420
Q2	1.213	2	141	.300
Q3	2.593	2	140	.078
Q4	3.106	2	139	.048
Q5	.828	2	140	.439
Q6	2.342	2	140	.100
Q7	.324	2	140	.724
Q8	.859	2	141	.426
QTotal	1.752	2	138	.177
C1	4.451	2	245	.013
C2	.293	2	245	.746
C3	2.681	2	245	.071
Grade	2.817	2	255	.062

Appendix III - Statistical Analysis Output
IV.1.3 Identification of a Carboxylic Acid

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Q1	Between Groups	4.318	2	2.159	.749	.475
	Within Groups	406.682	141	2.884		
	Total	411.000	143			
Q2	Between Groups	3.387	2	1.694	.408	.665
	Within Groups	584.550	141	4.146		
	Total	587.938	143			
Q3	Between Groups	7.017	2	3.508	1.184	.309
	Within Groups	414.871	140	2.963		
	Total	421.888	142			
Q4	Between Groups	2.119	2	1.060	.412	.663
	Within Groups	357.824	139	2.574		
	Total	359.944	141			
Q5	Between Groups	11.292	2	5.646	2.208	.114
	Within Groups	358.047	140	2.557		
	Total	369.339	142			
Q6	Between Groups	3.795	2	1.898	.606	.547
	Within Groups	438.684	140	3.133		
	Total	442.479	142			
Q7	Between Groups	3.458	2	1.729	.965	.384
	Within Groups	250.867	140	1.792		
	Total	254.325	142			
Q8	Between Groups	.452	2	.226	.074	.928
	Within Groups	428.713	141	3.041		
	Total	429.165	143			
QTotal	Between Groups	3.414	2	1.707	.801	.451
	Within Groups	294.291	138	2.133		
	Total	297.706	140			
C1	Between Groups	142.186	2	71.093	6.398	.002
	Within Groups	2722.524	245	11.112		
	Total	2864.710	247			
C2	Between Groups	200.616	2	100.308	4.899	.008
	Within Groups	5016.606	245	20.476		
	Total	5217.222	247			
C3	Between Groups	119.811	2	59.906	3.193	.043
	Within Groups	4597.185	245	18.764		
	Total	4716.996	247			

Appendix III - Statistical Analysis Output
IV.1.3 Identification of a Carboxylic Acid

Grade	Between Groups	1106.335	2	553.167	4.937	.008
	Within Groups	28570.444	255	112.041		
	Total	29676.779	257			

Multiple Comparisons

		(I) (J)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Q1	Tukey HSD	1.00	2.00	.35045	.36759	.608	-.5203	1.2212
			3.00	-.14122	.33329	.906	-.9307	.6483
		2.00	1.00	-.35045	.36759	.608	-1.2212	.5203
			3.00	-.49167	.41018	.456	-1.4633	.4799
		3.00	1.00	.14122	.33329	.906	-.6483	.9307
			2.00	.49167	.41018	.456	-.4799	1.4633
	Games-Howell	1.00	2.00	.35045	.36062	.597	-.5164	1.2173
			3.00	-.14122	.32473	.901	-.9152	.6328
		2.00	1.00	-.35045	.36062	.597	-1.2173	.5164
			3.00	-.49167	.38557	.414	-1.4176	.4342
		3.00	1.00	.14122	.32473	.901	-.6328	.9152
			2.00	.49167	.38557	.414	-.4342	1.4176
Q2	Tukey HSD	1.00	2.00	.17928	.44070	.913	-.8646	1.2232
			3.00	-.25405	.39958	.801	-1.2006	.6924
		2.00	1.00	-.17928	.44070	.913	-1.2232	.8646
			3.00	-.43333	.49177	.653	-1.5982	.7315
		3.00	1.00	.25405	.39958	.801	-.6924	1.2006
			2.00	.43333	.49177	.653	-.7315	1.5982
	Games-Howell	1.00	2.00	.17928	.37292	.881	-.7121	1.0706
			3.00	-.25405	.42005	.818	-1.2569	.7488
		2.00	1.00	-.17928	.37292	.881	-1.0706	.7121
			3.00	-.43333	.43449	.581	-1.4745	.6078
		3.00	1.00	.25405	.42005	.818	-.7488	1.2569
			2.00	.43333	.43449	.581	-.6078	1.4745
Q3	Tukey HSD	1.00	2.00	.18904	.37333	.868	-.6953	1.0734
			3.00	-.41096	.33864	.447	-1.2132	.3913
		2.00	1.00	-.18904	.37333	.868	-1.0734	.6953
			3.00	-.60000	.41577	.322	-1.5849	.3849
		3.00	1.00	.41096	.33864	.447	-.3913	1.2132
			2.00	.60000	.41577	.322	-.3849	1.5849

Appendix III - Statistical Analysis Output
IV.1.3 Identification of a Carboxylic Acid

	Games- Howell	1.00	2.00	.18904	.38335	.875	-.7325	1.1106
			3.00	-.41096	.30851	.381	-1.1446	.3227
		2.00	1.00	-.18904	.38335	.875	-1.1106	.7325
			3.00	-.60000	.37959	.263	-1.5149	.3149
		3.00	1.00	.41096	.30851	.381	-.3227	1.1446
			2.00	.60000	.37959	.263	-.3149	1.5149
		1.00	2.00	.25319	.35218	.753	-.5812	1.0875
			3.00	.23767	.31563	.732	-.5101	.9854
		2.00	1.00	-.25319	.35218	.753	-1.0875	.5812
			3.00	-.01552	.39131	.999	-.9426	.9115
Q4	Tukey HSD	3.00	1.00	-.23767	.31563	.732	-.9854	.5101
			2.00	.01552	.39131	.999	-.9115	.9426
		1.00	2.00	.25319	.30313	.683	-.4746	.9810
			3.00	.23767	.34438	.770	-.5868	1.0622
		2.00	1.00	-.25319	.30313	.683	-.9810	.4746
			3.00	-.01552	.37735	.999	-.9200	.8889
		3.00	1.00	-.23767	.34438	.770	-1.0622	.5868
			2.00	.01552	.37735	.999	-.8889	.9200
		1.00	2.00	.50946	.34614	.308	-.3105	1.3294
			3.00	-.30336	.31644	.604	-1.0530	.4463
Q5	Tukey HSD	2.00	1.00	-.50946	.34614	.308	-1.3294	.3105
			3.00	-.81282	.38836	.095	-1.7328	.1072
		3.00	1.00	.30336	.31644	.604	-.4463	1.0530
			2.00	.81282	.38836	.095	-1.072	1.7328
		1.00	2.00	.50946	.37714	.375	-.4048	1.4237
			3.00	-.30336	.31289	.598	-1.0525	.4457
		2.00	1.00	-.50946	.37714	.375	-1.4237	.4048
			3.00	-.81282	.42619	.146	-1.8377	.2121
		3.00	1.00	.30336	.31289	.598	-.4457	1.0525
			2.00	.81282	.42619	.146	-.2121	1.8377
Q6	Tukey HSD	1.00	2.00	.19944	.38781	.865	-.7192	1.1181
			3.00	.37703	.34739	.525	-.4459	1.2000
		2.00	1.00	-.19944	.38781	.865	-1.1181	.7192
			3.00	.17759	.43173	.911	-.8451	1.2003
		3.00	1.00	-.37703	.34739	.525	-1.2000	.4459
			2.00	-.17759	.43173	.911	-1.2003	.8451
		1.00	2.00	.19944	.31355	.801	-.5507	.9495
			3.00	.37703	.38034	.585	-.5329	1.2870
		2.00	1.00	-.19944	.31355	.801	-.9495	.5507
			3.00	.17759	.39378	.894	-.7667	1.1218
		3.00	1.00	-.37703	.38034	.585	-1.2870	.5329

Appendix III - Statistical Analysis Output
IV.1.3 Identification of a Carboxylic Acid

			2.00		-.17759	.39378	.894	-1.1218	.7667
Q7	Tukey HSD	1.00	2.00		.28145	.29327	.604	-.4133	.9762
			3.00		.32973	.26270	.423	-.2926	.9520
		2.00	1.00		-.28145	.29327	.604	-.9762	.4133
			3.00		.04828	.32648	.988	-.7251	.8217
		3.00	1.00		-.32973	.26270	.423	-.9520	.2926
			2.00		-.04828	.32648	.988	-.8217	.7251
	Games- Howell	1.00	2.00		.28145	.27837	.573	-.3904	.9533
			3.00		.32973	.27931	.469	-.3392	.9986
		2.00	1.00		-.28145	.27837	.573	-.9533	.3904
			3.00		.04828	.33434	.989	-.7536	.8501
		3.00	1.00		-.32973	.27931	.469	-.9986	.3392
			2.00		-.04828	.33434	.989	-.8501	.7536
Q8	Tukey HSD	1.00	2.00		.14009	.37741	.927	-.7539	1.0341
			3.00		.00676	.34220	1.000	-.8038	.8173
		2.00	1.00		-.14009	.37741	.927	-1.0341	.7539
			3.00		-.13333	.42115	.946	-1.1309	.8642
		3.00	1.00		-.00676	.34220	1.000	-.8173	.8038
			2.00		.13333	.42115	.946	-.8642	1.1309
	Games- Howell	1.00	2.00		.14009	.32575	.903	-.6396	.9198
			3.00		.00676	.36133	1.000	-.8564	.8699
		2.00	1.00		-.14009	.32575	.903	-.9198	.6396
			3.00		-.13333	.38387	.936	-1.0531	.7865
		3.00	1.00		-.00676	.36133	1.000	-.8699	.8564
			2.00		.13333	.38387	.936	-.7865	1.0531
QTotal	Tukey HSD	1.00	2.00		.37300	.31799	.471	-.3804	1.1264
			3.00		-.01866	.28870	.998	-.7027	.6654
		2.00	1.00		-.37300	.31799	.471	-1.1264	.3804
			3.00		-.39167	.35270	.509	-1.2273	.4440
		3.00	1.00		.01866	.28870	.998	-.6654	.7027
			2.00		.39167	.35270	.509	-.4440	1.2273
	Games- Howell	1.00	2.00		.37300	.27735	.375	-.2900	1.0360
			3.00		-.01866	.29720	.998	-.7274	.6900
		2.00	1.00		-.37300	.27735	.375	-1.0360	.2900
			3.00		-.39167	.30776	.415	-1.1291	.3458
		3.00	1.00		.01866	.29720	.998	-.6900	.7274
			2.00		.39167	.30776	.415	-.3458	1.1291
C1	Tukey HSD	1.00	2.00		.30650	.52952	.832	-.9421	1.5551
			3.00		-1.44644*	.49770	.011	-2.6200	-.2728
		2.00	1.00		-.30650	.52952	.832	-1.5551	.9421
			3.00		-1.75294*	.54236	.004	-3.0318	-.4740

Appendix III - Statistical Analysis Output
IV.1.3 Identification of a Carboxylic Acid

		3.00	1.00	1.44644 *	.49770	.011	.2728	2.6200
			2.00	1.75294 *	.54236	.004	.4740	3.0318
	Games- Howell	1.00	2.00	.30650	.58047	.858	-1.0685	1.6815
			3.00	-1.44644 *	.46697	.006	-2.5504	-.3425
		2.00	1.00	-.30650	.58047	.858	-1.6815	1.0685
			3.00	-1.75294 *	.53649	.004	-3.0264	-.4795
		3.00	1.00	1.44644 *	.46697	.006	.3425	2.5504
			2.00	1.75294 *	.53649	.004	.4795	3.0264
C2	Tukey HSD	1.00	2.00	1.64056	.71879	.060	-.0544	3.3355
			3.00	-.61238	.67560	.637	-2.2055	.9807
		2.00	1.00	-1.64056	.71879	.060	-3.3355	.0544
			3.00	-2.25294 *	.73621	.007	-3.9890	-.5169
		3.00	1.00	.61238	.67560	.637	-.9807	2.2055
			2.00	2.25294 *	.73621	.007	.5169	3.9890
	Games- Howell	1.00	2.00	1.64056	.74367	.074	-.1204	3.4015
			3.00	-.61238	.66375	.627	-2.1811	.9564
		2.00	1.00	-1.64056	.74367	.074	-3.4015	.1204
			3.00	-2.25294 *	.72428	.006	-3.9692	-.5367
		3.00	1.00	.61238	.66375	.627	-.9564	2.1811
			2.00	2.25294 *	.72428	.006	.5367	3.9692
C3	Tukey HSD	1.00	2.00	1.04628	.68808	.283	-.5762	2.6688
			3.00	-.73313	.64674	.494	-2.2582	.7919
		2.00	1.00	-1.04628	.68808	.283	-2.6688	.5762
			3.00	-1.77941 *	.70477	.033	-3.4413	-.1175
		3.00	1.00	.73313	.64674	.494	-.7919	2.2582
			2.00	1.77941 *	.70477	.033	.1175	3.4413
	Games- Howell	1.00	2.00	1.04628	.74558	.342	-.7209	2.8134
			3.00	-.73313	.60553	.448	-2.1643	.6981
		2.00	1.00	-1.04628	.74558	.342	-2.8134	.7209
			3.00	-1.77941 *	.72274	.040	-3.4941	-.0647
		3.00	1.00	.73313	.60553	.448	-.6981	2.1643
			2.00	1.77941 *	.72274	.040	.0647	3.4941
Grade	Tukey HSD	1.00	2.00	2.12105	1.62899	.395	-1.7193	5.9614
			3.00	-3.04380	1.57073	.130	-6.7468	.6592
		2.00	1.00	-2.12105	1.62899	.395	-5.9614	1.7193
			3.00	-5.16485 *	1.66194	.006	-9.0828	-1.2469
		3.00	1.00	3.04380	1.57073	.130	-.6592	6.7468
			2.00	5.16485 *	1.66194	.006	1.2469	9.0828
	Games- Howell	1.00	2.00	2.12105	1.76134	.452	-2.0468	6.2889
			3.00	-3.04380	1.47684	.101	-6.5344	.4468

Appendix III - Statistical Analysis Output

IV.1.3 Identification of a Carboxylic Acid

2.00	1.00	-2.12105	1.76134	.452	-6.2889	2.0468
	3.00	-5.16485 *	1.65186	.006	-9.0785	-1.2512
3.00	1.00	3.04380	1.47684	.101	-.4468	6.5344
	2.00	5.16485 *	1.65186	.006	1.2512	9.0785

*. The mean difference is significant at the 0.05 level.

Appendix III - Statistical Analysis Output
IV.1.4 Properties of Solutions of Acids and Bases

IV.1.4 Properties of Solutions of Acids and Bases

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	1.00	69	7.9130	1.68679	.20307	7.5078	8.3183	3.00	10.00
	2.00	41	8.2317	1.70330	.26601	7.6941	8.7693	3.00	10.00
	3.00	46	8.1304	1.48487	.21893	7.6895	8.5714	5.00	10.00
	Total	156	8.0609	1.62971	.13048	7.8031	8.3186	3.00	10.00
Q2	1.00	69	8.0942	1.63886	.19730	7.7005	8.4879	3.00	10.00
	2.00	41	8.3659	1.65463	.25841	7.8436	8.8881	3.00	10.00
	3.00	46	8.3913	1.58434	.23360	7.9208	8.8618	5.00	10.00
	Total	156	8.2532	1.62292	.12994	7.9965	8.5099	3.00	10.00
Q3	1.00	69	8.0362	1.71995	.20706	7.6231	8.4494	3.00	10.00
	2.00	41	8.4878	1.50203	.23458	8.0137	8.9619	3.00	10.00
	3.00	46	8.3478	1.56656	.23098	7.8826	8.8130	4.00	10.00
	Total	156	8.2468	1.62192	.12986	7.9903	8.5033	3.00	10.00
Q4	1.00	69	7.8188	1.98519	.23899	7.3419	8.2957	1.00	10.00
	2.00	40	7.7750	1.68686	.26672	7.2355	8.3145	3.00	10.00
	3.00	46	7.9565	1.90854	.28140	7.3898	8.5233	3.00	10.00
	Total	155	7.8484	1.87895	.15092	7.5502	8.1465	1.00	10.00
Q5	1.00	69	8.4783	1.59603	.19214	8.0949	8.8617	2.00	10.00
	2.00	41	9.0976	1.31918	.20602	8.6812	9.5139	3.00	10.00
	3.00	46	9.0870	1.33460	.19678	8.6906	9.4833	4.00	10.00
	Total	156	8.8205	1.47555	.11814	8.5871	9.0539	2.00	10.00
Q6	1.00	69	8.1594	1.58692	.19104	7.7782	8.5406	4.00	10.00
	2.00	40	8.3875	1.45218	.22961	7.9231	8.8519	3.00	10.00
	3.00	46	8.4783	1.70931	.25202	7.9707	8.9859	3.00	10.00
	Total	155	8.3129	1.58744	.12751	8.0610	8.5648	3.00	10.00
Q7	1.00	69	8.3043	1.61841	.19483	7.9156	8.6931	3.00	10.00
	2.00	40	8.3000	1.53923	.24337	7.8077	8.7923	3.00	10.00
	3.00	46	8.2391	2.04597	.30166	7.6316	8.8467	1.00	10.00
	Total	155	8.2839	1.72644	.13867	8.0099	8.5578	1.00	10.00
Q8	1.00	69	7.9855	1.76771	.21281	7.5609	8.4102	3.00	10.00
	2.00	40	8.0750	1.68534	.26648	7.5360	8.6140	3.00	10.00
	3.00	46	8.1087	2.01360	.29689	7.5107	8.7067	1.00	10.00
	Total	155	8.0452	1.81298	.14562	7.7575	8.3328	1.00	10.00

Appendix III - Statistical Analysis Output
IV.1.4 Properties of Solutions of Acids and Bases

QTotal	1.00	67	8.1567	1.57444	.19235	7.7727	8.5408	3.00	10.00
	2.00	40	8.4250	1.44803	.22895	7.9619	8.8881	3.00	10.00
	3.00	45	8.2667	1.49848	.22338	7.8165	8.7169	4.00	10.00
	Total	152	8.2599	1.51370	.12278	8.0173	8.5025	3.00	10.00
C1	1.00	95	16.5789	3.22417	.33079	15.9221	17.2357	6.00	20.00
	2.00	63	17.8889	2.67070	.33648	17.2163	18.5615	10.00	20.00
	3.00	84	18.6905	2.07670	.22659	18.2398	19.1411	10.00	20.00
	Total	242	17.6529	2.86693	.18429	17.2899	18.0159	6.00	20.00
C2	1.00	95	30.7158	4.26431	.43751	29.8471	31.5845	20.00	39.00
	2.00	63	29.2540	4.92842	.62092	28.0128	30.4952	20.00	40.00
	3.00	84	32.3571	4.23878	.46249	31.4373	33.2770	24.00	40.00
	Total	242	30.9050	4.58159	.29452	30.3248	31.4851	20.00	40.00
C3	1.00	95	29.2632	3.98991	.40936	28.4504	30.0759	20.00	39.00
	2.00	63	28.3492	4.35949	.54924	27.2513	29.4471	20.00	38.00
	3.00	84	30.6190	4.76914	.52036	29.5841	31.6540	15.00	40.00
	Total	242	29.4959	4.44258	.28558	28.9333	30.0584	15.00	40.00
Grade	1.00	96	75.8229	12.14647	1.23969	73.3618	78.2840	6.00	96.00
	2.00	71	75.8592	9.32783	1.10701	73.6513	78.0670	50.00	96.00
	3.00	84	81.6667	9.38768	1.02428	79.6294	83.7039	59.00	100.00
	Total	251	77.7888	10.82955	.68356	76.4426	79.1351	6.00	100.00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Q1	.063	2	153	.939
Q2	.020	2	153	.980
Q3	.445	2	153	.641
Q4	.209	2	152	.812
Q5	2.282	2	153	.106
Q6	.918	2	152	.401
Q7	2.261	2	152	.108
Q8	1.205	2	152	.302
QTotal	.080	2	149	.924
C1	5.871	2	239	.003
C2	.875	2	239	.418
C3	1.636	2	239	.197
Grade	.446	2	248	.641

Appendix III - Statistical Analysis Output
IV.1.4 Properties of Solutions of Acids and Bases

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Q1	Between Groups	2.927	2	1.464	.548	.579
	Within Groups	408.744	153	2.672		
	Total	411.671	155			
Q2	Between Groups	3.142	2	1.571	.593	.554
	Within Groups	405.106	153	2.648		
	Total	408.248	155			
Q3	Between Groups	5.910	2	2.955	1.125	.327
	Within Groups	401.838	153	2.626		
	Total	407.748	155			
Q4	Between Groups	.814	2	.407	.114	.892
	Within Groups	542.874	152	3.572		
	Total	543.687	154			
Q5	Between Groups	14.495	2	7.248	3.433	.035
	Within Groups	322.979	153	2.111		
	Total	337.474	155			
Q6	Between Groups	3.106	2	1.553	.613	.543
	Within Groups	384.968	152	2.533		
	Total	388.074	154			
Q7	Between Groups	.131	2	.066	.022	.978
	Within Groups	458.878	152	3.019		
	Total	459.010	154			
Q8	Between Groups	.467	2	.233	.070	.932
	Within Groups	505.717	152	3.327		
	Total	506.184	154			
QTotal	Between Groups	1.806	2	.903	.391	.677
	Within Groups	344.179	149	2.310		
	Total	345.985	151			
C1	Between Groups	203.510	2	101.755	13.683	.000
	Within Groups	1777.332	239	7.437		
	Total	1980.843	241			
C2	Between Groups	352.266	2	176.133	8.944	.000
	Within Groups	4706.549	239	19.693		
	Total	5058.814	241			
C3	Between Groups	193.948	2	96.974	5.080	.007
	Within Groups	4562.548	239	19.090		
	Total	4756.496	241			

Appendix III - Statistical Analysis Output
IV.1.4 Properties of Solutions of Acids and Bases

Grade	Between Groups	1898.561	2	949.280	8.585	.000
	Within Groups	27421.248	248	110.570		
	Total	29319.809	250			

Multiple Comparisons

		(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Q1	Tukey HSD	1.00	2.00	-.31866	.32230	.585	-1.0815	.4441
			3.00	-.21739	.31112	.765	-.9537	.5189
		2.00	1.00	.31866	.32230	.585	-.4441	1.0815
			3.00	.10127	.35105	.955	-.7296	.9321
		3.00	1.00	.21739	.31112	.765	-.5189	.9537
			2.00	-.10127	.35105	.955	-.9321	.7296
	Games- Howell	1.00	2.00	-.31866	.33466	.609	-1.1172	.4799
			3.00	-.21739	.29861	.747	-.9273	.4926
		2.00	1.00	.31866	.33466	.609	-.4799	1.1172
			3.00	.10127	.34452	.954	-.7215	.9240
		3.00	1.00	.21739	.29861	.747	-.4926	.9273
			2.00	-.10127	.34452	.954	-.9240	.7215
Q2	Tukey HSD	1.00	2.00	-.27165	.32086	.675	-1.0310	.4877
			3.00	-.29710	.30973	.604	-1.0302	.4360
		2.00	1.00	.27165	.32086	.675	-.4877	1.0310
			3.00	-.02545	.34948	.997	-.8526	.8017
		3.00	1.00	.29710	.30973	.604	-.4360	1.0302
			2.00	.02545	.34948	.997	-.8017	.8526
	Games- Howell	1.00	2.00	-.27165	.32512	.682	-1.0474	.5041
			3.00	-.29710	.30577	.596	-1.0247	.4305
		2.00	1.00	.27165	.32512	.682	-.5041	1.0474
			3.00	-.02545	.34834	.997	-.8568	.8059
		3.00	1.00	.29710	.30577	.596	-.4305	1.0247
			2.00	.02545	.34834	.997	-.8059	.8568
Q3	Tukey HSD	1.00	2.00	-.45157	.31957	.337	-1.2079	.3048
			3.00	-.31159	.30848	.572	-1.0417	.4185
		2.00	1.00	.45157	.31957	.337	-.3048	1.2079
			3.00	.13998	.34807	.915	-.6838	.9638
		3.00	1.00	.31159	.30848	.572	-.4185	1.0417
			2.00	-.13998	.34807	.915	-.9638	.6838

Appendix III - Statistical Analysis Output
IV.1.4 Properties of Solutions of Acids and Bases

	Games- Howell	1.00	2.00	-.45157	.31289	.323	-1.1968	.2936
			3.00	-.31159	.31020	.576	-1.0493	.4261
		2.00	1.00	.45157	.31289	.323	-.2936	1.1968
			3.00	.13998	.32921	.905	-.6454	.9254
		3.00	1.00	.31159	.31020	.576	-.4261	1.0493
			2.00	-.13998	.32921	.905	-.9254	.6454
		1.00	2.00	.04384	.37557	.993	-.8451	.9328
			3.00	-.13768	.35973	.922	-.9891	.7138
		2.00	1.00	-.04384	.37557	.993	-.9328	.8451
			3.00	-.18152	.40857	.897	-1.1486	.7855
Q4	Tukey HSD	3.00	1.00	.13768	.35973	.922	-.7138	.9891
			2.00	.18152	.40857	.897	-.7855	1.1486
		1.00	2.00	.04384	.35812	.992	-.8092	.8969
			3.00	-.13768	.36919	.926	-1.0161	.7408
		2.00	1.00	-.04384	.35812	.992	-.8969	.8092
	Games- Howell		3.00	-.18152	.38771	.886	-1.1066	.7436
		3.00	1.00	.13768	.36919	.926	-.7408	1.0161
			2.00	.18152	.38771	.886	-.7436	1.1066
		1.00	2.00	-.61930	.28650	.081	-1.2974	.0588
			3.00	-.60870	.27656	.074	-1.2632	.0458
Q5	Tukey HSD	2.00	1.00	.61930	.28650	.081	-.0588	1.2974
			3.00	.01060	.31205	.999	-.7279	.7492
		3.00	1.00	.60870	.27656	.074	-.0458	1.2632
			2.00	-.01060	.31205	.999	-.7492	.7279
		1.00	2.00	-.61930	.28171	.077	-1.2899	.0513
	Games- Howell		3.00	-.60870	.27502	.073	-1.2623	.0450
		2.00	1.00	.61930	.28171	.077	-.0513	1.2899
			3.00	.01060	.28490	.999	-.6691	.6903
		3.00	1.00	.60870	.27502	.073	-.0450	1.2623
			2.00	-.01060	.28490	.999	-.6903	.6691
Q6	Tukey HSD	1.00	2.00	-.22808	.31626	.751	-.9766	.5205
			3.00	-.31884	.30293	.545	-1.0358	.3982
		2.00	1.00	.22808	.31626	.751	-.5205	.9766
			3.00	-.09076	.34406	.962	-.9051	.7236
		3.00	1.00	.31884	.30293	.545	-.3982	1.0358
	Games- Howell		2.00	.09076	.34406	.962	-.7236	.9051
		1.00	2.00	-.22808	.29869	.726	-.9402	.4841
			3.00	-.31884	.31625	.574	-1.0723	.4346
		2.00	1.00	.22808	.29869	.726	-.4841	.9402
			3.00	-.09076	.34093	.962	-.9042	.7227
		3.00	1.00	.31884	.31625	.574	-.4346	1.0723

Appendix III - Statistical Analysis Output
IV.1.4 Properties of Solutions of Acids and Bases

			2.00	.09076	.34093	.962	-.7227	.9042
Q7	Tukey HSD	1.00	2.00	.00435	.34529	1.000	-.8129	.8216
			3.00	.06522	.33073	.979	-.7176	.8480
		2.00	1.00	-.00435	.34529	1.000	-.8216	.8129
			3.00	.06087	.37564	.986	-.8282	.9500
		3.00	1.00	-.06522	.33073	.979	-.8480	.7176
			2.00	-.06087	.37564	.986	-.9500	.8282
	Games- Howell	1.00	2.00	.00435	.31175	1.000	-.7393	.7480
			3.00	.06522	.35911	.982	-.7922	.9226
		2.00	1.00	-.00435	.31175	1.000	-.7480	.7393
			3.00	.06087	.38760	.986	-.8642	.9860
		3.00	1.00	-.06522	.35911	.982	-.9226	.7922
			2.00	-.06087	.38760	.986	-.9860	.8642
Q8	Tukey HSD	1.00	2.00	-.08949	.36249	.967	-.9475	.7685
			3.00	-.12319	.34720	.933	-.9450	.6986
		2.00	1.00	.08949	.36249	.967	-.7685	.9475
			3.00	-.03370	.39434	.996	-.9671	.8997
		3.00	1.00	.12319	.34720	.933	-.6986	.9450
			2.00	.03370	.39434	.996	-.8997	.9671
	Games- Howell	1.00	2.00	-.08949	.34102	.963	-.9030	.7240
			3.00	-.12319	.36528	.939	-.9941	.7477
		2.00	1.00	.08949	.34102	.963	-.7240	.9030
			3.00	-.03370	.39894	.996	-.9856	.9182
		3.00	1.00	.12319	.36528	.939	-.7477	.9941
			2.00	.03370	.39894	.996	-.9182	.9856
QTotal	Tukey HSD	1.00	2.00	-.26828	.30369	.652	-.9872	.4507
			3.00	-.10995	.29293	.925	-.8034	.5835
		2.00	1.00	.26828	.30369	.652	-.4507	.9872
			3.00	.15833	.33027	.881	-.6235	.9402
		3.00	1.00	.10995	.29293	.925	-.5835	.8034
			2.00	-.15833	.33027	.881	-.9402	.6235
	Games- Howell	1.00	2.00	-.26828	.29903	.644	-.9812	.4446
			3.00	-.10995	.29478	.926	-.8115	.5916
		2.00	1.00	.26828	.29903	.644	-.4446	.9812
			3.00	.15833	.31987	.874	-.6051	.9218
		3.00	1.00	.10995	.29478	.926	-.5916	.8115
			2.00	-.15833	.31987	.874	-.9218	.6051
C1	Tukey HSD	1.00	2.00	-1.30994*	.44308	.010	-2.3549	-.2650
			3.00	-2.11153*	.40842	.000	-3.0748	-1.1483
		2.00	1.00	1.30994*	.44308	.010	.2650	2.3549
			3.00	-.80159	.45450	.184	-1.8735	.2703

Appendix III - Statistical Analysis Output
IV.1.4 Properties of Solutions of Acids and Bases

	Games- Howell	3.00	1.00	2.11153 *	.40842	.000	1.1483	3.0748
			2.00	.80159	.45450	.184	-.2703	1.8735
		1.00	2.00	-1.30994 *	.47185	.017	-2.4270	-.1929
			3.00	-2.11153 *	.40096	.000	-3.0599	-1.1631
		2.00	1.00	1.30994 *	.47185	.017	.1929	2.4270
			3.00	-.80159	.40566	.123	-1.7650	.1618
		3.00	1.00	2.11153 *	.40096	.000	1.1631	3.0599
			2.00	.80159	.40566	.123	-.1618	1.7650
		1.00	2.00	1.46182	.72102	.108	-.2386	3.1623
			3.00	-1.64135 *	.66463	.038	-3.2088	-.0739
		2.00	1.00	-1.46182	.72102	.108	-3.1623	.2386
			3.00	-3.10317 *	.73961	.000	-4.8475	-1.3589
C2	Tukey HSD	3.00	1.00	1.64135 *	.66463	.038	.0739	3.2088
			2.00	3.10317 *	.73961	.000	1.3589	4.8475
		1.00	2.00	1.46182	.75958	.136	-.3409	3.2645
			3.00	-1.64135 *	.63664	.029	-3.1463	-.1364
		2.00	1.00	-1.46182	.75958	.136	-3.2645	.3409
			3.00	-3.10317 *	.77424	.000	-4.9402	-1.2662
	Games- Howell	3.00	1.00	1.64135 *	.63664	.029	.1364	3.1463
			2.00	3.10317 *	.77424	.000	1.2662	4.9402
		1.00	2.00	.91395	.70991	.404	-.7603	2.5882
			3.00	-1.35589	.65438	.098	-2.8992	.1874
		2.00	1.00	-.91395	.70991	.404	-2.5882	.7603
			3.00	-2.26984 *	.72820	.006	-3.9872	-.5524
C3	Tukey HSD	3.00	1.00	1.35589	.65438	.098	-.1874	2.8992
			2.00	2.26984 *	.72820	.006	.5524	3.9872
		1.00	2.00	.91395	.68501	.379	-.7109	2.5388
			3.00	-1.35589	.66207	.104	-2.9219	.2102
		2.00	1.00	-.91395	.68501	.379	-2.5388	.7109
			3.00	-2.26984 *	.75660	.009	-4.0622	-.4774
	Games- Howell	3.00	1.00	1.35589	.66207	.104	-.2102	2.9219
			2.00	2.26984 *	.75660	.009	.4774	4.0622
Grade	Tukey HSD	1.00	2.00	-.03624	1.64593	1.000	-3.9171	3.8447
			3.00	-5.84375 *	1.57101	.001	-9.5480	-2.1395
		2.00	1.00	.03624	1.64593	1.000	-3.8447	3.9171
			3.00	-5.80751 *	1.69518	.002	-9.8045	-1.8105
		3.00	1.00	5.84375 *	1.57101	.001	2.1395	9.5480
			2.00	5.80751 *	1.69518	.002	1.8105	9.8045
	Games- Howell	1.00	2.00	-.03624	1.66202	1.000	-3.9671	3.8946
			3.00	-5.84375 *	1.60810	.001	-9.6449	-2.0426

Appendix III - Statistical Analysis Output
IV.1.4 Properties of Solutions of Acids and Bases

2.00	1.00	.03624	1.66202	1.000	-3.8946	3.9671
	3.00	-5.80751 *	1.50818	.001	-9.3779	-2.2371
3.00	1.00	5.84375 *	1.60810	.001	2.0426	9.6449
	2.00	5.80751 *	1.50818	.001	2.2371	9.3779

*. The mean difference is significant at the 0.05 level.

Appendix III - Statistical Analysis Output
IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

IV.2 KRA113

IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	1.00	98	6.6122	2.01352	.20340	6.2086	7.0159	2.00	10.00
	2.00	194	6.8454	1.78851	.12841	6.5921	7.0986	1.00	10.00
	3.00	157	7.3567	1.78675	.14260	7.0750	7.6384	1.00	10.00
	Total	449	6.9733	1.85867	.08772	6.8009	7.1457	1.00	10.00
Q2	1.00	98	7.5612	1.95868	.19786	7.1685	7.9539	1.00	10.00
	2.00	193	7.4560	1.90651	.13723	7.1853	7.7266	2.00	10.00
	3.00	158	6.9082	2.15619	.17154	6.5694	7.2470	1.00	10.00
	Total	449	7.2862	2.02411	.09552	7.0985	7.4739	1.00	10.00
Q3	1.00	96	7.5104	1.94121	.19812	7.1171	7.9037	1.00	10.00
	2.00	193	7.5440	1.75576	.12638	7.2948	7.7933	1.00	10.00
	3.00	158	7.3418	1.88109	.14965	7.0462	7.6374	1.00	10.00
	Total	447	7.4653	1.83953	.08701	7.2943	7.6363	1.00	10.00
Q4	1.00	98	7.7755	1.93998	.19597	7.3866	8.1645	2.00	10.00
	2.00	194	7.6289	1.70230	.12222	7.3878	7.8699	2.00	10.00
	3.00	156	8.0705	1.53712	.12307	7.8274	8.3136	2.00	10.00
	Total	448	7.8147	1.71036	.08081	7.6559	7.9735	2.00	10.00
Q5	1.00	98	8.0510	1.94445	.19642	7.6612	8.4409	1.00	10.00
	2.00	192	8.0885	1.71457	.12374	7.8445	8.3326	1.00	10.00
	3.00	158	8.2215	1.78680	.14215	7.9407	8.5023	1.00	10.00
	Total	448	8.1272	1.78970	.08456	7.9611	8.2934	1.00	10.00
Q6	1.00	98	6.7755	2.08347	.21046	6.3578	7.1932	1.00	10.00
	2.00	194	7.0825	1.85927	.13349	6.8192	7.3458	1.00	10.00
	3.00	157	7.2389	2.09593	.16727	6.9084	7.5693	1.00	10.00
	Total	449	7.0702	1.99695	.09424	6.8849	7.2554	1.00	10.00
Q7	1.00	98	7.9898	1.78479	.18029	7.6320	8.3476	2.00	10.00
	2.00	192	8.2917	1.56812	.11317	8.0684	8.5149	1.00	10.00
	3.00	156	8.4615	1.47838	.11837	8.2277	8.6954	3.00	10.00
	Total	446	8.2848	1.59412	.07548	8.1364	8.4331	1.00	10.00
Q8	1.00	98	6.9388	2.12407	.21456	6.5129	7.3646	1.00	10.00
	2.00	194	7.2577	1.93028	.13859	6.9844	7.5311	1.00	10.00

Appendix III - Statistical Analysis Output

IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

	3.00	157	7.4873	1.95293	.15586	7.1794	7.7951	1.00	10.00
	Total	449	7.2684	1.98764	.09380	7.0840	7.4527	1.00	10.00
QTotal	1.00	97	7.3918	1.58644	.16108	7.0720	7.7115	1.00	10.00
	2.00	190	7.5500	1.51671	.11003	7.3329	7.7671	3.00	10.00
	3.00	154	7.5195	1.59951	.12889	7.2648	7.7741	2.00	10.00
	Total	441	7.5045	1.55906	.07424	7.3586	7.6504	1.00	10.00
C1	1.00	104	17.9135	2.10460	.20637	17.5042	18.3228	10.00	20.00
	2.00	238	18.1723	2.66873	.17299	17.8315	18.5131	5.00	20.00
	3.00	226	18.5730	1.84758	.12290	18.3308	18.8152	12.00	20.00
	Total	568	18.2843	2.28032	.09568	18.0964	18.4723	5.00	20.00
C2	1.00	104	32.6250	2.91027	.28538	32.0590	33.1910	24.00	38.00
	2.00	238	31.6723	4.01497	.26025	31.1596	32.1850	15.00	40.00
	3.00	226	33.3429	3.52746	.23464	32.8805	33.8053	15.00	39.00
	Total	568	32.5114	3.71319	.15580	32.2054	32.8175	15.00	40.00
C3	1.00	104	32.5288	2.70905	.26564	32.0020	33.0557	25.00	38.00
	2.00	238	30.9496	4.17820	.27083	30.4160	31.4831	5.00	40.00
	3.00	226	33.4159	3.04551	.20258	33.0167	33.8151	24.00	40.00
	Total	568	32.2201	3.68454	.15460	31.9164	32.5237	5.00	40.00
Grade	1.00	104	83.0673	6.49909	.63729	81.8034	84.3312	65.00	94.00
	2.00	238	80.7941	8.00182	.51868	79.7723	81.8159	40.00	97.00
	3.00	226	85.3319	6.69265	.44519	84.4546	86.2091	60.00	98.00
	Total	568	83.0158	7.51141	.31517	82.3968	83.6349	40.00	98.00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Q1	2.559	2	446	.078
Q2	2.121	2	446	.121
Q3	.516	2	444	.597
Q4	2.768	2	445	.064
Q5	1.324	2	445	.267
Q6	1.247	2	446	.288
Q7	1.241	2	443	.290
Q8	1.483	2	446	.228
QTotal	.333	2	438	.717
C1	2.799	2	565	.062
C2	4.478	2	565	.012
C3	4.181	2	565	.016
Grade	.780	2	565	.459

Appendix III - Statistical Analysis Output
IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

ANOVA						
		Sum of Squares	df	Mean Square	F	Sig.
Q1	Between Groups	39.028	2	19.514	5.769	.003
	Within Groups	1508.652	446	3.383		
	Total	1547.679	448			
Q2	Between Groups	35.547	2	17.773	4.404	.013
	Within Groups	1799.928	446	4.036		
	Total	1835.474	448			
Q3	Between Groups	3.803	2	1.901	.561	.571
	Within Groups	1505.410	444	3.391		
	Total	1509.213	446			
Q4	Between Groups	17.059	2	8.529	2.941	.054
	Within Groups	1290.564	445	2.900		
	Total	1307.623	447			
Q5	Between Groups	2.261	2	1.131	.352	.704
	Within Groups	1429.487	445	3.212		
	Total	1431.748	447			
Q6	Between Groups	13.005	2	6.503	1.635	.196
	Within Groups	1773.535	446	3.977		
	Total	1786.540	448			
Q7	Between Groups	13.411	2	6.705	2.658	.071
	Within Groups	1117.426	443	2.522		
	Total	1130.836	445			
Q8	Between Groups	18.190	2	9.095	2.316	.100
	Within Groups	1751.721	446	3.928		
	Total	1769.911	448			
QTotal	Between Groups	1.661	2	.830	.341	.711
	Within Groups	1067.830	438	2.438		
	Total	1069.491	440			
C1	Between Groups	36.127	2	18.064	3.505	.031
	Within Groups	2912.203	565	5.154		
	Total	2948.331	567			
C2	Between Groups	325.190	2	162.595	12.261	.000
	Within Groups	7492.486	565	13.261		
	Total	7817.676	567			
C3	Between Groups	717.280	2	358.640	29.029	.000
	Within Groups	6980.211	565	12.354		
	Total	7697.491	567			
Grade	Between Groups	2387.306	2	1193.653	22.782	.000
	Within Groups	29603.551	565	52.396		

Appendix III - Statistical Analysis Output
IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

Total	31990.857	567			
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Multiple Comparisons

		(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Q1	Tukey HSD	1.00	2.00	-.23312	.22793	.563	-.7691	.3029
			3.00	-.74444 [*]	.23677	.005	-1.3012	-.1877
		2.00	1.00	.23312	.22793	.563	-.3029	.7691
			3.00	-.51133 [*]	.19744	.027	-.9756	-.0470
		3.00	1.00	.74444 [*]	.23677	.005	.1877	1.3012
			2.00	.51133 [*]	.19744	.027	.0470	.9756
	Games- Howell	1.00	2.00	-.23312	.24054	.597	-.8017	.3355
			3.00	-.74444 [*]	.24840	.009	-1.3313	-.1576
		2.00	1.00	.23312	.24054	.597	-.3355	.8017
			3.00	-.51133 [*]	.19189	.022	-.9631	-.0596
		3.00	1.00	.74444 [*]	.24840	.009	.1576	1.3313
			2.00	.51133 [*]	.19189	.022	.0596	.9631
Q2	Tukey HSD	1.00	2.00	.10527	.24918	.906	-.4807	.6912
			3.00	.65300 [*]	.25831	.032	.0456	1.2604
		2.00	1.00	-.10527	.24918	.906	-.6912	.4807
			3.00	.54773 [*]	.21553	.031	.0409	1.0546
		3.00	1.00	-.65300 [*]	.25831	.032	-1.2604	-.0456
			2.00	-.54773 [*]	.21553	.031	-1.0546	-.0409
	Games- Howell	1.00	2.00	.10527	.24079	.900	-.4635	.6741
			3.00	.65300 [*]	.26186	.036	.0351	1.2709
		2.00	1.00	-.10527	.24079	.900	-.6741	.4635
			3.00	.54773 [*]	.21968	.035	.0304	1.0650
		3.00	1.00	-.65300 [*]	.26186	.036	-1.2709	-.0351
			2.00	-.54773 [*]	.21968	.035	-1.0650	-.0304
Q3	Tukey HSD	1.00	2.00	-.03362	.22997	.988	-.5744	.5072
			3.00	.16864	.23828	.759	-.3917	.7290
		2.00	1.00	.03362	.22997	.988	-.5072	.5744
			3.00	.20227	.19755	.562	-.2623	.6668
		3.00	1.00	-.16864	.23828	.759	-.7290	.3917
			2.00	-.20227	.19755	.562	-.6668	.2623
	Games- Howell	1.00	2.00	-.03362	.23500	.989	-.5892	.5219
			3.00	.16864	.24829	.776	-.4177	.7550

Appendix III - Statistical Analysis Output
IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

		2.00	1.00	.03362	.23500	.989	-.5219	.5892
			3.00	.20227	.19588	.557	-.2589	.6635
		3.00	1.00	-.16864	.24829	.776	-.7550	.4177
			2.00	-.20227	.19588	.557	-.6635	.2589
Q4	Tukey HSD	1.00	2.00	.14664	.21105	.767	-.3497	.6429
			3.00	-.29500	.21951	.372	-.8112	.2212
		2.00	1.00	-.14664	.21105	.767	-.6429	.3497
			3.00	-.44165*	.18314	.043	-.8723	-.0110
		3.00	1.00	.29500	.21951	.372	-.2212	.8112
			2.00	.44165*	.18314	.043	.0110	.8723
	Games- Howell	1.00	2.00	.14664	.23096	.801	-.3993	.6926
			3.00	-.29500	.23141	.411	-.8421	.2521
		2.00	1.00	-.14664	.23096	.801	-.6926	.3993
			3.00	-.44165*	.17344	.030	-.8499	-.0334
		3.00	1.00	.29500	.23141	.411	-.2521	.8421
			2.00	.44165*	.17344	.030	.0334	.8499
Q5	Tukey HSD	1.00	2.00	-.03752	.22251	.984	-.5608	.4857
			3.00	-.17050	.23046	.740	-.7124	.3714
		2.00	1.00	.03752	.22251	.984	-.4857	.5608
			3.00	-.13298	.19252	.769	-.5857	.3197
		3.00	1.00	.17050	.23046	.740	-.3714	.7124
			2.00	.13298	.19252	.769	-.3197	.5857
	Games- Howell	1.00	2.00	-.03752	.23215	.986	-.5863	.5112
			3.00	-.17050	.24246	.762	-.7432	.4022
		2.00	1.00	.03752	.23215	.986	-.5112	.5863
			3.00	-.13298	.18846	.760	-.5767	.3107
		3.00	1.00	.17050	.24246	.762	-.4022	.7432
			2.00	.13298	.18846	.760	-.3107	.5767
Q6	Tukey HSD	1.00	2.00	-.30696	.24713	.429	-.8881	.2742
			3.00	-.46334	.25672	.169	-1.0670	.1403
		2.00	1.00	.30696	.24713	.429	-.2742	.8881
			3.00	-.15638	.21407	.746	-.6598	.3470
		3.00	1.00	.46334	.25672	.169	-.1403	1.0670
			2.00	.15638	.21407	.746	-.3470	.6598
	Games- Howell	1.00	2.00	-.30696	.24923	.436	-.8960	.2821
			3.00	-.46334	.26884	.199	-1.0980	.1713
		2.00	1.00	.30696	.24923	.436	-.2821	.8960
			3.00	-.15638	.21401	.745	-.6603	.3476
		3.00	1.00	.46334	.26884	.199	-.1713	1.0980
			2.00	.15638	.21401	.745	-.3476	.6603
Q7	Tukey HSD	1.00	2.00	-.30187	.19717	.277	-.7655	.1618

Appendix III - Statistical Analysis Output
IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

			3.00		-.47174	.20471	.056	-.9532	.0097
			2.00	1.00	.30187	.19717	.277	-.1618	.7655
			3.00		-.16987	.17119	.582	-.5725	.2327
			3.00	1.00	.47174	.20471	.056	-.0097	.9532
			2.00		.16987	.17119	.582	-.2327	.5725
	Games- Howell	1.00	2.00		-.30187	.21287	.334	-.8051	.2013
		3.00			-.47174	.21567	.076	-.9815	.0380
		2.00	1.00		.30187	.21287	.334	-.2013	.8051
		3.00			-.16987	.16376	.554	-.5554	.2156
		3.00	1.00		.47174	.21567	.076	-.0380	.9815
		2.00			.16987	.16376	.554	-.2156	.5554
Q8	Tukey HSD	1.00	2.00		-.31896	.24561	.397	-.8965	.2586
		3.00			-.54849	.25514	.081	-1.1485	.0515
		2.00	1.00		.31896	.24561	.397	-.2586	.8965
		3.00			-.22953	.21275	.528	-.7298	.2708
		3.00	1.00		.54849	.25514	.081	-.0515	1.1485
		2.00			.22953	.21275	.528	-.2708	.7298
	Games- Howell	1.00	2.00		-.31896	.25543	.426	-.9226	.2847
		3.00			-.54849	.26520	.099	-1.1749	.0779
		2.00	1.00		.31896	.25543	.426	-.2847	.9226
		3.00			-.22953	.20856	.514	-.7205	.2615
QTotal	Tukey HSD	1.00	2.00		-.15825	.19485	.696	-.6165	.3000
		3.00			-.12773	.20240	.803	-.6037	.3483
		2.00	1.00		.15825	.19485	.696	-.3000	.6165
		3.00			.03052	.16930	.982	-.3676	.4287
		3.00	1.00		.12773	.20240	.803	-.3483	.6037
		2.00			-.03052	.16930	.982	-.4287	.3676
	Games- Howell	1.00	2.00		-.15825	.19507	.697	-.6191	.3026
		3.00			-.12773	.20630	.810	-.6148	.3593
		2.00	1.00		.15825	.19507	.697	-.3026	.6191
		3.00			.03052	.16947	.982	-.3685	.4296
C1	Tukey HSD	3.00	1.00		.12773	.20630	.810	-.3593	.6148
		2.00			-.03052	.16947	.982	-.4296	.3685
		1.00	2.00		-.25881	.26687	.596	-.8859	.3683
		3.00			-.65955*	.26901	.039	-1.2917	-.0274
		2.00	1.00		.25881	.26687	.596	-.3683	.8859
		3.00			-.40074	.21086	.139	-.8963	.0948
		3.00	1.00		.65955*	.26901	.039	.0274	1.2917
		2.00			.40074	.21086	.139	-.0948	.8963

Appendix III - Statistical Analysis Output

IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

	Games- Howell	1.00	2.00	-.25881	.26929	.602	-.8938	.3762
			3.00	-.65955*	.24020	.018	-1.2272	-.0919
		2.00	1.00	.25881	.26929	.602	-.3762	.8938
			3.00	-.40074	.21220	.143	-.8998	.0984
		3.00	1.00	.65955*	.24020	.018	.0919	1.2272
			2.00	.40074	.21220	.143	-.0984	.8998
C2	Tukey HSD	1.00	2.00	.95273	.42805	.068	-.0532	1.9586
			3.00	-.71792	.43149	.220	-1.7319	.2960
		2.00	1.00	-.95273	.42805	.068	-1.9586	.0532
			3.00	-1.67065*	.33822	.000	-2.4654	-.8759
		3.00	1.00	.71792	.43149	.220	-.2960	1.7319
			2.00	1.67065*	.33822	.000	.8759	2.4654
	Games- Howell	1.00	2.00	.95273*	.38623	.038	.0424	1.8630
			3.00	-.71792	.36945	.129	-1.5892	.1534
		2.00	1.00	-.95273*	.38623	.038	-1.8630	-.0424
			3.00	-1.67065*	.35041	.000	-2.4946	-.8467
		3.00	1.00	.71792	.36945	.129	-.1534	1.5892
			2.00	1.67065*	.35041	.000	.8467	2.4946
C3	Tukey HSD	1.00	2.00	1.57927*	.41316	.000	.6084	2.5502
			3.00	-.88708	.41648	.085	-1.8658	.0916
		2.00	1.00	-1.57927*	.41316	.000	-2.5502	-.6084
			3.00	-2.46635*	.32646	.000	-3.2335	-1.6992
		3.00	1.00	.88708	.41648	.085	-.0916	1.8658
			2.00	2.46635*	.32646	.000	1.6992	3.2335
	Games- Howell	1.00	2.00	1.57927*	.37936	.000	.6856	2.4730
			3.00	-.88708*	.33408	.023	-1.6753	-.0988
		2.00	1.00	-1.57927*	.37936	.000	-2.4730	-.6856
			3.00	-2.46635*	.33822	.000	-3.2618	-1.6709
		3.00	1.00	.88708*	.33408	.023	.0988	1.6753
			2.00	2.46635*	.33822	.000	1.6709	3.2618
Grade	Tukey HSD	1.00	2.00	2.27319*	.85086	.021	.2738	4.2726
			3.00	-2.26455*	.85770	.023	-4.2801	-.2490
		2.00	1.00	-2.27319*	.85086	.021	-4.2726	-.2738
			3.00	-4.53774*	.67230	.000	-6.1176	-2.9579
		3.00	1.00	2.26455*	.85770	.023	.2490	4.2801
			2.00	4.53774*	.67230	.000	2.9579	6.1176
	Games- Howell	1.00	2.00	2.27319*	.82168	.017	.3353	4.2111
			3.00	-2.26455*	.77739	.011	-4.0998	-.4293
		2.00	1.00	-2.27319*	.82168	.017	-4.2111	-.3353
			3.00	-4.53774*	.68354	.000	-6.1450	-2.9305

Appendix III - Statistical Analysis Output

IV.2.1 Oxidation of Benzyl Alcohol: Synthesis of Benzoic Acid

3.00	1.00	2.26455 *	.77739	.011	.4293	4.0998
	2.00	4.53774 *	.68354	.000	2.9305	6.1450

*. The mean difference is significant at the 0.05 level.

Appendix III - Statistical Analysis Output
IV.2.2 Organic Functional Groups

IV.2.2 Organic Functional Groups

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	1.00	117	7.7991	1.54398	.14274	7.5164	8.0819	1.00	10.00
	2.00	169	7.5207	1.64421	.12648	7.2710	7.7704	1.00	10.00
	3.00	76	6.4605	2.32345	.26652	5.9296	6.9915	1.00	10.00
	Total	362	7.3881	1.84114	.09677	7.1978	7.5784	1.00	10.00
Q2	1.00	117	8.1453	1.51011	.13961	7.8688	8.4218	3.00	10.00
	2.00	169	8.0592	1.53803	.11831	7.8256	8.2927	1.00	10.00
	3.00	75	6.6267	2.24676	.25943	6.1097	7.1436	1.00	10.00
	Total	361	7.7895	1.79815	.09464	7.6034	7.9756	1.00	10.00
Q3	1.00	116	8.0431	1.62797	.15115	7.7437	8.3425	2.00	10.00
	2.00	169	7.9172	1.72661	.13282	7.6550	8.1794	1.00	10.00
	3.00	76	6.6842	2.24624	.25766	6.1709	7.1975	1.00	10.00
	Total	361	7.6981	1.88863	.09940	7.5026	7.8935	1.00	10.00
Q4	1.00	117	8.1197	1.64612	.15218	7.8182	8.4211	2.00	10.00
	2.00	168	7.8155	1.82347	.14068	7.5377	8.0932	1.00	10.00
	3.00	75	7.0000	2.43288	.28093	6.4402	7.5598	1.00	10.00
	Total	360	7.7444	1.95099	.10283	7.5422	7.9467	1.00	10.00
Q5	1.00	115	8.3391	1.84432	.17198	7.9984	8.6798	1.00	10.00
	2.00	168	8.4375	1.72007	.13271	8.1755	8.6995	1.00	10.00
	3.00	76	6.0395	2.58426	.29644	5.4489	6.6300	1.00	10.00
	Total	359	7.8983	2.18970	.11557	7.6711	8.1256	1.00	10.00
Q6	1.00	117	7.8632	1.79993	.16640	7.5337	8.1928	1.00	10.00
	2.00	168	7.8125	1.67286	.12906	7.5577	8.0673	1.00	10.00
	3.00	76	6.9342	2.24699	.25775	6.4208	7.4477	1.00	10.00
	Total	361	7.6440	1.87861	.09887	7.4496	7.8385	1.00	10.00
Q7	1.00	117	8.4487	1.25496	.11602	8.2189	8.6785	4.00	10.00
	2.00	168	8.4018	1.54596	.11927	8.1663	8.6373	1.00	10.00
	3.00	76	7.8816	1.93885	.22240	7.4385	8.3246	1.00	10.00
	Total	361	8.3075	1.56469	.08235	8.1455	8.4694	1.00	10.00
Q8	1.00	117	7.7778	1.86673	.17258	7.4360	8.1196	1.00	10.00
	2.00	168	7.8304	1.82615	.14089	7.5522	8.1085	1.00	10.00
	3.00	76	6.5263	2.47911	.28437	5.9598	7.0928	1.00	10.00
	Total	361	7.5388	2.05545	.10818	7.3260	7.7515	1.00	10.00

Appendix III - Statistical Analysis Output

IV.2.2 Organic Functional Groups

QTotal	1.00	117	8.1410	1.29961	.12015	7.9031	8.3790	4.00	10.00
	2.00	166	7.8765	1.46932	.11404	7.6513	8.1017	1.00	10.00
	3.00	75	6.5667	2.28735	.26412	6.0404	7.0929	1.00	10.00
	Total	358	7.6885	1.72599	.09122	7.5091	7.8679	1.00	10.00
C1	1.00	199	17.9548	2.15860	.15302	17.6530	18.2565	10.00	20.00
	2.00	233	17.9356	2.89808	.18986	17.5616	18.3097	5.00	20.00
	3.00	109	18.1147	2.33297	.22346	17.6717	18.5576	3.00	20.00
	Total	541	17.9787	2.53184	.10885	17.7649	18.1926	3.00	20.00
C2	1.00	199	33.4221	3.59049	.25452	32.9202	33.9240	24.00	40.00
	2.00	233	32.0730	4.32204	.28315	31.5151	32.6308	3.00	40.00
	3.00	109	32.9174	3.09758	.29669	32.3293	33.5055	25.00	40.00
	Total	541	32.7394	3.87830	.16674	32.4118	33.0669	3.00	40.00
C3	1.00	199	33.6482	3.78152	.26806	33.1196	34.1769	24.00	40.00
	2.00	233	31.8026	4.61954	.30264	31.2063	32.3988	5.00	40.00
	3.00	109	33.0917	3.18137	.30472	32.4877	33.6958	24.00	40.00
	Total	541	32.7412	4.14053	.17802	32.3915	33.0909	5.00	40.00
Grade	1.00	199	85.0251	8.08318	.57300	83.8952	86.1551	65.00	100.00
	2.00	233	81.8112	9.23314	.60488	80.6194	83.0029	40.00	100.00
	3.00	109	84.1239	6.68302	.64012	82.8550	85.3927	64.00	100.00
	Total	541	83.4593	8.46645	.36400	82.7443	84.1744	40.00	100.00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Q1	8.423	2	359	.000
Q2	9.379	2	358	.000
Q3	7.708	2	358	.001
Q4	5.969	2	357	.003
Q5	12.317	2	356	.000
Q6	4.187	2	358	.016
Q7	2.482	2	358	.085
Q8	6.140	2	358	.002
QTotal	17.304	2	355	.000
C1	8.416	2	538	.000
C2	2.271	2	538	.104
C3	3.997	2	538	.019
Grade	4.952	2	538	.007

Appendix III - Statistical Analysis Output
IV.2.2 Organic Functional Groups

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Q1	Between Groups	88.130	2	44.065	13.930	.000
	Within Groups	1135.589	359	3.163		
	Total	1223.719	361			
Q2	Between Groups	128.515	2	64.258	22.216	.000
	Within Groups	1035.485	358	2.892		
	Total	1164.000	360			
Q3	Between Groups	100.043	2	50.021	15.124	.000
	Within Groups	1184.046	358	3.307		
	Total	1284.089	360			
Q4	Between Groups	58.884	2	29.442	8.038	.000
	Within Groups	1307.605	357	3.663		
	Total	1366.489	359			
Q5	Between Groups	333.790	2	166.895	42.968	.000
	Within Groups	1382.749	356	3.884		
	Total	1716.539	358			
Q6	Between Groups	48.683	2	24.341	7.132	.001
	Within Groups	1221.827	358	3.413		
	Total	1270.510	360			
Q7	Between Groups	17.614	2	8.807	3.650	.027
	Within Groups	863.756	358	2.413		
	Total	881.370	360			
Q8	Between Groups	98.872	2	49.436	12.445	.000
	Within Groups	1422.085	358	3.972		
	Total	1520.957	360			
QTotal	Between Groups	124.215	2	62.107	23.473	.000
	Within Groups	939.308	355	2.646		
	Total	1063.523	357			
C1	Between Groups	2.562	2	1.281	.199	.819
	Within Groups	3458.944	538	6.429		
	Total	3461.506	540			
C2	Between Groups	199.692	2	99.846	6.780	.001
	Within Groups	7922.559	538	14.726		
	Total	8122.251	540			
C3	Between Groups	382.393	2	191.196	11.590	.000
	Within Groups	8875.378	538	16.497		
	Total	9257.771	540			

Appendix III - Statistical Analysis Output
IV.2.2 Organic Functional Groups

Grade	Between Groups	1168.962	2	584.481	8.377	.000
	Within Groups	37538.643	538	69.774		
	Total	38707.605	540			

Multiple Comparisons

		(I) (J)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Q1	Tukey HSD	1.00	2.00	.27844	.21390	.395	-.2250	.7818
			3.00	1.33862 [*]	.26202	.000	.7220	1.9553
		2.00	1.00	-.27844	.21390	.395	-.7818	.2250
			3.00	1.06018 [*]	.24564	.000	.4821	1.6383
		3.00	1.00	-1.33862 [*]	.26202	.000	-1.9553	-.7220
			2.00	-1.06018 [*]	.24564	.000	-1.6383	-.4821
	Games-Howell	1.00	2.00	.27844	.19071	.312	-.1711	.7280
			3.00	1.33862 [*]	.30234	.000	.6210	2.0563
		2.00	1.00	-.27844	.19071	.312	-.7280	.1711
			3.00	1.06018 [*]	.29501	.001	.3593	1.7611
		3.00	1.00	-1.33862 [*]	.30234	.000	-2.0563	-.6210
			2.00	-1.06018 [*]	.29501	.001	-1.7611	-.3593
Q2	Tukey HSD	1.00	2.00	.08613	.20454	.907	-.3953	.5675
			3.00	1.51863 [*]	.25157	.000	.9266	2.1107
		2.00	1.00	-.08613	.20454	.907	-.5675	.3953
			3.00	1.43250 [*]	.23597	.000	.8772	1.9879
		3.00	1.00	-1.51863 [*]	.25157	.000	-2.1107	-.9266
			2.00	-1.43250 [*]	.23597	.000	-1.9879	-.8772
	Games-Howell	1.00	2.00	.08613	.18300	.885	-.3453	.5176
			3.00	1.51863 [*]	.29461	.000	.8192	2.2180
		2.00	1.00	-.08613	.18300	.885	-.5176	.3453
			3.00	1.43250 [*]	.28514	.000	.7547	2.1103
		3.00	1.00	-1.51863 [*]	.29461	.000	-2.2180	-.8192
			2.00	-1.43250 [*]	.28514	.000	-2.1103	-.7547
Q3	Tukey HSD	1.00	2.00	.12594	.21928	.834	-.3901	.6420
			3.00	1.35889 [*]	.26838	.000	.7272	1.9905
		2.00	1.00	-.12594	.21928	.834	-.6420	.3901
			3.00	1.23295 [*]	.25117	.000	.6418	1.8241
		3.00	1.00	-1.35889 [*]	.26838	.000	-1.9905	-.7272
			2.00	-1.23295 [*]	.25117	.000	-1.8241	-.6418

Appendix III - Statistical Analysis Output
IV.2.2 Organic Functional Groups

	Games- Howell	1.00	2.00	.12594	.20122	.806	-.3484	.6003	
			3.00	1.35889 [*]	.29873	.000	.6504	2.0674	
		2.00	1.00	-.12594	.20122	.806	-.6003	.3484	
			3.00	1.23295 [*]	.28988	.000	.5448	1.9211	
		3.00	1.00	-1.35889 [*]	.29873	.000	-2.0674	-.6504	
			2.00	-1.23295 [*]	.28988	.000	-1.9211	-.5448	
	Q4	Tukey HSD	1.00	2.00	.30418	.23045	.385	-.2382	.8466
				3.00	1.11966 [*]	.28309	.000	.4534	1.7859
			2.00	1.00	-.30418	.23045	.385	-.8466	.2382
				3.00	.81548 [*]	.26578	.007	.1900	1.4410
			3.00	1.00	-1.11966 [*]	.28309	.000	-1.7859	-.4534
				2.00	-.81548 [*]	.26578	.007	-1.4410	-.1900
Games- Howell		1.00	2.00	.30418	.20725	.308	-.1843	.7927	
			3.00	1.11966 [*]	.31950	.002	.3612	1.8781	
		2.00	1.00	-.30418	.20725	.308	-.7927	.1843	
			3.00	.81548 [*]	.31418	.029	.0693	1.5617	
		3.00	1.00	-1.11966 [*]	.31950	.002	-1.8781	-.3612	
			2.00	-.81548 [*]	.31418	.029	-1.5617	-.0693	
Q5	Tukey HSD	1.00	2.00	-.09837	.23853	.911	-.6598	.4630	
			3.00	2.29966 [*]	.29135	.000	1.6140	2.9854	
		2.00	1.00	.09837	.23853	.911	-.4630	.6598	
			3.00	2.39803 [*]	.27245	.000	1.7568	3.0392	
		3.00	1.00	-2.29966 [*]	.29135	.000	-2.9854	-1.6140	
			2.00	-2.39803 [*]	.27245	.000	-3.0392	-1.7568	
	Games- Howell	1.00	2.00	-.09837	.21723	.893	-.6108	.4140	
			3.00	2.29966 [*]	.34271	.000	1.4867	3.1126	
		2.00	1.00	.09837	.21723	.893	-.4140	.6108	
			3.00	2.39803 [*]	.32478	.000	1.6260	3.1700	
		3.00	1.00	-2.29966 [*]	.34271	.000	-3.1126	-1.4867	
			2.00	-2.39803 [*]	.32478	.000	-3.1700	-1.6260	
Q6	Tukey HSD	1.00	2.00	.05075	.22245	.972	-.4728	.5743	
			3.00	.92904 [*]	.27217	.002	.2885	1.5696	
		2.00	1.00	-.05075	.22245	.972	-.5743	.4728	
			3.00	.87829 [*]	.25539	.002	.2772	1.4793	
		3.00	1.00	-.92904 [*]	.27217	.002	-1.5696	-.2885	
			2.00	-.87829 [*]	.25539	.002	-1.4793	-.2772	
	Games- Howell	1.00	2.00	.05075	.21059	.968	-.4459	.5474	
			3.00	.92904 [*]	.30680	.008	.2020	1.6561	
		2.00	1.00	-.05075	.21059	.968	-.5474	.4459	
			3.00	.87829 [*]	.28826	.008	.1938	1.5628	
		3.00	1.00	-.92904 [*]	.30680	.008	-1.6561	-.2020	

Appendix III - Statistical Analysis Output
IV.2.2 Organic Functional Groups

			2.00	-.87829*	.28826	.008	-1.5628	-.1938
Q7	Tukey HSD	1.00	2.00	.04693	.18704	.966	-.3933	.4871
			3.00	.56714*	.22884	.036	.0286	1.1057
		2.00	1.00	-.04693	.18704	.966	-.4871	.3933
			3.00	.52021*	.21473	.042	.0148	1.0256
		3.00	1.00	-.56714*	.22884	.036	-1.1057	-.0286
			2.00	-.52021*	.21473	.042	-1.0256	-.0148
	Games- Howell	1.00	2.00	.04693	.16639	.957	-.3452	.4390
			3.00	.56714	.25084	.066	-.0284	1.1627
		2.00	1.00	-.04693	.16639	.957	-.4390	.3452
			3.00	.52021	.25237	.102	-.0787	1.1191
		3.00	1.00	-.56714	.25084	.066	-1.1627	.0284
			2.00	-.52021	.25237	.102	-1.1191	.0787
Q8	Tukey HSD	1.00	2.00	-.05258	.23999	.974	-.6174	.5122
			3.00	1.25146*	.29363	.000	.5604	1.9425
		2.00	1.00	.05258	.23999	.974	-.5122	.6174
			3.00	1.30404*	.27552	.000	.6556	1.9525
		3.00	1.00	-1.25146*	.29363	.000	-1.9425	-.5604
			2.00	-1.30404*	.27552	.000	-1.9525	-.6556
	Games- Howell	1.00	2.00	-.05258	.22279	.970	-.5779	.4727
			3.00	1.25146*	.33264	.001	.4627	2.0402
		2.00	1.00	.05258	.22279	.970	-.4727	.5779
			3.00	1.30404*	.31736	.000	.5503	2.0577
		3.00	1.00	-1.25146*	.33264	.001	-2.0402	-.4627
			2.00	-1.30404*	.31736	.000	-2.0577	-.5503
QTotal	Tukey HSD	1.00	2.00	.26452	.19635	.370	-.1976	.7267
			3.00	1.57436*	.24061	.000	1.0081	2.1407
		2.00	1.00	-.26452	.19635	.370	-.7267	.1976
			3.00	1.30984*	.22632	.000	.7772	1.8425
		3.00	1.00	-1.57436*	.24061	.000	-2.1407	-1.0081
			2.00	-1.30984*	.22632	.000	-1.8425	-.7772
	Games- Howell	1.00	2.00	.26452	.16565	.249	-.1259	.6549
			3.00	1.57436*	.29016	.000	.8845	2.2642
		2.00	1.00	-.26452	.16565	.249	-.6549	.1259
			3.00	1.30984*	.28769	.000	.6257	1.9940
		3.00	1.00	-1.57436*	.29016	.000	-2.2642	-.8845
			2.00	-1.30984*	.28769	.000	-1.9940	-.6257
C1	Tukey HSD	1.00	2.00	.01915	.24475	.997	-.5561	.5944
			3.00	-.15991	.30215	.857	-.8700	.5502
		2.00	1.00	-.01915	.24475	.997	-.5944	.5561
			3.00	-.17906	.29424	.816	-.8706	.5125

Appendix III - Statistical Analysis Output

IV.2.2 Organic Functional Groups

		3.00	1.00	.15991	.30215	.857	-.5502	.8700
			2.00	.17906	.29424	.816	-.5125	.8706
	Games- Howell	1.00	2.00	.01915	.24385	.997	-.5544	.5927
			3.00	-.15991	.27083	.825	-.7992	.4794
		2.00	1.00	-.01915	.24385	.997	-.5927	.5544
			3.00	-.17906	.29322	.814	-.8703	.5122
		3.00	1.00	.15991	.27083	.825	-.4794	.7992
			2.00	.17906	.29322	.814	-.5122	.8703
C2	Tukey HSD	1.00	2.00	1.34915*	.37041	.001	.4786	2.2197
			3.00	.50468	.45727	.512	-.5700	1.5794
		2.00	1.00	-1.34915*	.37041	.001	-2.2197	-.4786
			3.00	-.84447	.44531	.141	-1.8910	.2021
		3.00	1.00	-.50468	.45727	.512	-1.5794	.5700
			2.00	.84447	.44531	.141	-.2021	1.8910
	Games- Howell	1.00	2.00	1.34915*	.38073	.001	.4537	2.2446
			3.00	.50468	.39091	.402	-.4170	1.4263
		2.00	1.00	-1.34915*	.38073	.001	-2.2446	-.4537
			3.00	-.84447	.41012	.100	-1.8107	.1218
		3.00	1.00	-.50468	.39091	.402	-1.4263	.4170
			2.00	.84447	.41012	.100	-.1218	1.8107
C3	Tukey HSD	1.00	2.00	1.84567*	.39205	.000	.9243	2.7671
			3.00	.55650	.48399	.484	-.5810	1.6940
		2.00	1.00	-1.84567*	.39205	.000	-2.7671	-.9243
			3.00	-1.28917*	.47133	.018	-2.3969	-.1814
		3.00	1.00	-.55650	.48399	.484	-1.6940	.5810
			2.00	1.28917*	.47133	.018	.1814	2.3969
	Games- Howell	1.00	2.00	1.84567*	.40429	.000	.8948	2.7965
			3.00	.55650	.40585	.358	-.4003	1.5133
		2.00	1.00	-1.84567*	.40429	.000	-2.7965	-.8948
			3.00	-1.28917*	.42947	.008	-2.3009	-.2775
		3.00	1.00	-.55650	.40585	.358	-1.5133	.4003
			2.00	1.28917*	.42947	.008	.2775	2.3009
Grade	Tukey HSD	1.00	2.00	3.21397*	.80628	.000	1.3190	5.1089
			3.00	.90127	.99537	.637	-1.4381	3.2406
		2.00	1.00	-3.21397*	.80628	.000	-5.1089	-1.3190
			3.00	-2.31269*	.96933	.046	-4.5908	-.0346
		3.00	1.00	-.90127	.99537	.637	-3.2406	1.4381
			2.00	2.31269*	.96933	.046	.0346	4.5908
	Games- Howell	1.00	2.00	3.21397*	.83319	.000	1.2544	5.1735
			3.00	.90127	.85912	.547	-1.1239	2.9264

Appendix III - Statistical Analysis Output

IV.2.2 Organic Functional Groups

2.00	1.00	-3.21397 *	.83319	.000	-5.1735	-1.2544
	3.00	-2.31269 *	.88070	.025	-4.3878	-.2376
3.00	1.00	-.90127	.85912	.547	-2.9264	1.1239
	2.00	2.31269 *	.88070	.025	.2376	4.3878

*. The mean difference is significant at the 0.05 level.

Appendix III - Statistical Analysis Output
IV.2.3 Thermochemistry: Enthalpy of Neutralisation

IV.2.3 Thermochemistry: Enthalpy of Neutralisation

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	1.00	87	6.4943	2.52832	.27106	5.9554	7.0331	1.00	10.00
	2.00	121	7.2397	1.92797	.17527	6.8926	7.5867	1.00	10.00
	3.00	53	6.8396	2.16567	.29748	6.2427	7.4366	1.00	10.00
	Total	261	6.9100	2.20849	.13670	6.6408	7.1791	1.00	10.00
Q2	1.00	87	7.1149	2.58540	.27718	6.5639	7.6660	1.00	10.00
	2.00	121	7.7521	1.45075	.13189	7.4909	8.0132	3.00	10.00
	3.00	53	7.4245	2.03195	.27911	6.8645	7.9846	1.00	10.00
	Total	261	7.4732	2.02182	.12515	7.2267	7.7196	1.00	10.00
Q3	1.00	87	7.3793	2.34393	.25130	6.8798	7.8789	1.00	10.00
	2.00	120	7.7917	1.39565	.12740	7.5394	8.0439	3.00	10.00
	3.00	53	7.6604	2.26973	.31177	7.0348	8.2860	1.00	10.00
	Total	260	7.6269	1.94600	.12069	7.3893	7.8646	1.00	10.00
Q4	1.00	86	6.9477	2.51353	.27104	6.4088	7.4866	1.00	10.00
	2.00	119	7.2731	2.04685	.18763	6.9015	7.6447	1.00	10.00
	3.00	53	7.1132	2.34447	.32204	6.4670	7.7594	1.00	10.00
	Total	258	7.1318	2.26848	.14123	6.8537	7.4099	1.00	10.00
Q5	1.00	87	7.4713	2.42966	.26049	6.9534	7.9891	1.00	10.00
	2.00	121	7.4298	2.25398	.20491	7.0240	7.8355	1.00	10.00
	3.00	53	7.7925	2.05088	.28171	7.2272	8.3577	1.00	10.00
	Total	261	7.5172	2.27120	.14058	7.2404	7.7941	1.00	10.00
Q6	1.00	86	6.9884	2.41317	.26022	6.4710	7.5058	1.00	10.00
	2.00	120	7.3000	2.11676	.19323	6.9174	7.6826	1.00	10.00
	3.00	53	7.3208	2.40811	.33078	6.6570	7.9845	1.00	10.00
	Total	259	7.2008	2.27521	.14137	6.9224	7.4792	1.00	10.00
Q7	1.00	86	7.5000	2.41929	.26088	6.9813	8.0187	1.00	10.00
	2.00	120	8.1917	1.42041	.12967	7.9349	8.4484	4.00	10.00
	3.00	53	7.8491	2.00381	.27524	7.2967	8.4014	1.00	10.00
	Total	259	7.8919	1.93946	.12051	7.6546	8.1292	1.00	10.00
Q8	1.00	86	6.1744	2.68412	.28944	5.5989	6.7499	1.00	10.00
	2.00	119	6.8992	2.30473	.21127	6.4808	7.3175	1.00	10.00
	3.00	53	6.8113	2.39436	.32889	6.1514	7.4713	1.00	10.00
	Total	258	6.6395	2.46807	.15366	6.3370	6.9421	1.00	10.00

Appendix III - Statistical Analysis Output
IV.2.3 Thermochemistry: Enthalpy of Neutralisation

QTotal	1.00	86	6.8198	2.32747	.25098	6.3208	7.3188	1.00	10.00
	2.00	119	7.3319	1.90814	.17492	6.9855	7.6783	1.00	10.00
	3.00	53	7.1509	2.12491	.29188	6.5652	7.7366	1.00	10.00
	Total	258	7.1240	2.10431	.13101	6.8660	7.3820	1.00	10.00
C1	1.00	188	18.6117	1.67819	.12239	18.3703	18.8532	12.00	20.00
	2.00	230	18.4043	2.44002	.16089	18.0873	18.7214	5.00	20.00
	3.00	79	18.5696	1.51644	.17061	18.2300	18.9093	14.00	20.00
	Total	497	18.5091	2.04496	.09173	18.3288	18.6893	5.00	20.00
C2	1.00	188	32.6277	3.56148	.25975	32.1152	33.1401	18.00	39.00
	2.00	230	32.3391	3.75654	.24770	31.8511	32.8272	20.00	40.00
	3.00	79	33.5696	2.71597	.30557	32.9613	34.1780	30.00	40.00
	Total	497	32.6439	3.55486	.15946	32.3306	32.9572	18.00	40.00
C3	1.00	188	33.1596	3.49883	.25518	32.6562	33.6630	24.00	39.00
	2.00	230	32.1087	3.72076	.24534	31.6253	32.5921	10.00	40.00
	3.00	79	34.2911	2.72289	.30635	33.6812	34.9010	30.00	40.00
	Total	497	32.8531	3.57700	.16045	32.5379	33.1684	10.00	40.00
Grade	1.00	188	84.3989	7.17433	.52324	83.3667	85.4312	67.00	98.00
	2.00	230	82.8522	6.81348	.44927	81.9669	83.7374	57.00	100.00
	3.00	79	86.4304	5.69679	.64094	85.1544	87.7064	76.00	100.00
	Total	497	84.0060	6.89597	.30933	83.3983	84.6138	57.00	100.00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Q1	5.127	2	258	.007
Q2	11.455	2	258	.000
Q3	10.356	2	257	.000
Q4	3.276	2	255	.039
Q5	.899	2	258	.408
Q6	.955	2	256	.386
Q7	8.188	2	256	.000
Q8	2.230	2	255	.110
QTotal	2.441	2	255	.089
C1	5.394	2	494	.005
C2	3.144	2	494	.044
C3	3.786	2	494	.023
Grade	2.616	2	494	.074

Appendix III - Statistical Analysis Output
IV.2.3 Thermochemistry: Enthalpy of Neutralisation

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Q1	Between Groups	28.451	2	14.225	2.961	.054
	Within Groups	1239.684	258	4.805		
	Total	1268.134	260			
Q2	Between Groups	20.702	2	10.351	2.563	.079
	Within Groups	1042.111	258	4.039		
	Total	1062.812	260			
Q3	Between Groups	8.650	2	4.325	1.143	.320
	Within Groups	972.161	257	3.783		
	Total	980.812	259			
Q4	Between Groups	5.310	2	2.655	.514	.599
	Within Groups	1317.209	255	5.166		
	Total	1322.519	257			
Q5	Between Groups	5.124	2	2.562	.495	.610
	Within Groups	1336.048	258	5.178		
	Total	1341.172	260			
Q6	Between Groups	5.824	2	2.912	.561	.572
	Within Groups	1329.736	256	5.194		
	Total	1335.560	258			
Q7	Between Groups	24.089	2	12.044	3.258	.040
	Within Groups	946.384	256	3.697		
	Total	970.473	258			
Q8	Between Groups	28.190	2	14.095	2.338	.099
	Within Groups	1537.287	255	6.029		
	Total	1565.477	257			
QTotal	Between Groups	13.144	2	6.572	1.490	.227
	Within Groups	1124.888	255	4.411		
	Total	1138.031	257			
C1	Between Groups	4.792	2	2.396	.572	.565
	Within Groups	2069.417	494	4.189		
	Total	2074.209	496			
C2	Between Groups	89.113	2	44.556	3.562	.029
	Within Groups	6178.851	494	12.508		
	Total	6267.964	496			
C3	Between Groups	308.478	2	154.239	12.620	.000
	Within Groups	6037.799	494	12.222		
	Total	6346.278	496			

Appendix III - Statistical Analysis Output
IV.2.3 Thermochemistry: Enthalpy of Neutralisation

Grade	Between Groups	799.561	2	399.781	8.667	.000
	Within Groups	22787.421	494	46.128		
	Total	23586.982	496			

Multiple Comparisons

		(I) (J)		Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Q1	Tukey HSD	1.00	2.00	-.74542 [*]	.30812	.043	-1.4718	-.0191
			3.00	-.34537	.38195	.638	-1.2458	.5550
		2.00	1.00	.74542 [*]	.30812	.043	.0191	1.4718
			3.00	.40005	.36107	.510	-.4511	1.2512
		3.00	1.00	.34537	.38195	.638	-.5550	1.2458
			2.00	-.40005	.36107	.510	-1.2512	.4511
	Games-Howell	1.00	2.00	-.74542	.32279	.057	-1.5094	.0185
			3.00	-.34537	.40245	.668	-1.3002	.6094
		2.00	1.00	.74542	.32279	.057	-.0185	1.5094
			3.00	.40005	.34527	.481	-.4228	1.2229
		3.00	1.00	.34537	.40245	.668	-.6094	1.3002
			2.00	-.40005	.34527	.481	-1.2229	.4228
Q2	Tukey HSD	1.00	2.00	-.63712	.28251	.064	-1.3031	.0288
			3.00	-.30959	.35020	.651	-1.1351	.5159
		2.00	1.00	.63712	.28251	.064	-.0288	1.3031
			3.00	.32754	.33105	.584	-.4528	1.1079
		3.00	1.00	.30959	.35020	.651	-.5159	1.1351
			2.00	-.32754	.33105	.584	-1.1079	.4528
	Games-Howell	1.00	2.00	-.63712	.30696	.099	-1.3652	.0910
			3.00	-.30959	.39336	.712	-1.2423	.6231
		2.00	1.00	.63712	.30696	.099	-.0910	1.3652
			3.00	.32754	.30870	.541	-.4104	1.0654
		3.00	1.00	.30959	.39336	.712	-.6231	1.2423
			2.00	-.32754	.30870	.541	-1.0654	.4104
Q3	Tukey HSD	1.00	2.00	-.41236	.27387	.290	-1.0580	.2332
			3.00	-.28107	.33890	.685	-1.0800	.5178
		2.00	1.00	.41236	.27387	.290	-.2332	1.0580
			3.00	.13129	.32077	.912	-.6249	.8875
		3.00	1.00	.28107	.33890	.685	-.5178	1.0800
			2.00	-.13129	.32077	.912	-.8875	.6249

Appendix III - Statistical Analysis Output
IV.2.3 Thermochemistry: Enthalpy of Neutralisation

	Games- Howell	1.00	2.00	-.41236	.28175	.312	-1.0804	.2556
			3.00	-.28107	.40044	.763	-1.2321	.6700
		2.00	1.00	.41236	.28175	.312	-.2556	1.0804
			3.00	.13129	.33680	.920	-.6752	.9378
		3.00	1.00	.28107	.40044	.763	-.6700	1.2321
			2.00	-.13129	.33680	.920	-.9378	.6752
		1.00	2.00	-.32543	.32167	.570	-1.0838	.4329
			3.00	-.16553	.39690	.909	-1.1012	.7701
		2.00	1.00	.32543	.32167	.570	-.4329	1.0838
			3.00	.15990	.37533	.905	-.7249	1.0447
Q4	Tukey HSD	3.00	1.00	.16553	.39690	.909	-.7701	1.1012
			2.00	-.15990	.37533	.905	-1.0447	.7249
		1.00	2.00	-.32543	.32965	.586	-1.1053	.4544
			3.00	-.16553	.42092	.918	-1.1649	.8338
		2.00	1.00	.32543	.32965	.586	-.4544	1.1053
	Games- Howell		3.00	.15990	.37271	.904	-.7285	1.0483
		3.00	1.00	.16553	.42092	.918	-.8338	1.1649
			2.00	-.15990	.37271	.904	-1.0483	.7285
		1.00	2.00	.04151	.31988	.991	-.7125	.7956
			3.00	-.32119	.39652	.697	-1.2559	.6135
Q5	Tukey HSD	2.00	1.00	-.04151	.31988	.991	-.7956	.7125
			3.00	-.36270	.37484	.598	-1.2463	.5209
		3.00	1.00	.32119	.39652	.697	-.6135	1.2559
			2.00	.36270	.37484	.598	-.5209	1.2463
		1.00	2.00	.04151	.33142	.991	-.7418	.8249
	Games- Howell		3.00	-.32119	.38368	.681	-1.2314	.5890
		2.00	1.00	-.04151	.33142	.991	-.8249	.7418
			3.00	-.36270	.34835	.553	-1.1905	.4651
		3.00	1.00	.32119	.38368	.681	-.5890	1.2314
			2.00	.36270	.34835	.553	-.4651	1.1905
Q6	Tukey HSD	1.00	2.00	-.31163	.32200	.598	-1.0707	.4475
			3.00	-.33238	.39800	.682	-1.2706	.6059
		2.00	1.00	.31163	.32200	.598	-.4475	1.0707
			3.00	-.02075	.37589	.998	-.9069	.8654
		3.00	1.00	.33238	.39800	.682	-.6059	1.2706
	Games- Howell		2.00	.02075	.37589	.998	-.8654	.9069
		1.00	2.00	-.31163	.32412	.602	-1.0781	.4548
			3.00	-.33238	.42087	.710	-1.3323	.6675
		2.00	1.00	.31163	.32412	.602	-.4548	1.0781
			3.00	-.02075	.38308	.998	-.9339	.8923
		3.00	1.00	.33238	.42087	.710	-.6675	1.3323

Appendix III - Statistical Analysis Output
IV.2.3 Thermochemistry: Enthalpy of Neutralisation

			2.00	.02075	.38308	.998	-.8923	.9339
Q7	Tukey HSD	1.00	2.00	-.69167*	.27165	.031	-1.3321	-.0513
			3.00	-.34906	.33576	.553	-1.1406	.4425
		2.00	1.00	.69167*	.27165	.031	.0513	1.3321
			3.00	.34261	.31711	.527	-.4050	1.0902
		3.00	1.00	.34906	.33576	.553	-.4425	1.1406
			2.00	-.34261	.31711	.527	-1.0902	.4050
	Games- Howell	1.00	2.00	-.69167*	.29133	.050	-1.3826	-.0008
			3.00	-.34906	.37923	.628	-1.2485	.5504
		2.00	1.00	.69167*	.29133	.050	.0008	1.3826
			3.00	.34261	.30426	.501	-.3847	1.0699
		3.00	1.00	.34906	.37923	.628	-.5504	1.2485
			2.00	-.34261	.30426	.501	-1.0699	.3847
Q8	Tukey HSD	1.00	2.00	-.72474	.34751	.095	-1.5440	.0945
			3.00	-.63690	.42877	.300	-1.6477	.3739
		2.00	1.00	.72474	.34751	.095	-.0945	1.5440
			3.00	.08784	.40547	.974	-.8681	1.0437
		3.00	1.00	.63690	.42877	.300	-.3739	1.6477
			2.00	-.08784	.40547	.974	-1.0437	.8681
	Games- Howell	1.00	2.00	-.72474	.35834	.110	-1.5722	.1227
			3.00	-.63690	.43811	.317	-1.6766	.4028
		2.00	1.00	.72474	.35834	.110	-.1227	1.5722
			3.00	.08784	.39090	.973	-.8427	1.0183
		3.00	1.00	.63690	.43811	.317	-.4028	1.6766
			2.00	-.08784	.39090	.973	-1.0183	.8427
QTotal	Tukey HSD	1.00	2.00	-.51217	.29726	.199	-1.2130	.1886
			3.00	-.33118	.36678	.639	-1.1959	.5335
		2.00	1.00	.51217	.29726	.199	-.1886	1.2130
			3.00	.18099	.34685	.861	-.6367	.9987
		3.00	1.00	.33118	.36678	.639	-.5335	1.1959
			2.00	-.18099	.34685	.861	-.9987	.6367
	Games- Howell	1.00	2.00	-.51217	.30592	.218	-1.2359	.2115
			3.00	-.33118	.38495	.666	-1.2449	.5826
		2.00	1.00	.51217	.30592	.218	-.2115	1.2359
			3.00	.18099	.34028	.856	-.6298	.9918
		3.00	1.00	.33118	.38495	.666	-.5826	1.2449
			2.00	-.18099	.34028	.856	-.9918	.6298
C1	Tukey HSD	1.00	2.00	.20735	.20124	.558	-.2657	.6804
			3.00	.04208	.27443	.987	-.6030	.6872
		2.00	1.00	-.20735	.20124	.558	-.6804	.2657
			3.00	-.16527	.26691	.810	-.7927	.4622

Appendix III - Statistical Analysis Output
IV.2.3 Thermochemistry: Enthalpy of Neutralisation

		3.00	1.00	-.04208	.27443	.987	-.6872	.6030
			2.00	.16527	.26691	.810	-.4622	.7927
	Games- Howell	1.00	2.00	.20735	.20215	.561	-.2682	.6829
			3.00	.04208	.20997	.978	-.4546	.5388
		2.00	1.00	-.20735	.20215	.561	-.6829	.2682
			3.00	-.16527	.23451	.761	-.7187	.3881
		3.00	1.00	-.04208	.20997	.978	-.5388	.4546
			2.00	.16527	.23451	.761	-.3881	.7187
C2	Tukey HSD	1.00	2.00	.28853	.34772	.685	-.5289	1.1060
			3.00	-.94196	.47419	.117	-2.0567	.1728
		2.00	1.00	-.28853	.34772	.685	-1.1060	.5289
			3.00	-1.23049 *	.46120	.021	-2.3147	-.1463
		3.00	1.00	.94196	.47419	.117	-.1728	2.0567
			2.00	1.23049 *	.46120	.021	.1463	2.3147
	Games- Howell	1.00	2.00	.28853	.35892	.701	-.5558	1.1328
			3.00	-.94196	.40105	.052	-1.8893	.0054
		2.00	1.00	-.28853	.35892	.701	-1.1328	.5558
			3.00	-1.23049 *	.39335	.006	-2.1598	-.3012
		3.00	1.00	.94196	.40105	.052	-.0054	1.8893
			2.00	1.23049 *	.39335	.006	.3012	2.1598
C3	Tukey HSD	1.00	2.00	1.05088 *	.34373	.007	.2428	1.8589
			3.00	-1.13156 *	.46875	.043	-2.2335	-.0296
		2.00	1.00	-1.05088 *	.34373	.007	-1.8589	-.2428
			3.00	-2.18244 *	.45591	.000	-3.2542	-1.1107
		3.00	1.00	1.13156 *	.46875	.043	.0296	2.2335
			2.00	2.18244 *	.45591	.000	1.1107	3.2542
	Games- Howell	1.00	2.00	1.05088 *	.35399	.009	.2182	1.8836
			3.00	-1.13156 *	.39871	.014	-2.0735	-.1896
		2.00	1.00	-1.05088 *	.35399	.009	-1.8836	-.2182
			3.00	-2.18244 *	.39248	.000	-3.1098	-1.2551
		3.00	1.00	1.13156 *	.39871	.014	.1896	2.0735
			2.00	2.18244 *	.39248	.000	1.2551	3.1098
Grade	Tukey HSD	1.00	2.00	1.54676	.66777	.054	-.0230	3.1166
			3.00	-2.03144	.91064	.067	-4.1722	.1093
		2.00	1.00	-1.54676	.66777	.054	-3.1166	.0230
			3.00	-3.57821 *	.88570	.000	-5.6603	-1.4961
		3.00	1.00	2.03144	.91064	.067	-.1093	4.1722
			2.00	3.57821 *	.88570	.000	1.4961	5.6603
	Games- Howell	1.00	2.00	1.54676	.68965	.065	-.0758	3.1693
			3.00	-2.03144 *	.82740	.040	-3.9866	-.0763

Appendix III - Statistical Analysis Output
IV.2.3 Thermochemistry: Enthalpy of Neutralisation

2.00	1.00	-1.54676	.68965	.065	-3.1693	.0758
	3.00	-3.57821 *	.78272	.000	-5.4299	-1.7265
3.00	1.00	2.03144 *	.82740	.040	.0763	3.9866
	2.00	3.57821 *	.78272	.000	1.7265	5.4299

*. The mean difference is significant at the 0.05 level.

Appendix III - Statistical Analysis Output

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

Descriptives									
		N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
						Lower Bound	Upper Bound		
Q1	1.00	99	6.8990	2.07755	.20880	6.4846	7.3134	1.00	10.00
	2.00	137	6.7482	1.99919	.17080	6.4104	7.0859	1.00	10.00
	3.00	49	6.1837	2.50561	.35794	5.4640	6.9034	1.00	10.00
	Total	285	6.7035	2.12728	.12601	6.4555	6.9515	1.00	10.00
Q2	1.00	99	7.6061	1.92098	.19307	7.2229	7.9892	1.00	10.00
	2.00	137	7.2007	2.15695	.18428	6.8363	7.5652	1.00	10.00
	3.00	49	6.8469	2.37654	.33951	6.1643	7.5296	1.00	10.00
	Total	285	7.2807	2.12799	.12605	7.0326	7.5288	1.00	10.00
Q3	1.00	99	7.9293	1.83087	.18401	7.5641	8.2945	1.00	10.00
	2.00	136	7.3603	1.99786	.17132	7.0215	7.6991	1.00	10.00
	3.00	49	7.1020	2.25689	.32241	6.4538	7.7503	1.00	10.00
	Total	284	7.5141	2.00745	.11912	7.2796	7.7486	1.00	10.00
Q4	1.00	99	7.4040	2.18958	.22006	6.9673	7.8407	1.00	10.00
	2.00	137	7.1569	1.96827	.16816	6.8244	7.4895	1.00	10.00
	3.00	49	6.7857	2.79881	.39983	5.9818	7.5896	1.00	10.00
	Total	285	7.1789	2.20864	.13083	6.9214	7.4365	1.00	10.00
Q5	1.00	99	8.1717	1.84634	.18556	7.8035	8.5400	1.00	10.00
	2.00	137	8.0620	1.82048	.15553	7.7545	8.3696	2.00	10.00
	3.00	47	7.4468	2.34807	.34250	6.7574	8.1362	1.00	10.00
	Total	283	7.9982	1.93535	.11504	7.7718	8.2247	1.00	10.00
Q6	1.00	98	7.4082	1.91487	.19343	7.0243	7.7921	1.00	10.00
	2.00	137	7.2226	2.01914	.17251	6.8815	7.5638	1.00	10.00
	3.00	48	6.6771	2.52327	.36420	5.9444	7.4098	1.00	10.00
	Total	283	7.1943	2.08576	.12399	6.9503	7.4384	1.00	10.00
Q7	1.00	98	7.8418	1.80434	.18227	7.4801	8.2036	2.00	10.00
	2.00	137	7.7518	1.85020	.15807	7.4392	8.0644	1.00	10.00
	3.00	48	7.7500	2.06799	.29849	7.1495	8.3505	1.00	10.00
	Total	283	7.7827	1.86692	.11098	7.5642	8.0011	1.00	10.00
Q8	1.00	98	6.8929	2.32894	.23526	6.4259	7.3598	1.00	10.00
	2.00	137	6.7044	2.31726	.19798	6.3129	7.0959	1.00	10.00
	3.00	48	5.9375	2.96365	.42777	5.0769	6.7981	1.00	10.00
	Total	283	6.6396	2.45508	.14594	6.3523	6.9268	1.00	10.00

Appendix III - Statistical Analysis Output

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

QTotal	1.00	94	7.4362	1.63008	.16813	7.1023	7.7700	2.00	10.00
	2.00	133	7.2030	1.95114	.16919	6.8683	7.5377	1.00	10.00
	3.00	47	6.7340	2.30277	.33589	6.0579	7.4102	1.00	10.00
	Total	274	7.2026	1.92250	.11614	6.9739	7.4312	1.00	10.00
C1	1.00	196	18.5969	1.81045	.12932	18.3419	18.8520	12.00	20.00
	2.00	225	18.7022	2.43032	.16202	18.3829	19.0215	5.00	20.00
	3.00	47	17.3404	2.76057	.40267	16.5299	18.1510	5.00	20.00
	Total	468	18.5214	2.26073	.10450	18.3160	18.7267	5.00	20.00
C2	1.00	196	33.9949	3.52354	.25168	33.4985	34.4913	25.00	40.00
	2.00	225	31.8000	4.12419	.27495	31.2582	32.3418	20.00	40.00
	3.00	47	33.6809	2.54615	.37139	32.9333	34.4284	30.00	38.00
	Total	468	32.9081	3.88955	.17979	32.5548	33.2614	20.00	40.00
C3	1.00	196	34.5918	3.32461	.23747	34.1235	35.0602	26.00	40.00
	2.00	225	32.0622	3.90463	.26031	31.5493	32.5752	10.00	40.00
	3.00	47	31.8723	5.56236	.81135	30.2392	33.5055	15.00	39.00
	Total	468	33.1026	4.07191	.18822	32.7327	33.4724	10.00	40.00
Grade	1.00	196	87.1837	7.44256	.53161	86.1352	88.2321	68.00	100.00
	2.00	225	82.5644	7.58856	.50590	81.5675	83.5614	45.00	98.00
	3.00	47	82.8936	6.91952	1.00932	80.8620	84.9253	67.00	96.00
	Total	468	84.5321	7.78162	.35971	83.8252	85.2389	45.00	100.00

Test of Homogeneity of Variances

	Levene Statistic	df1	df2	Sig.
Q1	2.623	2	282	.074
Q2	1.537	2	282	.217
Q3	3.047	2	281	.049
Q4	6.524	2	282	.002
Q5	2.388	2	280	.094
Q6	3.801	2	280	.024
Q7	.759	2	280	.469
Q8	4.364	2	280	.014
QTotal	3.038	2	271	.050
C1	1.374	2	465	.254
C2	6.234	2	465	.002
C3	5.019	2	465	.007
Grade	.510	2	465	.601

Appendix III - Statistical Analysis Output

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

		ANOVA				
		Sum of Squares	df	Mean Square	F	Sig.
Q1	Between Groups	17.298	2	8.649	1.924	.148
	Within Groups	1267.899	282	4.496		
	Total	1285.196	284			
Q2	Between Groups	20.576	2	10.288	2.293	.103
	Within Groups	1265.468	282	4.487		
	Total	1286.044	284			
Q3	Between Groups	28.603	2	14.302	3.615	.028
	Within Groups	1111.840	281	3.957		
	Total	1140.444	283			
Q4	Between Groups	12.659	2	6.330	1.300	.274
	Within Groups	1372.714	282	4.868		
	Total	1385.374	284			
Q5	Between Groups	17.829	2	8.914	2.404	.092
	Within Groups	1038.420	280	3.709		
	Total	1056.249	282			
Q6	Between Groups	17.433	2	8.716	2.018	.135
	Within Groups	1209.378	280	4.319		
	Total	1226.811	282			
Q7	Between Groups	.525	2	.262	.075	.928
	Within Groups	982.361	280	3.508		
	Total	982.885	282			
Q8	Between Groups	30.522	2	15.261	2.560	.079
	Within Groups	1669.215	280	5.961		
	Total	1699.737	282			
QTotal	Between Groups	15.447	2	7.723	2.107	.124
	Within Groups	993.561	271	3.666		
	Total	1009.008	273			
C1	Between Groups	74.026	2	37.013	7.442	.001
	Within Groups	2312.760	465	4.974		
	Total	2386.786	467			
C2	Between Groups	535.841	2	267.921	19.081	.000
	Within Groups	6529.208	465	14.041		
	Total	7065.049	467			
C3	Between Groups	749.367	2	374.684	24.912	.000
	Within Groups	6993.710	465	15.040		
	Total	7743.077	467			

Appendix III - Statistical Analysis Output

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

Grade	Between Groups	2375.348	2	1187.674	21.320	.000
	Within Groups	25903.171	465	55.706		
	Total	28278.519	467			

Multiple Comparisons

		(I)	(J)	Mean Difference (I-J)	Std. Error	Sig.	95% Confidence Interval	
							Lower Bound	Upper Bound
Q1	Tukey HSD	1.00	2.00	.15081	.27970	.852	-.5082	.8098
			3.00	.71532	.37037	.132	-.1573	1.5880
		2.00	1.00	-.15081	.27970	.852	-.8098	.5082
			3.00	.56450	.35295	.248	-.2671	1.3961
		3.00	1.00	-.71532	.37037	.132	-1.5880	.1573
			2.00	-.56450	.35295	.248	-1.3961	.2671
	Games- Howell	1.00	2.00	.15081	.26976	.842	-.4860	.7877
			3.00	.71532	.41439	.202	-.2739	1.7046
		2.00	1.00	-.15081	.26976	.842	-.7877	.4860
			3.00	.56450	.39661	.334	-.3849	1.5139
		3.00	1.00	-.71532	.41439	.202	-1.7046	.2739
			2.00	-.56450	.39661	.334	-1.5139	.3849
Q2	Tukey HSD	1.00	2.00	.40533	.27943	.317	-.2531	1.0637
			3.00	.75912	.37001	.102	-.1127	1.6309
		2.00	1.00	-.40533	.27943	.317	-1.0637	.2531
			3.00	.35379	.35261	.575	-.4770	1.1846
		3.00	1.00	-.75912	.37001	.102	-1.6309	.1127
			2.00	-.35379	.35261	.575	-1.1846	.4770
	Games- Howell	1.00	2.00	.40533	.26690	.284	-.2244	1.0350
			3.00	.75912	.39056	.133	-.1736	1.6918
		2.00	1.00	-.40533	.26690	.284	-1.0350	.2244
			3.00	.35379	.38629	.632	-.5692	1.2767
		3.00	1.00	-.75912	.39056	.133	-1.6918	.1736
			2.00	-.35379	.38629	.632	-1.2767	.5692
Q3	Tukey HSD	1.00	2.00	.56900	.26279	.079	-.0502	1.1882
			3.00	.82725*	.34744	.047	.0086	1.6459
		2.00	1.00	-.56900	.26279	.079	-1.1882	.0502
			3.00	.25825	.33143	.716	-.5227	1.0392
		3.00	1.00	-.82725*	.34744	.047	-1.6459	-.0086
			2.00	-.25825	.33143	.716	-1.0392	.5227

Appendix III - Statistical Analysis Output

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

	Games- Howell	1.00	2.00	.56900	.25141	.063	-.0242	1.1622
			3.00	.82725	.37123	.072	-.0592	1.7137
		2.00	1.00	-.56900	.25141	.063	-1.1622	.0242
			3.00	.25825	.36510	.760	-.6143	1.1308
		3.00	1.00	-.82725	.37123	.072	-1.7137	.0592
			2.00	-.25825	.36510	.760	-1.1308	.6143
Q4	Tukey HSD	1.00	2.00	.24711	.29103	.673	-.4386	.9328
			3.00	.61833	.38537	.245	-.2897	1.5263
		2.00	1.00	-.24711	.29103	.673	-.9328	.4386
			3.00	.37122	.36725	.571	-.4941	1.2365
		3.00	1.00	-.61833	.38537	.245	-1.5263	.2897
			2.00	-.37122	.36725	.571	-1.2365	.4941
	Games- Howell	1.00	2.00	.24711	.27696	.646	-.4069	.9011
			3.00	.61833	.45639	.370	-.4721	1.7088
		2.00	1.00	-.24711	.27696	.646	-.9011	.4069
			3.00	.37122	.43375	.670	-.6689	1.4113
		3.00	1.00	-.61833	.45639	.370	-1.7088	.4721
			2.00	-.37122	.43375	.670	-1.4113	.6689
Q5	Tukey HSD	1.00	2.00	.10967	.25403	.902	-.4889	.7082
			3.00	.72491	.34113	.087	-.0789	1.5287
		2.00	1.00	-.10967	.25403	.902	-.7082	.4889
			3.00	.61524	.32554	.143	-.1518	1.3823
		3.00	1.00	-.72491	.34113	.087	-1.5287	.0789
			2.00	-.61524	.32554	.143	-1.3823	.1518
	Games- Howell	1.00	2.00	.10967	.24213	.893	-.4619	.6812
			3.00	.72491	.38954	.157	-.2068	1.6566
		2.00	1.00	-.10967	.24213	.893	-.6812	.4619
			3.00	.61524	.37616	.238	-.2867	1.5172
		3.00	1.00	-.72491	.38954	.157	-1.6566	.2068
			2.00	-.61524	.37616	.238	-1.5172	.2867
Q6	Tukey HSD	1.00	2.00	.18554	.27496	.778	-.4623	.8334
			3.00	.73108	.36614	.115	-.1316	1.5938
		2.00	1.00	-.18554	.27496	.778	-.8334	.4623
			3.00	.54554	.34858	.263	-.2758	1.3669
		3.00	1.00	-.73108	.36614	.115	-1.5938	.1316
			2.00	-.54554	.34858	.263	-1.3669	.2758
	Games- Howell	1.00	2.00	.18554	.25918	.754	-.4261	.7972
			3.00	.73108	.41238	.186	-.2551	1.7173
		2.00	1.00	-.18554	.25918	.754	-.7972	.4261
			3.00	.54554	.40299	.371	-.4197	1.5108
		3.00	1.00	-.73108	.41238	.186	-1.7173	.2551

Appendix III - Statistical Analysis Output

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

			2.00		-.54554	.40299	.371	-1.5108	.4197
Q7	Tukey HSD	1.00	2.00		.09001	.24781	.930	-.4939	.6739
			3.00		.09184	.32999	.958	-.6857	.8694
		2.00	1.00		-.09001	.24781	.930	-.6739	.4939
			3.00		.00182	.31417	1.000	-.7384	.7421
		3.00	1.00		-.09184	.32999	.958	-.8694	.6857
			2.00		-.00182	.31417	1.000	-.7421	.7384
	Games- Howell	1.00	2.00		.09001	.24126	.926	-.4794	.6595
			3.00		.09184	.34974	.963	-.7428	.9265
		2.00	1.00		-.09001	.24126	.926	-.6595	.4794
			3.00		.00182	.33776	1.000	-.8058	.8094
		3.00	1.00		-.09184	.34974	.963	-.9265	.7428
			2.00		-.00182	.33776	1.000	-.8094	.8058
Q8	Tukey HSD	1.00	2.00		.18848	.32303	.829	-.5727	.9496
			3.00		.95536	.43015	.069	-.0582	1.9689
		2.00	1.00		-.18848	.32303	.829	-.9496	.5727
			3.00		.76688	.40953	.149	-.1981	1.7318
		3.00	1.00		-.95536	.43015	.069	-1.9689	.0582
			2.00		-.76688	.40953	.149	-1.7318	.1981
	Games- Howell	1.00	2.00		.18848	.30748	.813	-.5373	.9143
			3.00		.95536	.48819	.130	-.2115	2.1223
		2.00	1.00		-.18848	.30748	.813	-.9143	.5373
			3.00		.76688	.47136	.241	-.3625	1.8962
		3.00	1.00		-.95536	.48819	.130	-2.1223	.2115
			2.00		-.76688	.47136	.241	-1.8962	.3625
QTotal	Tukey HSD	1.00	2.00		.23316	.25801	.638	-.3749	.8412
			3.00		.70213	.34207	.102	-.1040	1.5083
		2.00	1.00		-.23316	.25801	.638	-.8412	.3749
			3.00		.46896	.32492	.320	-.2968	1.2347
		3.00	1.00		-.70213	.34207	.102	-1.5083	.1040
			2.00		-.46896	.32492	.320	-1.2347	.2968
	Games- Howell	1.00	2.00		.23316	.23852	.592	-.3297	.7960
			3.00		.70213	.37562	.155	-.1974	1.6016
		2.00	1.00		-.23316	.23852	.592	-.7960	.3297
			3.00		.46896	.37610	.430	-.4314	1.3694
		3.00	1.00		-.70213	.37562	.155	-1.6016	.1974
			2.00		-.46896	.37610	.430	-1.3694	.4314
C1	Tukey HSD	1.00	2.00		-.10528	.21790	.879	-.6176	.4071
			3.00		1.25651*	.36221	.002	.4049	2.1082
		2.00	1.00		.10528	.21790	.879	-.4071	.6176
			3.00		1.36180*	.35767	.000	.5208	2.2028

Appendix III - Statistical Analysis Output

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

		3.00	1.00	-1.25651 [*]	.36221	.002	-2.1082	-.4049
			2.00	-1.36180 [*]	.35767	.000	-2.2028	-.5208
	Games- Howell	1.00	2.00	-.10528	.20730	.868	-.5929	.3823
			3.00	1.25651 [*]	.42293	.012	.2382	2.2748
		2.00	1.00	.10528	.20730	.868	-.3823	.5929
			3.00	1.36180 [*]	.43404	.007	.3195	2.4041
		3.00	1.00	-1.25651 [*]	.42293	.012	-2.2748	-.2382
			2.00	-1.36180 [*]	.43404	.007	-2.4041	-.3195
C2	Tukey HSD	1.00	2.00	2.19490 [*]	.36612	.000	1.3341	3.0557
			3.00	.31405	.60860	.864	-1.1169	1.7450
		2.00	1.00	-2.19490 [*]	.36612	.000	-3.0557	-1.3341
			3.00	-1.88085 [*]	.60096	.005	-3.2939	-.4678
		3.00	1.00	-.31405	.60860	.864	-1.7450	1.1169
			2.00	1.88085 [*]	.60096	.005	.4678	3.2939
	Games- Howell	1.00	2.00	2.19490 [*]	.37275	.000	1.3182	3.0716
			3.00	.31405	.44864	.764	-.7545	1.3826
		2.00	1.00	-2.19490 [*]	.37275	.000	-3.0716	-1.3182
			3.00	-1.88085 [*]	.46209	.000	-2.9796	-.7821
		3.00	1.00	-.31405	.44864	.764	-1.3826	.7545
			2.00	1.88085 [*]	.46209	.000	.7821	2.9796
C3	Tukey HSD	1.00	2.00	2.52961 [*]	.37892	.000	1.6387	3.4206
			3.00	2.71950 [*]	.62987	.000	1.2385	4.2005
		2.00	1.00	-2.52961 [*]	.37892	.000	-3.4206	-1.6387
			3.00	.18988	.62197	.950	-1.2725	1.6523
		3.00	1.00	-2.71950 [*]	.62987	.000	-4.2005	-1.2385
			2.00	-.18988	.62197	.950	-1.6523	1.2725
	Games- Howell	1.00	2.00	2.52961 [*]	.35235	.000	1.7009	3.3584
			3.00	2.71950 [*]	.84539	.006	.6822	4.7567
		2.00	1.00	-2.52961 [*]	.35235	.000	-3.3584	-1.7009
			3.00	.18988	.85209	.973	-1.8617	2.2415
		3.00	1.00	-2.71950 [*]	.84539	.006	-4.7567	-.6822
			2.00	-.18988	.85209	.973	-2.2415	1.8617
Grade	Tukey HSD	1.00	2.00	4.61923 [*]	.72924	.000	2.9046	6.3339
			3.00	4.29006 [*]	1.21221	.001	1.4399	7.1402
		2.00	1.00	-4.61923 [*]	.72924	.000	-6.3339	-2.9046
			3.00	-.32917	1.19700	.959	-3.1436	2.4853
		3.00	1.00	-4.29006 [*]	1.21221	.001	-7.1402	-1.4399
			2.00	.32917	1.19700	.959	-2.4853	3.1436
	Games- Howell	1.00	2.00	4.61923 [*]	.73386	.000	2.8931	6.3454
			3.00	4.29006 [*]	1.14076	.001	1.5614	7.0187

Appendix III - Statistical Analysis Output

IV.2.4 Determination of the Freezing-Point Depression Constant for Cyclohexane

2.00	1.00	-4.61923 *	.73386	.000	-6.3454	-2.8931
	3.00	-.32917	1.12901	.954	-3.0317	2.3734
3.00	1.00	-4.29006 *	1.14076	.001	-7.0187	-1.5614
	2.00	.32917	1.12901	.954	-2.3734	3.0317

*. The mean difference is significant at the 0.05 level.