Imperial College of Science Technology & Medicine

Department of Chemistry

2nd Year Synthesis Course

Techniques

Autumn Term 2002

Student Laboratory Manual

Laboratory Supervisors:

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1 General:

A. Safety.

i) **YOU MUST WEAR A LAB COAT AND SAFETY GLASSES OR GOGGLES AT ALL TIMES IN THE LABORATORY**. Failure to do so means that you will be asked to leave the laboratory.

ii) Eating and drinking and the carrying of either are forbidden in the lab.

iii) Use of mobile phones is not allowed; please turn them off before entering the lab; failure to do so will result in their confiscation.

iv) Make sure that you read and understand the safety regulations given on page 6 of this booklet, and that you have read the safety documents you were given for the Foundation Course. If you have any questions about safety rules or about the safety aspects of any experiments in this course, ask a demonstrator. Please avoid wearing open toed shoes or sandals in the laboratory.

B. Course Dates.

Autumn Term

Group A: 21st October - 15th November 2002
Group B: 18th November - 13th December 2002

Spring Term

Group A: 13th January - 14th February 2003
Group B: 17th February - 21st March 2003

C. Laboratory Hours.

The labs are open during the course from 11am-5pm Monday, Tuesday, Thursday and Friday.

2 Running of the laboratory

A. Allocation, Handing in and Marking of Experiments.

The experiments in the autumn term are all worth 100 marks. If you have time and carry out an extra experiment your worst mark will be eliminated (across both SPRING and AUTUMN Courses; *Experiments 5 to 10 only*). You will be allocated six experiments at the start of the course.

You should attempt to complete and write up each experiment in turn. However, since many experiments involve one or more long processes efficient use of lab time can be achieved by starting another experiment whilst the first is still in progress.

Experimental Reports **MUST** be handed in accordance with the following schedule:

Group A

Week 4				Week 5				Week 6				Week 7			
M	T	T	F	M	T	T	F	M	T	T	F	M	T	T	F
				1@12pm				**2@12pm**				**1@12pm**			**2@1pm**

***i.e.* one report in on second Monday of the course, two the next Monday and so on.**

Group B

Week 8				Week 9				Week 10				Week 11			
M	T	T	F	M	T	T	F	M	T	T	F	M	T	T	F
				1@12pm				2@12pm				1@12pm			2@1pm

i.e. **one report in on second Monday of the course, two the next Monday and so on.**

Each lab report must be logged in the book on the demonstrators' bench by a demonstrator and yourself with a date and time.

Late hand-ins are liable to incur a penalty of 10% for Monday between 12-5 and then 20% each day thereafter. The final two reports must be handed in between 1 and 5 pm on the final Friday of the course BUT will not be accepted unless your bench and fumecupboard have been cleaned and inspected by a demonstrator

One or two specific demonstrators mark each experiment. This ensures uniformity of marking and also easily allows the staff to identify instances where collaboration/copying (i.e., plagiarism) has taken place.

EXPERIMENT 2-4 REPORTS SHOULD BE HANDED IN TO THE DEMONSTRATOR (AND SIGN IT IN!) AND THE SAMPLES PLACED IN THE DRAWERS PROVIDED.

FOR EXPERIMENTS 5-10 REPORTS SHOULD BE SUBMITTED FOR MARKING BY ENCLOSING YOUR WRITE-UP AND LABELLED SAMPLES IN ONE OF THE PLASTIC ENVELOPES PROVIDED AND HANDING IT IN TO A DEMONSTATOR (SIGN IT IN!).

ALL samples must be clearly labelled with the date, your name, what it is and the experiment number.

3 Laboratory Records and Reports.

It is vital (and mandatory) to keep an accurate Laboratory Record while you work. (In industry and in some academic institutions, these records are the property of your employer or institute; you may be allowed to keep a copy, but this is not always the case). You should record all essential experimental details, on which your Report is based, including amounts of materials, relevant equations, summaries of procedures, observations, measurements (including balance readings for magnetic determinations and weight loss studies, *etc*.) and product yields. From these, you will compile a report.

The Report should ideally be TYPE WRITTEN on A4 paper. **Put your name, the experiment number and the date on the front page.** The Laboratory Record for any experiment must be available and may be checked and assessed at any time.

Guidelines for report writing can be found at the end of each experiment. Please be aware that due to the differing and varied nature of the experiments in this course, these guidelines do vary slightly from experiment to experiment.

If you make a statement based on the literature you should quote the reference. Literature references should be given as superscript numbers in the text: *e.g*. "the (M-X) band at 697 cm^{-1} corresponds well with the literature[1] value of 698 cm^{-1}", and the quoted references should be listed at the end. *e.g.*

1 M.J. Mays and J.D. Robb, *J. Chem. Soc. A*, **1968**, 329.
2 H.L. Conder and W.R. Robinson, *Inorg. Chem*., **1972**, 11, 1527.

Textbooks and Literature. Some of the practical textbooks (referred to in the lab manual by the abbreviations given below) are available in the laboratory. To ensure general availability and to prevent damage or loss they must not be taken to the workbenches or for photocopying. They are also available in the Departmental library, but on restricted loan.

Abbreviations: IS = Inorganic Syntheses; Palmer = Experimental Inorganic Chemistry; M and R = Marr and Rockett, Practical Inorganic Chemistry.

Collected photocopies of many of the literature references quoted in the lab manual are available, and should be used in preference to the original journals. Folders are kept in the PERKIN lab for overnight loan against your signature. **Failure to return these folders will result in loss of marks.** If you come across additional material that might well be included in these collections, please discuss it with Drs. Davies and Braddock.

4 Apparatus, chemicals and instruments.

Equipment not in the bench sets may be obtained from the service room; it must be returned immediately in clean state when it is no longer required. Hoarding of items will lead to a general shortage for everyone. Do not leave unwanted apparatus in or on the benches or in the fume cupboards overnight. This will be taken into account in the 'tidiness' assessment.

Most Starting Chemicals required for each experiment are obtainable from the technicians; some may be in the freezer or on the benches; if in doubt ask a demonstrator. Other chemicals are also issued from the Service Room. Chemicals, even the common ones, are expensive nowadays so please don't waste them - take only as much as you need. Take care not to contaminate the stock bottles and always re-seal any container from which you have taken chemicals. Never leave the caps off solvent bottles or reagent containers. Unless otherwise stated, we don't recover organic solvents after use, but please remember that they MUST NOT BE PUT DOWN THE SINKS, instead put them in the special containers provided. Please try not to remove standard reagents, solvents and stock solutions from their correct places on the shelves.

Instruments: If you find that a spectrometer or other instrument does not work properly, report the fact immediately to the lab staff so that we can have it repaired promptly. As the spectrometers are heavily used we may have to use a booking sheet system. Please take care of IR salt-plates/cell windows and be economical with chart paper.

5 Miscellaneous Random Bits of Advice.

- Prepare **before** you come to lab. Plan your day and the sequence of steps that you wish to take. Make sure you have all the equipment ready for the next time you'll come to lab.
- If you don't know why you're doing something then you shouldn't be doing it!
- Keep a good notebook. Do not write information on scrap paper -- it is a waste of time. If you keep a really good lab notebook you can write your lab reports in a fraction of the time it would take otherwise.
- Learning is not a one-way street. If we have not made a point clear it is your responsibility to let us know. Ask questions. Ask why. There are no stupid questions except for the ones you didn't ask because you were afraid of looking stupid.
- If you have any concerns regarding the course, content *etc.* then please make them known to us as early as possible. Feedback (both positive and negative) is welcome. No, it will not affect your grade.

SAFETY REGULATIONS

YOU MUST ATTEND THE SAFETY TALK BEFORE YOU CAN COMMENCE WORK IN THE LABORATORY

1. The laboratories are open at the times shown in the Timetable and on the notice boards; practical work must not be done at any other times when no staff demonstrator is present.
2. Wear a lab coat and safety spectacles or goggles **at all times** (these will be provided). Do not wear contact lenses if you have any alternative. However, if you do have to wear contact lenses, please take particular care to wear goggles and tell the senior technician that you wear contact lenses. If you get corrosive liquids in your eye, it is essential to remove the contact lenses immediately; the necessary equipment is available in the service room.
3. Do not eat, drink or smoke, whilst in the laboratory. No mobile phones allowed in lab either.
4. Note the positions of the fire extinguishers, fire blankets, emergency sprays and first aid kits.
5. Any accident involving personal injury, however trivial, must be reported to the member of staff in charge of the laboratory and to the chief technician.
6. Before using any chemical, you should check its properties (flammability, toxicity, etc) by reference to the Wall Charts and books on Hazardous Chemicals and the list in this manual; if it is not mentioned there, consult a Demonstrator.
7. Experiments using dangerous or noxious chemicals (HCl, Br_2, HNO_3, etc) must be carried out in a fume cupboard. After use clear the fume cupboard immediately.
8. Bunsen burners should be used in fume cupboards unless specific permission is given for their use elsewhere in the lab. Pay particular attention that there are no flammable chemicals in the fume cupboard you are using. Do not carry flammable solvents about the lab in open vessels such as beakers.
9. Note carefully, before starting an experiment, any safety points pertinent to that experiment, *e.g.*, do not put sodium residues or organic liquids down the drains, take care when pushing glass tubing or thermometers through holes in rubber bungs or corks, *etc*.
10. Waste organic liquids and solvents should be put into the special containers provided. They must NOT be put down the drains.
11. DO NOT PIPETTE ANY SOLUTIONS BY MOUTH; use only the pipette fillers available from the Service Room.
12. Use vacuum desiccators only for the purpose recommended, and only in conjunction with adequate screening (ask first how to use them).
13. Don't put chemicals in bottles other than those for which they are intended.
14. Don't relabel bottles.
15. Clear up all the spillages immediately, (except mercury spillage, which must be reported to the Service Room immediately).
16. Get a demonstrator to inspect any experiment which is to be left running overnight, and get him to leave a signed notice for the night security men, who will otherwise turn it off. Rubber tubing carrying water must be wired on to the nozzles of taps and condensers.
17. Obtain the assistance of the laboratory technician; demonstrator or member of staff to separate jammed Quickfit apparatus.
18. Don't leave clothing on the benches; use your locker / drawer.
19. Don't leave retort stands, bags, stirrers *etc*. in the aisles. Take care not to block the aisles with stools.
20. Do not sit on the laboratory benches. Also, it is unwise to sit in front of an experiment involving a glass vessel containing a hot or corrosive liquid in case of breakage and subsequent splashing.
21. Samples placed in the refrigerator must be well stoppered and clearly labelled with the sample identity and your name.
22. Fume cupboards. The proper way to use these is with the windows as far down as possible. As soon as you have finished any manipulation in a fume cupboard shut the windows. Make sure there is nothing to impede the closing of the windows. As soon as you have finished with a fume cupboard leave it ready for the next user.

EXPERIMENT 1

Identification of an Unknown Compound by Spectroscopy

Introduction

A synthetic chemist must be able to identify (chemists coin the phrase "*characterise"*) any material that he or she makes, whether it was prepared intentionally or it was an unexpected side-product of a reaction. We have many spectroscopic techniques at our disposal in the 21st century and the mainstays of these are infrared (IR), ultraviolet (UV), nuclear magnetic resonance (NMR) and mass spectroscopy (MS). Typically, the mass spectrum gives the mass (!) of the molecule, the IR provides information about functional groups, and the NMR gives the carbon framework/relative *arrangements* of the functional groups and hydrocarbon residues. In this exercise you are given an IR spectrum, a UV spectrum (if applicable) an NMR spectrum and a mass spectrum (note that each of you will have a different compound to identify!). You will also be provided with a melting point or a boiling point. An optical rotation will be provided if applicable.

You have met all the above techniques (IR, MS, UV, NMR) in your first year lecture courses and the aim of this paper exercise is for you to ***determine the structure of your compound by analysis of the spectra provided***. The texts given in the reference section may prove useful for tables and correlation charts for characteristic frequencies, absorptions, chemicals shifts etc.

Procedure

(a) Infrared (IR)

An infrared spectrum is provided; analyze your spectrum as fully as possible, clearly identifying absorptions due to the specific functional groups within the molecule. You should not try to assign the peaks in the "fingerprint region" except those diagnostic of particular functional groups *e.g.*, ethers, sulphones.

(b) Ultra-violet (UV)

Ultra-violet data (λ_{max} and log ε) are provided. In the analysis of the spectrum, any absorptions above 230 nm should be correlated to particular *chromophores* within the molecule.

(c) Nuclear magnetic resonance (NMR)

A ^{1}H NMR spectrum of the unknown is provided. The NMR spectrum of your unknown should be analysed as fully as possible. For each resonance you should tabulate its *chemical shift,* its *intensity* (integration), and *multiplicity* (singlet, doublet, triplet, etc.), and if possible, the structural assignment. If the peak is a simple multiplet, the relevant *coupling constants* must be measured off the spectrum.

(d) Mass spectrometry (MS)

A mass spectrum of the unknown is provided. The *molecular ion* should be identified along with any *major fragmentations*. For example, the loss of a fragment of 18 m.u. might be associated with the loss of water from the compound.

(e) Other properties

You are told the m.p. or b.p. of your unknown. This will allow you to check your assignment with the literature value [Hint: Beilstein on line might be useful here]. In addition an optical rotation may also be provided if your molecule is a single enantiomer – and this value can also be checked against the literature value of your proposed compound.

Report

In your report discuss the reasoning that established the structure of your unknown compound. You can approach this in one of two ways. You may state what you think your molecule is and then discuss the spectra to support your assignment, or you may choose to explain each spectrum and culminate with the proposed structure (either approach will earn equal credit). In particular, the assignments of the IR, UV, MS and NMR spectra should be given in as much detail as possible. An account of the theories of spectroscopy is not required. Note: When you are first given your spectra, it might be helpful to make photocopies of them all; use these photocopies to make your preliminary assignments.

Hand in with the report: all assigned spectra.

Allocation of marks (Total 100):

Correct identity of unknown	20
NMR interpretation	20
IR interpretation	20
MS interpretation	20
Other (UV, $[\alpha]_D$ etc)	10
General Style	10

References

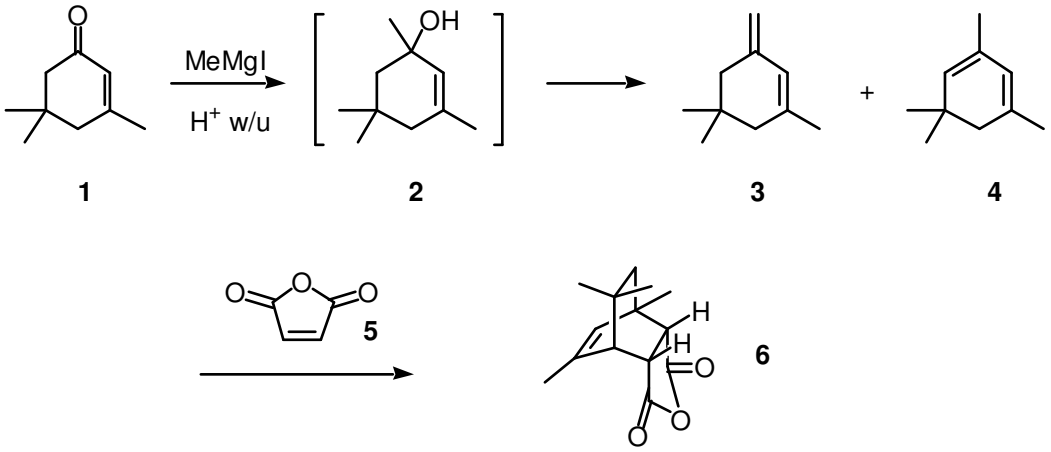
1. Harwood and Moody, *Experimental Organic Chemistry,* Blackwell Scientific Publications, 1989.
2. Williams and Fleming, *Spectroscopic Methods in Organic Chemistry*, McGraw-Hill, 5th Ed., 1995.
3. For an excellent introduction to NMR see Clayden, Greeves, Warren and Wothers *Organic Chemistry*, Oxford University Press, 2001; Chapters 3 and 11. (Please also refer to your lecture notes!)

EXPERIMENT 2

Addition of Grignard Reagents to Isophorone; Computer Assisted Molecular Modelling

Introduction

Reactions that lead to new carbon-carbon bonds are of fundamental importance to organic synthesis. In general, apart from free radical reactions, a new carbon-carbon bond is formed by the reaction of a nucleophilic carbon species with an electrophilic carbon species. This experiment illustrates the reaction between a Grignard reagent (commonly used as a *nucleophilic* carbon species) and an α,β-unsaturated ketone as the electrophilic component. In principle nucleophiles can react with α,β-unsaturated carbonyl compounds in two ways: either at the carbonyl carbon atom (called "1,2-addition") or at the β-carbon which is rendered electrophilic by conjugation (called "1,4-addition"). Grignard reagents generally prefer 1,2-addition (but this preference can be changed to 1,4-addition if a catalytic quantity of a copper(I) salt is added). In the present case we will examine the 1,2-addition of methyl magnesium iodide (which you will make from iodomethane and magnesium turnings) to isophorone **1**. After initial 1,2-attack, acidic work-up results in elimination of water from tertiary alcohol **2** and the formation of dienes **3** and **4**, which can be purified by distillation - the ratio of **3**:**4** can be estimated by GC. Treatment of the diene mixture with maleic anhydride **5** results in the formation of crystalline Diels-Alder adduct **6**.



In the second part of this experiment, the computer assisted molecular modelling package is used to model the Diels-Alder adduct **6**.

Safety Information	
Diethyl ether	Highly flammable
Iodomethane	Toxic, potential carcinogen, very volatile; MUST BE USED IN A FUME HOOD
Isophorone	Irritant, lachrymator
Hydrochloric acid	Highly corrosive
Maleic anhydride	Corrosive, moisture sensitive
Toluene	Highly flammable

Experimental

Part A: Grignard formation and addition to isophorone

1,5,5-Trimethyl-3-methylenecyclohexene **3** and 1,3,5,5-Tetramethylcyclohexa-1,3-diene **4**

All glassware (not the rotaflow tap in the dropping funnel!) used in the Grignard formation/reaction should be dried in the oven overnight before use (remember to put the stirrer bar in the flask as well!)

In a fume hood, set up a dry 250 mL 3-neck flask containing a magnetic stirrer bar, fitted with a 100 mL pressure equalized dropping funnel, a condenser protected with a calcium chloride drying tube and a thermometer. Add dry magnesium turnings (2.0 g, 83 mmol) and dry diethyl ether (10 mL) to the flask, and place a solution of iodomethane [**CARE: carcinogen! – handle in hood**] (5.5 mL, 88 mmol) in dry diethyl ether (10 mL) in the dropping funnel.

Add a few mL of the iodomethane solution to the magnesium and stir the mixture. The formation of the Grignard reagent should start immediately (if it does not consult a demonstrator). When the initial reaction has moderated, add the remainder of the iodomethane solution dropwise at such a rate as to maintain gentle refluxing (the addition usually takes 5-15 minutes).The mixture is stirred for a further 30 min at room temperature, and when the formation of the organometallic reagent is complete, (all the magnesium turning should have been consumed) the solution is cooled to 5 ^{o}C, (use an ice-water bath) and a solution of isophorone (10 mL) in dry diethyl ether (10 mL) is added dropwise at such a rate which maintains the temperature at about 15^{o}C. The mixture is then heated in an oil bath under reflux for 1 hour, and then allowed to cool.

While the reaction mixture is refluxing, prepare an ice cold solution of dilute hydrochloric acid by CAREFULLY adding 15 mL of concentrated hydrochloric acid (CARE: wear gloves) to approximately 75g of crushed ice and swirling until most of the ice has melted. Carefully add the dilute hydrochloric acid, **DROPWISE INITIALLY** (CARE: vigorous effervescence), until all the HCl solution has been added. Then separate the diethyl ether layer; the aqueous layer is then further extracted with diethyl ether (2 x 10 mL). The combined ether layers are washed successively with water (20 mL), 10% sodium thiosulphate (20 mL), saturated sodium bicarbonate (20 mL) and saturated sodium chloride solutions (20 mL), dried over magnesium sulphate, filtered under gravity, and concentrated on the rotary evaporator.

Note the mass of the diene mixture you obtain, and hence calculate a yield. Note the colour of the mixture and retain a small sample (*ca*. 50 mg) to be handed in with your report. Record an IR spectrum of the product mixture. Record a GC (This should be carried out under the direct guidance of a demonstrator) of your mixture in diethyl ether and from that estimate the ratio of dienes in your sample (done by photocopying the trace, enlarging as much as possible and weighing the cut out areas of each peak). Note the *retention times* of your dienes. Record the IR of isophorone for comparison.

Part B: Diels-Alder Reaction

The mixture of dienes **3** and **4** [5.1 g, 37.5 mmol] and maleic anhydride **5** (3.68 g, 37.5 mmol) are dissolved in dry toluene (7.5 mL) in a 25 mL round-bottomed flask fitted with a reflux condenser. The mixture is heated under reflux (use an oil bath) for 2 hours. On cooling, crystals of the Diels-Alder adduct **6** separate.

Filter off the crystals, and recrystallise from 40-60^{o}C petroleum spirit. Remember that unreacted maleic anhydride is still in your mixture and is insoluble in petroleum spirit. Record the colour, yield, m.p. and IR spectrum (nujol spectrum). Record the m.p. and an IR spectrum of maleic anhydride for comparison. ^{1}H NMR spectrum of **6** is provided.

The second part of this experiment involves molecular modelling and database searching and can be found at: http://www.ch.ic.ac.uk/local/organic/t2.html. Go to this URL and follow the instructions.

Report

1. A brief **introduction** stating the aims and objectives of the experiment including balanced equations for the transformations you have performed. Specifically, make reference to the factors affecting the addition of organometallic nucleophiles to isophorone with reference to methyl lithium, lithium dimethyl cuprate and methylmagnesium iodide in the presence of copper(I) chloride.

2. A **method and procedures** section, written in the *past passive tense* including any deviations from the experimental procedure given in the script and any relevant observations you have made (colour changes, exotherms etc). *There is no need to describe experimental set-up*, but you must describe what you did. For example: " A solution of iodomethane (5.5 mL, 88 mmol) in Et_2O (10 mL) was added dropwise to a suspension of Mg turnings (2.0 g, 83 mmol) in Et_2O at such a rate as to maintain gentle reflux. After 15 minutes the magnesium had been consumed to form a dark green solution… etc"

3. A **results** section giving your yields, melting points and any other relevant physical characteristics. Make sure you compare them with the literature values [Hint: Use Beilstein on-line to locate these values] and reference that work. Also please describe the nature of your final products (colourless liquid, orange solid etc).

4. A **discussion** section. In this section you should critically discuss the experiment you have performed with regard to your method and results. Reaction mechanisms, possible side-products and competing reactions should be discussed here. Your spectra should be assigned, annotated and commented upon (i.e. does your spectral data support the notion that you have made the compound - very important!) and presented along with your report. Specifically, what is the ratio of dienes formed in your experiment? Rationalize this in mechanistic terms. In the diene mixture, only the endocyclic diene, the cyclohexa-1,3-diene **4**, can react in the Diels-Alder reaction. Why is this? However, if the diene mixture is treated with a catalytic quantity of conc. sulphuric acid before the Diels-Alder reaction, then a virtually quantitative yield of Diels-Alder adduct can be obtained. Why? Fully assign the IR and NMR spectra of your products. The NMR spectrum of the Diels-alder adduct is particularly interesting, and is fully interpretable. Assign chemical shifts to all the protons in the molecule and identify the appropriate coupling constants (*J* values).

5. The results of the molecular modelling.

6. A **Conclusion section.** Briefly, what conclusions can you draw from your experiment?

Hand in with your report	Sample of Diene mixture; Sample of the Diels-Alder adduct; IR spectra (with peak assignments); Fully assigned NMR spectra; GC traces; data from the computer modelling exercise.	
Allocation of marks (Total 100):	Introduction	10
	Grignard method (style/content)	5
	Diels-Alder method (style/content)	5
	Samples (Yield/quality/m.p.'s)	15
	GC (Analysis/quality)	10
	IRs (Quality/analysis)	10
	Discussion (mechanisms etc)	15
	NMR (assignment)	15
	Modelling (results/description)	10
	Conclusion	5

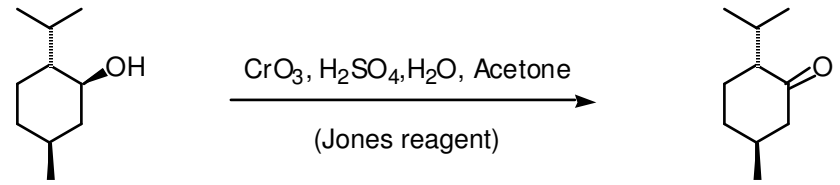
EXPERIMENT 3

Oxidation of Alcohols

The conversion of an alcohol into a carbonyl compound is a frequently encountered process in organic synthesis, and many reagents have been developed for this very important transformation. Primary alcohols are oxidised first to aldehydes, but since aldehydes are themselves easily oxidised, the oxidation of primary alcohols often continues to the carboxylic acid stage. However, by appropriate choice of reagent, the oxidation can be controlled and stopped at the aldehyde stage. Secondary alcohols are readily oxidised to ketones, but tertiary alcohols are not usually oxidised, although under acidic oxidising conditions, they may dehydrate to alkenes that may themselves be subject to oxidation.

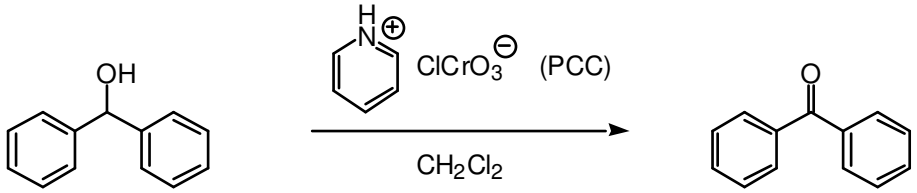
Many laboratory oxidising agents are inorganic compounds; metal salts with high oxidation potential such as Cr(VI), Mn(VII), Mn(IV), Ag(I), or Ag(II).Of these, oxidants based on Cr(VI) are the most common. Another particularly useful reagent for the oxidation of alcohols is dimethyl sulphoxide (DMSO) used in combination with an activating agent such as dicyclohexyl carbodiimide (DCC) [the Pfitzner-Moffat oxidation] or oxalyl chloride [the Swern oxidation]. Alcohols, particularly ethanol, can be oxidised biologically; in mammalian systems ingested ethanol is oxidised primarily in the liver by an enzyme called alcohol dehydrogenase.

This experiment illustrates two variants of the use of chromium(VI) compounds in the oxidation of secondary alcohols to ketones. The first experiment uses a variant of aqueous chromic acid (Jones reagent) to oxidise menthol to menthone. After aqueous work-up, the crude product is analysed by gas liquid chromatography (GLC) to determine its purity and quantify the amount of unreacted alcohol (if any). Finally, the ketone product is purified by distillation under reduced pressure, and a small amount is converted into the crystalline 2,4-dinitrophenylhydrazone derivative.



menthol menthone

The second experiment involves the use of a more recent chromium(VI) reagent: pyridinium chlorochromate, $PyH^+ ClCrO_3^-$ (PCC). This reagent, developed by E.J. Corey of Harvard University, is a crystalline solid, and is therefore particularly easy to use. The reagent, which is used in dichloromethane as solvent, is used to oxidise the secondary alcohol benzhydrol to benzophenone. The ketone product is a solid and can be purified by recrystallisation.



benzhydrol benzophenone

Safety Information	
Chromium(VI) compounds	Potential carcinogens, powerful oxidants
Sulphuric acid	Highly corrosive
Diethyl ether, petroleum spirit	Highly flammable
2,4-Dinitrophenylhydrazine	Avoid skin contact
Ethanol and Methanol	Toxic, Flammable
Dichloromethane	Avoid inhalation
Cyclic alcohols	Irritant
Cyclic ketones	Irritant

Experimental

Part A: Oxidation of menthol

Record an IR spectrum of menthol for comparison with the product.

Make up the solution of oxidant as follows: dissolve chromium trioxide (7 g) (**carcinogen!**: wear gloves; do **NOT** grind it up, do not spill it everywhere on the balance and do not wash apparatus with acetone but with water) in water (50 mL) in a conical flask with stirring. After cooling in an ice-water bath, **carefully** add concentrated sulphuric acid (6.1 ml) to the stirred chromium trioxide solution (**heat is generated**), and keep the oxidising solution cool in a ice bath so that it is ready for use. [NB] This solution (the Jones reagent) **MUST** be bright orange in colour; if it is not see a demonstrator.

Set up a 250 mL conical flask with a magnetic stirrer, and a dropping funnel with the flask immersed in an ice-water bath. Dissolve menthol (7.8 g, 50 mmol) in of acetone (30 mL) and add this solution to the conical flask. Add the well chilled oxidising solution **dropwise** via a dropping funnel to the stirred acetone solution, checking by thermometer that the temperature does not rise above about 15^{o}C.

After a further 30 minutes of continued stirring, the ice bath should be removed, and the mixture allowed to come to room temperature and stirred. The progress of the reaction can be checked by analytical TLC until complete (usually within 3 hours). A 10% sodium bisulphite solution is the added until the red brown colour of chromic acid is gone from the upper layer.

The top layer containing an acetone solution of the product is decanted into a round bottomed flask and the bulk of the acetone removed on the rotary evaporator, without heating above 30^{o}C. Extract the green aqueous layer thoroughly with diethyl ether (3 x 30 mL) and combine the ether extracts with the original product from the acetone layer. **Don't forget to put the Cr/aqueous waste in the waste labeled bottle.**

Wash the combined ether solution with saturated sodium bicarbonate solution (2 x 25 mL) (**care !, carbon dioxide evolved**) then with water (25 mL), and finally with saturated sodium chloride (2 x 25 mL). Dry the ether solution over magnesium sulphate, filter off the drying agent. Remove an aliquot of the dried ether solution (approx 1mL – a shortform pasteur pipette's worth) and place in a vial ready for GLC analysis (below). Evaporate the ether on the rotary evaporator, transfer the residue to a B10 distillation set, and distill it under reduced pressure using water pump vacuum. Record the b.p. and mmHg, yield, the IR spectrum and the optical rotation of your distilled product in $CHCl_3$.

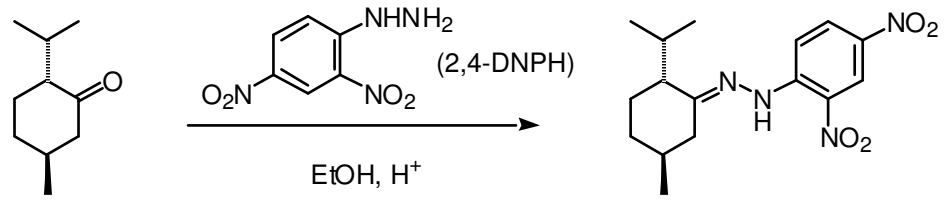
GLC Analysis of Reaction Product

The ethereal solution of the crude product is subjected to GLC analysis on the gas chromatograph using a carbowax column. This should be carried out under the direct guidance of a demonstrator. A sample of the starting alcohol in ether (solution provided) is run for reference. From comparison of your GLC

traces, determine the purity of the crude product ketone (from the amount of unreacted alcohol present), and the amount of any isomenthone (the C-3 methyl epimer) present.

Preparation of 2,4-Dinitrophenylhydrazine derivative

Convert a portion (approx 0.5 g) of the distilled ketone to its 2,4-dinitrophenylhydrazone derivative by adding a solution of the ketone in the minimum amount of ethanol to 20 mL of the 0.1M solution of the available 2,4-dinitrophenylhydrazine (2,4-DNPH) reagent and warming briefly (2-5 minutes) on the steam bath until the product starts to crystallise. Recrystallise the derivative from ethanol to constant m.p. Record the yield, colour and m.p. of the product.



menthone 2,4-DNP derivative

Part B: Oxidation of benzhydrol to benzophenone with PCC.

Record an IR spectrum of benzhydrol for comparison with your product.

Dissolve 2 mmol of benzhydrol in 10 mL dichloromethane in a 25 mL round bottomed flask fitted with a magnetic stirrer bar. Stir the solution magnetically and add pyridinium chlorochromate (0.646 g, 3mmol). Place a condenser on the flask and stir at room temperature for 2 hours (can be longer if necessary) and check that the reaction has proceeded to completion by TLC

Add 10 mL dry diethyl ether to the flask, and decant the supernatant solution from the black gum. Wash the residue several times with 10 mL portions of ether, decant off the washings, and combine them with the previous ether/dichloromethane solution. If the organic solution is still darkly colored, filter it through a short pad of silica gel (a one inch deep layer of flash column silica gel in a sintered glass funnel) and wash through with diethyl ether (2 x 20 mL). Evaporate the ether solution to dryness on the rotary evaporator, and recrystallise your product from petroleum spirit b.p 60-80^{o}C. If you have difficulties with this crystallisation, ask a demonstrator for a seed crystal. Record the yield, colour, m.p., and IR spectrum of your recrystallised material.

Report

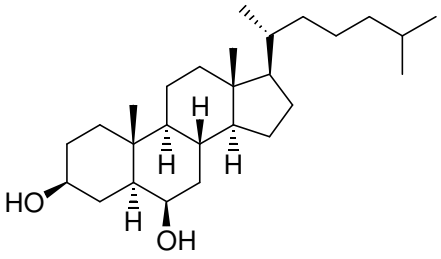
1. A brief **introduction** stating the aims and objectives of the experiment including balanced equations for the transformations you have performed.

2. A **method and procedures** section, written in the *past passive tense* including any deviations from the experimental procedure given in the script and any relevant observations you have made (colour changes, exotherms etc). *There is no need to describe experimental set-up*, but you must describe what you did. For example: " Pyridinium chlorochromate (0.65 g, 3 mmol) was added to a stirred solution of benzhydrol (2 mmol) in CH_2Cl_2(10 mL)…etc"

3. A **results** section giving your yields, boiling points, melting points and any other relevant physical characteristics. Make sure you compare them with the literature values [Hint: Use Beilstein on-line to locate these values] and reference that work. Also please describe the nature of your final products (colourless liquid, orange solid etc).

4. A **discussion** section. In this section you should critically discuss the experiment you have performed with regard to your method and results. Reaction mechanisms, possible side-products and competing reactions should be discussed here. Your spectra should be assigned, annotated and commented upon (i.e. does your spectral data support the notion that you have made the compound - very important!) and presented along with your report. Specifically, discuss the mechanism of chromium(VI) oxidation of alcohols, clearly identifying the intermediates involved. For the steroidal diol **A** shown below, use the mechanism you have discussed to decide and explain which of the two hydroxyl groups is oxidised faster by chromium(VI) reagents. (Note: a three-dimensional representation will be necessary).

5. A **Conclusion section.** Briefly, what conclusions can you draw from your experiment?



A

Hand in with the report :	samples of distilled menthone and the 2,4-dinitrophenylhydrazone derivative. IR spectra (assigned) GLC traces sample of recrystallised benzophenone	
Allocation of marks (Total 100):	Aims	5
	Methods and procedure (style/content)	10
	Sample appearance	10
	Yields	10
	m.p. for DNP deriv and benzophenone	10
	b.p. for menthone	5
	Assignment of IR and GC traces	15
	General mechanism of Cr(IV) oxidation	10
	Product of steroidal oxidation (explanation/mechamism)	20
	Conclusion/overall style	5

References

J. Meinwald, J. Crandall, W. E. Hymans, *Org. Synth., Coll. Vol. V*, p. 863.
E. J. Corey, J. W. Suggs, *Tetrahedron Lett.*, **1975**, 2647.

EXPERIMENT 4

An Introduction to Flash Column Chromatography

Introduction

The routine purification of organic compounds, especially in large quantities, was originally carried out by tedious long column chromatography. Good separations often required prolonged elution with solvents of low polarity. In 1978, the technique of flash chromatography was introduced.[1] Flash Chromatography involves the purification of an organic compound by partition between a finely divided stationary phase, usually Merck Keiselgel H, and a rapidly moving organic solvent. The technique is highly attractive in that separations are rapid (5-10 min), resolution of compounds of similar polarities are excellent, and the technique is inexpensive. Choice of the elutant is easily found by prior examination by thin layer chromatography (TLC).

In this experiment you will be provided with a binary mixture of compounds (one of mixtures A-F). The objective of this experiment is to separate them by flash column chromatography! After separation, the individual column fractions - which are collected - are checked for purity by TLC. Appropriate fractions are combined; the separated compounds are isolated, and finally purified by crystallisation.

	Safety Information
Unknown mixtures	Treat as toxic compounds, avoid contact with skin and eyes
Silica gel	Avoid breathing dust
Petroleum Spirit	Highly flammable
Ethyl Acetate	Highly flammable

Experimental

Prior to commencing this experiment, you are strongly advised to read Still's initial communication (provided) detailing the technique.[1]

Determination of a suitable solvent for analytical TLC and for running the column

Establish an analytical TLC system for the mixture provided by trial and error, using varying proportions of an ethyl acetate/petroleum spirit (b.p 60-80 ^{o}C) mixture *e.g.,* 0%, 10%, 25%, 50%, 75% vol/vol such that both components are well separated (note that ethyl acetate is more polar than petroleum ether, so increasing the percentage of ethyl acetate in the mixture will move your compounds further up the TLC plate). Both components of mixtures A-C are coloured and are readily detected by eye, for mixtures D-F only one component is coloured, therefore the TLC plates should be examined either under UV light or placed in a jar containing a few crystals of iodine. The solvent mixture for running the column should then be selected such that the R_f value of the fastest running component is about 0.35.

Preadsorption of the mixture

Using the four-figure balance, dissolve an accurately weighed amount (approx 0.1g) of the mixture supplied in chloroform (mixtures A-C) or ethanol (D-F). Add this solution to a round bottomed flask containing ≈ 1g of Merck Keiselgel H silica (**CARE**:****All dry silica should be handled in the fume hood****) and evaporate all of the solvent using the rotary evaporator, until a free flowing powder is obtained. A plug of cotton wool placed in the adaptor of the rotary evaporator helps to ensure the adsorbed mixture remains in the round-bottomed flask.

Preparation of the chromatography column

Cover the sintered glass column with the plastic safety webbing provided and clamp vertically over a conical flask. In another conical flask slurry (stir vigorously with a glass rod to make sure all the silica is wet) Merck Keiselgel H (24 g) (**CARE**:****All dry silica should be handled in the fume hood****) with petroleum spirit b.p 60-80^{o}C. Pour the slurry into the column and wash in the residue with more solvent. Using the hand bellows, force the solvent through the column and thus compact the silica. It is essential that the level of solvent is not forced below the surface of the silica otherwise channels will form. The surface of the silica pad **must** be as flat as possible. Using a Pasteur pipette and rotating it around the inside of the column, carefully add more petroleum spirit to the column; do not disturb the silica surface. If cracking or channeling occurs, repack. Again force the petroleum spirit through the column so that the solvent is approximately 1 cm above the level of the silica surface.

At this stage, the adsorbed silica mixture to be separated is transferred from the round-bottomed flask to the top of the column, and silica particles adhering to the sides are rinsed down using petroleum spirit and a pasteur pipette. The surface of the silica is then compacted again using the hand bellows, making sure that the level of the level of the liquid is just flush with the silica surface.

Running the column

Using the solvent mixture established for optimum $R_f = 0.35$ by TLC analysis 50 mL is then added to the top of the column. Pouring the solvent carefully down the inside of the column over the blade of a wide spatula or rinsing with a pasteur pipette is helpful to avoid disturbing the silica surface. The solvent is then rapidly forced through the column using the hand bellows, and 15-20 ml fractions collected in test tubes. Solvent mixture is added periodically to the top of the column and elution continued until **the entire** first component has been eluted, as judged by checking each fraction by using analytical TLC plates.

When the first component has been eluted the polarity of the solvent mixture can, if necessary, be gradually increased in stages by increasing the percentage of ethyl acetate in the mixture, *e.g.*, 5%, 10%, 20%, 30%, 50% etc. The total volume of elutant used should be about 400 ml.

Isolation and recrystallisation of separate components

Fractions containing a single component, as judged by TLC, should be combined, transferred to a preweighed flask, and evaporated to complete dryness on the rotary evaporator. Weigh the flask again, and record the yield of each component. Check that the sum of the isolated components does not exceed the original weight of the mixture. The separated components should be recrystallised to constant m.p. from a suitable solvent (see below). Record the yield, colour, and m.p. of the recrystallised material; identification of the compounds is not required.

Recrystallisation solvents:
Mixtures A-C: both components from water
Mixtures D-F: colourless component from methanol
yellow component from petroleum spirit, b.p 60-80 ^{o}C

Report

1. A brief **introduction** stating the aims and objectives of the experiment.

2. A brief **theory** section, demonstrating that you understand the different types of chromatography systems, eluotropic series, and R_f values (see Harwood and Moody for a general discussion).

3. A **results** section describing the outcome of your chromatography (details regarding packing the column are not required). Include details of how the optimum solvent system was identified, the distribution of your compounds in your fractions as determined by tlc analysis, the quantities of compounds isolated, and melting points before and after recrystallisation. Also please describe the nature of your final products (colourless liquid, orange solid etc).

4. A **discussion** section. In this section you should critically discuss the experiment you have performed with regard to your method and results. Use the isolated weights of each component prior to recrystallisation to deduce the original composition of the mixture

5. A **conclusion section.** Briefly, what conclusions can you draw from your experiment?

Hand in with your report: Samples of recrystallised separated components of the mixture.

Allocation of marks (Total 100):

Aim	5
Theory	10
Finding correct solvent system for $R_f = 0.35$	10
Description of fractions/tlc plates (successful sep.?)	25
Sample appearance	10
Quantities	10
m.p.'s	10
m,p,'s after recrystallisation	10
Conclusion/style	10

Reference

1. W. C. Still, M. Kahn, A. Mitra, *J. Org. Chem.* **1978**,43, 2923.

EXPERIMENT 5

Preparation of *bis*(triphenylphosphine)copper(I) tetrahydroborate and study of its thermal decomposition products.

Introduction

There is appreciable interest in the use of transition metal hydrides and tetrahydroborates as selective reducing agents. The copper(I) tetrahydroborate complex you prepare in this experiment is also of interest because: (a) two of the hydrogen atoms of the BH_4^- ion bridge the copper and boron atoms in the solid compound and (b) the catalytic nature of the thermal decomposition of the complex has found use in various imaging processes.

Safety Information

Chloroform is poisonous and a possible carcinogen, handle in a fume cupboard.

Experimental

Add finely powdered (using mortar and pestle) hydrated copper sulfate (1.5 g) to a solution of ground triphenylphosphine (7.5 g) in ethanol (100 cm^3). Stir the mixture and warm it on a hotplate until the blue solid has dissolved (the yellowish solution may be decanted from any small amount of blue residue). Cool the solution to 50 °C. Carefully add powdered sodium tetrahydroborate (1.5 g) with stirring, until precipitation is complete and the vigorous effervescence has subsided. Filter off the crude solid and stir it with 75 cm^3 of chloroform. Filter the solution. Warm the $CHCl_3$ filtrate on a hotplate to about 50 °C and then add ethanol slowly with constant stirring (keeping the solution hot) until the faint cloudiness produced changes to fine, white crystals. It may be necessary to add ethanol in a quantity of up to 150% of the vol. of $CHCl_3$ that you start with. Allow the mixture to cool, filter off the product, wash it with diethyl ether and dry it in air. Record the yield, m.p. and an infrared spectrum of your product. (A further crop of the compound can sometimes be obtained by concentration of the mother liquor - but do not mix the two samples - record the amounts and melting points separately.)

Thermal Decomposition.
Examine the products of the thermal decomposition of the *bis*(triphenylphosphine)copper(I) tetrahydroborate and record your observations during the decomposition:

Take about 1.5 g of the dried complex and heat it gently in a test tube (yellow Bunsen flame with about 1 min. of gentle spasmodic heating). Allow the residue to cool and then wash it with 3 x 5 cm^3 toluene. Filter the combined toluene washings and evaporate off the toluene on a rotary evaporator to leave a crude solid. Wash this crude solid with 3 x 5 cm^3 ethanol and retain both the combined ethanol washings (**A**) and the residue (**B**).

Ethanol solution (**A**): Heat the solution gently to boiling and then add water dropwise, maintaining boiling, until the solution is permanently cloudy. Allow the mixture to cool and then filter off and air-dry the white crystals of triphenylphosphine. Record the m.p. and an infrared spectrum of your product.

Residue (**B**): Extract residue B into about 15 cm^3 toluene and filter. Concentrate the solution by evaporating off most of the toluene on a rotary evaporator. Allow the solution to cool when crystals of Ph_3PBH_3 should form. Filter these off and air-dry them. Record the m.p. and an infrared spectrum of your product. Write an equation to account for your observations.

Report

1. Briefly indicate the aims of the experiment.
2. Do not reproduce the experimental procedure unless your experiment differed.
3. Write an equation for the formation of $[Cu(PPh_3)_2(BH_4)]$ and give the yield.
4. Record your observations for the decomposition of $[Cu(PPh_3)_2(BH_4)]$. Give the yields of the products and write an equation for the thermal decomposition.
5. With respect to the IR spectra of $[Cu(PPh_3)_2(BH_4)]$ and Ph_3PBH_3; assign the ν(B-H) vibrations and comment on any differences between the two compounds. What are the point groups for both compounds and for BH_3 and BH_4^- ?
6. Give a brief account of the structure of $[Cu(PPh_3)_2(BH_4)]$ and of the bonding between the metal and the BH_4^- ions.[2]
7. Write a short conclusion.

Hand in with the report: Samples of $[Cu(PPh_3)_2(BH_4)]$, Ph_3PBH_3 and PPh_3.
Infrared Spectra of all samples

Allocation of marks (Total = 100):

Experimental write-up/presentation		10
Samples (quality/yields)		20
Questions	1. Equations	10
	2. Point groups	10
	3. IR assignment	10
	4. Bonding explanation	10
Melting points		10
IR spectra quality		10
Conclusion / Results and Discussion		10

References

1. Lippard and Ucko, *Inorg. Chem.*, **1968**, 7, 1051.
2. Lippard and Melmed, *Inorg. Chem.,* **1967**, 6, 2223.

EXPERIMENT 6

Nitrosyl Complexes of Iron and Nickel

Introduction

The nitric oxide (NO) molecule is closely akin to the carbon monoxide (CO) molecule except that it contains one more electron, which resides in a π^* orbital. There is some similarity between the NO molecule and carbon monoxide and nitric oxide does form a series of binary nitrosyls analogous to the binary carbonyls of the first row transition metals. However, unlike carbon monoxide, nitric oxide is not stable in air as it is rapidly oxidised to NO_2. This experiment illustrates two methods of forming nitrosyl complexes without the use of free NO.

Safety Information

Chloroform is extremely harmful and very easily ingested. Work in a fume cupboard.
Most of the reagents and the product are toxic to some degree. Wear gloves.

Experimental

Preparation of $Fe(NO)(S_2CNEt_2)_2$

Dissolve ferrous sulphate (approx. 5.6 g) in dilute sulfuric acid (25 cm^3) (in a fume cupboard). Mix together solid sodium nitrite (1.5 g) and solid sodium diethyldithiocarbamate (10 g) and then add this mixture to the ferrous sulphate solution and stir vigorously for 5 min. Place the reaction mixture in a 100 cm^3 separatory funnel and extract successively with 1 x 50 cm^3 and 2 x 25 cm^3 chloroform. (Chloroform is denser than water so less than the volume added can be run out of the funnel even if the interface is difficult to see). Dry the combined chlorocarbon extracts over $MgSO_4$, filter, and remove the solvent on a rotary evaporator. The crude compound is purified and recrystallised simultaneously by Soxhlet extraction with 150 cm^3 of 80-100 ^oC petroleum ether - it is helpful to fill the Soxhlet with solvent when you set up the apparatus - (3-4 hours should be sufficient; longer periods, especially if solid starts to separate in the flask, may lead to loss of product and the formation of impurities). You may wish to consider replacing the round bottom flask with a second flask containing a fresh solution of pet. ether after 2-3 h. and thus collect two crops. Dark green crystals should separate from the extract on cooling (if they do not - concentrate slightly on the rotary evaporator). If you concentrate the solution too much, then crystals of $Fe(S_2CNEt_2)_3$ will also come down. Record the infrared spectrum of the compound. Calculate your yield based on the amount of ferrous sulphate used.

Preparation of $NiBr(NO)(PPh_3)_2$

This preparation requires the use of $NiBr_2(PPh_3)_2$. Synthesize this by adding the stoichiometric amount of nickel bromide in ethanol (*ca*. 30 cm^3) to a refluxing solution (0.5h; if there appears to be a large quantity of unreacted $NiBr_2$ (brownish) in your mixture - dissolve the material in THF and filter to remove it) of triphenylphosphine in propan-2-ol (*ca*. 80 cm^3) (NOTE: Please try and figure this out yourselves before coming and asking a demonstrator). Place finely powdered, dry sodium nitrite (8 g) in a flask with $NiBr_2(PPh_3)_2$ (5 g), triphenylphosphine (1.8 g) and tetrahydrofuran (50 cm^3). Stir under reflux for about 35 minutes. Cool and filter the solution and reduce the volume to about 25 cm^3 by evaporation on a steam bath (fumecupboard). Slowly add petrol (25 cm^3) to the warm solution with stirring. Allow to cool to room temperature, filter the purple product and dry it at the pump. Record the infrared spectrum of the compound.

Report

1. Briefly indicate the aims of the experiment.
2. Do not reproduce the experimental procedure unless your experiment differed.
3. Write balanced equations for the formation of the complexes and give your yields.

4. Tabulate the IR spectra, assigning ν(NO).
5. What is the point group symmetry at the metal centre for $Fe(NO)(S_2CNEt_2)_2$ and for $NiBr(NO)(PPh_3)_2$?
6. Comment on the ESR spectrum of the complex (available from a demonstrator) and answer the questions below.
7. What oxidation state are the metals in your complexes; are the M-NO group linear or bent (see Vaciago, *et al.*, *J.C.S. Chem. Commun.*, **1967**, 584); do the complexes obey the 18 electron rule?
8. Write a short conclusion.

Hand in with the report:	Samples of $Fe(NO)(S_2CNEt_2)_2$ and $NiBr(NO)(PPh_3)_2$	
	Infrared Spectra of both samples	
	Assigned ESR Spectrum	
Allocation of marks (Total = 100):	Experimental write-up/presentation	20
	Samples (quality/yields)	20
	Spectra (quality/interpretation	20
	Questions/discussion/conclusions	40

Reference

M. Colapietro, A. Domenicano, L. Scaramuzza, A. Vaciago and L. Zanbonelli, *J. Chem .Soc., Chem. Commun.*, **1967**, 583.

Questions to Accompany the ESR Spectrum of Fe(NO)(dithiocarbamate)$_2$.

Electron spin resonance is a form of magnetic resonance in which an unpaired electron in a magnetic field is excited from one spin to another by a quantum of energy in the microwave region of the electromagnetic spectrum. It is entirely analogous to nuclear magnetic resonance but the appearance of the spectrum is usually rather different because it is normally presented as the first derivative of the absorption with respect to field, plotted against field. In practical terms what this means is that a peak position is precisely measured by the field value at which the derivative crosses the baseline. The spectrum is characterised by two parameters, g and a.

The *g* Value. This is analogous to chemical shift in NMR. The free electron value is 2.0023; the value for a free radical in which the unpaired electron is centred on carbon is usually around 2.003; and if centred on nitrogen around 2.006. Metal ions can have very different g values (in general between about 1 and 8) but if there is only one unpaired electron the shift away from 2.0023 is often no more than about 0.2.

Calculate the g value from the field position of the central line using the formula $h\nu = g\beta B$ which gives $g = 0.0714484\ \nu(GHz)/B(tesla)$.

The *a* Value. This is the symbol for the isotropic hyperfine coupling constant which arises when a nearby nucleus interacts with the electron; it is analogous to the spin-spin coupling constant in NMR. In your molecule the unpaired electron clearly interacts with a nitrogen nucleus which has spin I = 1 having three projections along the magnetic field characterised by M_I = +1, O, -1. The isotropic hyperfine coupling constant a_N may be measured in field units by measuring the separation between two adjacent lines. To convert to frequency units use a (MHz) = g x 13.99626 x a(mT).

Question 1. What can you say about your molecule from its g value?

Question 2. Given that an unpaired electron situated entirely on a free nitrogen atom has an isotropic hyperfine coupling constant a_o of 1540 MHz, calculate by direct ratio of the coupling constants the percentage probability of finding an unpaired electron on nitrogen in your molecule. What does this value tell you about the electronic structure?

EXPERIMENT 7

Nitration of cobalt(III) acetylacetonate.

Introduction

Coordination of organic molecules to metal ions frequently modifies the nature of the chemical reactions which they can undergo. In this experiment coordinated acetylacetone can be readily nitrated.

Safety Information

Acetic anhydride is an irritant. Avoid contact, handle in a fume cupboard.
Chloroform should be used in a fume cupboard.

Experimental

Preparation of Cobalt(III) acetylacetonate

A mixture of cobalt(II) carbonate (1.25 g) and 2,4-pentanedione (acetylacetone) (10 cm^3) in a 100 cm^3 conical flask is heated to 90 to 100 ˚C. Heating is stopped while 12% hydrogen peroxide (provided in the refrigerator) - *avoid skin contact* - (15 cm^3) is added dropwise with rapid stirring over a period of 10-15 min. (Do not add the hydrogen peroxide rapidly or the heat evolved will cause frothing). When addition is complete, cool the mixture in an ice-bath and then filter off the green solid and dry it at 110 ˚C. Dissolve the product in the minimum amount of hot toluene, filter if necessary, and then add 80-100 petroleum ether (*ca*. 75 cm^3) to the warm toluene solution. Cool in an ice-bath and filter off and air-dry the dark green crystals. Record the m.p.

Nitration of Cobalt(III)acetylacetonate

A mixture of finely ground copper(II)nitrate trihydrate (2.7 g) and acetic anhydride (50 cm^3) is stirred for 15 min. at 0^{o}C in a conical flask fitted with calcium chloride drying tube. To the resulting slurry add cobalt (III) acetylacetonate (1.25 g) and then stir for 2 hrs at 0^{o}C, followed by l h at room temperature. The blue green solution is then mixed with water (150 cm^3), ice (150 g), and sodium acetate (4 g). Stir the two-phase liquid for 2 hours, during which time a finely divided green precipitate appears. Continue stirring until any gummy substance has gone (the mixture should consist of a green solution and a fine green powder). Filter off the green solid, wash it with two portions of water (15 cm^3) and one portion of cold ethanol (15 cm^3) and then air-dry it. Dissolve the dry solid in boiling chloroform (10 cm^3) in a beaker (in a fume cupboard as chloroform is toxic and inflammable). Add hot ethanol (10 cm^3) and boil the mixture carefully, allowing the chloroform to distil off until crystals appear in the solution. Allow the mixture to cool, chill in an ice bath and then filter off the green solid. Wash with two portions of cold ethanol (5 cm^3) and air dry. Record the decomposition point of the product.

Record the IR spectrum of both complexes and make band assignments.[1] Collect the ^{1}H-NMR spectra of both complexes in $CDCl_3$ from a demonstrator.

Report

1. Briefly indicate the aims of the experiment.
2. Do not reproduce the experimental procedure unless your experiment differed.
3. Write balanced equations for both reactions giving yields and m.p. of the products.
4. Tabulate the IR spectra of both complexes and give full band assignments.[1,2]

5. What are the point groups for both $Co(acac)_3$ and the product from the nitration ?
6. Tabulate and fully assign the ^1H NMR of both complexes.
7. Write a short conclusion

Hand in with the report: Samples of Cobalt(III)acetylacetonate and its nitration product
Infrared Spectra of both samples
Fully labelled NMR Spectra of both samples

Allocation of marks (Total 100):		
	Experimental write-up/presentation	10
	Samples (quality/yields)	20
	NMR (interpretation)	20
	IR (quality/interpretation)	20
	Point group	10
	Conclusion / Results and Discussion	20

References

1. J. P. Collman, R. L. Marshall, W.L. Young and S.D. Golby, *Inorg. Chem.,* **1962**, 1, 704 .
2. K. Nakamoto, P. J. McCarthy, A. Ruby and A. E. Martell, *J. Am. Chem. Soc*., **1961**, 83, 1066.

EXPERIMENT 8

Influence of ligand field tetragonality on the ground state spin

Introduction

Regularly octahedral first transition element complexes of configuration d^n (n = 4-7) may either be high- or low-spin depending primarily on the strength, Δ of the ligand field. For distorted ligand fields a wider range of possibilities exists for changes in ground state spin. Changes in spin can have important effects, *e.g.*, high spin octahedral iron(II) complexes are much more labile than their low-spin counterparts. Moreover, the haem complexes that are involved in haemoglobin, catalase, cytochrome C, *etc*., contain the iron atom in either a high- or low-spin state, depending on the axial ligand.

The effects of changes in the axial ligands, X, on the electronic properties of a tetragonally distorted complex *trans*-ML_4X_2, are well illustrated by the magnetic properties and d-d spectra (and hence colours) of a series of nickel(II) complexes of formula $Ni(Et_2en)_2X_2$, where Et_2en = *N,N*-diethylethylenediamine ($Et_2NCH_2CH_2NH_2$) and X = Cl^-, I^-, NCS^-, Br^-, *etc*.

Safety Information

N,N-diethylethylenediamine has an unpleasant smell. Use it in the fume-cupboard and treat it as a potentially toxic compound. Make sure you do not use ethylenediamine or diethylamine by mistake. Also wear gloves when working with solutions of the nickel salts and their complexes, to avoid the possibility of heavy metal skin allergy.

Experimental

Preparation of $Ni(Et_2en)_2(NCS)_2$

Prepare an ethanolic solution of nickel thiocyanate (0.6 g) by dissolving the required amounts of nickel nitrate hexahydrate and potassium thiocyanate separately in hot absolute ethanol and mixing the two solutions. (For your guidance the solubility of nickel nitrate in hot ethanol is ca. 50 g/100 cm^3 and that of powdered potassium thiocyanate is *ca.* 10 g/100 cm^3). Keep the volume of solution to a minimum and allow the mixture to cool thoroughly before filtering off the precipitated potassium nitrate. Using a syringe, add 1 cm^3 of Et_2en to the filtrate with shaking and filter off the percipitated complex. Keep *ca*. 0.4 g of the dry crude product for the magnetic measurements (see below) and recrystallise the remainder from methanol (record the m.p., the yields of crude and of purified products).

Preparation of $Ni(Et_2en)_2I_2$

Prepare an ethanolic solution of nickel iodide (*ca*. l g) using nickel nitrate and sodium iodide (solubility of NaI in hot ethanol *ca*.16 g/100 cm^3) as for the nickel thiocyanate above. Add Et_2en (l cm^3), filter off the product, wash it with a little ethanol but do not attempt to recrystallise it.

Preparation of $Ni(Et_2en)_2Br_2$ and $Ni(Et_2en)_2Br_2.2H_2O$

The nickel bromide complexes of Et_2en exist in two forms; the anhydrous complex is orange and diamagnetic but it readily forms a blue paramagnetic dihydrate.[1] Slurry nickel bromide (1.5 g) (available in the lab.) in hot ethanol (20 cm^3) and, using a syringe, add Et_2en (1.5 cm^3) with stirring. Collect the solid product, wash it with a little ethanol and dry it in a dessicator. Record your observations at all stages.

Depending on the reaction conditions your product may be the orange anhydrous complex, the blue hydrated form or a mixture of the two. You should aim to hand in both the orange and the blue products separately. Samples of orange compound (or a mixture) can be converted to the dihydrate by moistening with alcohol and exposure to the air for several hours. Samples of the dihydrate (or a mixture) can be dehydrated to give the orange form by heating in a drying pistol at *ca*. 80 - 100 ˚C.

Measurements

$Ni(Et_2en)_2I_2$ is reported[1] to be diamagnetic and you do not need to measure its susceptibility. First read the background theory, procedure, and method of calculation of magnetic susceptibilities given in the Appendix to this experiment. (Make sure that you understand how to apply the tube correction and the corrections for the diamagnetism of the Et_2en ligand). Then measure the magnetic properties of $Ni(Et_2en)_2(NCS)_2$, using the dry crude product and also the recrystallized sample if the latter consists of small, fine crystals (crushing tends to cause problems with electrostatic charge). Record the IR spectrum of $Ni(Et_2en)_2(NCS)_2$ and identify the CN stretch of the NCS groups.

Report

1. Briefly indicate the aims of the experiment.
2. Do not reproduce the experimental procedure unless your experiment differed.
3. Write balanced equations for the formation of the complexes giving your yields and m.p.
4. Report the magnetic susceptibility of $Ni(Et_2en)_2(NCS)_2$ and identify its CN stretch from the IR spectrum.
5. Report your observations about the formation of the nickel bromide complexes. Suggest how you might confirm that the colour changes in the bromide involve the uptake and loss of water molecules.
6. Draw the crystal field diagram for a tetragonally distorted octahedron and account for your observations in parts 4 and 5; you may assume that the anion in the 'thiocyanate' complex is bonded via N, *i.e.*, it is an iso-thiocyanate complex. This fact can be demonstrated by its IR spectrum.
7. To which point groups do the products that you have made belong?
8. Write a short conclusion.

Hand in with the report:	Samples of $Ni(Et_2en)_2(NCS)_2$, $Ni(Et_2en)_2I_2$, $Ni(Et_2en)_2Br_2$ and $Ni(Et_2en)_2Br_2.2H_2O$ Infrared Spectrum of $Ni(Et_2en)_2(NCS)_2$	
Allocation of marks (Total 100):	Experimental write-up/presentation	10
	Samples (quality/yields/m.p.)	34
	Spectra (quality/interpretation)	6
	Calculations/discussion/conclusion	50

References

1. D. M. L. Goodgame and L. M. Venanzi, *J. Chem. Soc.*, **1963**, 616.

Appendix

Magnetic Susceptibility Balance with Direct Digital Read-out

This involves the same basic principle as in the Standard Gouy method, but in this apparatus it is the force that the sample exerts on the magnet that is measured. Two magnets (samarium-cobalt alloy; field strengths 0.44T are used. These are mounted back-to-back and suspended from beryllium-copper torsion strips. When a sample tube is placed between the poles of one of the magnets, the system tilts, and a metal 'flag' moves between two opto-interruptors. The resultant signal from the opto-interruptors is amplified, and fed back, via a standard resistance, through a coil mounted between the poles of the other magnet. This feedback current tends to restore the magnets to their original position.

An equilibrium is reached in which the current through the coil exerts a force exactly equal to that of the sample. This current is read off from a digital voltmeter connected across the standard resistance. An electrical zero is provided by a variable voltage applied to a second coil.

Packing the sample tube

When packing a special sample tube to a length of approximately 2.5 cm, it is important that the column of substance in the tube should be uniformly packed. This is best achieved by placing the substance in the tube a little at a time and tapping the tube gently on a rubber bung between each addition. Crystalline specimens may require powdering, but the grinding process may cause the sample to gain electrostatic charge and this will prevent accurate measurements on the balance. To minimise this samples should be ground using a plastic spatula and then left for at least 15 minutes after grinding to allow the static charge to subside before packing. An antistatic gun may be used if available.

Operation of the magnetic susceptibility balance

1) Turn the left-hand knob to RANGE 1, and allow 5-10 min. for the apparatus to warm up. [If the apparatus is to be used frequently, it should be left on all day].
2) Adjust zero knob until display reads 000.
3) Gently place the sample tube into the holder and take reading $\mathbf{R_0}$ in cm^2. This value should be negative since glass is diamagnetic.
4) Weigh the sample tube.
5) Pack the sample tube as explained above and weigh the combination of sample tube and sample to obtain the sample mass, **m**, in g.
6) Gently place the sample tube into the holder and take reading **R** in cm^2. If the measurement goes off scale, remove the sample tube turn the RANGE knob to X10 (measurement divided by 10). Rezero the instrument. Reinsert the sample tube and record the reading. Multiply the reading by 10.
7) Remove the tube and gently tap the tube on a rubber bung.
8) Place the tube back in the balance and record the reading.
9) Repeat steps 8) and 9) until a constant reading is obtained.
10) Measure sample length, **l**, in cm. Record the ambient temperature, **T**, in K.

Calculations

The mass susceptibility χ_g (c.g.s. units) is calculated from the following equation:

$$\chi_g = \frac{C(R-R_0)l}{10^9 m}$$

where **l** is sample length (cm); **m** is sample mass (g); $\mathbf{R_0}$ is the empty tube reading; **C** is the dimensionless calibration constant (involving the field strength etc).

This value can then be converted to the molar susceptibility χ_m ($cm^3\ mol^{-1}$) by multiplying by the formula weight.

Next, in order to get a value that is related to the number of unpaired electrons pulling the sample into the magnetic field, the effect of all the diamagnetic pairs repelling it must be removed, including the paired electrons in the paramagnetic atom itself to give the corrected molar susceptibility, χ'_m. Note that since the diamagnetic repulsions oppose (weaken) the paramagnetic attraction, χ'_m is always larger than χ_m. A table of these diamagnetic corrections can be found next to the balance or in most good chemistry databooks.

Finally, the effective magnetic moment μ_{eff} (BM units) can be calculated using the following equation:

$$\mu_{eff} = (8\ \chi'_m\ T)^{½}$$

where χ'_m is the corrected molar susceptibility ($cm^3\ mol^{-1}$) and **T** is the temperature in K.

EXPERIMENT 9

[Co(dinosar)]Cl_3: An Encapsulation Complex prepared by a Template Reaction.

Introduction

Reactions of ligands coordinated to metal centres are of great synthetic importance. One such type of reaction is the template reaction in which the metal coordination sphere acts as a shape former, bringing appropriate parts of the ligands into close contact to allow subsequent reaction with each other or with an external agent and thus minimising unfavourable entropy contributions to reaction energies. The natural syntheses of many metalloproteins and metalloenzymes are based on template reactions. In some cases the new molecule will decoordinate from the metal, however in this experiment the resulting macrobicyclic species, dinosar (1,8-dinitro-3,6,10,13,16,19-hexaazabicyclo-6.6.6-eicosane) - formed from a template "capping" on three 1,2-diaminoethane (ethylenediamine, en) ligands - completely encapsulates the cobalt.

Safety Information

Hydrogen peroxide is a powerful oxidant and its aqueous solutions cause skin damage rapidly. Avoid any contact. Formaldehyde is toxic and carcinogenic and any solutions containing it must be handled in a fume cupboard. All other reagents and products (namely the cobalt complexes, 1,2 diaminoethane, and nitromethane) should be regarded as toxic. Avoid ingestion via nose, skin or mouth and wear gloves. Hot acetic acid and concentrated hydrochloric acid are corrosive and noxious. Wear rubber gloves and work in a fume cupboard. Ethanol, acetic acid and nitromethane are flammable.

Experimental

Preparation of [$Co(en)_3$]Cl_3

Dissolve $CoCl_2.6H_2O$ (6.0 g) in water (17.5 cm^3). Whilst dissolution is in progress, add anhydrous 1,2-diaminoethane (4.5 cm^3) to water (12.5 cm^3) in a conical flask, cool the mixture in ice and then cautiously introduce 6M aqueous HCl (4.5 cm^3; concentrated hydrochloric acid is approximately 12M). With continuous stirring, add the $CoCl_2$ solution to the diaminoethane solution, followed by 30% aqueous H_2O_2 (5.0 cm^3). Continue stirring for several minutes until effervescence has ceased then place the flask on a hot plate (in a fume cupboard) and boil gently. When the solution has evaporated to a volume of approximately 30 cm^3 (but no less, otherwise a green byproduct may be recovered), add an equal volume of concentrated hydrochloric acid, followed by ethanol (60 cm^3). Cool in ice and filter off the precipitate under suction. Wash with ethanol (2 x 20 cm^3) and two of diethylether (20 cm^3) and air-dry the product. Record the yield and measure the electronic spectrum (300-600 nm) of an aqueous solution of your product. [NB you should use a known concentration since you must report extinction coefficients].

Preparation of [Co(dinosar)]Cl_3

Dissolve [$Co(en)_3$]Cl_3 (2.45 g) and Na_2CO_3 (1.2 g) in water (25 cm^3) in a conical flask. With continuous stirring, add 40% aqueous formaldehyde (18 cm^3 CAUTION) followed by nitromethane (2.85 g). Then, either (a) maintain the mixture at 30-40 °C (water bath on hotplate) for 60-90 minutes or (b) allow to stand at ambient temperature for (at least) 5 hours. If no precipitate appears, addition of a small quantity of ethanol (5 cm^3) should encourage it. The resulting solid is filtered under suction and cautiously dissolved in the minimum volume (*ca.* 7 cm^3) of hot 3 M hydrochloric acid. (Note that you may actually need to use slightly more than this). Cool this solution in ice/water and add ethanol (20-25 cm^3). Filter the recrystallised product under suction, air dry and place in a vacuum desiccator.

Record the electronic spectrum of a known concentration (300-600 nm) of an aqueous solution and the infrared spectrum of a nujol mull. High field NMR spectra (^1H **and** ^{13}C) are available from a demonstrator.

Report

1. Briefly indicate the aims of the experiment.
2. Do not reproduce the experimental procedure unless your experiment differed.
3. Give balanced equations for both stages together with yields of the products.
4. Report the electronic spectra of both complexes.
5. Tabulate the NMR data for $[Co(dinosar)]Cl_3$ and assign the spectra.
6. Assign the characteristic vibrations in the IR spectrum.
7. What is the point group symmetry at Cobalt?
8. Briefly suggest a plausible mechanism for the capping reaction.
9. Write a short conclusion.

Hand in with the report:	Samples of $[Co(en)_3]Cl_3$ and $[Co(dinosar)]Cl_3$
	Electronic Spectra for both samples
	Fully assigned ^{1}H and ^{13}C NMR spectra of $[Co(dinosar)]Cl_3$
	Fully assigned infrared spectrum of $[Co(dinosar)]Cl_3$

Allocation of marks (Total 100):	Experimental write-up/presentation	25
	Samples (quality/yields)	25
	Spectra (quality/interpretation)	25
	Conclusion / Results and Discussion	25

Reference

R. J. Geve, T. W. Hambley, J. M. Harrowfield, A. M. Sargeson and M. R. Snow, *J. Am. Chem. Soc.*, **l984**, 106, 5478, and references therein.

EXPERIMENT 10

Anomalous Paramagnetism in some Iron(III) Chelates Studied by the Evans NMR Method

Introduction

Crawford and Swanson have described the use of the Nuclear Magnetic Resonance technique to determine magnetic moments in solution.[1] The method relies on measuring the separation (Δf) in the resonance positions of two identical protons in two solutions. One of the solutions contains the paramagnetic material and the other contains pure solvent. The separation, Δf in Hertz, is related to the mass susceptibility, χ_g, of the dissolved paramagnetic substance by the following relationship

$$\chi_g = \frac{3\Delta f}{2\pi f m} + \chi_O \qquad \textbf{(1)}$$

where f is the frequency of operation of the machine, m is the concentration of paramagnetic substance (g/cm^3) and χ_o is the mass susceptibility of the pure solvent. The magnetic moment is then calculated using eqns **2** and **3**.

$$\chi_M = \chi_g . M \qquad \textbf{(2)}$$

where χ_M is the molar susceptibility and M is the molar weight of the complex. This gives your answer in c.g.s. units.

$\chi_M{}'$ is obtained from χ_M by including a diamagnetic correction for the ligands. This is done by summing the diamagnetic corrections for each ligand atom.[2] Finally, the effective magnetic moment μ_{eff} can be calculated using the equation **3**.

$$\mu_{eff} = (8\ \chi_M{}'\ T)^{1/2} \qquad \textbf{(3)}$$

where T is the temperature of the NMR probe.

In this experiment the technique is applied to the study of the anomalous paramagnetism of iron(III) *N,N*-dialkyldithiocarbamates. These complexes are anomalous in that their behaviour is neither "high spin" nor "low spin".[3,4] Depending on the nature of the alkyl substituents on the ligand, the value of the magnetic moments can be pure low spin, pure high spin, or intermediate between these values.

The explanation is that the ligand field energies for these complexes lie close to the crossover between the high-spin, weak field ground state configuration, ($t_{2g}{}^3 e_g{}^2$) and low-spin strong-field ($t_{2g}{}^5$) states. Thus the spin pairing energy for these complexes must be close to the ligand field strength. The high-spin configuration has 5 unpaired electrons and the low-spin configuration has one unpaired electron. For $Fe(S_2CNR_2)_3$ complexes, the low-spin case occurs for R = isopropyl, and isobutyl, and high spin for 2R = pyrrolidyl. Intermediate magnetic moments are observed for R = methyl, ethyl, benzyl. A spin equilibrium is suggested for these complexes.[3,4]

The iron dithiocarbamates also have the advantage of being easy to prepare and purify and of having good solubility in solvents such as chloroform. As paramagnetic shift, Δf, in eq. 1 depends on concentration, it is an advantage to have as high a concentration as possible for accurate measurement of the shift. For these complexes, shifts of 5-40 Hz are observed for 0.02 g/cm^3 chloroform solutions.

Safety Information

Chloroform should be used in a fume cupboard. Carbon disulfide is toxic and must be used in a fumecupboard (wear gloves too). Both amines are irritating to eyes, face and respiratory system, again use gloves and work in a fumecupboard.

Experimental

Make $Fe(S_2CNR_2)_3$ for NR_2 = N,N-dicyclohexyl and N,N-dibenzyl as follows: Solutions of sodium salts of the ligands are prepared by adding CS_2 (0.05 mol; density = 1.266) to a stirred solution of the amine (0.05 mol) in ethanol (50 cm^3). 6 M NaOH (10 cm^3) is then added with stirring.

The complexes are prepared by mixing 0.017 mol of 60% w/v $FeCl_3$ aqueous solution with the solution from the ligand preparation. A black-brown precipitate immediately forms. This should be recovered by vacuum filtration, the precipitate washed with ethanol and air-dried. The complex is recrystallized by dissolution in hot $CHCl_3$ (30 cm^3) (**in a fume hood**), vacuum filtration, and addition of ethanol (30 cm^3) to the filtrate. Black or dark brown crystals form on cooling; the crystals are recovered by vacuum filtration and are washed with ethanol and air-dried.

The magnetic moments are determined by preparing a chloroform solution of accurately known concentration of the complex (ca. 0.1 g in ca. 0.5 cm^3 - use a pipette). An internal reference is used by placing a sealed capillary containing pure $CHCl_3$ in an NMR tube containing the complex solution. The NMR spectrum is then recorded in the region of the $CHCl_3$ peak. A large, broad solvent peak is observed due to paramagnetic broadening by the complex and a smaller, sharp peak is observed downfield to this peak. The magnetic moments can then be calculated.[1,2]

[NB] For the purposes of this experiment you may calculate the susceptibility of the solvent relativity using the values in reference 2 or see experiment 8.

Report

1. Briefly indicate the aims of the experiment.
2. Do not reproduce the experimental procedure unless your experiment differed.
3. Give balanced equations for the formation of the complexes and yields.
4. Give the magnetic moments (as determined by the Evans NMR method) of the two complexes. Comment on the values obtained.
5. What are the point groups of the compounds that you have made?
6. What sources of both systematic and random error are there in this experiment? Which are most significant errors and how might they be minimised?

Hand in with the report: Samples of both iron(III) chelates
NMR Spectra for both samples

Allocation of marks (Total 100):

Experimental write-up/presentation	10
Samples (quality/yields)	20
Spectra (quality/interpretation)	20
Discussion/conclusions	25
Calculations	25

(continued overpage)

References

1. T. H. Crawford and J. Swanson, *J. Chem. Ed*., **1971**, 48, 382.
2. B. N. Figgis and J. Lewis, in *Modern Coordination Chemistry*; Lewis and Wilkins, Eds., Interscience, New York, 1960, Ch. 6; J. A. Pople, W. G. Schneider and H. J. Bernstein, *High Resolution Nuclear Magnetic Resonance*, McGraw Hill, **1959**, chapter 2. [See also expt. 8]
3. A. H. White, R. Roper, E. Kokot, H. Waterman and R. L. Martin, *Aust. J. Chem*., **1964**, 17, 294.
4. A. H. Ewald, R. L. Martin, E. Sinn, and A. H. White, *Inorg. Chem*., **1969**, 8, 1837.