THE EXPERIENCES OF FIRST YEAR CHEMISTRY STUDENTS LEARNING SPECTROSCOPY BY AN ENQUIRY-BASED APPROACH

by

TIMOTHY LUCAS

A thesis submitted to
the University of Birmingham
for the degree of
MASTER OF PHILOSOPHY

School of Chemistry
The University of Birmingham
June 2009

Acknowledgements

Most importantly I would like to thank my supervisor, Natalie Rowley. Without her guidance and immense help and support, none of this work would have been possible. I am extremely grateful that she kept me motivated through some very difficult times. Her supervision was superb throughout my MPhil and I am lucky to have had the opportunity to work with her. Someone who also deserves a special mention is Norman Reid. I am genuinely honoured to have met him and had the chance to discuss my work with him on many occasions. Words are not enough to describe how grateful I am to Norman and Natalie for all their input.

I would also like to thank the Chemistry Department as a whole for its support throughout my MPhil, in particular I would like to thank Peter Byers and Liam Cox for all the work they completed on my behalf that enabled me to obtain this qualification. I would also like to thank Tina Overton for her input, expertise and guidance in the area of Chemical Education. Her help was always prompt and highly valued.

Obviously my family deserve great praise, especially my parents, Barry and Liz. I know that I can always rely on them. My sister Jane was also an invaluable influence on me during the writing of this thesis.

I am blessed with some very good friends, as shown by their colossal support during my writing up year. Unfortunately, I am unable to discuss each one individually but I would like to thank Emma Packham, Rebecca Lacey, Mona Vadher, Alexis Nielson, Jenny Readman, Rob Winn, Mark Beltcher, David Hewett, Andrew Britton, Natalie Davies, Rachel Hassey, Ellie Tubby, Christopher Henry Richardson-Wright, Lucy Wetton and Matthew Turnbull for all their help and support. Everything worked out in the end!

TABLE OF CONTENTS

Page

Tables

Figures

CHAPTER 1

INTRODUCTION

1.1 Background to the Study

This study took place in the School of Chemistry at the University of Birmingham between October 2006 and June 2008. This research was one of the University's Learning Development Unit "Learner Independence Projects", supported by Teaching Quality Enhancement Funds.

The aim of the Learner Independence Projects is to support the "Vision for Learning" at the University of Birmingham, as laid out in the Learning and Teaching Strategy (Randall, 2007). The strategy recommends that curricula should be developed to support the new learning culture of the University. Central to this new learning culture, across all disciplines, is Enquiry-Based Learning (EBL) (Chapter 2). The action framework, which serves as the plan for the implementation of the new Learning and Teaching Strategy, suggests one method of achieving this is to "*stimulate development of a curriculum that fosters independent, enquiry-led learning, whilst recognising the differences between various disciplines* (Randall, 2007, p. 1)". Randall says "*at Birmingham, we are committed to enabling all our students to profit from a culture of learning, aligned with our research ethos, which is based upon critical enquiry, debate and self-motivation* (Randall, 2007, p. 1)"

The strategy also outlines several key activities that should be used to encourage students to become independent learners. EBL was seen as an ideal method of teaching that would fulfil the objectives of the latest Learning and Teaching Strategy. The potential benefits of an EBL approach, and how these relate to the revised Learning and Teaching Strategy, will be discussed further in Chapter 2.4.

The main aim of the "Learner Independence Projects" is to move students away from a teacher-centred view of education, and to prepare them better for the more autonomous learning that they will encounter at university and in the work place. Malcolm Knowles used the term "andragogy" for his theories of adult learning, as opposed to "pedagogy": the science of educating children. Knowles suggests that adults should be given responsibility for decision making and should be considered as being capable of self-direction. Although it was initially used to describe adult learning, andragogy is more recently accepted to apply to learner-focussed education for people of all ages (Conner, *et al.*, 1996). It is suggested that students should be encouraged to become self-directed, taking responsibility for their own learning (Knowles, 1990).

1.2 My Position as Researcher

Before this project I undertook a three year Bachelors Degree in Chemistry at the University of Birmingham. My final year research project dissertation was entitled "Investigation of Web-based Support for Teaching Year 1 Stereochemistry". This research involved the design and evaluation of a web-based resource for supporting teaching of first year Stereochemistry. The web-based resource involved the use of online quizzes and the use of interactive 3-D models of molecules to aid in the visualization of various aspects of Stereochemistry. This project gave me an interest in Education in Chemistry, and, around this time, the opportunity arose to explore my interests further by undertaking an MPhil in Chemical Education, in the area of Enquiry-Based Learning. My position as a recent graduate from the undergraduate Chemistry course provided a unique viewpoint on teaching and learning within the School of

Chemistry. I recalled finding myself sitting in the same lecture theatre for four hours on a Friday afternoon, clock watching. Thus, I found the opportunity to explore a method of teaching that would potentially break away from a lecture-based approach intriguing, with Enquiry-Based Learning perhaps offering alternative learning approach that might appeal to university students. Inevitably, I was not a completely neutral observer in that I developed the EBL approach and was now seen as a member of staff.

1.3 Purpose of the Study and Research Questions

In investigating the effect of introducing EBL into a small part of the course in the School of Chemistry at the University of Birmingham, the following three broad issues need addressing; "*can it be done?*", "*how do students react?*" and "*does what we implement help learning?*"

When asking if something can be done, it is important to consider if learning material in specific subject areas can be redeveloped in a form that enables enquiry-based learning to be undertaken. There are, of course, time and resource implications to this, both for staff and students.

When assessing how students react to the introduction of EBL, students' experiences and reactions to this approach must be considered. Students have largely been brought up in a teacher-centred learning environment, both at schools and at university. Asking students to adopt a very different learning strategy may generate internal mental conflicts, where they might not feel they are coping with a new approach.

The final issue is to investigate whether a new approach helps learning. At the simplest level this may be investigated by seeing if the new approach affects examination performance. Deeper considerations are: whether the approach assists students to better understand the subject material, and does any change affect their approach to learning in a beneficial way? These deeper issues are, by their nature, very difficult to assess by typical examination.

Time prevents this research from addressing all of these issues. The focus here will be on the student experience of EBL. The reason for this focus is that, unless the student experience is perceived as acceptable and valuable, then it is unlikely that students' learning and their views of learning will be enhanced (Reid, 2006a). This led to the following research question for this project:

> **"What are the experiences of first year Chemistry students of a new EBL approach to teaching Spectroscopy?"**

This question was then broken down into two sub-questions, as follows:

a) "What are the students' attitudes towards the processes of EBL, and how do these attitudes change through the course?"
b) "How does student perceived confidence (in handling the subject matter and in their learning) change, if at all, as a result of their experience in using EBL in the Spectroscopy course?"

Each is now discussed.

"What are the students' attitudes towards the processes of EBL and how do these attitudes change through the course?"

This question will be addressed by looking specifically at student attitudes towards skills development. Students' attitudes to group work will be evaluated, along with an investigation into any other transferable skills that the students perceive they have developed as a result of their EBL activities. A further consideration is whether there is any evidence for any development perceived by students in their learning skills and wider, transferable, skills. Attitudes towards the activities undertaken by the students (for example, whether they enjoyed learning by means of an EBL approach) will be evaluated. The students' attitudes towards the learning process behind these activities will also be assessed. Finally, student attitudes towards the role of staff members in the EBL approach will be investigated. These various attitudes will be examined during the EBL sessions (mid-EBL), and after the EBL and a series of related lectures has been delivered, assessing any changes in attitude towards their experience of EBL in Spectroscopy.

"How does student perceived confidence (in handling the subject matter and in their learning) change, if at all, as a result of their experience in using EBL in the Spectroscopy course?"

This will involve an investigation into how EBL affects student confidence in handling the subject matter and in their learning. Two areas of Spectroscopy will be investigated: their confidence in interpreting spectra of various spectroscopic techniques, and their confidence in their knowledge of the theory behind these techniques.

These two sub-questions therefore provide two different areas to be investigated in this study: student perceived confidences in Spectroscopy, and students' attitudes towards various aspects of the EBL course in Spectroscopy. The research tools for use in this study will be described in Chapter 3. Before this is addressed, it is important to consider the literature surrounding EBL (Chapter 2).

1.4 Structure of the Thesis

A review of literature will be presented in the next chapter (Chapter 2), introducing what is understood by the term *"Enquiry-Based Learning"*. It is important to consider what types of teaching can be considered as being EBL, and the characteristics of EBL approaches to teaching. The main focus of this review will concentrate on the form of EBL that is implemented in this project, and will consider some suggested advantages and disadvantages of this approach.

After providing the reader with a deeper understanding of the literature associated with EBL, the methodology of research will be discussed (Chapter 3). The existing, traditional course used to teach Spectroscopy will be outlined and the chapter will also address why the research tools were chosen, and how they were developed for use in the study. How EBL was implemented in the Chemistry course will be discussed, with justification of the design of the implementation, in light of the literature presented in Chapter 2.

Once the reader has been given a clear idea of the design of the research tools and of the EBL course, results obtained from the study will be presented and discussed in Chapter 4. This section will present data relating to the two research questions outlined in Section 1.3. Data from the various collection methods will be presented together, in appropriate sections, to present a overall view of the students' attitudes and perceived confidences.

After the results from the study have been presented, Chapter 5 will draw some conclusions from the data presented and discussed in Chapter 4. This chapter will then consider to what extent it is possible to answer the specific research questions of this study, and suggest further work which may be of interest as a result of this research. Finally limitations of this study will be discussed in detail.

CHAPTER 2

REVIEW OF LITERATURE: ENQUIRY-BASED LEARNING

In this chapter, a brief overview of EBL will be given in Section 2.1, followed by a more detailed discussion of EBL, and examples of previous implementation of the technique within a university Chemistry context (Sections 2.2 and 2.3 respectively). The approach adopted in this study can also be classified as a Problem-Based Learning (PBL) approach. Hence, the literature surrounding PBL will also be addressed (Section 2.4 and subsections therein), with an emphasis on the process of learning (Section 2.4.2), and the suggested effective design of a PBL course (Section 2.4.3). Issues of facilitation of group work in PBL will be considered (Section 2.4.4), as the role of a facilitator used in EBL and PBL is very different to that used in a more traditional teaching approach. Additionally, as a PBL approach involves group work, issues surrounding group size and selection will be explored in Section 2.5. Section 2.6 addresses the issue of assessment in the context of EBL, as this method of teaching often requires alternative methods of assessment. Section 2.7 examines the potential advantages and disadvantages of an EBL approach, and how these relate to the research questions presented in Section 1.3. This discussion will include aspects of theories of learning, where appropriate, that relate to the issues raised. This discussion will focus on the literature associated with the research questions, as given in Section 1.3. Finally, Section 2.8 addresses the conclusions from the findings of the previous sections.

2.1 Introduction to EBL

Before discussing Enquiry-Based Learning (EBL), it is important to define what is meant by the term "learning". The Oxford English Dictionary defines learning as "*the action of receiving instruction or acquiring knowledge*" (Oxford University Press, 2008). Bloom, *et al.* (1956) define knowledge as "*involving the recall of specifics and universals, the recall of methods and processes, or the recall of a pattern structure or setting*" (Bloom, Englehart, Furst, Hill, and Krathwohl, 1956, p. 201).

Psychologists and educators would agree that the learning process is subject to change through training or experience (Hamachek, 1990). It is clear that there are many wide-ranging definitions for the term "learning". There are also many diverse learning models which consider learning at different stages of life. Examples of such models include: Piaget's Cognitive Development (Piaget, 1962/1945), Malcolm Knowles Model of Andragogy (Knowles, 1990), Constructivism (Glasersfeld, 1991), and the Information Processing Model (Johnstone, 1997). Although these models of learning are important to consider, the focus of this literature survey will be on the area of EBL, and models of learning will only be included where appropriate.

EBL is a broad umbrella term used to describe approaches to learning that are driven by a process of enquiry, which actively involves students in discussion, questioning, and investigation (Kahn and O'Rourke, 2005). A strict definition is avoided to prevent the term being too restrictive to staff who are implementing some form of EBL in their teaching (CIBL, 2008).

EBL is an example of an "active" type of learning, which takes a strongly student-centred approach to education, and has been implemented in Higher Education world-wide. Active learning is described as students becoming more engaged with the learning material, in comparison to a passive approach such as a lecture (Benware and Deci, 1984). This approach promotes “deep learning”, as opposed to some traditional passive approaches that foster “surface learning” (Entwistle, 1988). Deep learning is preferential to surface learning, because a student will put meanings in their own terms, focusing on arguments and conclusions, relating new ideas to previous assumptions, distinguishing argument from evidence, and organising content into structures (Adams and Hamm, 1996). In surface learning, a student will simply memorise information for examinations, and associate facts and concepts without structure. Surface learning does not allow the conceptual growth that deep learning allows (Adams and Hamm, 1996).

An enquiry-based approach is very different to a lecture-based approach. Lectures are the most common form of teaching at universities, and it has been suggested that the method is over-used in Higher Education (Exley and Dennick, 2004). Traditionally, a lecture-based approach is a teacher-centred approach to learning that requires students to listen passively and take notes. It is seen as a cost effective method for communicating information to a large number of students in a short period of time. The assumption is that the communication of knowledge results in learning, but this may not be the case (Fetherston, 2001). Studies have shown that attention drops significantly in a lecture after the first ten to fifteen minutes, highlighting the passive learning encouraged by a lecture-based approach (Stuart and Rutherford, 1978). If students sit passively in a lecture and are told what is important for tests and difficult points are explained, then they are not taking responsibility for their learning, and are not making effective use of the resources available to them (Waite, Jackson, and Diwan, 2003).

In EBL, the tutor establishes the task and facilitates the process but, fundamentally, the students follow their own lines of enquiry, drawing upon their existing subject knowledge, and identifying their own learning requirements (Kahn and O'Rourke, 2005). The enquiry process encourages students to identify what they already know, so that they can identify their own learning requirements.

A facilitator may present a question (which is often open ended), or can encourage students to ask their own questions. Tasks should stimulate curiosity in students so that they then seek out relevant evidence for themselves, as opposed to being told the required information upfront in a lecture. Students take responsibility for analysing and presenting the information which they have found, thus developing research skills which, perhaps, can be transferred to other areas (Kahn and O'Rourke, 2005). Students can do this either as part of a group, or as an individual, supported by others. It is said that learning is "*largely a social enterprise and most human labour is performed by teams*", and for this reason group collaboration is an important part of the learning process (Bonk and Kim, 1998). Von Glasersfeld suggested that social interactions, or group learning, have several advantages (Glasersfeld, 1991). A student explaining something to a peer can lead to them understanding things in more depth, and also can help them to spot inconsistencies in their thoughts. Indeed, information is better understood, processed and retrieved if students have a chance to elaborate on the information concerned (Schmidt, 1983). This can be achieved by teaching peers and discussing material with peers. Having an error explained by a peer is also seen to be less "painful" than having a teacher tell a student that they are wrong (Glasersfeld, 1991, p. 177). Cooperative learning in groups has also been shown to improve student motivation and academic performance (Adams and Hamm, 1996). Von Glasersfeld suggested that if one group member finds an answer then this can generate motivation for students to tackle a new problem (Glasersfeld, 1991).

During the EBL process students have to make decisions, some of which may take them down unproductive avenues and fail to reach an outcome. Such mistakes are part of the learning process, as they can teach students that there are often no straightforward or ready-made answers. As such, EBL scenarios are created so that they are open-ended, so that there are, often, many different outcomes.

The exploratory nature of EBL allows students to look at ideas in different ways and promotes creative thinking concerning problems (Hutchings, 2006). Such opportunities are unlikely to arise in a traditional lecture-based approach. EBL is usually organised around collaborative group work, and encourages students to create and conduct their own enquiries. As a result it allows students to develop a wide range of abilities that may not be subject specific (transferable skills), whilst still engaging them in the process of learning (Kahn and O'Rourke, 2004). Such transferable skills are valued by employers in science-based organisations (Cole and Mattews, 1996). Such transferable skills include; oral communication, personal skills, social skills, written communication and problem solving. Development of these transferable skills in undergraduate students is also seen as important by the QAA (QAA, 2007).

2.2 Types of EBL

Although the fundamental principles of EBL remain consistent throughout, there are several different approaches to learning that can be defined using the term ‘EBL’ (Figure 2.1).

Despite their subtle differences, problem-based learning (PBL), small scale investigations and project work (project-based learning) are all approaches that are driven by a process of enquiry.

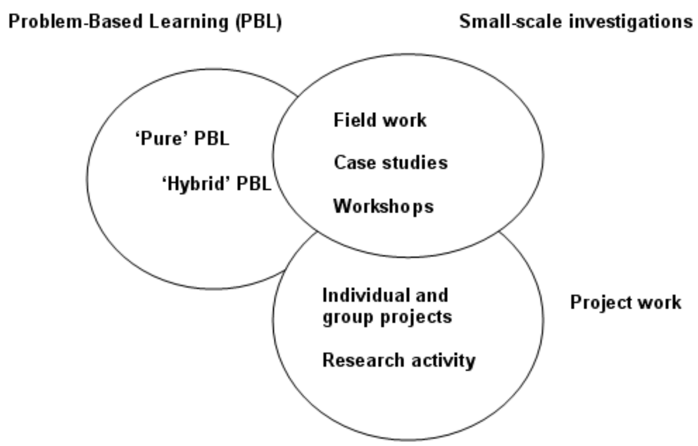


Figure 2.1: Different approaches that are covered in EBL (Kahn and O'Rourke, 2004).

There are varying and often confusing definitions of what constitutes EBL: for example, some authors consider EBL to be a separate entity to PBL. Here it is considered that the approaches covered in Figure 2.1 can all be defined as EBL. By this definition, PBL can also be defined as a type of EBL.

2.2.1 Problem-Based Learning (PBL)

In PBL, the exploration of a scenario/problem drives the learning process, and encourages groups of students to conduct their own enquiries in order to solve the problem or reach a stated outcome. The problem is encountered first in the learning process, and the learning comes from the students working towards the understanding and resolution of the problem (Savin-Baden and Major, 2004). This is in contrast to a more "traditional" approach, where problems will only be encountered after a body of information has been mastered. PBL will be examined in more detail in Section 2.4 and the subsections therein.

2.2.2 Case Studies

A case study is a description of a real life occurrence, which is placed in a context that requires students to make decisions and take actions after being presented with the facts of the case. As in PBL, such work is often carried out in teams (Cheng, 1995). Case studies are often used in Problem-Based Learning activities, thus illustrating the lack of strict definitions involving the area of EBL.

2.2.3 Project-Based Learning

Project-Based Learning is often abbreviated to PBL, which may cause confusion with "Problem-Based Learning". Here, the term PBL will always refer to Problem-Based Learning. Project-Based Learning differs from PBL because it is focused on an "endpoint". In PBL, the output (if any) is only one piece of evidence for achievement of the learning outcomes (Savery, 2006). An extended piece of project-work, with the production of a dissertation, is commonly found in the final year of degree programmes. This usually occurs after a given body of information has already been learnt, and the skills required for using and analysing knowledge have already been developed (Kahn and O'Rourke, 2004). Kahn and O'Rourke (2004) suggest that project-work can be used to learn a given body of knowledge, prior to formal teaching, rather than simply making connections within an existing body of knowledge (after formal teaching). It is suggested that project work, on a smaller scale, could be introduced earlier in a degree programme (Kahn and O'Rourke, 2005).

2.3 Previous Applications of EBL in University Chemistry

Whether it is in the form of Project-Based Learning or Problem-Based Learning, EBL has previously been implemented in university Chemistry departments worldwide. The approach is known as Inquiry-Based Learning in American English. Much is almost certainly not published. EBL is widely used in areas such as medicine, and, though less common, there has nevertheless still been a significant amount of EBL implemented in Chemistry internationally. Such implementation in Chemistry, however, often does not include published, detailed analysis of the outcomes of any change found as a result of its use.

It is not possible to discuss all examples of EBL implemented in university Chemistry here, but a few, more detailed studies will be considered. One such example is of the implementation of EBL in Chemistry laboratories. There are many examples of an EBL approach in the Chemistry laboratory, and these often take the format of research-based laboratories (Ford, Prudente, and Newton, 2008). In order to engage first year students in research, Ford, Prudente, and Newtone (2008) altered a traditional laboratory course to a research-focused curriculum with a central theme of measurement and analysis. They suggest that students gained an appreciation of a broad range of areas that employ chemical techniques. Implementation of EBL in laboratory courses appears much more prevalent than in non-laboratory courses. Despite this, it has been used in other areas of the Chemistry curriculum. Belt *et al.* (2002) suggest that Chemistry provides many opportunities for tasks to be contextualised in areas such as Analytical Chemistry, Forensic Science and Industrial Chemistry. Environmental Chemistry appears to lend itself well to an EBL approach, with case studies being used at such institutions as the University of Hong Kong and King Fahd University (Seddigi and Overton, 2003). Seddigi and Overton (2003) used a case study concerning environmental problems along a river bank to teach Environmental Chemistry to engineering students taking a course in Chemistry. However, case studies are not limited to the area of Environmental Chemistry. They have also been used to illustrate principles such as gas density, solubility, acid-base reactions, and buffering. At Willamette University, case studies have also been used to teach a wide range of topics away from the laboratory (Brink, Goodney, Hudak, and Silverstein, 1995). Case studies included topics such as lasers and bioenergetics in order to teach a variety of topics, such as, the periodic table and redox reactions.

In the UK, case studies have been piloted at the University of Plymouth with students studying for degrees in Analytical Chemistry and Applied Chemistry (Belt, Leisvik, Hyde, and Overton, 2005). A case study called "Capital City" has been used to teach students Thermodynamics and Kinetics. The case study was set in the context of a domestic energy related theme and was delivered over several sessions. The case-study took the form of a three-way liaison between the head of a city council department, a project manager and an advisory team (the students). Belt *et al.* (2005) suggest that students appreciated the opportunity to study in an applied context, leading students to perceive the task as relevant, and also to develop their knowledge in the areas of Thermodynamics and Kinetics.

There are also a number of online resources containing case studies for use (Kennesaw State University, 2005) (The National Center for Case Study Teaching in Science, 2008). One such example is a large selection of pre-prepared case studies from The National Centre for Case Study Teaching in Science, including cases for use in Stereochemistry, Avagadro's number, and the mole: (http://ublib.buffalo.edu/libraries/projects/cases/ubcase.htm; Accessed 26-Oct-2008). This highlights that EBL may have applications in a wide area of chemical topics.

EBL has been used to teach Spectroscopy to university students at the State University of New York (Kandel and Tonge, 2001). Online problems were used to develop interpretive skills needed for an upcoming laboratory-based project in Spectroscopy. In the laboratory, students worked in small groups and students were asked to indentify an unknown compound after they had purified it. The focus of the course was to teach students how to use the spectroscopic equipment in the correct manner and to teach them how to interpret the spectra produced by the various instruments. The spectroscopic techniques covered in this approach were IR, ^{1}H and ^{13}C NMR Spectroscopy, and Mass Spectrometry. Unfortunately, the published evaluation of this approach lacked detail.

EBL has, therefore, had a number of previous applications in Chemistry, with some positive findings. Case studies, taught by PBL and EBL, utilised in the laboratory seem to be the most popular area of implementation. Areas such as Analytical Chemistry seem to lend themselves well to an EBL approach, but other topics such as Spectroscopy, Thermodynamics and Kinetics have also seen EBL implementation.

2.4 Problem-Based Learning

2.4.1 Introduction

PBL is becoming more popular within Higher Education, although it has been used successfully for over thirty years. It was first implemented in a medical course at McMaster University, Canada, and it is now widely used within medical schools around the world (Raine and Symons, 2005). However, PBL is increasingly being used in many more disciplines (Barrows and Tamblyn, 1980) (Savin-Baden and Major, 2004).

It is argued that PBL should not be seen as a particular way or method of learning. Instead it should be seen as learning that has many different forms. It is suggested that PBL differs according to the discipline and the goals of the particular programme (Savin-Baden and Major, 2004). Despite this, some have tried to define PBL, *e.g.* "*the learning that results from the process of working towards the understanding of a resolution of a problem. The problem is encountered first in the learning process*" (Savin-Baden and Major, 2004) (Barrows and Tamblyn, 1980). Knowles (1990) suggests that adult learners are problem-centred in their orientation to learning. They are motivated to learn to the extent that they perceive will help them perform tasks which they confront in their life situations. It is suggested that instruction should be problem-centred, as in problem-based learning, rather than content-oriented.

Generally speaking, PBL is an instructional student-centred approach that allows students to conduct research, to make connections between theory and practice, and to apply their knowledge and skills to develop solutions to a defined, but ill-structured problem that is often based in the real world (Raine and Symons, 2005). The problem is contextualised in PBL, although this is not always the case in an EBL approach.

2.4.2 The Problem-Based Learning Process

There are in reality, different forms of PBL. In practice, most have elements in common, but also some contain elements that were developed in relation to organisational and discipline needs, local constraints, and the critical thinking of the curriculum designers themselves. Schmidt (1983) outlined a generic, seven step problem-based learning process (Figure 2.2) although there is no evidence that students actually work this way.

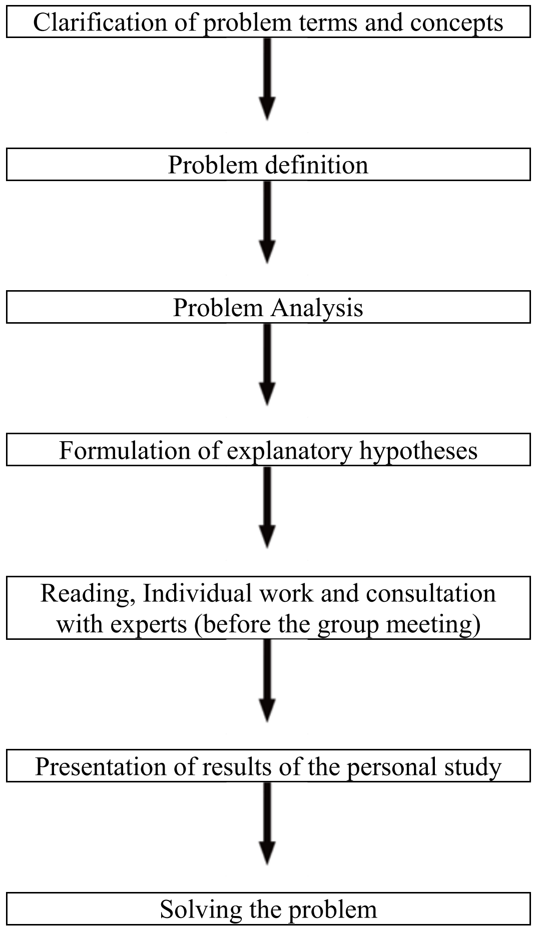


Figure 2.2: The seven stage problem-based learning process (Schmidt, 1983).

The exact number of defined steps in the process can vary in the literature. For example, Ram (1999) outlines a five-step model of PBL. Despite the varying number of steps, the general processes outlined in the literature are essentially the same as those defined by Schmidt (1983). Savin-Baden and Major (2004) suggested an “operational definition” of PBL, based on this seven step process, which outlined the learning process that should occur during PBL.

Savin-Baden and Major (2004) suggest that the PBL process begins with students defining a problem, interpreting the information presented to them. After the initial definition of the problem, students should brainstorm their collective prior knowledge as a group, to identify what they already know about the problem area, and they can then identify what information they need to learn in order to solve the problem. After formulating their own learning objectives, and identifying the background knowledge required to solve the problem, students then engage in independent study on the learning issues that they created themselves. When this is complete, after a given amount of time, students come back to the sessions and share the information that they have learned with the rest of their group. The students then work on the problem, as a group, using peer teaching to solve the problem and to produce a solution.

This sharing of knowledge and collaboration is seen as an essential part of the PBL process (Problem Based Learning Initiative, 2008). After the solution has been presented, it is suggested that students should review what they have learned during the course of working on the problem (Savin-Baden and Major, 2004). Barrows and Tamblyn (1980) suggest that this can be achieved by self, peer, and tutor review of the PBL process, looking at each student's contribution to that process.

Generic problem solving is a common occurrence in a chemist's work, and there are various factors that can improve or hinder its success. In a study of educational research that considered "Cooperative" *versus* "Competitive" Problem Solving, it was shown that solving non-linguistic problems, such as mathematical problems, can be improved by co-operation between peers (Qin, Johnson, and Johnson, 1995). A study of college students' problem solving abilities showed that group problem solutions were better than individual solutions on matched, context-rich Physics problems (Heller, Keith, and Anderson, 1992).

The 'PBL Initiative' is a group of teachers and researchers involved in PBL who discuss the essential characteristics of PBL (Problem Based Learning Initiative, 2008). They suggest that, due to the differing curricular and time demands of teacher-centred learning diminishing the value PBL, PBL should not form part of a didactic curriculum, and should instead be the pedagogical basis of the curriculum. Despite this recommendation, hybrid-PBL, which incorporates other teaching methods, such as lectures, into the curriculum is also used.

Armstrong (1998) suggests that the retention of information from lectures in a new hybrid PBL approach accommodated a variety of learning styles, to prevent the new system from being "one sided" (favouring one learning style over another) compared to the previous, traditional approach. In a study at Harvard University, the number of lectures delivered was reduced and the lecture content changed, so that the lectures could be used to teach more conceptually difficult material that students may not have assimilated during their independent study (Armstrong, 1998). O'Kelly (2005) suggests that the main differences between the hybrid-PBL method and the "pure PBL" method are that the problems are often shorter than in pure PBL, there is inclusion of at least one lecture a week, and the assessment methods may differ (for example the inclusion of traditional exams). Lectures can be adapted to suit the style of PBL teaching better, with problem-solving in groups of two during the lecture, and with answers provided after the students have attempted the problems (O'Kelly, 2005). As referred to previously, the exact structure of any PBL implementation can vary from institution to institution, and from department to department. Although the principles of PBL remain constant, there are some elements of any PBL implementation that may be unique to its use in a particular instance.

2.4.3 Problem Design

In PBL, the problem itself is the stimulus for learning, and provides motivation and thrust for learning (Wee, Kek, and Sim, 2001). It is suggested that a well-structured problem can lead to students becoming less motivated to develop a solution (Barrett, 2005). Good problem design is absolutely essential for a PBL course to be successful. It is suggested that a problem should be ill-structured in order to encourage “free enquiry” (Problem Based Learning Initiative, 2008). It has been shown by Barrett (2005) that motivation increases when a student has responsibility for the solution of a problem and the process of obtaining a solution. The Problem Based Learning Initiative suggest that this ill-structured type of problem is representative of the “real world”, and any activities carried out in PBL should be the same activities that a professional would encounter in the real world. Duch (1996) suggests that a problem should draw the students into discussion. Duch (1996) also agrees that an effective problem should relate the subject to the real world, and also suggests that the problem should engage students’ interests, and motivate them to probe more deeply for an understanding of the concepts presented. This can be achieved by including a controversial topic, which is open ended, so that there is not just one correct answer. Although independent research carried out by students is important, a problem should be designed so that the cooperation of all the group members is necessary for the task to be completed. This can be achieved by designing the length or complexity of the problem to ensure that the “divide and conquer” method of tackling the problem would not be successful (Duch, 1996).

2.5 Group Selection and Facilitation in EBL

It is clear that group work is a major feature of EBL and particularly PBL, and, while the task can be designed so that it encourages students to collaborate on the task, there are other methods available for encouraging effective group work. Consideration should be given to the selection (membership) and size of the groups, as well as to how the groups are “managed” during the EBL process. Issues or group selection and size along with facilitation are issues that concern most forms of EBL.

Groups can be formed by random assignment, self selection, or assignment based on criteria such as student ability. Most published advice recommends the final method of group selection, by attempting to "engineer" a successful group, but the first two methods are the most commonly used (Huxham and Land, 2000). This may be because it can be difficult to devise appropriate selection criteria by which to allocate groups. By creating balanced groups in relation to student ability, it is assumed that weaker students will have an opportunity to learn from stronger students (Muller, 2007).

Group size is an important consideration when implementing EBL. Group functioning can be hampered by fewer than four students (Könings, Wiers, Wiel, and Schmidt, 2005). Indeed, groups of three students are suggested to be too small due to problems with triads (Simmel, 1950). Also, personality clashes and disputes in smaller groups are more difficult to resolve, and absences are more significant than in larger groups (Rau and Heyl, 1990). Small groups may lack diversity, and, as a result, lack varied expertise that would help with collective decision making.

Large groups of students also provide problems. One or more members can become inactive in the process (Rau and Heyl, 1990). It has been shown that member participation decreases as group size increases (between two and twelve members), and groups of six are most conducive to the appearance of effective and efficient leadership (Cummings, Huber, and Eugene, 1974). Although member participation is affected by group size, studies have shown that group performance is not significantly affected by group size from a range of five to nine (Cummings, Huber, and Eugene, 1974).

There are various opinions on optimal group size. A permanent group size of five or six students has been recommended (Rau and Heyl, 1990). However, a group size of between six and eight students has also been suggested to be the optimum number (Barrows, 1980). Group size selection is not only controlled by preference, but it may also be controlled by practical issues such as the work space, or the total number of students. If there is a non-functioning group, it may be necessary to split the group up, but students put into other, pre-existing, groups may struggle to integrate properly with their new group (Rau and Heyl, 1990).

Group size is clearly an important concern when designing any EBL-based tasks, but facilitation is also an essential consideration. Facilitation can be used to ensure that all information has been shared between the group members by asking appropriate questions (Raine and Symons, 2005). Facilitation is essential in EBL, as students need to be prevented from losing sight of the main thrust of the open-ended enquiry. The tutor may find it hard to adjust to the change in role from a context expert to facilitator, and may need even more guidance than that given to the students (Kahn and O'Rourke, 2004).

It has been observed that many facilitators oscillate between being directive towards students, creating a counter-productive student dependency, and facilitators who say nothing at all, leading to students to think that it is the facilitator’s way of avoiding a declaration of their own agenda (Kahn and O'Rourke, 2004). The balance is important: too much tutor intervention may stifle the enquiry process; too little intervention and the students may feel unsupported or anxious.

Although the main principles of facilitation are maintained there are different models of facilitation in EBL (Raine and Symons, 2005). A common form of facilitation is the use of a “fixed” facilitator, where a tutor is assigned to each group to guide student discussion during sessions, but it is the students’ responsibility to meet up outside of the sessions. In this model of facilitation, each facilitator is required to be with their group. Thus, if all the groups have their EBL sessions at the same time, several staff are required to facilitate the groups. A way around this problem would be to have different groups timetabled at different times, so that one facilitator can facilitate more than one group.

Another facilitation model is the use of “floating” facilitators. In this model, the facilitator moves from group to group, listening to students, and asking students questions to investigate their understanding. In this model it may be necessary to include a “mini-lecture” on certain topics, and to dedicate some time to class debates (Raine and Symons, 2005). It is suggested that group size is limited to five in this method of facilitation to increase student accountability.

2.6 Assessment of EBL

Assessment drives the learning experience, especially when the significant majority of learning occurs outside the classroom (Khan and O’Rourke, 2004). Good assessment of students’ knowledge, skills and ability is crucial to the learning process. Traditional assessment methods may not be suitable for use in any EBL implementation, thus requiring consideration of different assessment methods that may be applied to an EBL style of teaching.

It is suggested that evidence for assessment should be generated as a product of enquiry, as opposed to being a separate exercise. Assessment in EBL should be focused more on assessing a student’s ability to perform in a professional situation, rather than assessing how much a student knows (Macdonald 2005). There is an increasing realisation that some conventional forms of assessment often test only a narrow range of knowledge and skills. Increasingly, employers want to see what applicants can do as well as what they know

(Baume 2001). It is suggested that for effective collaborative learning, there must be "group goals" along with "individual accountability" (Slavin, 1989).

There are a wide range of assessment methods that can be employed to assess EBL activities (such as PBL), due to the wide range of learning outcomes that are generated. Group reports, on the enquiry as a whole, can be used, and are a straightforward way of assessing outcomes (Kahn and O'Rourke, 2004). A written report can also develop students' written communication skills. Peer review, after completion of the task, has already been highlighted as an important part of the PBL/EBL process (Section 2.4.2). Peer assessment can be used in EBL as it aligns with a group based-process (Kahn and O'Rourke, 2004). It emphasizes the collaborative nature of the EBL environment, although some students may have difficulty with this form of assessment, due to them having come from a more competitive college environment (Kahn and O'Rourke, 2004). Students must be able to understand the marking criteria, and, as a result, the criteria against which the enquiry will be judged. This is particularly effective when it is used on a formative basis.

Constraints in which EBL is used may necessitate the use of an examination. It is likely that existing examinations will only assess a limited range of the relevant learning outcomes. An enquiry-based exam could be used, where students work individually with new data, and have to make sense of a situation. Students would still have to prepare for the exam but could not simply 'rote learn'. A student can possess relevant knowledge (by memorising key facts), but may be unable to use this knowledge to solve problems. "Rote learning" occurs when students are unable to use their knowledge because they do not understand the material (Mayer, 2002). Mayer (2002) proposed that, if a student can recall important facts and use the information to solve problems and generate many possible solutions, this is called "meaningful learning". The student possesses the relevant knowledge, and can also use the knowledge to solve problems and understand new concepts. It is suggested that meaningful learning occurs when "*students build the knowledge and cognitive processes needed for successful problem solving*" (Mayer, 2002).

2.7 Advantages and Disadvantages of an EBL Approach

Although the effective design of EBL course material, such as problems in PBL, is essential for the success of any EBL implementation, it must be considered why institutions are implementing EBL in their teaching courses. Although there are a wide range of possible advantages and disadvantages that may be associated with EBL as a process of learning, this section will focus on issues relating to the research questions of this study as laid out in Section 1.3. One of the aims of assessing students' attitudes towards the processes of EBL was to investigate to what extent the students felt that they had developed various skills, such as learner independence, team working, and other transferable skills. These skills are now considered in more detail (Section 2.7.1 and subsections therein).

2.7.1 Transferable Skills

2.7.1.1 Learner Independence

The aim of the University of Birmingham's Learner Independence Projects, and the University's revised Learning and Teaching Strategy (Randall, 2007) is primarily to foster independent learning within the University. EBL is inherently a student-centred approach, and students setting their own learning objectives and carrying out their own individual independent study is vital (Savin-Baden and Major, 2004). The University's Learning and Teaching strategy refers to students being able to manage their own learning process, both individually and collaboratively (Randall, 2007). Although it is difficult assess to what degree an EBL approach fosters independent learning, studies have shown that an EBL approach can promote learner autonomy (Oliver and McLoughlin, 1999).

There are, however, some potential disadvantages of the promotion of learner independence. The working memory is a limited working space in the brain where information is held and manipulated before it is passed onto the long term memory for storage (Johnstone, 1997). If there is too much information to hold, there is not enough space for processing the information, and *vice-versa*. It has been suggested that free-enquiry can generate a heavy load on the working memory, which would be detrimental to learning (Kirschner, Sweller, and Clark, 2006). Wood (2003) suggests students may suffer from information overload, have difficulty in deciding how much self-directed study they need to do, and in deciding what information is useful and relevant. It has been shown that students with a high working memory capacity perform better than students with a lower working memory capacity in a Chemistry test based on questions normally tackled by students, an early study being that of Johnstone and El-Banna (1986,1989).

Studies have shown there to be a link between working memory capacity and students' performance. It was shown that when a question makes a demand in terms of information to be handled simultaneously which is greater than a student's working memory capacity, performance drops significantly (Danili and Reid, 2004). It is suggested that the available working memory is reduced with excessive and unnecessary information, and thus a student's ability to cope with chemical exercises is reduced (Danili and Reid, 2004). Kirschner, Sweller and Clark (2006) suggest that a guided approach (such as a lecture-based course) produces a quicker recall of facts and more transferable skills than an unguided approach. They do concede, however, that a guided approach, such as the use of worked examples, can be hindered by its design, which is a potential downfall that may be encountered in EBL. If the core design of a new EBL approach is flawed, then so its effectiveness to teach students will be diminished.

2.7.1.2 Team Working Skills

Not only does EBL have the potential to promote student autonomy but it can also develop team working skills due its collaborative nature (Dunlap, 2005). Barrows and Kelson (1993) state that the EBL (specifically PBL) learning process is designed to develop collaborative team working skills, and to encourage students to work and learn effectively as a team, and this is not done at the expense of the development of the individual. The University's Learning and Teaching strategy suggests that students should be able to share their knowledge and experience with other students from differing backgrounds and perspectives. Thus, it would seem that an EBL approach may be able to fulfil this aim (Randall, 2007). Despite the collaborative nature of EBL allowing the development of team working skills, it may also lead to unequal participation in the groups (Hospitality, Leisure, Sport and Tourism Network, 2009). Although there will always be students who will not engage with the learning process, there are methods of reducing this problem, such as facilitation and appropriate assessment.

2.7.1.3 Other Transferable Skills

Team working skills are not the only skills that can be developed *via* EBL. Students can also develop a wide range of other "transferable skills" (of which team work skills are a part) that are valued by employers (Martin, Bill, and West, 2006). Ward and Lee (2002) state that an

EBL approach can develop other generic skills such as problem-solving and communication skills. Although a direct measure of skills development in students is a difficult task, student perceptions and attitudes have been used to measure skills development. Students have been shown to demonstrate increased motivation (Martin, Bill, and West, 2006). The University's Learning and Teaching strategy also refers to skills development, and it is suggested that students should be able to engage with complex and real problems (Randall, 2007). The Quality Assurance Agency (QAA) publishes general guidelines for the academic review of degree programmes with honours in Chemistry (QAA, 2007). They suggest that the development of these generic skills, that are of value in chemical and non-chemical professions, are one of the main aims of a degree programme in Chemistry, in particular, problem-solving skills although it has to be noted that the meaning of 'problem solving skills' is rarely offered, one exception being in Wood and Sleet (1993).

2.7.2 Core Knowledge

Although the development of transferable skills is important, the QAA primarily emphasizes the development of a core knowledge base (QAA, 2007). It has been found that students can learn content through EBL as effectively as they can through a lecture-based approach (Ward and Lee, 2002). Although some studies have shown that students who undertake an EBL-based course show lower multiple choice test scores compared to a lecture-based course, students can retain their knowledge more effectively after EBL (Ward and Lee, 2002). Other studies conducted have shown no significant difference in multiple choice test scores between a lecture-based and problem-based course, although students who undertook an EBL course scored significantly higher in short essay questions (Antephol and Herzig, 1999). This finding may be due to EBL fostering deeper learning (as opposed to surface learning), thus leading to an improved understanding of subject material (Wood, 2003). This highlights that an existing assessment method may not be appropriate for an EBL approach, hence the assessment may need to be completely changed in order to reflect the EBL approach.

2.7.3 Student Confidence

It is likely that a change in students' perceived confidence in a topic will be related to development of core knowledge in a given body of information. Despite the potential pitfalls of using an approach that is unfamiliar to students, some argue that EBL can increase students' self-confidence, due to them learning more effectively compared to more traditional approaches such as lectures (Braye, Lebacq, Mann, and Midwinter, 2003). Student confidence relating to learning outcomes in a third-year Electrical and Electronic Engineering module taught using EBL have been investigated (Powell, Peaker, William, Hicks, and Canavan, 2007). Of the eight learning outcomes considered, students suggested that their confidence had increased, post-EBL, in seven. Interestingly, there was one learning outcome, relating to image perception, which showed a decrease in student confidence, but this was attributed to the fact that the topic was only covered in an introductory lecture, and did not form any part of the groups' enquiries.

When given the choice, students prefer to remain in their 'comfort zone' (Vaughn and Baker, 2001). Students tend to be more comfortable with familiar approaches to learning, and if students are not familiar with an approach to teaching they may react negatively (Rees, Atkin, and Zimmerman, 2005). This lack of familiarity and comfort in students can lead to comments and responses which appear to be contradictory to other students' responses (OIRA, 2007). With responsibility being put onto the students through EBL, some students might see an excessive demand on their time through independent study, and with a variety of learning styles likely to be present, students may lack confidence in a PBL approach (Hospitality, Leisure, Sport and Tourism Network, 2009). Although some students prefer familiar and non-threatening situations, this may not be the case for every student (Boekaerts, 1996).

2.7.4 Student Enjoyment

The University of Birmingham's Learning and Teaching Strategy also suggests that students should enjoy their work, which should be "rewarding and fun" (Randall, 2007). Woods (2003) suggests that students are motivated more by an EBL approach in comparison to a traditional approach, and that students and tutors find the process "fun". This can be attributed to the fact that all of the students are required to engage in the learning process (Duncan, Lyons, and Al-Nakeeb, 2007).

It is likely that enjoyment of an activity will be related to the students' motivation to engage with, and complete, the activity. It is suggested that students become more enthusiastic for EBL courses as they engage in the EBL process (Kennedy and Navey-Davis, 2004). A student who engages with the EBL process will find that learning is more enjoyable compared to more traditional methods of teaching (Pawson, Fournier, Haigh, Muniz, Trafford, and Vajoczki, 2006).

Despite Woods (2003) suggesting that the tutor can find the process "fun", some tutors may find the role of facilitator frustrating, as they are unable to provide answers directly to the students (Hospitality, Leisure, Sport and Tourism Network, 2009). It is likely that students may also become frustrated by the lack of direct answers being provided by facilitators.

2.8 Conclusions

It is clear that, although there are varying forms of EBL that may vary from case to case, it is important to consider the basic principles of EBL that are generic to all forms of EBL. Although it may appear that EBL is most prevalent on medical courses, it has also been implemented with some Chemistry courses. It is interesting to note that a form of PBL has previously been used in the area of Spectroscopy. However, it is unfortunate that more detailed results of the implementation are unavailable.

There are various potential advantages and disadvantages of EBL compared to a more traditional teaching approach. Although not all advantages and disadvantages are discussed, it apparent that EBL may be able to foster independent learning in students, along with a number of other transferable skills. These skills are valued by employers and are highlighted as important features of students' learning at university by the QAA.

If any form of EBL is to be assessed, it is important to ensure, as much as possible, that the design of any EBL implementation is consistent with recommendations laid out in the literature. If the course suffers from poor design and implementation, then results will not provide a valid test of EBL.

CHAPTER 3

METHODOLOGY

Having discussed EBL, this chapter will now introduce the literature of the two main methods of attitude measurement used in this study. Questionnaires and their design will be discussed and a new method for analysing data will also be introduced. The use of interviewing as an alternative and, perhaps, complementary method of attitude measurement will be outlined.

The chapter will then go on to discuss the area of the undergraduate Chemistry curriculum that was chosen for the EBL implementation. The development of learning materials and the pilot stages will be outlined. Finally, full implementation of EBL will be described, along with the various research tools used in the main study.

3.1 Research Tools

In order to address the research questions presented in Section 1.3, measurement of student attitudes towards various factors concerning their EBL experience is required. Generally, an attitude is thought of as an individual's evaluation of an entity in question (Ajzen and Fishbein, 1977). Attitudes tend to be stable and consistent over time, but they are open to a certain amount of modification and development. Despite this, deeply held attitudes are "highly internalised" and are resistant to change (Reid, 2006a). Reid (2006a) notes that attitudes stored in the long term memory remain "latent constructs" and cannot be measured directly. However, observed behaviour can be measured, and, by working backwards, the possible attitude underpinning that behaviour can be explored.

There are various methods of trying to measure an attitude For example, questions can be asked, interviews can be conducted, or actual behaviour can be considered (for example, students course choices). A commonly used method is that of a questionnaire, which is the focus of the following Subsection 3.1.1.

At this point it is appropriate to note that the original design for the EBL delivery was that lectures would not be included, but EBL scenarios should be adapted to guide the students towards considering the theory behind the techniques. However, there were concerns (from staff not involved in this research project) about the EBL sessions failing to teach students the theory behind the spectroscopic techniques to the correct level. As a result, lectures had to be included into the Spectroscopy course as a "safety-net". As some research data needed to be collected from the EBL sessions, to keep the data produced as valid as possible, the lectures were timetabled *after* the EBL sessions.

3.1.1 Questionnaires

Questionnaires are widely used as instruments for collecting information. They can be administered without the presence of the researcher, and the data are comparatively easy to analyse, as the data are often numerical and structured (Wilson and McLean, 1994).

3.1.1.1 Methods for Attitude Measurement Using Questionnaires

The traditional way to develop questionnaires is to use them as rating scales. This approach has its origins in Psychology, but depends on the attitude being measured being unidimensional. Wright and Masters (1982) define unidemensionality as being essential for measurement of attitudes. Unidimensionality, in this sense, refers to a set of questions which are all closely related to one specific attitude dimension. Strictly speaking, the unidimensionality has to be demonstrated, and this is usually achieved using some form of factor analysis. Factor analysis is a method for analysing data and can be used to indicate if there are constructs which may explain the observed correlations between questions. Use of rating scales in an educational context is heavily criticized (see Reid, 2006a and references therein).

There are four main types of rating scale: Thurstone (Thurstone, 1928), Likert (Likert, 1932), Guttman scaling (Guttman, 1944), Semantic Differential (Osgood, Suci, and Tannenbaum, 1957). The Guttman scale is rarely used today, but each of the other approaches is outlined briefly below.

It was generally believed that it was impossible and unworkable to measure attitudes until Thurstone (1929) developed the use of attitude questionnaires. Through his book "*The Measurement of Attitudes*" (Thurstone and Chave, 1929), he laid a mathematical basis for scaling, and developed a method summarised by a series of steps:

"*(1) Specification of attitude variable*
(2) Collection of wide range (200) statements and opinions related to attitude.
(3) Editing these to give about 100 statements judged to be relevant, valid and covering a wide range of opinion, including neutral positions, to the attitude variable.
(4) About 300 judges are asked to sort the statements into all 11 piles from "anti" position to attitude to "pro" position, pile of 6 being neutral.
(5) Analysis of these judgements.
(6) Elimination of statements because they have wide ranges in the judgement, or are irrelevant.
(7) Selection of 20 statements along the scale 1-11
(8) Each person tested is asked to mark those items with which he agrees,
(9) The score for each person is the average scale value of all the statements he has endorsed."

Clearly, the Thurstone method is time-consuming and involves many people. The method is rarely used nowadays, but it opened a new horizon for researchers interested in attitude measurement.

A few years later, Likert (1932), developed a simpler method to Thurstone's approach. His method is widely used nowadays, and provides similar results to the Thurstone method, but is less protracted, as it avoids the cumbersome collating of statements. An example of a Likert scale type question illustrates the idea:

	Strongly Agree	*Disagree*	*Neutral*	*Agree*	*Strongly Agree*
I can easily get access to a computer on-campus	☐	☐	☐	☐	☐

The respondent is asked to tick one of the five categories provided, and, in this way, can express the level of their agreement or disagreement with a specific statement. Originally, Likert's method was introduced as a scale that helped estimate the respondent's attitude by the value of the total score obtained. This total score is the sum of scores from an evaluation of the different items selected (*e.g.* 'strongly agree' = 5 down to 'strongly disagree' = 1). The responses for all questions are then correlated with the total score, and the questions correlating best with each other are selected and used to measure the attitude towards a specific attitude object. However, this approach assumes unidimensionality, rarely seen in education.

Osgood *et al.* (1957) developed a simple technique which they named the semantic-differential approach and this is very popular among attitude researchers today. Initially, this method had a seven-point rating scale, providing bipolar word-pairs placed at the opposite ends of a scale. Later, Heise (1970) revised and changed this from a seven-point scale to a four or five-point scale. The respondent's task is to tick only one box on each line to rate the attitude.

A semantic differential scale differs from a Likert type question because it places an adjective (or adjectival phrase) at one end of the scale and the opposite adjective at the other end of the scale, thus defining both ends of the scale clearly. An example to illustrate this technique is given in Figure 3.1.

Consider your induction folder.
Place one tick on each line to indicate your view of it.

Useful						Useless
Badly produced						Well-produced
Easy to follow						Difficult to follow
Too short						Too long
Important for my course						Not important for my course

Figure 3.1 Examples of semantic differential questions.

The respondent marks on the scale the place that most represents how they feel. In the original work of Osgood and his team, semantic meaning was being explored. An extensive factor analysis showed that this resolved into three dimensions: "evaluative" (good-bad), "potency" (large-small), and "activity" (quick-slow) (Osgood, Suci, and Tannenbaum, 1957). They rapidly appreciated that by using adjectival word pairs (or adjectival phrases) which mapped onto the evaluative dimension, they had developed a powerful tool for exploring attitudes.

Although widely used as a method of research, rating scales do have many limitations:

(a) They assume that all the questions are measuring the same variable;

(b) They assume that the intervals between categories are the same for all questions;

(c) They assume a linear dimensionality for each evaluation;

(d) They use ordinal numbers and treat them as of integer significance;

(e) They employ parametric statistics on data where the distribution may be far from normal.

For these reasons, Reid (2006a) has presented strong arguments against the use of rating scales within educational research. Consequently, these rating methods were not used in this study.

However, the style of questions developed by Likert (1932) and Osgood *et al.* (1957) are extremely useful, and, in this study, both approaches were adopted.

All questionnaires have potential weakness, irrespective of how the data are handled. There is no way of knowing if the respondent is telling the truth. Indeed, younger respondents (younger school students) may not know the truth, in the sense that they may express their view in terms of what they would like it to be. There is also an issue with interpretation of the categories, as one respondent's "strongly agree" may be another's "agree". However, the subtlety of response which is built into the technique makes the Likert approach a useful and widely used tool in research (Cohen, Manion, and Morrison, 2000).

The wording of statements used should be carefully considered. Research shows that a person's response to a question can depend on the way the question is worded (Loftus, 1975). When constructing a questionnaire it is important to avoid including "leading" questions (Oppenheim, 1998). Leading questions suggest to the respondent that a certain answer is desirable, or indicate the authors' point of view. An example of leading question is seen below:

"Don't you agree that my EBL course is more enjoyable than sitting in lectures?"

In this question, the use of the words *"Don't you agree..."* encourages agreement from the respondent, and the use of the word *"my"* may result in a response directly offending someone. Another way of accidently including a leading question through wording is to assume a common state of mind (*e.g.* won't it?).

EBL will lead to students retaining their knowledge better, won't it?

It is also possible to include a leading question if the responses are biased so that they only emphasise one side of a response (positive or negative) (Peterson, 2000).

How well do you like our facilitation of EBL?

Extremely well
Very well
Pretty Well
Not too well

These possible responses are biased, thus making the question non-subjective, and the question also included the term "our", which, as mentioned previously may also introduce bias.

There are other issues to be considered when wording a question. "Double-barrelled" questions (such as the one seen below) that address more than one issue should be avoided, as a respondent may want to answer differently to each part of the question (Oppenheim, 1998).

Do you think that the feedback you received was adequate and timely?

Caution should also be taken with including words that may contain alternative meanings. For example some people understand the word "dinner" to mean an evening meal whereas others may perceive the word to mean a cooked meal. Even a simple question can be worded incorrectly or include ambiguous words, so care must be taken to word a question correctly. It is suggested that, as a "golden rule", questions should be kept as short and simple as possible

(Cohen, Manion, and Morrison, 2000). Wherever possible, single sentences per question item should be used. This is consistent with the limitations imposed by working memory capacity.

Questionnaires based on the styles of Likert and Osgood do not allow respondents to include any other comments they may have on the issue in question. To add authenticity, richness, and depth of response to the data collected *via* questionnaire, open-ended questions can be included (Cohen, Manion, and Morrison, 2000). However, data handling is a problem: responses cannot be converted easily into numbers for analysis and will not necessarily aggregate easily (Cohen, Manion, and Morrison, 2000). However, the advantages of open-ended questions make them an important consideration when collecting attitude data.

In this study, questions of Likert and semantic differential formats were used, accompanied by a small number of open-ended questions. This combination allows for some quantitative measurement, reinforced by the rich insights which open-ended questions can generate - the open-ended questions may illuminate the closed questions of Likert and semantic differential formats. In order to gain a more detailed insight into the students' attitudes, focus group discussions (Section 3.1.2) were held. All of these approaches were seeking to probe the perceptions of students, and to glean as holistic a picture as possible.

3.1.1.2 An Alternative Approach to Data Analysis

It is possible to analyse the data from Likert questions using the statistic "chi-square" (which tests if an observed frequency distribution differs from a theoretical distribution). Thus, the views of students who have completed the programme in Spectroscopy using an Enquiry-Based approach can be compared to their views before they completed the programme. Unfortunately, this analysis is difficult if the sample size is too low, as it makes the findings from chi-square calculations invalid (Reid, 2006a).

This study adopted another approach to analysing data. This novel approach can be used to evaluate individual student shifts on a rating scale between two data sets, and will additionally be valid when the sample size is too small to use an appropriate statistical approach such as chi-square. The method uses the integer values given to each response on a rating scale and then evaluates the shift in this integer value in another data set (Table 3.1). Also three categories are assigned to the five available ordinal responses (Negative, Neutral and Positive).

Response	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Value	-2	-1	0	1	2
Category	Negative		Neutral	Positive	

Table 3.1: How a five point Likert question is considered in the alternative method.

When a pre-and post-intervention data set are available, the *difference* between a student's responses can be evaluated on a rating scale using this method (Figures 3.2 and 3.3).

The procedure is now illustrated with some fictional data.

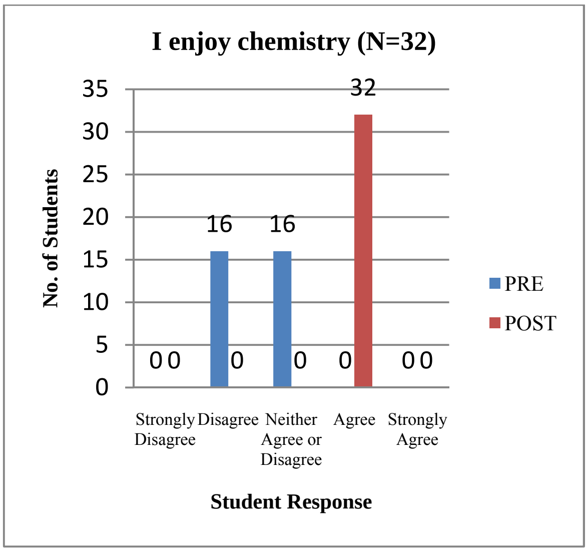


Figure 3.2: Two different data sets.

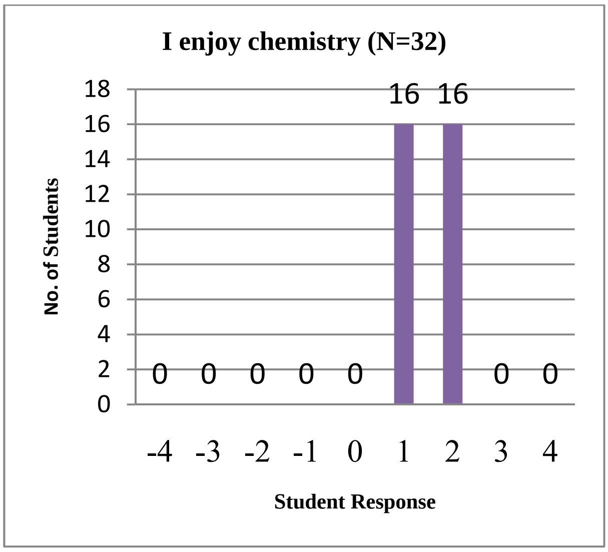


Figure 3.3: Shifts in students' responses from Figure 3.2.

Figure 3.3 shows the shifts in responses from each respondent. In this example, a change after some form of intervention is being evaluated, and the value for this change is generated from subtracting the post-intervention integer value from the pre-intervention integer value (values for each response are presented in Table 3.1). Thus, a positive value represents a shift towards the positive end of the rating scale, and *vice versa*. As the shifts are derived from ordinal numbers, they cannot be considered as integer values, and for this reason they will subsequently be referred to as "moves", where a positive move would be considered as a respondent shifting towards the positive end of the rating scale (as outlined in Table 3.1). As an example a respondent whose shift is shown in the +2 column in Figure 3.2 would be described as two positive "moves".

This new method can be used to investigate similar graphs to determine the amount of variation of responses between two data sets. Although two graphs may look similar, there may be a degree of change in students' responses in different data sets (Figure 3.4 and 3.5).

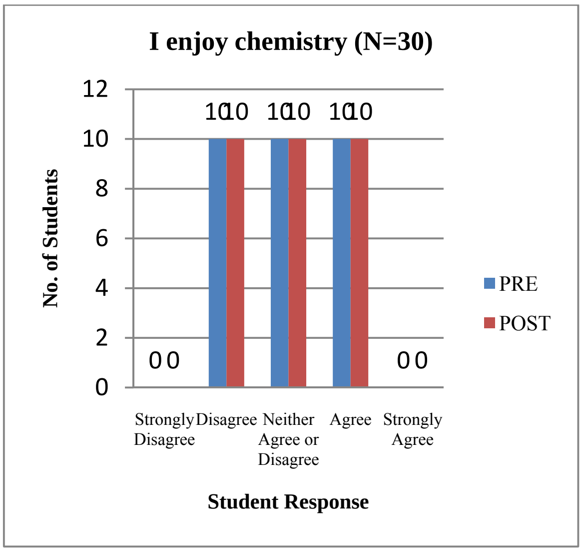


Figure 3.4: Apparently identical graphs from two data sets.

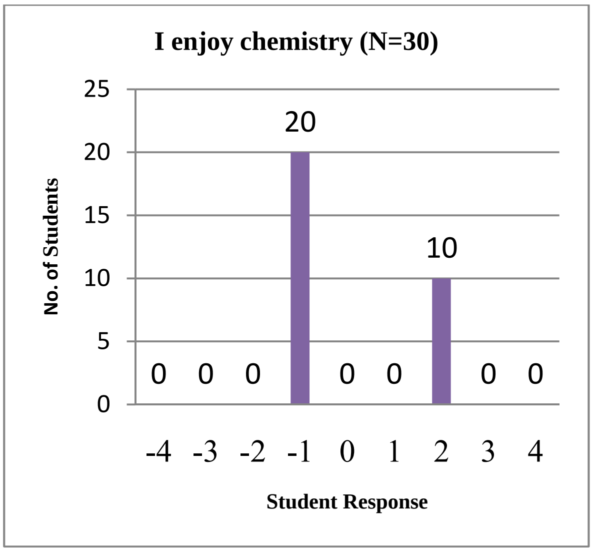


Figure 3.5: Moves in students' responses from Figure 3.4.

Although the example presented in Figure 3.4 is an extreme case, in this fictional data set none of the individual's responses remain consistent between data sets. Clearly real life data sets are unlikely to show such extreme shifts in student responses.

There is a variety of information which can be deduced from the shifts in students' responses using this approach (Table 3.2).

Moves (+/-)	Information provided
0	A move of zero shows that an individual is responding identically in both data sets.
1	In most cases, moves of +/- 1 do not provide any specific information on individuals' responses, but a trend may be observed (*i.e.* if there are a lot of responses in this category). In most cases there are a number of +/- 1 shifts.
2	A move of 2 represents a distinct change of category on the rating scale (*i.e* from a negative response to a neutral or positive response, or *vice versa*).
3	A move of 3 illustrates a major shift in response.Two possible examples are a change from a "Disagree" to a "Strongly Agree" or from a "Strongly Disagree" to an "Agree" response.
4	A move of 4 is the most extreme shift, being from one end of the scale to the other ("Strongly Agree" to "Strongly Disagree" or *vice versa*).

Table 3.2: Information which may be obtained from the new method.

Although Table 3.2 gives a general overview of information which may be deduced from the graphs of students' shifts, more precise comments may be made about an individual's shift on the rating scale. Another example of fictional data is given in Figures (3.6 and 3.7)

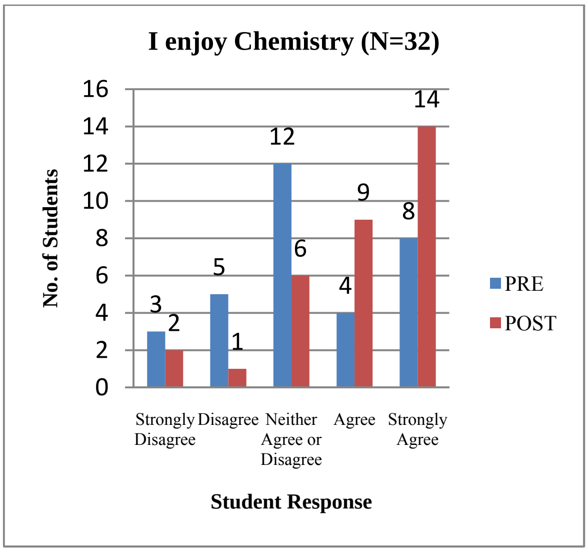


Figure 3.6: Graphs from two fictional data sets.

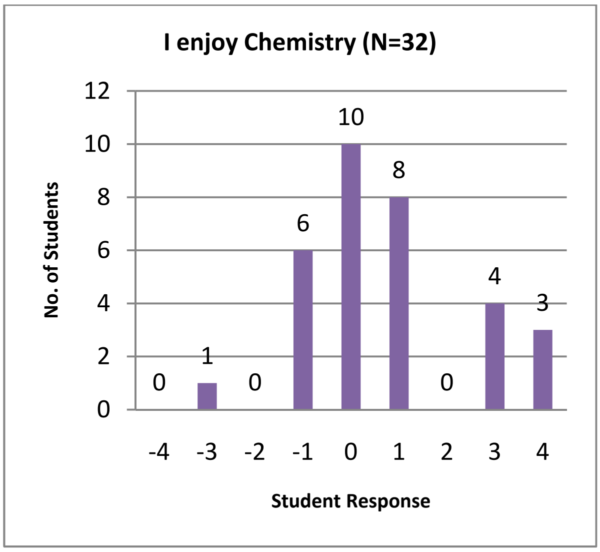


Figure 3.7: Moves in students' responses from Figure 3.6.

The conclusions which can be drawn from each set of data will vary, but Figure 3.7 allows several comments to be made about the change in students' responses between the pre- and post data sets:

- The three respondents who strongly disagreed with the statement pre-intervention all strongly agreed post intervention (three individuals who showed four positive moves).
- Four of the five individuals who responded "disagree" pre-intervention responded "strongly agree" post-intervention (the four individuals who showed three positive moves). It should be noted that in some circumstances three moves could represent a shift from a "Strongly Disagree" response to an "Agree" response. In this case all of the respondents are accounted for with four positive moves.

- 32% (10/32) of the individuals responded the same in both data sets. It can't be deduced from Figure 3.7 exactly which respondents are remaining the same. Overall 47% (15/32) of the individuals shifted positively on the rating scale and 22% (N=7) negatively.
- The "-3" move represents someone who responded "agree" pre-intervention and "strongly disagree" post-intervention. This can be concluded due to the lack of any "-2" or "-4" moves.

Although this method can provide useful information, it should be noted that the sample size is small, and that the 'average' move (the total number of moves divided by the sample size) must not be taken as some kind of integer shift. Furthermore, the method is using ordinal numbers, and indicates only the general direction and extent of change in a semi-quantitative way. The examples given here are all 5-point Likert questions, but the method is also applicable to other rating scales such as a Thurstone rating scale.

3.1.1.3 Questionnaire Layout

Although there are a wide range of methods available to measure attitudes using a questionnaire, it is essential to consider whether questions are open-ended or closed, and how the various questionnaire items are combined into a questionnaire. There is a commonly held view that questionnaires are highly unreliable and of limited value, but a well-structured questionnaire can provide valuable insights into attitudes (Reid, 2006b). The appearance of any questionnaire is extremely important - the design should be clear and simple. Instructions should be included at various stages in order to guide respondents (Cohen, Manion, and Morrison, 2000). It is suggested that these instructions should be clear, unambiguous, attractive, and boldly displayed, as it is essential that respondents know exactly what is required of them (Cohen, Manion, and Morrison, 2000). It is also important to explain to participants how the information collected will be used, and participants should be assured of their anonymity and confidentially before they complete the questionnaire.

Peterson (2000) suggests that the first and overriding consideration when structuring a questionnaire should be to make the questionnaire easy to administer, and that it should be easy for answers to be transferred to a format which enables them to be analysed. Cohen *et al.* (2000) suggest that more closed-questions than open-ended questions should be asked, due to their ease of data analysis, and that several questionnaire items should be used to measure specific concepts or issues. The latter issue can ensure validity (Black, 1999). It is also suggested that there should be a balance between positive and negative question items in the questionnaire, to remove the temptation for a respondent to mark all of the responses the same, thus reducing bias (Black, 1999).

Black (1999) suggests that a questionnaire should be no longer than four pages, to encourage participants to complete the questionnaire. It is a careful balance between length, presentation, and number of questionnaire items included. If the questionnaire appears too long, then there is a tendency for participants not to complete it. Additionally, participants may become "irritated" if the font is too small, and the lines are too close together.

Overall, questionnaire design needs careful attention, not only involving the wording of questions, but also paying attention to length, presentation and layout.

3.1.2 Interviews

Although questionnaires are a widely used research tool for the measurement of attitudes, they are not the only method that can be used. Interviews allow participants to discuss their interpretation of the world, and to express their own points of view regarding certain situations (Cohen, Manion, and Morrison, 2000). They provide opportunities to ask in-depth questions and to probe attitudes, which is often difficult using a questionnaire (Cohen, Manion, and Morrison, 2000). The interviewer, and the coding of responses, however, introduce more potential sources of error (Oppenheim, 1998). Interviews can be used after a questionnaire has been administered to gain further insight into results that have been produced by quantitative data (Stewart and Shamdasani, 1990).

Although interviews are powerful tools, as much can be learned by talking to students about their learning, Reid (2006b) suggests there are several pitfalls in their use. They take up both staff and students' time, and an interview may last up to thirty minutes. Consequently, individually interviewing students would consume a large amount of staff time. Interviews do not necessarily have to be on a one-on-one basis as focus groups can also be used to interview participants. A focus group is a discussion, planned in advance, that is designed to investigate attitudes towards a specific area of interest in a permissive, non-threatening environment (Kreuger, 1988). An interview of a group of participants can generate a wider range of responses that an individual interview (Cohen, Manion, and Morrison, 2000).

Focus groups can be advantageous. Thus, for example, interviewing a hesitant student in an individual interview may be problematic, but in a group of two or three, students can support each other and may become more relaxed (Reid, 2006b). Stewart and Shamdasani (1990) suggest that the participants of a focus group must consist of representative members of the larger population. The number of participants can vary, but most focus groups consist of between six and twelve students, although smaller numbers can be used when participants have had intense or lengthy experience of a topic of interest (Kreuger, 1988).

A potential disadvantage of this method is that one participant's views may dominate the group, and participants may be restrained in front of others, particularly if they are peers (Cohen, Manion, and Morrison, 2000). A group interview may also suggest an attitude produced by the group discussion that an individual may not agree with, but the participant may not want to speak out in front of the others.

Reid (2006b) suggests there are three differing formats of interview. The first format is a highly structured interview, with all the questions decided beforehand, this being an advantage if several interviewers are being used. Although this form of interview makes data analysis easier, respondents are forced to fit their experiences and feelings into the interviewer's categories (Cohen, Manion, and Morrison, 2000).

Another format of interview is the open interview. This format offers a very general question (*e.g.* tell me what you thought of the course?) and, essentially allows the interviewee to determine the agenda. This format of interview may be unpredictable and long, with data being hard to analyse effectively.

Finally, there is the *"semi-structured"* interview. A series of well defined questions are used, with plenty of time left for open-discussion, depending on the way the students react. This allows a degree of freedom to the interview, but when conversation "dries up", the interviewer can move on to the next question.

The issue of who assumes the role of interviewer is an important consideration. The interviewer is responsible for many tasks during the interview, such as creating a non-threatening environment, facilitating discussion among participants and remaining non-judgemental (Basch, 1987). Kreuger (1988) adds that an interviewer for a focus group should have experience in listening to others in group situations, and be mentally alert and free from anxieties and distraction.

The relationship between interviewer and interviewee is clearly very important - if the interviewee suspects some form of agenda, then their responses may not be completely truthful (Reid, 2006b). The interviewer should not be seen as an authority figure, and the use of experienced interviewers, from university teaching support departments, may be useful. It is important that whoever conducts an interview explains the purpose of the interview, and ensures that students understand that anonymity will be retained. Reid (2006b) suggests that familiar surroundings should be used for the interview location, and informality should be promoted by the provision of drinks or snacks. The familiar surrounding would go some way in creating a non-threatening environment, which is recommended by Basch 1987.

Interviews are often transcribed after the interview has taken place, and, depending on the structure of the interview, it can be difficult to translate this evidence into a neat summary of general ideas (Cohen, Manion, and Morrison, 2000). An interviewer often records the session, and then produces a written transcript at a later date.

3.2 The Study Focus and Context

Having explored the approaches used in this study, the specific area of the undergraduate Chemistry curriculum chosen for EBL implementation is now discussed.

For this study, a suitable part of the Chemistry degree course was needed. It was important that the subject matter lent itself readily to an enquiry-based approach, and that the organization and resources of the School of Chemistry were compatible with this approach. Firstly, it was decided to work with first year students. They are, perhaps, more open to change, and are further away from the demanding pressures of final examinations.

After reviewing the current first year course, it was decided that the best area to implement some initial EBL was in a module entitled “Structure and Bonding”, specifically in the area of Spectroscopy. Spectroscopy was seen as an ideal place for this first implementation of EBL in Chemistry at Birmingham for several reasons. The current course had laid great emphasis on the interpretation of spectra. Problem solving was already a key component of this course, with one of the main learning outcomes from this course being that students are able to deduce unknown compounds from interpretation of various spectra. Although much of this is fairly artificial, it was easy to see how this could be adapted to make it an apparently real world application of Spectroscopy. Scenarios that were clearly based in the real world could easily be developed. There was one further advantage in that the staff member was enthusiastic to assist in this new approach.

The Spectroscopy course covered four main spectroscopic techniques that can be used for the determination of the identity of unknown compounds. These four techniques were: Mass Spectrometry, ^{13}C and ^{1}H NMR Spectroscopy, and IR Spectroscopy. Examples of spectra produced by means of these methods can be seen in Figures 3.8 to 3.11.

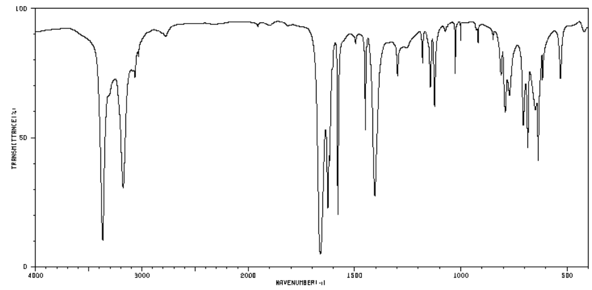


Figure 3.8: An example of an IR spectrum.

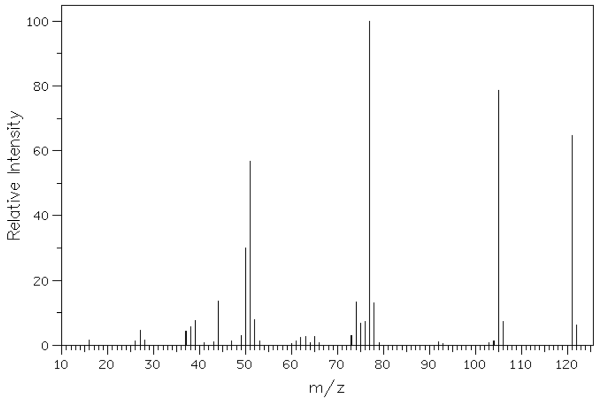


Figure 3.9: An example of a Mass spectrum.

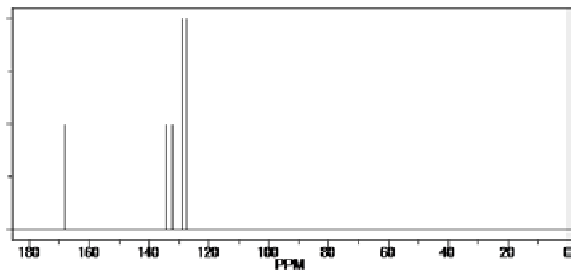


Figure 3.10: An example of a ^{13}C NMR spectrum.

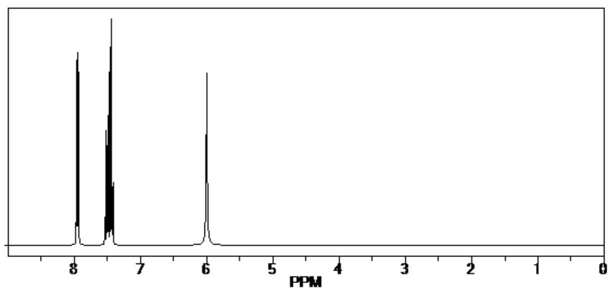


Figure 3.11: An example of a ^{1}H NMR spectrum.

The learning objectives for this course can be seen in Appendix 1. The emphasis of the course was on the ability to interpret spectra, with the ultimate aim that the students would be able to use the information provided by the four different techniques to determine the structure of an unknown compound.

The lecture course also covered the theory underpinning all of the techniques. The word "theory" is used here in the scientific sense. This encompasses the understandings which have been derived from past experiments, which rationalize and make sense of the processes involved in the production and interpretation of spectra.

The argument is that it is essential for students to understand the theory behind the techniques in order to be able to interpret the spectra given to them. Thus, it is not just a matter of the student learning 'rules of thumb', and then applying them in a routine fashion, operating in a “skilled technician” mode. The aim is that students understand *why* the various features of the spectra appear as they do, and are then able to interpret backwards to deduce the possible molecular structures which might have generated such patterns. The perception is that this fits with the description of understanding, defined here as being able to apply what is known in novel situations, with some prospect of success. Indeed, in the practical world of Spectroscopy, as a chemical technique of widespread application, such skills are seen as vitally important.

The IR spectra and Mass spectra for use in this course were obtained from the Spectral Database for Organic Compounds (SDBS), web-accessed (AIST, 2009). The ^{1}H and ^{13}C NMR spectra were generated using the ChemDraw Ultra program, which produces simulated spectra. Both of these sources provide “clean” spectra of pure compounds, which enables easier interpretation than, for example, a poorly prepared, impure sample.

The Spectroscopy part of the module was taught in previous years with 6 hours of lectures and 12 hours of workshops. A timeline of the traditional course can be seen in Table 3.3.

	Topic	
Lecture 1	*Mass Spectrometry*	**Workshop 1**
Lecture 2	*IR Spectroscopy*	**Workshop 2**
Lecture 3	*^{13}C NMR Spectroscopy*	**Workshop 3**
Lecture 4	*^{1}H NMR Spectroscopy*	**Workshop 4**
Lecture 5	*^{1}H NMR Spectroscopy*	**Workshop 5**
Lecture 6	*Elemental Analysis and UV/Visible Spectroscopy*	**Workshop 6**

Table 3.3: The timeline for the traditional course.

Each lecture covered a specific technique and was followed by a workshop which introduced problems of increasing complexity involving more of the techniques. An example of a typical set of lecture notes for the existing course can be seen in Appendix 2, and the handout that was given out in the workshop relating to this lecture can be seen in Appendix 3. The workshops were run by postgraduate and postdoctoral students, and the undergraduate students were given a handout containing the spectra to be interpreted, which they worked through in the workshops. The demonstrators (the postgraduate students) were present to support the undergraduate students and provide answers as appropriate. The undergraduate students typically worked in small peer groups of two or three in the workshops. Attendance tended to be low, with some students only attending to get the workshop handout before leaving. The aim had been that the workshops contained an element of problem solving, both individually and collaboratively.

3.3 The Pilot Study

3.3.1 EBL Questionnaire

The questionnaire used in this study, to investigate students' attitudes towards EBL, was adapted from an existing questionnaire designed by Ivan Moore. This is available for use from the CEEBL web site (Moore, 2007) (Appendix 4). The original questionnaire designed by Moore (2007) was developed by lecturers engaged with implementing and evaluating EBL to provide a tool for staff, supported by CEEBL, who were developing new EBL material (Moore, 2006). The original questionnaire was four pages long, which is the maximum suggested length (Black, 1999). The first two pages (Section 1 of the questionnaire) consisted of 5-point Likert-style questions (thirty nine in total), with responses ranging from "Strongly Agree" to "Strongly Disagree". The third page of the questionnaire comprised open-ended questions (Section 2 of the questionnaire) addressing the students' attitudes towards an EBL activity, and the final page of the questionnaire examined students' experiences of the participating in the whole course (irrespective of discipline).

No evidence was found regarding any attempt to validate the original questionnaire. It has been argued that most questionnaires need to be evaluated by a pre-test before they are formally used (Peterson, 2000). There are several senses in which validation may be important. There is the need to know if the questionnaire 'works' in the sense that students are able and willing to complete it and the time given is roughly right. A pre-test, perhaps with ensuing discussion with participants, can help to pick out potential confusions in the text and the instructions, as well as detect any possible ambiguities. However, it is more important to check if the questions actually measure what they are intended to measure (Oppenheim, 1998) and this is much more difficult.

A pilot study allowed the questionnaire to be pre-tested. Although the participants used in the pilot study were students who had already attended the traditional course, they were nonetheless first year students who were experiencing EBL for the first time. Peterson (2000) suggests that the sample size of the pilot study should be similar to the main study, but it was not possible or practical to obtain a whole year group of students for the pilot study. Indeed, it is more important that a pre-test sample reflects the actual population to be studied.

In designing any questionnaire, it is important for the designer to know the population being studied, and to allow others, who know the population as well, to comment on the proposed questions. In this way, many of the potential problems can be removed from the outset. In this study, the draft questionnaire was discussed with several experienced Chemistry teachers before being adjusted and then used in the pilot study.

Nine of the existing Likert-style statements were removed from the original questionnaire developed by Moore (2007). The removed statements can be seen in Table 3.4.

No.	Statement
2	I learned about how to present my findings to an audience.
6	During the module, I was given opportunities to establish my own research questions
13	This activity helped me to discover what was expected of me as a learner
16	I needed support in establishing my own questions to research
19	I had opportunities to lead the group
20	I feel that I am better able to make an oral presentation
28	As a result of this activity, I am now more confident about my ability to establish my own research questions
36	I feel I am better able to present my findings
39	I was able to see good ways of presenting information

Table 3.4: Statements removed from the original questionnaire.

Not all of the questions from the original questionnaire were relevant to our study, and for this reason they were removed. For example, statements 2, 20, 36 and 39 were seen as relating to students' use of oral presentations, which were not part of the main study, so these questions were removed. It was argued that statements 36 and 39 could relate to students presenting their work *via* other methods, such as a written report, but they were removed to prevent confusion. Although students were expected to set their own learning objectives during their EBL activities, the issue of research questions was removed (statements 16 and 28), as first year students were not expected to be aware of the concept of research questions. Statement 13 was perceived as being confusing, so for this reason the statement was removed. Setting of a "group leader" was not specifically asked of students in the main study, so statement 19 was also removed.

The removal of these statements left thirty Likert-style statements from the existing questionnaire, along with the more open-ended questions. Some of the original statements were reworded slightly. As an example, rather than referring to the EBL sessions as an “activity”, the word “activities” was used, as more than one scenario was planned to be used in the main study. This rewording was done to provide more clarity to the statement. In addition to this, seven extra statements were added, as seen below in Table 3.5.

	Statement
A	I would prefer lectures to the EBL sessions.
B	I am enthusiastic about the EBL sessions.
C	I receive adequate feedback.
D	I receive timely feedback.
E	I find the discussion boards in WebCT helpful.
F	I understand the role of the postgraduate students in the sessions.
G	The learning was relevant to my needs

Table 3.5: Statements added to the provisional questionnaire.

Statements A and B were added to further evaluate students’ attitudes towards the EBL sessions. It is suggested that students should be enthusiastic about EBL, due to students engaging with the problems *via* active learning (Kennedy and Navey-Davis, 2004). Statement B was an attempt to assess to what extent students were enthusiastic towards their activities. Academic performance aside, statement A was an attempt to investigate the students’ attitudes towards EBL as a style of learning in comparison to lectures. Feedback is an essential part of the learning process, and, as a result, statements C and D were included to evaluate the students’ attitudes towards the feedback they received. Statement E was included to assess students’ attitudes towards the WebCT discussion boards that were provided to support students in their EBL activities. Statement F was added to further explore students’ attitudes towards staff members, and to assess whether they had understood the role of the postgraduate students as facilitators. Care was taken to avoid leading questions, and the questions were intentionally kept brief, as recommended by Cohen *et al*. (Cohen, Manion, and Morrison, 2000). Statements C and D were intentionally kept as separate statements, to avoid the problems associated with double-barrelled questions as suggested by Oppenheim (1998).

The removal of nine statements and the addition of seven statements meant that thirtyseven Likert-style statements remained in the questionnaire. These statements can be seen in full in Appendix 5. The questionnaire was adapted from that developed by Moore due to its apparent "good fit" with the research questions, particularly the sub-question investigating students' attitudes towards the process of EBL. This research sub-question covers students' attitudes towards skills development (*e.g.* transferable skills), attitudes towards the EBL activities, their learning processes, and their attitudes towards the staff members. It was possible to group the Likert-style statements into categories that related to the issues discussed in this research sub-question. This made the analysis of students' responses easier, as they were responding on similar themes that gave an overview of each theme as a whole. This in turn allowed the responses for each theme to be discussed in relation to the research question as a whole. The themes to be investigated were based on the issues discussed in the research sub-question and were as follows: *"group work", "other transferable skills", "the activities", "student enjoyment", "the learning process"* and *"staff*". Clearly these themes are interconnected and address similar issues, but it was perceived that these specific themes would provide an effective overview of students' attitudes towards the EBL process that they experienced.

There were a number of statements that specifically addressed students' attitudes towards skills developments. These could be split into two categories: statements regarding group work, and statements regarding any other transferable skills. The statements regarding skills development are presented in Table 3.6:

Attitudes Towards Group Work	A. These activities helped me to develop my team working skills B. The group was effective in developing shared goals C. I found the team members to be helpful in my learning D. My group worked well as a team E. The group worked well to overcome any difficulties or problems we encountered F. I can see a range of ways in which I can contribute to a group task G. The group appreciated my inputs H. Any interpersonal difficulties were cleared up in a positive manner I. I developed an understanding of technical processes through working with my group
Attitudes Towards Other Transferable Skills	J. I learnt how to plan my learning K. I feel I am better able to find information from different sources L. I am more confident in my ability to evaluate the information I have found M. I feel I am better able to evaluate different sources of information N. I feel I am better able to communicate with others O. I feel more confident in my ability to solve problems

Table 3.6: Statements addressing transferable skills.

The statements regarding attitudes towards group work cover various aspects of working in a group, such as whether the students found the collaborative learning aspects of the group work helpful (statement C), and whether any friction between students was effectively resolved (statement H). Students' attitudes as to how well their group worked were also investigated (statements B, D, E, G and H). It is essential to determine if students felt that their groups worked efficiently, as team working skills may not have been developed if the groups did not function effectively. Other transferable skills such as problem-solving skills (statement O) and communication skills (statement N) were assessed, along with the students' ability to find reliable information for themselves (statements K, L and M). These fourteen statements were expected to give a wide overview of students' attitudes towards transferable skills, and their development in these skills.

The activities that the students undertook will have had a significant influence on their attitudes towards the processes in EBL, and these were examined by means of a research sub-question. The statements that investigated students' attitudes towards the EBL activities are presented in Table 3.7.

Attitudes Towards The Activities	P. I found these activities difficult Q. I found the activity challenging R. I felt I had to work hard to complete this activity S. I would have prefer lectures to the EBL sessions T. I was enthusiastic about the EBL sessions U. The activities were more about analysing and evaluating information than it was about memorising it V. I felt I could get through the activity simply by memorising things W. I didn't need to apply anything I learned X. There was a lot to learn

Table 3.7: Statements relating to students' attitudes towards the activities.

The scenarios were the driving force behind the learning process. Thus, it was essential to consider students' attitudes towards the activities they undertook. The first three statements in Table 3.7 (statements P, Q and R) relate to the difficulty of the scenarios, which, if too difficult, may have resulted in an overall negative attitude towards EBL. The issue of whether students could just memorise information by means of rote learning in order to complete the tasks is addressed with statements U and V. It is perceived that students apply knowledge they have learned, through independent study, back to the task, so statement W investigates this issue. These statements along with statements S, T and X provide a wide range of measurements of attitudes towards the activities.

Another issue that needed to be addressed from the research question was students' attitudes towards the learning process behind the activities. Statements relating to this issue are seen in Table 3.8.

Attitudes Towards The Learning Process	Y. I understood the learning process in this activity Z. I enjoyed working in this way AA. I enjoyed working as a member of a team BB. The learning was relevant to my needs CC. I felt I was able to take more responsibility for my own learning DD. I felt a sense of control over my learning

Table 3.8: Statements relating to students attitudes towards the EBL learning process.

As EBL was likely to be a new approach to learning for the students, it was important to assess whether the students thought that they understood the EBL learning process (statement Y). Students' enjoyment of the scenarios is addressed with statements Z and AA, and although statement AA may have been categorised into the "group work" category discussed earlier, the two statements test similar attitudes. If learning is not perceived as relevant then students may not engage with the scenarios. Thus, statement BB investigates students' attitudes towards the relevance of their learning. Statements CC and DD relate to learner independence, and investigate students' attitudes towards taking responsibility for, and control over their own learning. It is expected that these statements will have provided a measurement of various issues that reflect the students' attitudes towards the learning processes of EBL.

The final issue that needed to be investigated in order to address the students' attitudes of the processes of EBL was the issue of staff (Table 3.9).

Attitudes Towards Staff	EE. I understood the role of the postgraduate students in the sessions FF. I needed a lot of support from staff in this activity GG. The staff gave me the support I needed to learn in this module HH. I received adequate feedback II. I received timely feedback JJ. The staff focused more on encouraging me to find information than on giving me the facts KK. I found the discussion boards in WebCT helpful

Table 3.9: Statements relating to students' attitudes towards staff.

Statements EE, FF, GG and JJ relate directly to the students' attitudes towards facilitation, which is an essential part of EBL. Students' attitudes towards feedback provided by staff are addressed in statements HH and II. Statement KK did not fit neatly into any of the categories, but as feedback was given by a staff member through the online discussion boards, it was placed into this category.

An online delivery for the questionnaire was decided upon, due to the ease of data collection and presentation compared to paper-based methods (Lumsden and Morgan, 2005). Despite these advantages of an online-delivery, there are several disadvantages, such as coverage error (not all participants have an equal opportunity to be sampled), which is increased by an online approach due to the "digital divide" (Lumsden and Morgan, 2005). As the pilot was labelled as "revision" to students who had already completed the original Spectroscopy course, and only included one scenario over two sessions, eleven of the Likert-style statements were removed from the online questionnaire. The statements removed are shown in Table 3.10.

Statements Removed
1. I am more confident in my ability to evaluate the information I have found
2. I feel I am better able to evaluate different sources of information
3. I would have prefer lectures to the EBL sessions
4. I was enthusiastic about the EBL sessions
5. I received adequate feedback
6. I received timely feedback
7. I found the discussion boards in WebCT helpful
8. The learning was relevant to my needs
9. Any interpersonal difficulties were cleared up in a positive manner
10. I understood the role of the postgraduate students in the sessions
11. I learnt how to plan my learning

Table 3.10: Likert-style statements removed for pilot study.

The statements that remained in the questionnaire were those that were seen as being the most relevant to the students who undertook the pilot study. A list of these Likert-type statements is presented in Appendix 6.

The open-ended questions were omitted from the questionnaire, as it was thought that students would not see the relevance of the questions. For example, question six from the original questionnaire (Appendix 4), asks students to consider how they can improve as a learner. Additionally, the use of a number of open-ended questions would create difficulty in analysing the responses, as discussed by Cohen, Manion, and Morrison (2000). The piloted questionnaire, therefore, did not include any open-ended responses. Questions were entered into Questionmark Perception software, creating a database of questions. These questions were then assembled into an online questionnaire by the associated Assessement Manager. The online questionnaire was embedded in WebCT, and the questions were presented on a single page (simultaneously) where students had to click the circles that indicated thier response. A screen shot of how the questions appeared is presented in Figure 3.12.

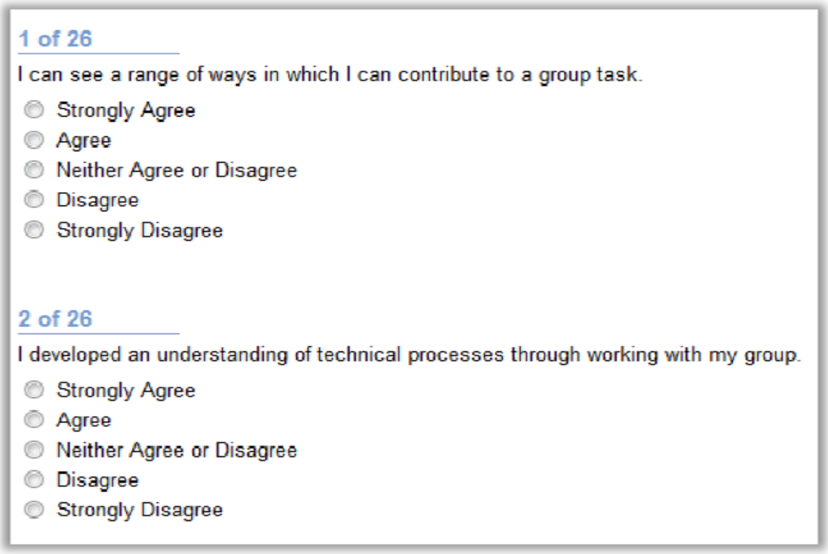


Figure 3.12: How the online questions appeared on screen.

Students completed each question, and then clicked “submit” at the bottom of the page which then stored their answer. Once all of the students had completed the questionnaire, Questionmark Perception was able to produce a report for each of the Likert-type statements. An example of such a report is seen in Appendix 7.

3.3.2 The First EBL Scenario

Once the pilot questionnaire was designed, it was essential to develop an EBL scenario to trial in the pilot study. With the specific teaching area identified for the first year EBL implementation, it was decided that an EBL scenario should be piloted on current first year students who had already completed the existing Spectroscopy course before any full scale implementation. This would not only allow the testing of the EBL material, but also allow the trialling of the online questionnaire.

It was decided that the type of EBL that would be utilised would be PBL, due to the strong emphasis on problem solving in the original course (Section 3.2). Wee, Kek and Sim (2001) state that the problem itself is the stimulus for students’ learning. Therefore, it was necessary to develop an initial PBL scenario. The PBL scenario would need to be suitable for use with students allocated into groups, as group work is a major component of PBL (Savin-Baden and Major, 2004). It was difficult to devise a scenario that was not contrived, just to fit the learning objectives of the course. A scenario was developed that involved analysing waste water from a fictional university laboratory. The students played the role of graduate chemists in a fictional commercial laboratory that analysed the samples. To add authenticity to the problem, a fictional memo was created to give to the students during the introduction to the problem. The handout given to students in the pilot study, including spectra, can be seen in

Appendix 8. The internal memo from the Chief Executive Officer of Rummidge Laboratories outlined the reason for the task.

The correct disposal of chemical waste in laboratories is a serious consideration. Upon discussing the issue of the School of Chemistry's waste water with a colleague, it was found that the University's waste water is sampled for purity, and that preventing contamination of waste water is an important concern. The aim of the scenario produced was to relate the activity to a real world situation, as suggested as good practice by Duch (1996). The pilot scenario gave students various spectra relating to a number of unknown molecules. The students had to interpret the information, from each technique, to determine the structures of the unknown molecules. Students needed to use information sources to obtain data required to complete the task. Additionally, students needed to possess relevant knowledge of the theory behind the techniques in order to explain various spectral features, for example, the splitting and integration of peaks in ^{1}H NMR spectra. This analysis of spectral features may have required students to carry out independent study in order to obtain relevant information, if they did not already understand the various features based upon their prior knowledge.

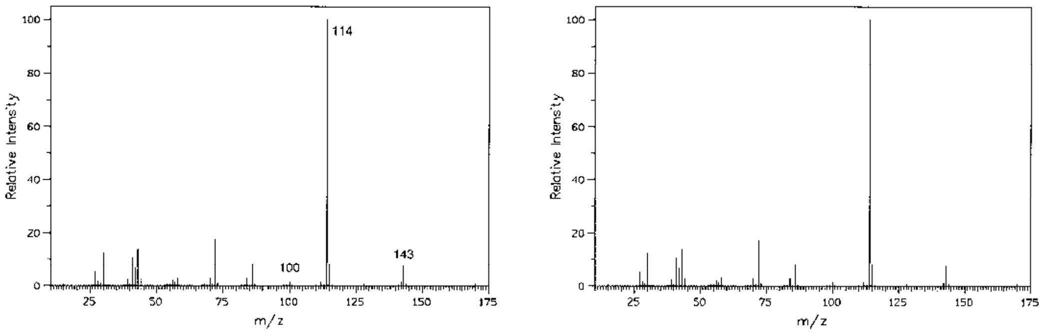
To make the scenario as "true to life" as possible, the molecules that were chosen to be present in the analysis were based on chemicals that the undergraduate students use in laboratory sessions. It was therefore feasible that students may have actually disposed of these chemicals incorrectly (although it is unlikely that this happens in reality). Molecules from first year practical laboratories were used, as this added authenticity to the scenario, and gave students an insight into the structures of some of the chemicals actually used in the undergraduate laboratories.

The first year laboratory manual was examined and a list of suitable molecules was drawn up. The molecules used in the scenario had to have an IR spectrum and Mass spectrum available online from the Spectral Database for Organic Compounds (AIST, 2009). These had to be not too complicated in order that students would be able to effectively deduce their structure from spectra provided. As in the traditionally-taught course, the ^{1}H and ^{13}C NMR spectra were then simulated using ChemDraw Ultra. The predicted spectra produced by ChemDraw Ultra are not entirely realistic, but this method of obtaining spectra was chosen due to its ease, cost effectiveness, and the fact that the spectra were "ideal" and did not contain any impurities that may complicate interpretation. The initial list of molecules can be seen in Appendix 9. The member of staff was then consulted regarding the list of molecules, and eight molecules were selected for use in this scenario. The eight molecules were chosen to give a wide range of features in their spectra. For example, the presence of a chlorine atom in a molecule can be detected by its isotope peaks in Mass spectra, and carbonyl bonds appear as characteristically strong peaks in IR spectra.

One of the main considerations when designing the problem was that the scenario should make students carry out activities that would be representative of real world situations, as recommended by the Problem-Based Learning Initiative (2008). It was decided that the students would be presented with "raw" spectra, which had already been produced from the isolated contaminants. In reality, it would have taken several steps to separate the chemicals from the waste water, but students were only asked to consider the spectra given to them, as opposed to considering how the samples were obtained and purified.

Some information which was given to students in traditional workshops on Spectroscopy, such as *m/z* values of useful peaks in the mass spectra, DEPT, and values of integration of the

^1H NMR peaks, were removed to make the task appear more realistic. Although a mass spectrometer will provide values for all the peaks in the spectra, or label peaks above a certain intensity, it cannot label the peaks that students should be specifically looking at in order to determine the molecule's structure.



Typical spectrum with key peaks labelled given in traditional workshops.

Spectrum provided for problem scenario given in EBL sessions.

Figure 3.13: Comparison of spectra provided.

With the key peaks labelled, students can ignore the rest of the spectrum and concentrate just on the peaks of interest (in Figure 3.13, the peaks at *m/z* 100, 114 and 143) in order to interpret the spectra. This is not a true reflection of the interpretation skills students require to interpret the various spectra in real life. IR spectrometers produce spectra with wavelength and transmittance values for the peaks, but they do not label key functional groups for students to focus their attention on.

For the interpretation of ^1H NMR spectra, it is necessary to measure the height of integration traces to obtain ratios for the integrals of the peaks. Although the spectrometer will attempt to calculate these ratios, they are often misleading, and therefore it is good practice to physically measure the integrals. In the traditional approach to teaching Spectroscopy, the integral values were given to students. Typical ^{13}C NMR spectra produced within the School are PENDANT ^{13}C NMR. These spectra indicate if there are an odd or even number of hydrogen atoms bonded to various carbon atoms (*i.e.* CH and CH_3 are considered odd, C and CH_2 are considered even). Use of standard ^{13}C NMR spectra (not PENDANT) would, therefore, not have been realistic, but it was envisaged that the students would ask for more spectral information, such as DEPT information on the ^{13}C NMR spectra, rather than just be given all of the information at the start. Despite the lack of realism for the ^{13}C NMR Spectra, it was expected that this would make the students consider what information they needed to know in order to be able to complete the problem, which is considered an important part of any EBL process (Kahn and O'Rourke, 2005).

Another section was added to the scenario, whereby students were asked to prepare a presentation on how each of the techniques works, for a new environmental scientist at the company, who had little previous knowledge on the techniques. This was included to encourage students to fully understand how each spectroscopic technique worked. After informed advice, it was decided to ask the students to prepare a briefing paper on the working of the techniques instead of a presentation. This was done to reduce staff time required to assess the students.

3.3.3 Running the Pilot Study

The initial scenario and questionnaire was trialled with sixteen first year students who had already completed the traditional Spectroscopy course (27% of the year group). The sessions were labelled as Spectroscopy "revision" sessions, as the timing was just before the end of (first) year exams. In addition, to improve uptake, a free lunch was organized for the students at the end of the sessions. Of the sixteen, twelve attended the first session but this reduced to eight for the second session.

It was decided to run two, two hour sessions for the task. The problem scenario was altered to remove the briefing paper task, as the students had already received a lecture course and workshops on Spectroscopy. Instead, students were asked, in groups, to produce an A1 poster on how the techniques worked, and what information each of these spectroscopic techniques provides. After this, the students were asked to post this information onto an online discussion board in WebCT, which all of the other students in their group could access. This was set up to allow all members of the group access to the information, and the ability to communicate outside of the sessions, and therefore promote collaborative learning, which is an important aspect of the PBL learning process (Savin-Baden and Major, 2004).

Students were given a flavour of the EBL approach to learning. This was achieved by the students taking part in structured activities and "ice breakers". For the discussion of how each technique works and what information the techniques provide, the students were divided into three groups.

Students were then split into two groups of six for the problem scenario, as this has been suggested as an optimum number for collaborative group work (Barrows, 1980). As there were eight compounds, two were removed from the problem set to match the number of students in each group. There were concerns at the time that students would simply use the "divide and conquer technique" to tackle the problem. Students were allowed access to moderated, online discussion boards to discuss each molecule, and to ask for any further information. Each group for the problem scenario only had access to their own group's discussion board, *i.e.* they could not access or post on the other group's discussion board. The students were then allowed to leave the session and attempt to complete the task before the next session. Students were given OHP slides of each spectrum before they left, so that they could label the spectra and present the reasoning behind their interpretation in the second session.

Between the sessions the students were expected to work in their groups to deduce the unknown molecules using the spectra. Each morning the discussion boards were moderated, with feedback left for students where appropriate.

At the end of the second session students were asked to log onto WebCT and complete the online questionnaire. Results from the online questionnaire are presented in Appendix 10.

3.4 The Main Study

3.4.1 Research Tools

3.4.1.1 Mid and Post-EBL Questionnaires

The pairs of questions from the pilot study questionnaire, seen in Figures 3.14 to 3.19, can be used to examine the consistency of response in the online questionnaire.

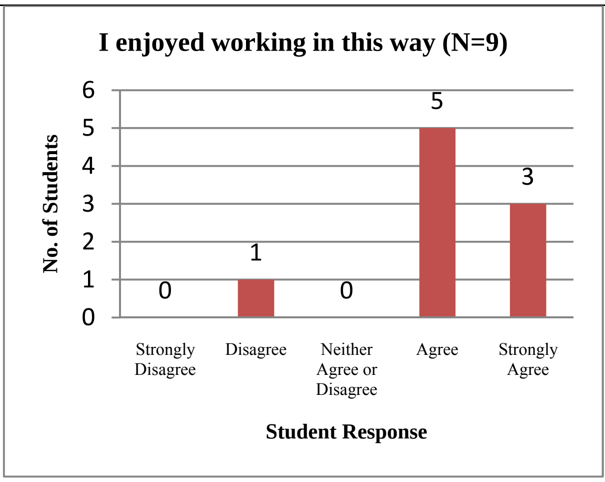


Figure 3.14: Feedback from the pilot study on student enjoyment.

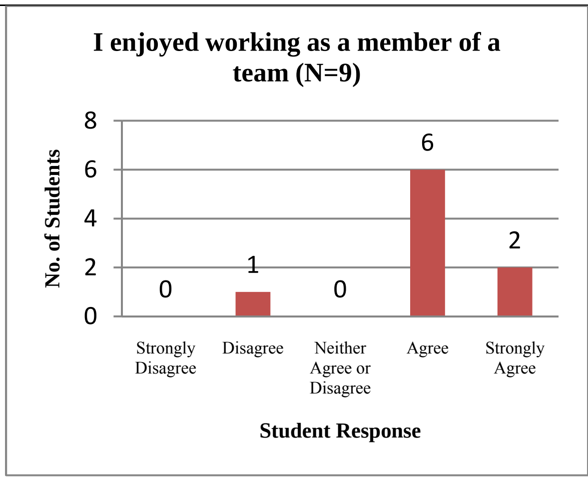


Figure 3.15: Feedback from the pilot study on student enjoyment of working as a member of a team.

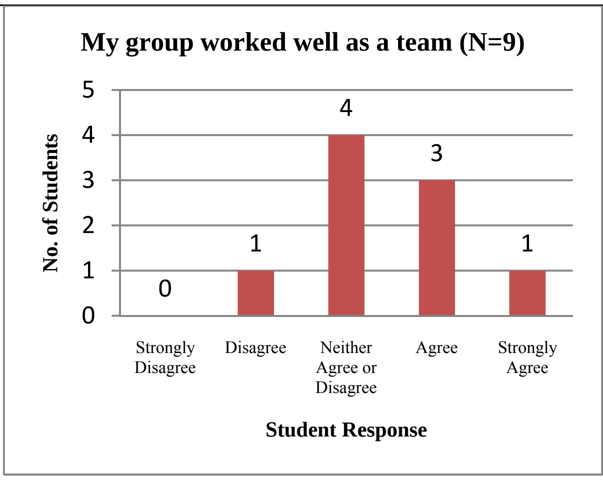
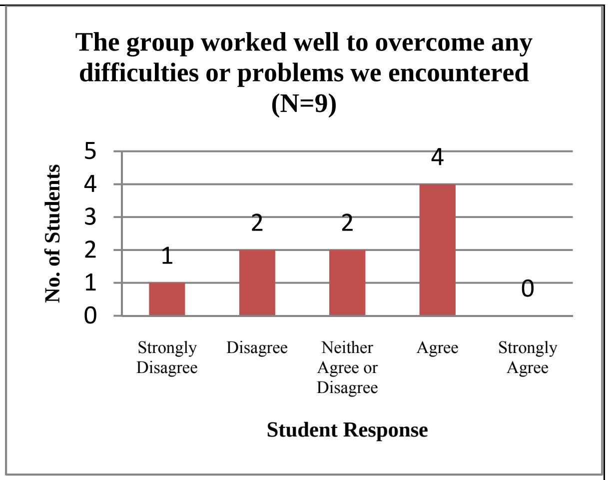


Figure 3.16: Feedback from the pilot study on how well the grouped worked as a team.



3.17: Feedback from the pilot study on how well the groups worked to overcome any difficulties or problems.

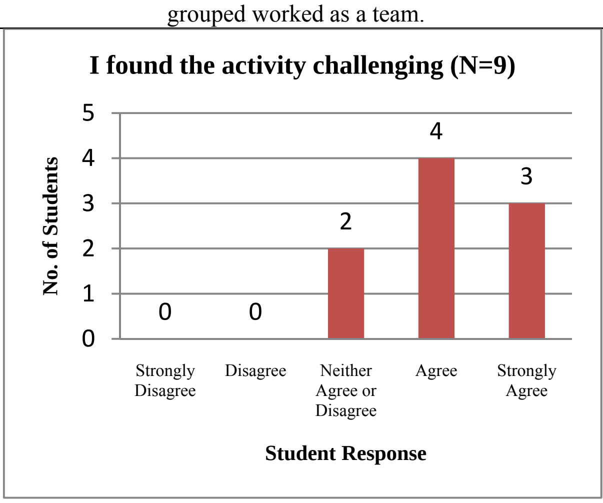


Figure 3.18: Feedback from the pilot study on how challenging students found the activity.

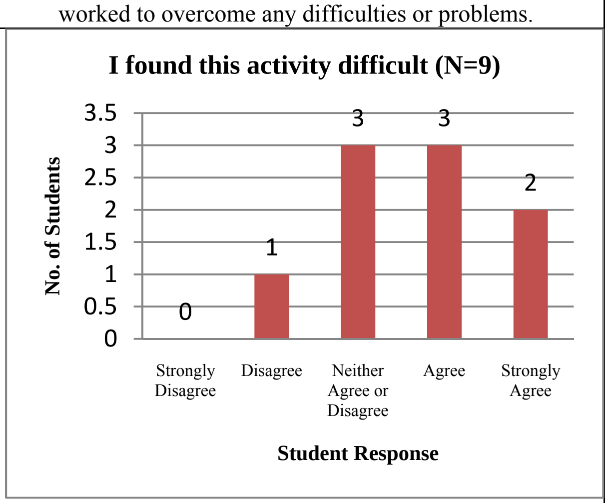


Figure 3.19: Feedback from the pilot study on how difficult the students found the activity.

Despite the very small sample size, responses appear to be steady in the four question groups (Figures 3.14 to 3.19), suggesting a degree of consistency to the questionnaire. The students completing the questionnaire commented that they didn't fully understand the statement;

"I developed an understanding of technical processes through working with my group"

For this reason this question was removed from the list of Likert-style statements used in the final questionnaire. The students needed a lot of guidance in finding and completing the online questionnaire, and the lack computer terminals in the room meant that the students had to wait for each other to fill out the questionnaire. To prevent the difficulties that online questionnaires introduce into data collection, as described by Lumsden and Morgan 2005, a paper-based questionnaire was developed as a replacement. This would also maximise sample size, as it was possible to ensure that students filled out the questionnaire in the EBL session/lecture before they left.

It was clear that the data obtained from the online questionnaire was limited due to the removal of the short answer questions. As the short answer questions from the original questionnaire possessed their disadvantages (Section 3.31), four, new short answer questions were introduced for the full scale implementation:

> *"What are the positive things about the course?"*
>
> *"What are the negative things about the course?"*
>
> *"What suggestions would you make to improve the course?"*
>
> *"Any other comments?"*

Cohen, Manion and Morrison (2000) suggest that the inclusion of open ended questions can provide more depth to the data from the Likert-type statements.

The template for the original CEEBL questionnaire (Appendix 4) was used. An introduction to the questionnaire was included at the beginning, with instruction on how to fill out the questionnaire. The short answer questions were placed after the Likert-type statements. This final questionnaire can be seen in Appendix 11. The questionnaire was intentionally kept to less than five pages, as recommended by Black (1999).

The students were given this questionnaire mid-EBL and post-lectures, in order to track student attitudes through the course. Student ID numbers were used, so that it was possible to track individual student's responses from one questionnaire to the next, whilst retaining anonymity. Due to the questionnaire being used during and after the Spectroscopy course, it was necessary to change the wording of the questionnaire between the present and past tenses, as appropriate. In addition, the post-EBL questionnaire (Appendix 12) included an extra Likert-statement:

"I was frustrated that the postgraduate demonstrators would not provide the answers"

This was included because discussions with the post-graduate facilitators indicated that students were frustrated by not being given the answers, so students' attitudes towards this were investigated by the inclusion of this statement.

3.4.1.2 Student Confidence Questionnaire

In order to investigate aspects of student confidence in relation to the topic of Spectroscopy, a second questionnaire was developed for use pre- and post-EBL (Appendices 13 and 14). As with attitudes, confidence is a latent construct, so they cannot be seen or measured directly. For this reason *perceived* confidence was being measured. This questionnaire was given to students before they began the EBL sessions, and directly after the EBL sessions. This questionnaire was intentionally kept very simple. A semantic differential scale (Osgood, Suci, and Tannenbaum, 1957) was used so that both ends could be clearly defined. The adjectives used were *"Understand"* and *"Don't Understand"*. This questionnaire was again shown to other members of staff and minor amendments incorporated. A misprint in one question meant that it is not included in the analysis.

3.4.1.3 Interviews

A focus group was conducted with the first year students who had completed the Spectroscopy course, and an individual interview was conducted with a postgraduate demonstrator/facilitator. The focus group allowed the views of several students to be considered in a free and unthreatening atmosphere. To ensure objectivity and to allow freedom for the students to be totally honest, the interviewer was an experienced interviewer from the Staff Development Unit. Experience in listening to group conversations and being free from anxiety are suggested by Kreuger (1988) as important attributes in any potential interviewer. Reid (2006b) suggests that the use of such interviewers can reduce the problems associated with the interviewer-interviewee relationship as discussed in Section 3.1.2. It was also perceived that students would be more open and honest with an external interviewer who not involved in any teaching within the School.

Clearly the interviewer would not have been able to conduct the focus group without any guidance and support. The aim of the focus group was to try to gain further insight into the information produced from the questionnaires. A semi-structured approach was adopted for the focus group, with a series of well-defined questions provided to the interviewer, prior to the focus group. A semi-structured approach was adopted to allow more discussion on certain questions, which would not have been possible with a highly structured approach, but, at the same time, ensuring that certain issues were investigated during the focus group. Also, there were concerns with an open-ended interview being too long and unpredictable, while at the same time not addressing the required issues.

The aim of the focus group was to further investigate the students' attitudes towards the EBL process. The following six questions were devised for use in the focus group:

"How did you find working in groups?"

As will be discussed later in Section 4.2, the questionnaire responses showed that students were, on the whole, positive to aspects of their group work, but there were some negative responses relating to unequal participation. This question was included to start students discussing their attitudes towards group work, without prompting them towards any specific issue indicated by students in the short answer questionnaire responses (such as some students not pulling their weight). As discussed in Section 1.3, students' attitudes towards group work were part of the research question relating to students attitudes of the processes of EBL.

"Did you find the discussion boards in WebCT useful for preparing your work in groups? What did you think of the EBL scenarios?"

As part of the implementation of EBL, online discussion boards were provided for students, to facilitate contact between group members outside of the EBL sessions. There was a mixed response to the question addressing the use of the discussion boards in WebCT in the questionnaire (question 33). As the short answer responses from the questionnaire did not provide any insight into this issue, this question was raised in the focus group to gain a deeper understanding of students' attitudes towards their use during the EBL sessions.

"Would you have been happy to have just had the EBL sessions to learn about Spectroscopy, or do you feel that you needed the lectures too?"

There was a varied response to question 29 on the EBL questionnaires, and the issue of the inclusion as well as placement of lectures was highlighted in the short answer responses to the

EBL questionnaires. For this reason, this question was included in the focus group to further explore the students' attitudes towards the lectures in the Spectroscopy course.

"Do you feel that with the EBL, you've learnt more than the information covered in the lectures, or could you have got away with just the lectures?"

Following on from the previous question, this was included in the focus group to examine how much information the students felt that they had actually learned *via* the EBL sessions. It was important to investigate if students would have been happy with just lectures, or if they valued their EBL work.

"How did you find the style of demonstrating?"

Finally, the issue of facilitation was considered. Despite the majority of students indicating that they received the support they needed in this course, some students suggested that they were frustrated with not being given the answers (question 38 in the post-lectures questionnaire). This question was included in the focus group to further investigate the issue of facilitation in EBL.

In a meeting with the interviewer, these questions were agreed, and the interviewer was given an explanation of the study and the EBL implementation. This was done to provide the interviewer with the necessary background information and reasons for conducting the interview so that they could effectively probe the students' responses. A non-threatening environment in the familiar surroundings within the School of Chemistry was used, and participants were provided with snacks.

Six first year students responded to an email seeking volunteers, and the focus group was set up. While it has to be recognised that students might volunteer for all kinds of motives, it was unlikely that this would have generated a badly-biased picture of student views, given the purpose of the focus group. The group was as in line with the suggestions of Kreuger (1988).

The focus group was run solely by the external interviewer, and a transcript of the interview was provided for analysis, along with a report on the findings of the interview (Appendix 15). It was also decided to run an interview with one of the postgraduate demonstrators who facilitated the EBL sessions. This was decided as the postgraduate student had experience of demonstrating the traditional Spectroscopy workshops, as well as facilitating on the new Spectroscopy EBL course. The same external interviewer was used for the individual interview as for the focus group, again due to their experience in conducting interviews, and, as it was clearly preferential to have an interviewer who had no hidden agenda, and had no bias towards the EBL sessions. A semi-structured style was also used for this interview, in order to allow probing of any specific issues that arose from the interview.

The reason for conducting this interview was to assess the facilitator's experience of EBL and to try to gauge their perceptions of how students saw facilitation (where questions were not answered directly, but guidance towards the correct answer was given), as opposed to traditional demonstrating (within which students would have been given direct answers to any questions raised). This was expected to give a further insight into the students' attitudes towards the role of staff members who facilitated the EBL sessions. The interviewer was given a clear background as to the purpose of the post-graduate student interview. A list of interview questions was drawn up, in consultation with the member of staff in control of the Spectroscopy course:

"Do you feel that you had adequate training for facilitating the EBL sessions as opposed to normal demonstrating?"

"Was the concept of EBL explained enough so that you knew what to expect and what to do with the sessions?"

These two questions were included in order to investigate whether the facilitator felt that the postgraduate facilitators had been adequately prepared for facilitating the EBL sessions.

"From your perspective, how did you find facilitating compared to demonstrating?"

This question was included to investigate further the experience of facilitation of the EBL sessions compared to more traditional demonstrating in workshops. Kahn and O'Rourke (2004) suggest that staff can find it hard to adjust to their new role. This question may also have given an insight as to how students reacted to the facilitators, a point which was further probed by the next question;

"How do you feel the students found the EBL sessions compared to the previous workshops?"

This was an important consideration as the postgraduate student was able to give a unique comparison of their perception of the students' attitudes towards traditional workshop teaching as compared to the EBL sessions in Spectroscopy. These findings would be compared to the attitudes expressed by the students directly, both through the questionnaires and through the focus group.

"What do you think of the concept of EBL as a way of learning and how it compares with the more traditional way of learning?"

Finally it was decided to ask the post-graduate student what their attitude was towards the EBL sessions. Although this may have been discussed previously within the interview, this question was specifically included to ensure that it was raised. The postgraduate student's opinions were valued highly, since they were not directly involved in this research, but took part in all of the EBL sessions, and would therefore have had considerable interaction with the first year students, providing a further insight into students' attitudes towards the EBL process. The transcript for this focus group interview is presented in Appendix 16.

As with the focus group, this interview was conducted independently, in a room within the School of Chemistry, and a transcript was later provided by the interviewer for analysis.

A second semi-structured focus group was run by the original interviewer and interviewees, approximately one year after the first focus group. The reasoning for this will be explained in Chapter 4 (Section 4.2.3). The second focus group was additionally attended by me, to gain experience of running a focus group, although the session was conducted by the original interviewer. As the second focus group did not address students' attitudes towards the EBL sessions, which may have altered with time, (they had subsequently received further teaching using EBL), it was decided that their attitude to the issue of interest would not have altered, hence the findings would be valid for this research. I personally transcribed the findings of the second focus group (Appendix 17).

3.4.2 The EBL scenarios

For the main study, it was decided that four EBL scenarios would be required to drive the learning process, and to ensure that students had an adequate opportunity to cover the subject matter. The scenarios are discussed in Sections 3.4.2.1 to 3.4.2.4. With eighty two students, it was decided that there would be fourteen groups of six students. Within the context of the pilot study (Section 3.3), this group size has been suggested as an optimum number (Barrows, 1980). Students were asked to complete a group report for the first three scenarios, which gave their analysis of the spectra provided, identified the unknown molecules represented by the spectra, and gave reasons for their interpretation. On advice from staff from other universities with experience in PBL, the idea of asking to students to complete a briefing paper was dropped, as it was suggested that the task was "artificial", and that students would cover this information while interpreting the various spectra.

For the first three scenarios (Sections 3.4.2.1 to 3.4.2.3) all of the key peaks were labelled for the students. This was done to allay fears (from staff from outside this research project) that students would struggle with the tasks. Consequently, supplementary data, such as DEPT information, was provided on the spectra (apart from in the final scenario), in line with the information which students had normally received on the traditional course. This was done to lower the perceived difficulty of the scenarios. As with the spectra provided to the students in the pilot study (Section 3.3.2), the ^{13}C and ^{1}H NMR spectra were simulated using ChemDraw Ultra, and the mass and IR spectra were obtained from SDBS. Group reports were used, in conjunction with peer assessment, to assess the students in the first three scenarios. It was expected that group reports combined with individual marks from peer assessment, would encourage effective collaborative learning (Slavin, 1989).

An attempt was made to order the four scenarios in order of difficulty (from easiest to hardest) to aid the students' learning process, gradually building up their skills in interpreting various spectra. These are now discussed in more detail.

3.4.2.1 "Waste Disposal" Scenario

The first new scenario, created to supplement the existing scenario used in the pilot study, was named "Waste Disposal". The labelling of containers of chemicals is an important safety consideration in any laboratory. Disposal of unknown chemicals is much more difficult and dangerous than chemicals whose identity is already known. The chemical unknowns must be identified before an attempt can be made to dispose of them correctly. This was the basis of a scenario centred on a problem that may be encountered in the "real world", as opposed to being contrived for the sake of an enquiry-based task. The handout given to students for this scenario is given in Appendix 18. As with the scenario in the pilot study (Section 3.3.2), the first year laboratory manual was used to identify appropriate molecules to include in the scenario. It was decided that a variety of commonly-used solvents would be used in this scenario - sixteen solvents were chosen (Appendix 19).

Each group of six students was allocated eight molecules to interpret. The number of molecules to identify in the scenario was deliberately kept above the number of students in the group, to try to promote group work in this task. It was found in the pilot study that, when given a number of molecules to interpret that matched the number of students in the group, the students simply analysed one molecule each, and did not collaborate with their group members as had been expected. This approach to problem solving was described by Duch (1996) as the "divide and conquer method". This is not desired, because group work and collaborative learning are an essential part of the PBL process (Savin-Baden and Major, 2004). The use of a total of sixteen molecules in this scenario meant that most groups could be given a subset of spectra to interpret that were different from other groups' sets of spectra. This was a deliberate attempt to try to encourage students to work in their own group, rather than trying to find out the answers from peers in another group.

There were several reasons for choosing solvents as the basis of this scenario. The solvents used in first year undergraduate laboratories are fairly simple molecules, whose spectra are relatively easy to interpret. As "Waste Disposal" was to be the first scenario the students encountered, it was decided that this scenario would allow students to begin the EBL process with molecules that they had a good chance of being able to interpret. Discussions with other members of staff within the School of Chemistry confirmed that the spectra were perceived as being easier for the students to interpret than the spectra provided for the pilot study. Another reason for basing a scenario upon solvents is that the products from students' reactions in laboratories often contain impurities, such as solvent. It would therefore be advantageous if students were able to recognise these common contaminants in the future.

In this scenario students were presented with spectra (Mass, IR, ^{1}H and ^{13}C NMR) of eight unknown compounds, and were subsequently asked to identify the molecules to which the spectra belong. Although students were given data sheets, which indicated the regions of the spectra where characteristic features appear (for example, in which region students would expect a carbonyl peak to appear in an IR spectrum), they were given no other information to aid their interpretation of these spectra. Students were required to know (or to find out) about chemical shifts, splitting, and integration of peaks in ^{1}H NMR spectra; about the molecular ion peak (which usually identifies the molecule's molecular weight), and fragmentation peaks in mass spectra; the reasons for the characteristic appearance of a common functional groups in IR spectra (very strong peaks in characteristic regions); and the reasoning behind chemical shifts and numbers of peaks in ^{13}C NMR spectra.

Students were required to identify the unknown molecules, and to give full reasoning of their conclusions, based on their interpretation of the various spectra. Students therefore needed to indentify the information that they required in order to complete the tasks. They would then have to conduct their own enquiries in order to establish their group's prior knowledge, and, where appropriate, organise the retrieval of any information they required (as discussed in Section 2.4.2). It is important to reiterate that facilitators were not there to provide the students with answers, but to support them in the EBL process. Students identifying their own learning issues and carrying out their own lines of enquiry are important features of any EBL process (Kahn and O'Rourke, 2005).

3.4.2.2 "Down the Drain" Scenario

The original scenario used in the pilot study (Section 3.3.2) was adapted for the use in the main study, and was named "Down the Drain". The number of compounds used in this scenario was increased from eight to sixteen, and these molecules are illustrated in Appendix 20. The inclusion of additional molecules was for the same reasoning as in the "Waste Disposal" scenario (Section 3.4.2.1). As mentioned earlier (Section 3.4.2), the briefing paper activity was removed from this scenario. Apart from these minor modifications, the scenario was essentially the same as that used in the pilot study. The handout given to students for this activity is given in Appendix 21. This scenario was considered to be harder than the "Waste Disposal" scenario, as the structures of the molecules used in this scenario were perceived as more complex by members of staff within the School of Chemistry. Consequently, it was perceived that, on the whole, the spectra used in this scenario would be harder to interpret.

The scenario requires the students to carry out exactly the same activities as the previous "Waste Disposal" scenario. The only major difference is that the scenario has a different context. The first two scenarios, therefore, give students ample opportunity to interpret a variety of unknown molecules, this being one of the key learning objectives for the Spectroscopy course.

3.4.2.3 "Carbonyl Conundrum" Scenario

The third scenario that was developed was called "Carbonyl Conundrum". This scenario required students to "work backwards" to match six compounds (whose structures were given) to their corresponding sets of spectra. Students were provided with twenty four randomly-ordered spectra (four spectra for each of the six molecules), and, within their groups they had to match up the various spectra to the correct molecule. Although the structures of the molecules were given, students had to correctly select the spectrum for each technique that belonged to each molecule. This meant that students still had to use their knowledge of the spectroscopic techniques to interpret the various spectra. In this scenario students were asked to assign the various spectra to the molecules, but were not required to provide a written report outlining their reasoning. The six molecules were chosen by consulting with a member of staff who was not directly involved in this module (the molecules selected are illustrated in Appendix 22).

The aim was to identify three pairs of compounds, with each molecule in the pair very similar structurally, giving closely related spectra. This meant that students needed a higher level of sophistication in their spectral interpretation in order to successfully complete this task. This similarity between pairs of compounds was introduced to the scenario to demonstrate to students that the answers to problems are not always clear-cut and unique – a feature of PBL which was outline by Duch (1996). For this reason, this third scenario was perceived to be more difficult than the first two (Section 3.4.2.1 and 3.4.2.2) by the member of staff involved in the teaching of this module. The handout given to students for this scenario can be seen in Appendix 23.

It was difficult to develop a scenario for use that was open-ended and possessed no correct answer - often a feature of EBL activities (Hutchings, 2006). However, an attempt was made to add authenticity to the final scenario, which involved students interpreting “real” spectra, as opposed to simulated and/or pure spectra.

3.4.2.4 “Reaction Dilemma” Scenario

The fourth scenario was also created in consultation with a member of staff. For this final scenario the students were given “real” spectra, produced in the laboratory by myself. This meant that “key peaks” were not labelled by the spectrometers, and the spectra were not ideal and occasionally contained some impurities. This approach was taken, as students encounter “real life” spectra produced by the spectrometers within the School of Chemistry as part of their undergraduate laboratory. This meant that this final scenario was seen as being the hardest of the four scenarios used.

The scenario involved the reduction of benzamide to give benzyl amine, which had failed because a supplier had provided an incorrect starting material to a postgraduate student for use in the reaction. Students were provided with a printout of an email from a (fictional) postgraduate student, asking for their help in interpreting the spectra of the product (benzyl alcohol) provided (Appendix 24). Students were told that the second stage of the postgraduate student’s reaction, using this product, had failed. Students were then asked to contact the fictional postgraduate student, *via* email, with their interpretation of the spectra and explanation of what had gone wrong in the reaction. The process ultimately led to the students discovering that the wrong reactant had been supplied (this was one of the following compounds, each of which reduce to give benzyl alcohol: benzaldehyde, benzoic acid, methyl benzoate, ethyl benzoate or propyl benzoate).

Students were asked to email the postgraduate student by the end of the first (of two) EBL sessions on this scenario. With “real” spectra being used in this task, it took students longer to complete the analysis of the spectrum for one molecule. If groups deduced that the desired product had not been made, they received an email in advance of the second session, outlining the next stage of the scenario, and including the spectra of the actual starting material

(Appendix 25). If groups had mistakenly identified the first molecule as being correct, they did not get to the next stage of the scenario after their initial email, but were directed back to the original spectra to check their interpretation, through an email suggesting that they may have got the interpretation wrong, as the reaction was still not working. Decisions which take students down unproductive avenues are seen as a part of the EBL process (Kahn and O'Rourke, 2004).

The second stage of the problem required students to identify the actual (incorrect) starting material which had originally been used. Once they had correctly assigned this and deduced how this gave rise to the initial product from the postgraduate student’s reaction, they were introduced to the final part of the problem, which asked them to ascertain if the student had now obtained the correct product by re-running the reaction with the re-supplied correct starting molecule (Appendix 26). One of five different starting molecules was given to each group, which would have gone some way to prevent students copying from other groups, and encouraging students to work together within their groups.

For this task students were asked to complete an individual report, along with peer assessment (based on their group activities). The individual report gave a reflection of the individual student’s competence in Spectroscopy, as well as dispelling any notions that students not doing any work were achieving the same mark as students who did the majority of the work.

3.4.3 Course Structure

The structure of the original course (lectures and workshops), as outlined in Section 3.2, was altered for the implementation of EBL. Students were given six, two hour EBL sessions, in which they encountered the various scenarios relating to Spectroscopy. The EBL sessions were then followed by five, one hour lectures to explain how theory underpins the interpretation of the spectra. Unfortunately, the University uses block timetables and the EBL sessions had to be timetabled after two hours of lectures, from 4-6 pm on a Friday afternoon. In previous years, students would have had four hours of lectures (2-6 pm). The use of a large, flat room with large tables was provided for the EBL sessions. In addition, students could spill out into a room opposite if required.

The continual assessment of the 1C1 Structure and Bonding module comprised 25% of the final module mark (Appendix 1). As it was recognised that traditional assessment methods may not be appropriate for an EBL approach (Section 2.6), group reports, peer assessment, and one individual report were introduced into the continuous assessment component of the module.

Two assessed worksheets were included in this continuous assessment - one post-EBL and pre-lectures and one post-EBL and post-lectures. The questionnaire investigating students' attitudes towards the processes of EBL will be referred to as "post-lectures" from this point forward. The assessed worksheet was delivered in the same format used previously. The end of (first) year examination questions were kept in an identical format, to allow some basic comparison of students' performance.

The breakdown of continuous assessment marks (25% of the total module mark) is seen in Table 3.11.

Total %	Break down of marks for each component		
10% for EBL Work	Revision	10% Group Report	
	Waste Disposal	18% Group Report	2% Peer Assessment
	Down the Drain	18% Group Report	2% Peer Assessment
	Carbonyl Conundrum	10% Group Report	
	Reaction Dilemma	36% Individual Report	4% Peer Assessment
15% for Assessed Worksheets	50% Assessed Worksheet 1 50% Assessed Worksheet 2		

Table 3.11: First year assessment scheme.

A timeline of the implementation is shown in Tables 3.12 and 3.13.

Timeline		*Student Tasks*	*Data Collection*
Induction	*Pre-EBL*	Assess their own abilities in Spectroscopy for group allocation	Questionnaire on prior knowledge
Week 1	***Session 1***	Ice breaker Setting up of group rules Introduction to EBL Assess their prior knowledge Introduction to spectra of two molecules	
Week 2	***Session 2***	Hand in group report on the spectra Member of staff ran through answers in the session Introduction to "Waste Disposal" scenario	
Week 3	***Session 3***	Hand in of "Waste Disposal" scenario Introduction to "Down the Drain" scenario	
Week 4	*No Session*		Mid-EBL evaluation questionnaire
Week 5	***Session 4***	Hand in "Down the Drain" scenario "Carbonyl Conundrum" scenario (in session)	
Week 6	***Session 5***	Introduction to "Reaction Dilemma" scenario	Assessed work sheet 1 (Pre-lectures)
Week 7	***Session 6***	Work on "Reaction Dilemma" scenario	Student confidence questionnaire
Week 8-11		5 x 1 hour lectures	Assessed worksheet 1 and "Reaction Dilemma" handed in before lecture 1

Table 3.12: Timeline of implementation of EBL and lectures

Timeline	*Student Tasks*	*Data Collection*
Post EBL and lectures		Assessed worksheet 2 (Post-Lectures + EBL) Post-lectures evaluation questionnaire Focus groups with students Interview with postgraduate demonstrator End of year examination

Table 3.12: Data collected post-EBL and lectures

During Induction, students filled in the paper-based questionnaires that investigated their perceived confidences in the various types of Spectroscopy (Section 3.4.1.2).

Based on how students rated themselves on their ability to interpret spectroscopic data, students were allocated into groups. Each group had a student who saw themselves as being able in each technique. This was not the most scientific method for assigning groups, but it was seen as a better technique than assigning groups randomly. Of course, a student may rate themselves as being very capable in interpreting spectra, but this did not necessarily mean that they actually were very capable. The aim of this method of group assignment was to try to ensure that all of the groups had a good mixture of abilities in different areas, as is recommended by Huxham and Land (2000). Glasersfeld (1991) suggests that a student can benefit from explaining a concept to a peer, spotting inconsistencies in their own knowledge. By attempting to create groups of mixed abilities, it was expected that such opportunities would arise more frequently.

As in previous years, there were four postgraduate facilitators assigned to this course. They were given a brief guide to EBL (Appendix 27), and their role was explained to them before the first session. This meant that six staff would be present in the sessions, hence floating facilitating was used. Although a group size of no more than five has been suggested for this model of facilitation (Raine and Symons, 2005), it was decided, for practical reasons, that a group size of around six students would be used.

In the first session students were allocated groups and participated in a "pub quiz" style icebreaker (Appendix 28). This gave them a chance to get to know the other members of their group in a non-academic, team-based task. After this, the students were introduced to EBL as a method of learning, and each group was asked to establish their own group rules, which were posted onto the WebCT-based online discussion board after the session by the students. The students were provided with information on the learning process encountered in EBL (Appendix 29). Towards the end of the first session the students were given spectra of two simple molecules to interpret before the next session (this was not an EBL scenario). The task introduced two simple molecules to introduce some basic interpretation of spectra. Throughout all of the EBL scenarios, students had access to the online discussion boards to allow them to communicate easily with each other outside of the sessions (Appendix 30). A "helpdesk" thread was included so that students could contact staff if necessary. The discussion boards were also used to give the groups feedback on each component of the assessment, so that this could be done in a timely fashion.

During the second session in week two, the interpretation of the spectra from the previous session was discussed by the member of staff, and students were questioned at each stage. This was decided as it has been suggested that, in the floating facilitation model, mini-lectures may be appropriate, and student discussion should be encouraged (Raine and Symons, 2005). The groups' interpretations of the spectra were collected in before the answers were discussed. The written answers were marked, and feedback was given to the individual groups *via* WebCT. In the second session, students were introduced to the first "proper" scenario - the "Waste Disposal" scenario (Section 3.4.2.1). The students were asked to work on this scenario, and hand in a group report and their peer assessment forms at the start of the third session in week three. After this had been completed, the “Down the Drain” scenario (Section 3.4.2.2) was introduced, and students were allowed to begin their work on this in the session, to be completed by, and handed in at the start of the fourth session.

There was a two week gap between the third and fourth sessions due to timetabling. During the week with no session, the mid-EBL, paper-based questionnaire (Section 3.4.1.1) was handed out in an unrelated first year lecture and collected back in at the end of this lecture.

In the fourth session, after the two week break, students were asked to hand in their group report and peer assessment for the “Down the Drain” scenario. They were then introduced to the “Carbonyl Conundrum” scenario, and were asked to complete and hand in this scenario at the end of the session. Some groups completed the task quickly and those groups were allowed to leave early.

The fifth session saw the students introduced to the final EBL scenario, “Reaction Dilemma”. Before the fifth session, the first assessed work sheet was handed out to the students. This was also handed in before the first lecture.

The final questionnaire investigating students’ confidence in Spectroscopy (Section 3.4.1.2) was completed after the final EBL session. This was done prior to the lectures so that the students’ confidence was assessed after just the EBL sessions. The students then had five, one hour lectures, on how theory underpins interpretation of spectra. These lectures were well attended by the students.

After the lectures, another assessed work sheet was given out for the students to hand in after the Christmas holiday. The post EBL questionnaire was handed out in the final lecture, to allow a comparison of students’ responses from mid-EBL to post-lectures.

In the spring term, a focus group was conducted with six of the first year students along with the interview with the postgraduate demonstrator (Section 3.4.1.3).

CHAPTER 4

FINDINGS AND DISCUSSION

Chapter 3 discussed the development and implementation of the research tools and the EBL scenarios in the study. Chapter 4 will present and discuss the findings obtained from the research tools that were used in this research. Chapter 4 is divided into two sections, as each section represents data that relate to a specific research sub-question as presented in Section 1.3.

Consequently, Section 4.1 will present and discuss the data obtained in relation to students' *perceived* confidence in Spectroscopy. Section 4.2 will present and discuss students' attitudes to various aspects of the EBL implementation. Data from both mid-EBL and post-lecture questionnaires will be presented together, in order to investigate any changes in attitudes between these two points. Findings from a focus group with first year students, and a one-to-one interview with a postgraduate demonstrator, will also be presented alongside the questionnaire data. The presentation of data will be structured into themes as outlined in Section 3.3.1, in relation to both mid-EBL and post-lecture questionnaires.

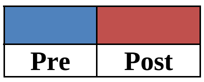
4.1 Student Perceived Confidence Questionnaires

"How does student perceived confidence (in handling the subject matter and in their learning) change, if at all, as a result of their experience in using EBL in the Spectroscopy course?"

Section 4.1 presents data that were collected in order to address the research sub-question shown above. These questions possess different sample sizes, as not all students responded to every question in both questionnaires. This became apparent when it was noted that more students responded to the first page of questions than to the second page of questions. As data analysis required a direct comparison of students' responses, the sample size fluctuates from question to question, but is always a direct comparison of individual student responses.

4.1.1 Students' Confidence in Understanding How the Spectroscopic Techniques Work

Students were asked to self-assess their confidence in understanding how the various spectroscopic techniques work, both before and after they had participated in the EBL sessions, but before they had received any lectures on the topic. The pre-EBL questionnaire is presented in Appendix 13 and the post-EBL questionnaire in Appendix 14. The data presented in Figures 4.1, 4.3 and 4.5 represent changes in students' self-evaluation of their understanding of how the spectroscopic techniques work, both pre-EBL and post-EBL (but before lectures). Figures 4.2, 4.4 and 4.6 track moves in student responses.



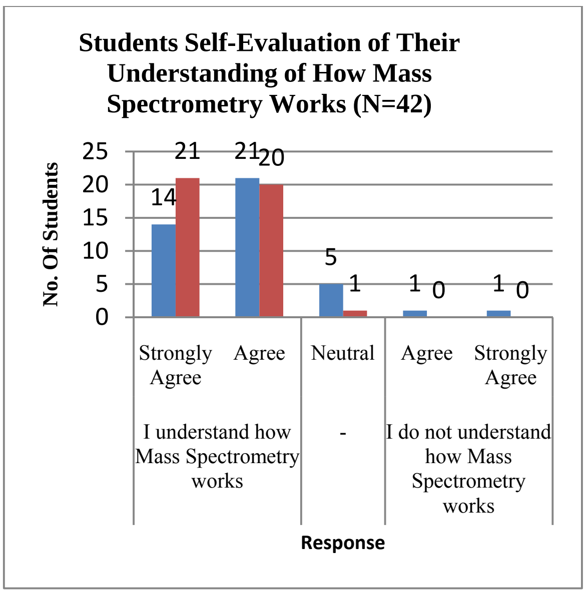


Figure 4.1: Students' confidence in understanding how mass spectrometry works.

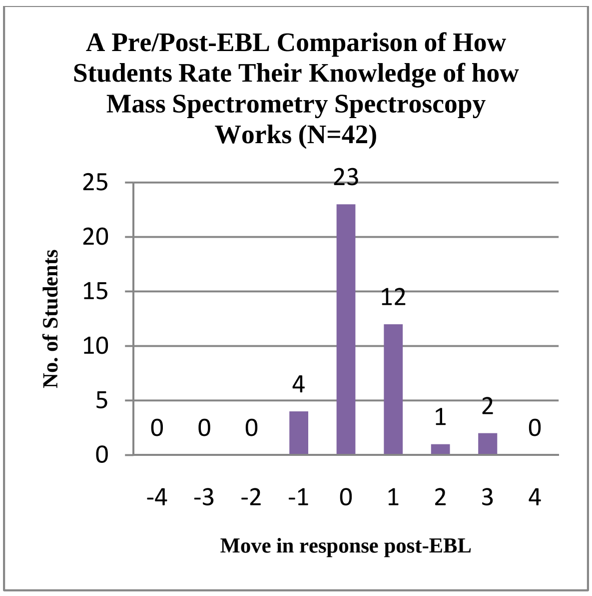


Figure 4.2: Moves in students' responses from Figure 4.1.

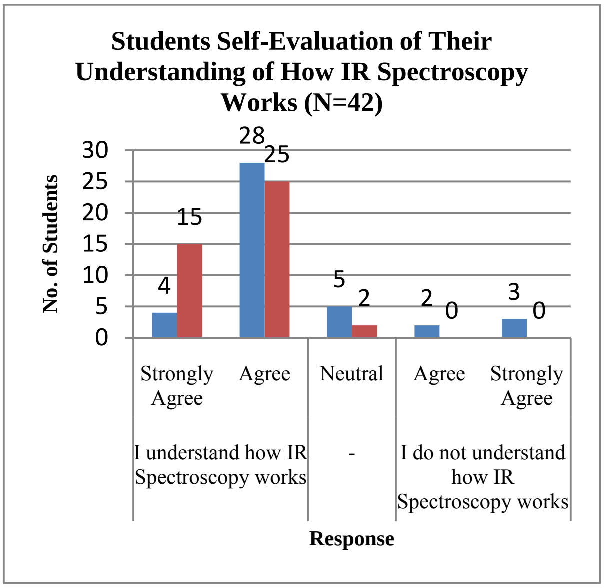


Figure 4.3: Students' confidence in understanding how IR Spectroscopy works.

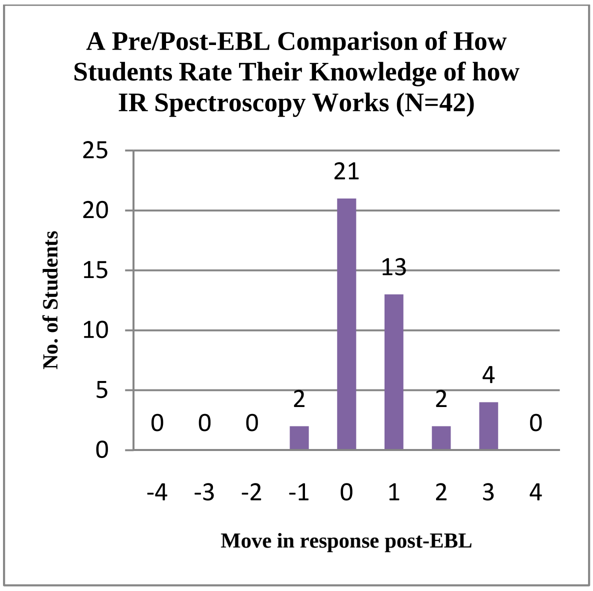


Figure 4.4: Moves in students' responses from Figure 4.3.

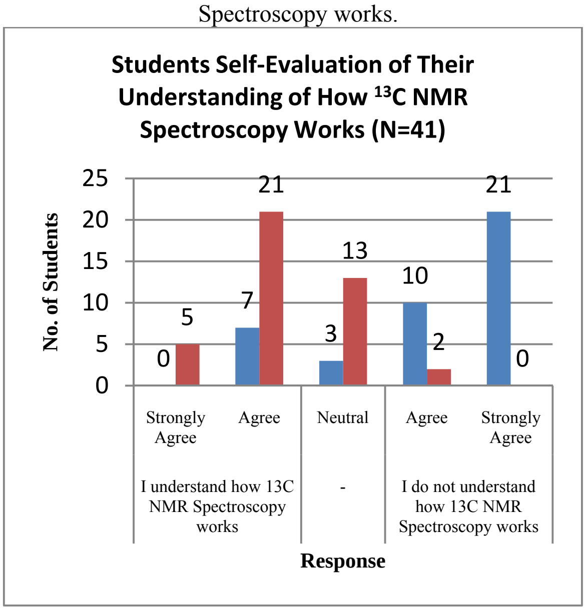


Figure 4.5: Students' confidence in understanding how ^{13}C NMR Spectroscopy works.

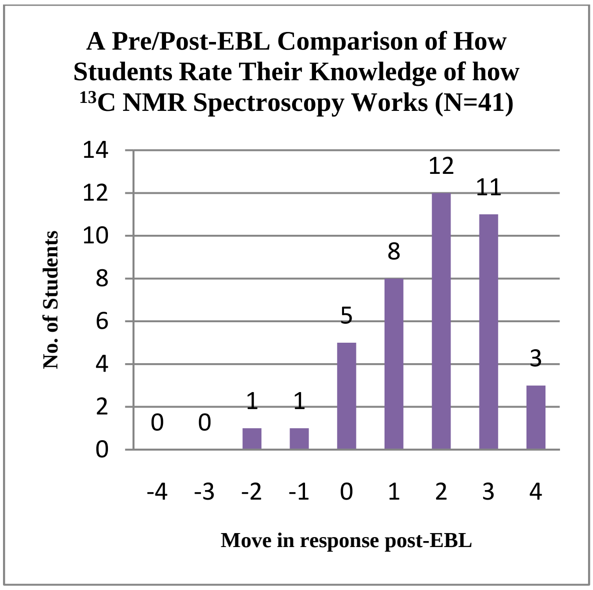


Figure 4.6: Moves in students' responses from Figure 4.5.

Figures 4.1 and 4.3 illustrate that the majority of students possess a degree of confidence, both before and after the EBL sessions, in understanding how the Mass Spectrometry and IR Spectroscopy techniques function. This is not the case for ^{13}C NMR Spectroscopy, however, with 76% students suggesting they lack confidence by responding "Agree" or "Strongly Agree" to the statement "I do not understand how ^{13}C NMR Spectroscopy works" (Figure

4.5). Post-EBL, 63% of students responded “Strongly Agree” or “Agree” at the other end of the scale, suggesting an overall increase in students perceived confidence in their knowledge of how ^{13}C NMR Spectroscopy works.

These results suggest that, generally, students begin the course with a degree of perceived self confidence in understanding how Mass Spectrometry and IR Spectroscopy work. This can be explained by these two techniques being covered, to some degree, in A-level syllabi. In contrast, most students start the course lacking self confidence in understanding how ^{13}C NMR Spectroscopy works, although this is to be expected as students are less likely to have received in-depth teaching in ^{13}C NMR Spectroscopy at A-level. However, eighteen of the eighty-two students who had enrolled on this course had encountered the technique before, due to completing a Foundation Year in the School, where ^{13}C NMR Spectroscopy is covered (as well as the other spectroscopic techniques). Of the seven students in the sample from Figure 4.5, who responded either “Strongly Agree” or “Agree” to being confident in interpreting ^{13}C NMR spectra pre-EBL, five students had completed the Foundation Year course before entering the first year.

Overall, there are positive moves in the area of perceived knowledge of theory behind the techniques. A summary of the changes in responses is presented in Table 4.1.

%	*Increase*	*No change*	*Decrease*
Mass Spectrometry	36	55	9
IR Spectroscopy	45	50	5
^{13}C NMR Spectroscopy	83	12	5

Table 4.1: Changes in student confidences in understanding how the techniques work.

It can be seen that roughly half of the students’ responses remained the same pre- and post-EBL for Mass Spectrometry and IR Spectroscopy. Due to the degree of perceived confidence in understanding of these two techniques pre-EBL, there is little scope for major shifts. This may account for the number of students showing no move post-EBL.

It is clear from Table 4.1, that ^{13}C NMR Spectroscopy showed the largest increase in confidence of the three techniques, with 83% of students changing category in the positive direction (*i.e.* negative, neutral and positive). Figure 4.5 shows that no student responded “Strongly Agree” in relation to understanding how ^{13}C NMR works pre-EBL, but post-EBL there were five students. It is of interest to note that three of these five students responded “Strongly Agree” to the statement “I do not understand how ^{13}C NMR works” pre-EBL (the three students showing four positive moves in response post-EBL). Figures 4.1 and 4.2 show that the two students at the negative end of the scale have moved to the positive end of the scale for understanding of the Mass Spectrometry technique. This is indicated by a loss of all respondents in the negative category in Figure 4.1, and the two respondents who exhibited three moves in the positive direction in Figure 4.2. Figures 4.3 and 4.4, relating to confidence in understanding of the IR Spectroscopic technique, indicate that four of the five students who responded negatively in the pre-EBL evaluation, responded positively in the post-EBL evaluation. This is demonstrated by the loss of all responses in the negative category (Figure 4.3), and four students who exhibited three moves in the positive direction (Figure 4.4).

Despite the majority of students being confident in their knowledge of how IR Spectroscopy and Mass Spectrometry work, the students who perceived that they lacked confidence the most in this area pre-EBL were some of the more confident students post-EBL.

It is apparent that the students lacking the most confidence in the area of understanding how the spectroscopic techniques work showed the largest increases in confidences post-EBL (Figure 4.2, 4.4 and 4.6). This suggests that EBL has the potential to help students who are not confident in understanding how the spectroscopic techniques work to improve in confidence. Of course, it must also be born in mind that they are also the few who have the potential to show the largest number of moves in response post-EBL.

There is, however, a decrease in perceived confidence in understanding of the techniques amongst a small number of students. This decrease in perceived confidence is of interest, because Figures 4.1 and 4.3 indicate that for IR Spectroscopy and Mass Spectrometry there is a complete loss of negative response after the EBL sessions.

4.1.2 Students' Confidences in Their Ability To Interpret Spectra

Students were asked to self-assess their confidence in interpreting spectra, in each of the techniques, both before and after they had participated in the EBL sessions, but before they had received any lectures on the topic. The data presented in Figures 4.7, 4.9, 4.11 and 4.13 represent changes in students' self-evaluation of their ability to interpret spectra pre-EBL and post-EBL (but pre-lectures). Figures 4.8, 4.10, 4.12 and 4.14 track moves in student responses.

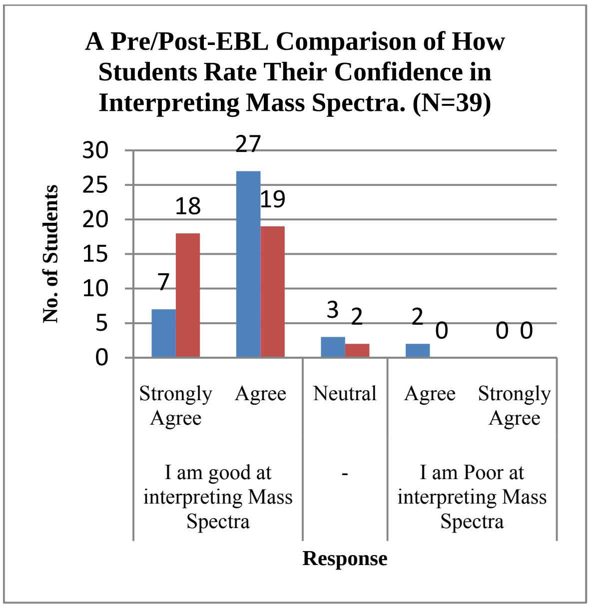


Figure 4.7: Students' confidence in interpreting Mass spectra.

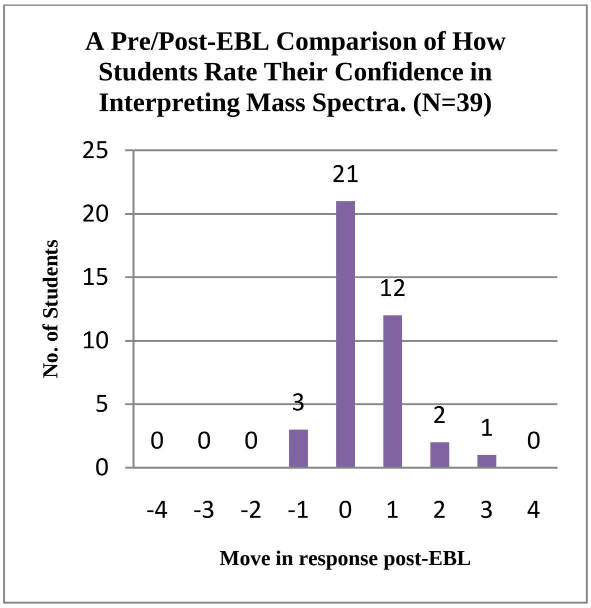


Figure 4.8: Moves in students' responses from Figure 4.7.

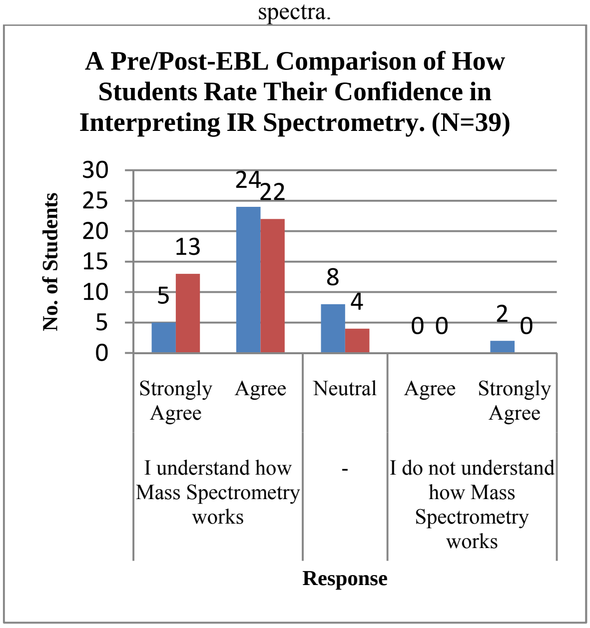


Figure 4.9 Students' confidence in interpreting IR spectra.

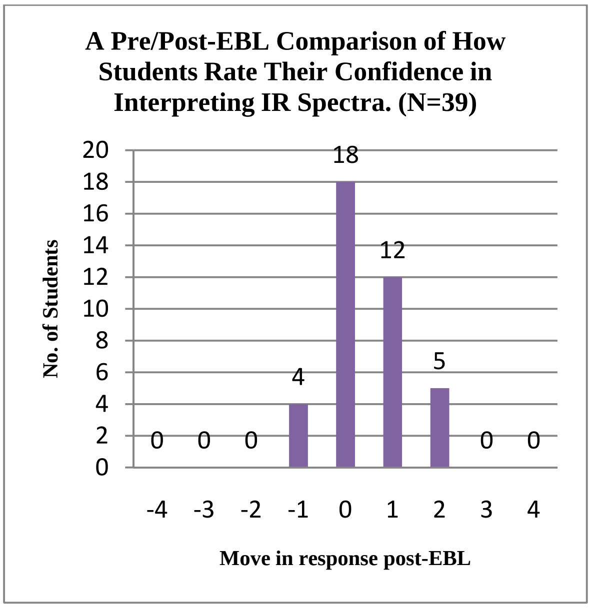
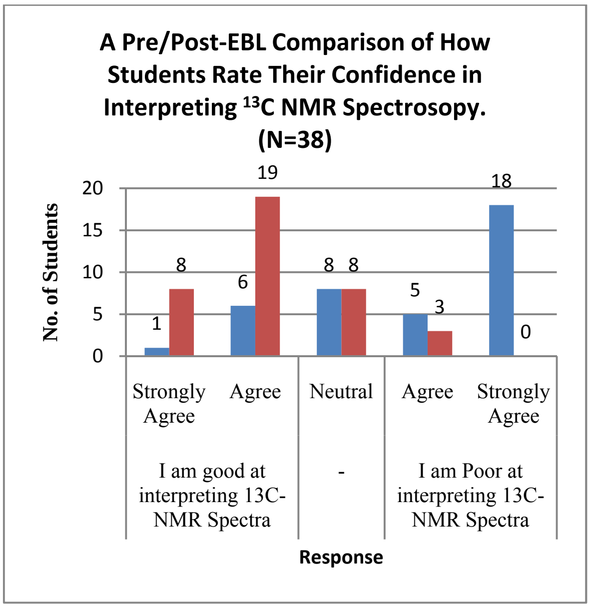


Figure 4.10: Moves in students' responses from Figure 4.9.



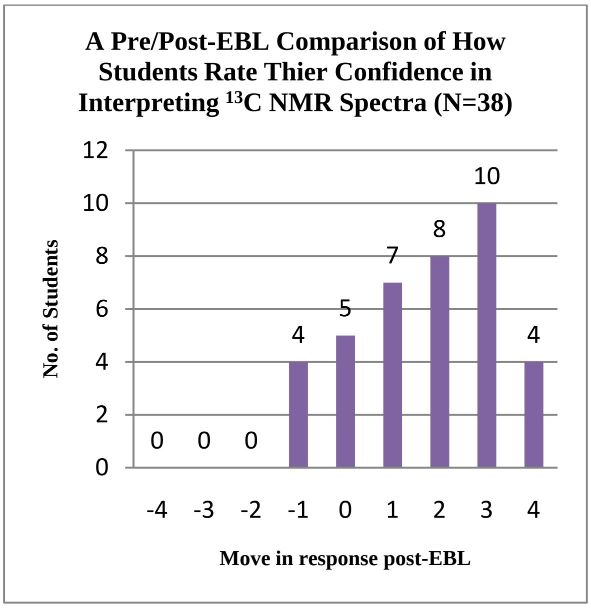
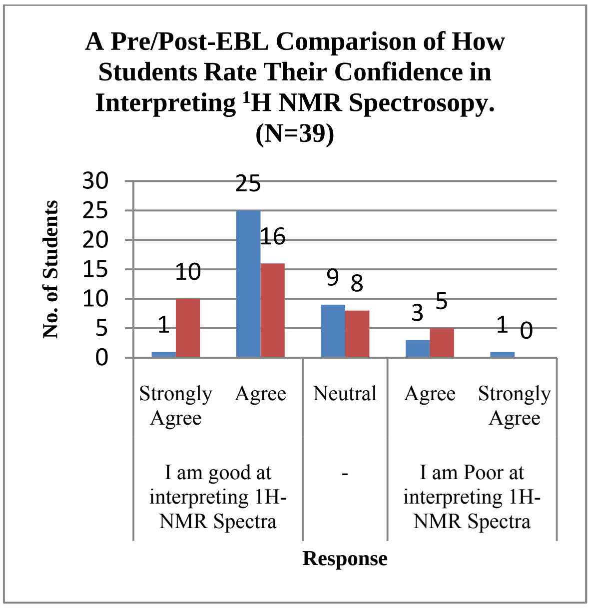


Figure 4.11 Students' confidence in interpreting ^{13}C NMR spectra.

Figure 4.12: Moves in students' responses from Figure 4.11.



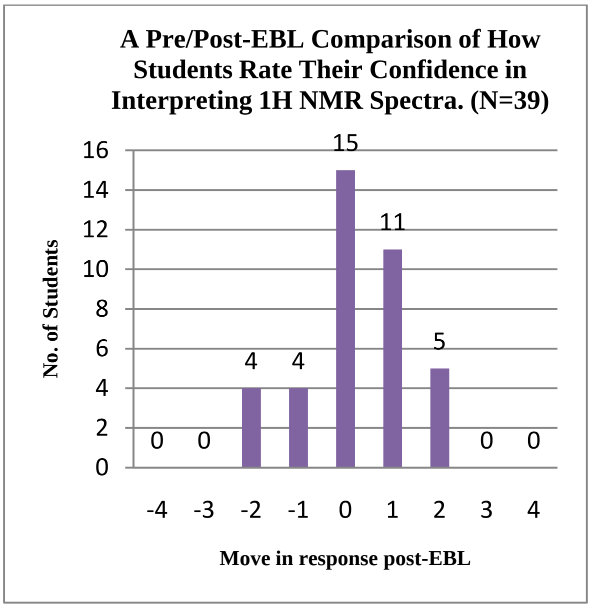


Figure 4.13 Students' confidence in interpreting ^{1}H NMR spectra.

Figure 4.14: Moves in students' responses from Figure 4.13.

Figures 4.7, 4.9 and 4.13 indicate that, both pre- and post-EBL, when given the statement "I am good at interpreting spectra", the majority of students rate their understanding of the techniques as "Agree" or "Strongly Agree". However, Figure 4.11 illustrates that students were noticeably less confident in their interpretation of ^{13}C NMR spectra pre-EBL, though post-EBL the majority of students lie at the positive end of the rating scale. As mentioned in Section 3.1.1, this is consistent with most students receiving no formal teaching in ^{13}C NMR Spectroscopy prior to their arrival at university. Of the seven students in the sample from Figure 4.11, who responded either "Strongly Agree" or "Agree" to being confident in interpreting ^{13}C NMR spectra, five students had completed the Foundation Year course before entering the first year. As with students' perceived knowledge of theory behind the techniques discussed in Section 4.1.1, students generally seem to be most confident in the techniques of IR Spectroscopy and Mass Spectrometry.

Figures 4.7, 4.9, 4.11 and 4.13 show a noticeable increase in students who "Strongly Agree" that they are good at interpreting spectra. Figure 4.11 indicates that, although there were eighteen students pre-EBL who strongly agreed at the negative end of the scale, there were no students who gave this response post-EBL. On the whole, there is a loss in number of students who respond that they lack self-confidence in interpreting spectra (Figures 4.7, 4.9 and 4.11). However, this is not the case for ^{1}H NMR Spectroscopy (Figure 4.13), where an increase in students responding in the negative category is found.

Changes in students' responses can be further explored by examining Figures 4.8, 4.10, 4.12 and 4.14 which show students' moves post-EBL. A summary of the changes in student confidence in interpreting spectra is given in Table 4.2.

%	Increase	No change	Decrease
Mass Spectrometry	38	54	8
IR Spectroscopy	44	46	10
^{1}H NMR Spectroscopy	41	38	21
^{13}C NMR Spectroscopy	76	13	11

Table 4.2: Changes in student confidence in interpreting spectra.

There is a general increase in students' perceived confidence in interpreting spectra in all of the techniques (Figures 4.8, 4.10. 4.12 and 4.14), with ^{13}C NMR Spectroscopy showing the most marked increase (Figure 4.12). Figure 4.12 demonstrates that at least twenty-two students (58%) had changed category (*i.e.* negative, neutral, positive) post-EBL. Four students moved from one end of the scale to the other in the positive direction, with these students now constituting half of the "Strongly Agree" category on the positive end of the scale. Figures 4.8, 4.10 and 4.14 illustrate that there are also marked increases in student confidence in interpreting Mass, IR and ^{1}H NMR spectra. Due to the lack of three or four moves in response, it not possible to ascertain from Figure 4.14 how students who indicated that they lacked confidence pre-EBL, responded post-EBL. From Figure 4.8 it is possible to deduce that one of the students who responded "Agree" to lacking confidence pre-EBL, responded "Strongly Agree" to having confidence post-EBL. It can be seen from Figure 4.10 that the two respondents who strongly agree in lacking confidence pre-EBL, both responded "Neutral" post-EBL.

The percentage of positive moves in students' confidence to interpret spectra (Table 4.2: Mass Spectrometry 38%, IR Spectroscopy 44%, ^{13}C NMR Spectroscopy 76%, respectively) is comparable to the percentage of positive moves shown in students' confidence in understanding the theory behind the techniques (Table 4.1: Mass Spectrometry 36%, IR Spectroscopy 45%, ^{13}C NMR Spectroscopy 83%, respectively). However, it must be noted that categories have been grouped in Tables 4.1 and 4.2, with the "increase" category representing one to four positive moves, and the "decrease" category representing one to four negative moves.

Figures 4.8, 4.10, 4.12 and 4.14, however, illustrate that a few students show a decrease in confidence post-EBL in interpreting spectra for each of the spectroscopic techniques. In spite of this, there are no “Strongly Agree” responses at the negative end of the scale for any of the spectroscopic techniques. Indeed, the data for Mass Spectrometry (Figure 4.7) and IR Spectroscopy (Figure 4.9) do not show any responses suggesting a lack of confidence in interpreting spectra post-EBL. Figure 4.14 shows that the most noted decreases in student confidences (21%) in interpreting spectra post-EBL occur for ^{1}H NMR Spectroscopy. This is also true of students’ perceived confidence knowledge of how the techniques work (Table 4.1). ^{1}H NMR Spectroscopy produces arguably the most complex spectra of the four spectroscopic techniques, which may account for this drop in confidence in some students.

4.1.3 Student Confidence in Both Understanding and Interpreting Spectra

As mentioned in Sections 4.1.1 and 4.1.2, similarities can be found in student responses both in understanding how a technique works and in how to interpret its spectra, for all three spectroscopic techniques. Unfortunately, a similar comparison for ^{1}H NMR Spectroscopy was not possible due to an error in the confidences questionnaire. As a result of these apparent similarities between understanding of a technique and interpreting its spectra, the pre-and post-EBL questionnaire data was re-examined to investigate any differences between individual student’s responses to the statements regarding these areas. The data shown in Figures 4.15 to 4.17 represent the differences in an individual student’s responses, pre- and post-EBL, to the statements relating to their ability to interpret spectra from a particular spectroscopic technique, and their knowledge of how the particular technique works. A positive move on the rating scale represents a student indicating that they are more confident in interpretation of spectra than in understanding the theory behind the technique, whereas a negative move on the rating scale represents a student indicating that they are more confident in understanding the theory behind the technique than in interpretation of its spectra.

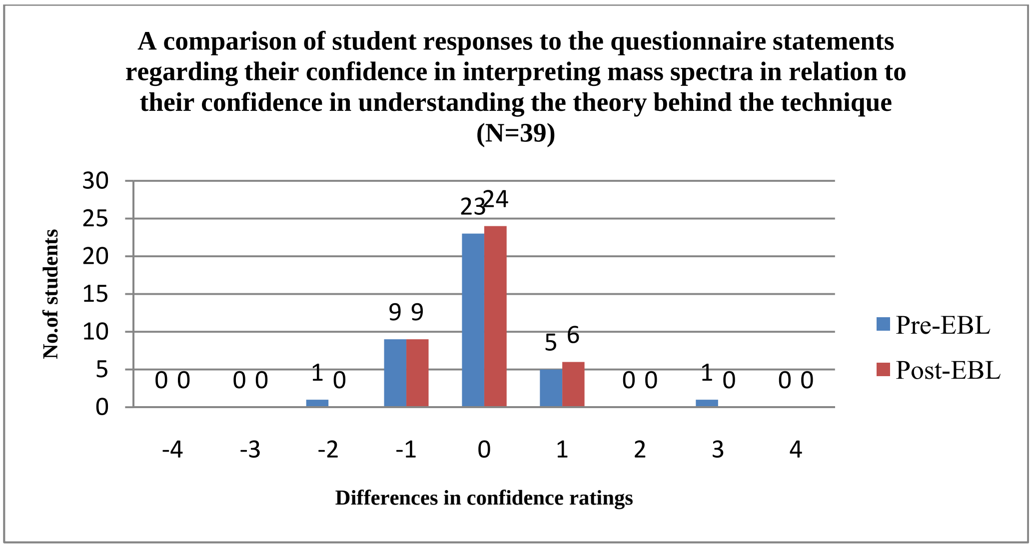


Figure 4.15: Differences in student's responses to the questionnaire statements regarding spectral interpretation and theoretical understanding of Mass Spectrometry.

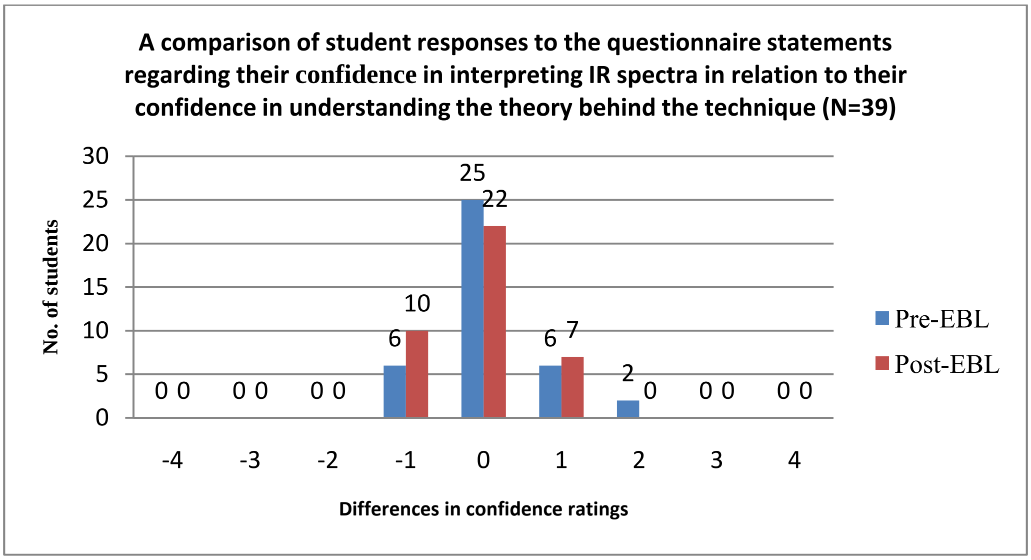


Figure 4.16: Differences in student's responses to the questionnaire statements regarding spectral interpretation and theoretical understanding of IR Spectroscopy.

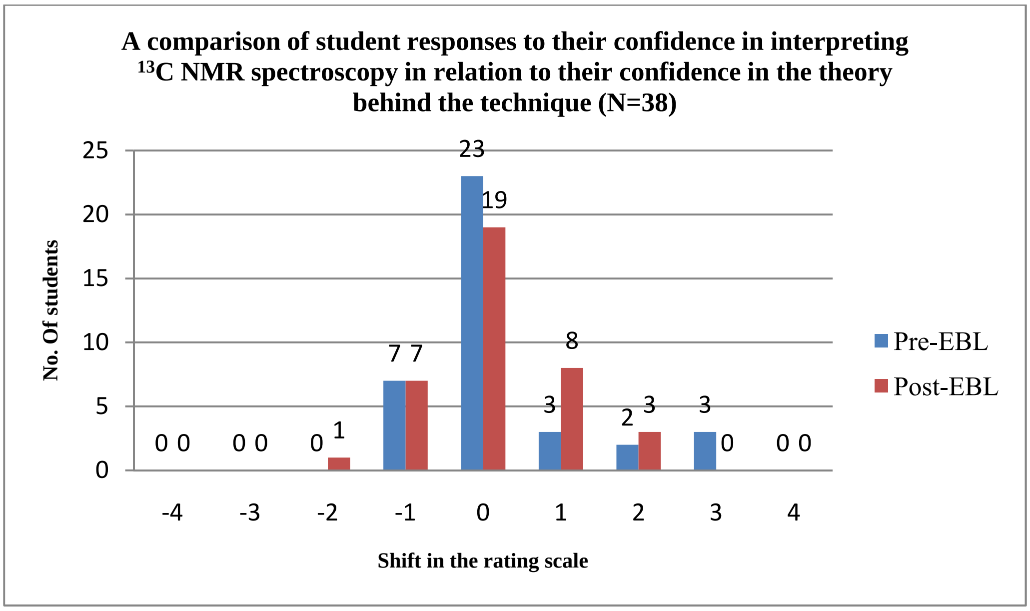


Figure 4.17: Differences in student's responses to the questionnaire statements regarding spectral interpretation and theoretical understanding of ^{13}C NMR Spectroscopy.

There are some differences between student responses, pre- and post-EBL, for each spectroscopic technique (Figures 4.15 to 4.17). Despite this, the majority of students (~60%) indicated the same level of perceived confidence regarding spectral interpretation and theoretical understanding of the corresponding spectroscopic technique. In addition, it can be seen in Figures 4.15 to 4.17, that the pre- and post- EBL data are very similar. A comparison of differences in confidence in interpreting spectra *versus* theoretical understanding of the corresponding spectroscopic technique, both pre- and post-EBL is presented in Table 4.3. All positive moves have been grouped together and represent students indicating that they are more confident in interpretation of spectra than in understanding the theory behind the technique, whereas all the negative moves have been grouped together and represent students indicating that they are more confident in understanding the theory behind the technique than in interpretation of its spectra.

		%		
		More confident in theoretical knowledge	**No difference**	**More confident in interpretation**
Mass Spectrometry	*Pre*	26	59	15
	Post	23	62	15
IR Spectroscopy	*Pre*	15	64	21
	Post	26	56	18
^{13}C NMR Spectroscopy	*Pre*	18	61	21
	Post	21	50	29

Table 4.3: A pre/post-EBL comparison of differences in student confidence in spectral interpretation and theoretical understanding of the corresponding spectroscopic technique.

For each spectroscopic technique, the majority of students indicated the same degree of confidence to both statements, pre- and post-EBL (Table 4.3). Overall there appears to be no major difference between the number of students who are "more confident in their theoretical knowledge" than students who suggested that they were "more confident in interpretation skills".

4.1.4 Discussion

The general increase in confidence would suggest that the EBL activities have increased students' perceived confidence, both in their perceived knowledge of theory behind the techniques, and in their confidence in interpreting spectra. These findings are consistent with those of Braye, Lebacq and Midwinter (2003), who suggest that EBL can lead to students' self-confidence increasing, due to them learning more effectively (Section 2.7.3). It is not possible to attribute this increase in confidence to any one particular part of the EBL process however, *e.g.* students learning in a more "active" manner.

Although the emphasis of the EBL course was on interpreting spectra, the overall increase in confidence in the theory behind the spectroscopic techniques (Table 4.1) indicates that students have explored this area to some extent during their independent study, and have gained a degree of perceived confidence in this area prior to the lectures.

It is of interest to note that there are a small number of students who show a decrease in confidence in all areas. As self-confidence and perceived knowledge are being assessed here, this may lead to students being *"over-confident"* in their assessment of their knowledge of the theory behind these techniques pre-EBL. After completing the course and covering the techniques in more depth, students may have gained a more realistic judgement of their confidence in and understanding of the techniques. As discussed in Section 2.7.3, students are more comfortable with approaches to teaching that are familiar to them, and this may explain some of the decrease in confidence, *i.e.* this may be due to different learning styles that are present in student cohort (Boekaerts, 1996).

It is not possible to draw any detailed conclusions from the investigation into the relationship between students' responses to the "interpretation of spectra" and "knowledge of theory behind the techniques" statements. There is variation in student response to these two areas in each technique, but the majority of students responded the same (Table 4.3). Students were assumed to have some degree of knowledge of the theory behind the spectroscopic techniques in order to interpret the spectra that these techniques produce. This may explain the lack of major variation in students' responses in the areas of interpretation and knowledge of theory for each of the techniques.

4.2 Questionnaire and Interview Data on the EBL process

"What are the students' attitudes towards the processes of EBL and how do these attitudes change through the course?"

Section 4.2 presents data that addresses the research sub-question seen above. The data from the students' responses to the paper-based questionnaire (Appendix 11 and 12) conducted mid-EBL (pre-lectures) and post-lectures are presented in Figures 4.18 to 4.96. For each question, students' responses are tracked from mid-EBL to post-lectures, and these are presented in graphs representing students' changes in attitude. Along with data from the Likert-style questions from the questionnaires (Appendix 11 and 12), data from the short answer questions (also on the questionnaire), focus group with students, and an interview with a postgraduate demonstrator are presented. For some questionnaire items, the sample size is reduced, due to students not responding to the statement in both questionnaires (mid-EBL and post-lectures).

Some students did not respond to any of the short answer questions in both the mid-EBL and post-lectures questionnaires. In the mid-EBL questionnaire, five students (16%) did not respond to any of the questions, and in the post-lectures questionnaire this number of non-respondents increased to twelve students (38%). As a result, there are fewer comments on the post-lectures questionnaire than the mid-EBL questionnaire, making it harder to draw conclusions from the student responses. When discussing percentages of *"respondents"*, this refers to students who wrote at least one comment on the short answer questions. For example, the sample size (N) for respondents in the mid-EBL short answer questionnaire is 27 and for the post-lectures questionnaire is 20. The short answer responses from the mid-EBL and post-lectures questionnaires can be seen in Appendix 31 and 32 respectively. Transcripts from both focus groups and the one to one interview can be seen in Appendices 15 to 17.

Mid-EBL	Post-Lectures

4.2.1 Group work

To test the consistency of response in the questionnaires, the linked questions shown in Figures 4.18 to 4.23 can be examined.

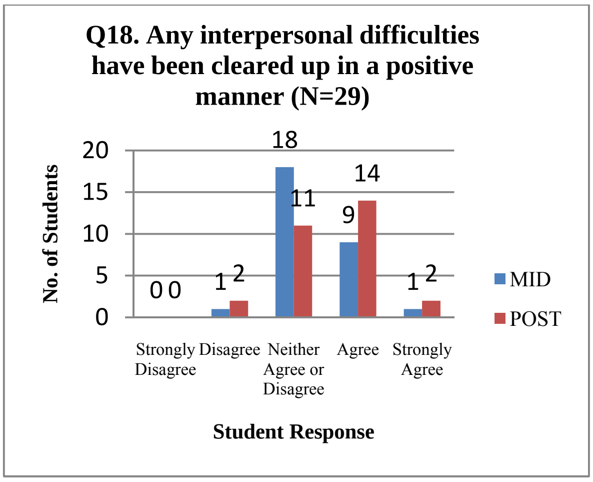


Figure 4.18: Feedback on interpersonal difficulties.

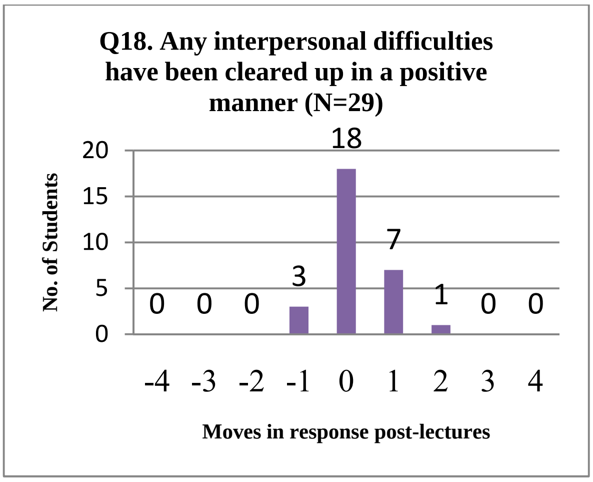


Figure 4.19: Moves in students' responses from Figure 4.18.

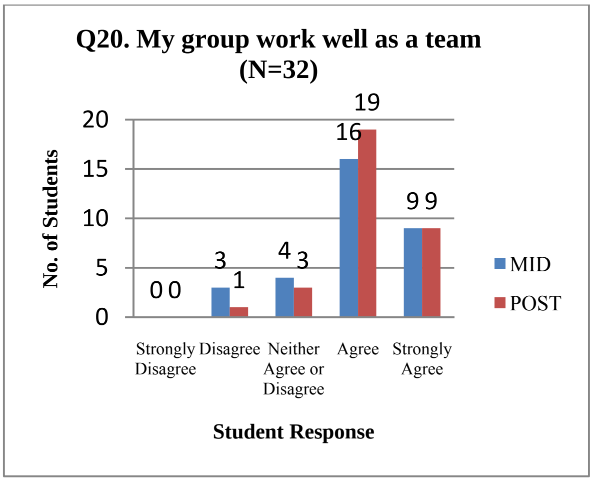


Figure 4.20: Feedback on how well groups worked as a team.

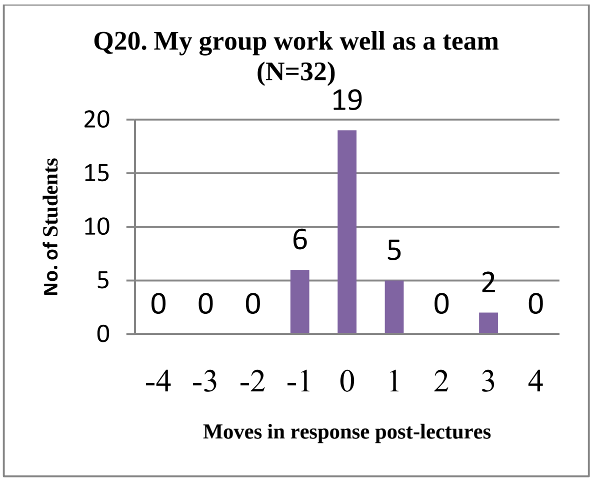


Figure 4.21: Moves in students' responses from Figure 4.20.

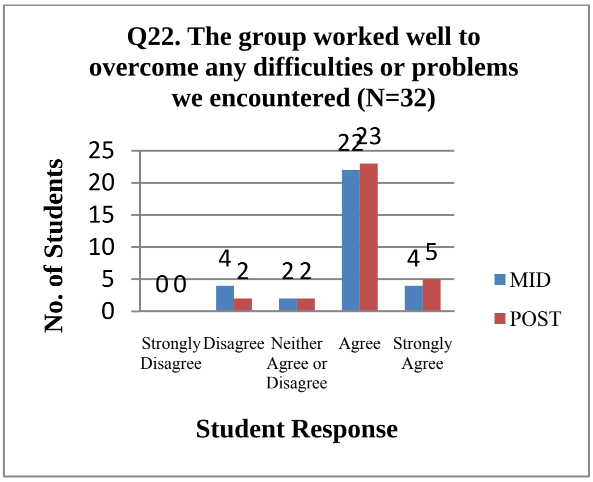


Figure 4.22: Feedback on problems encountered.

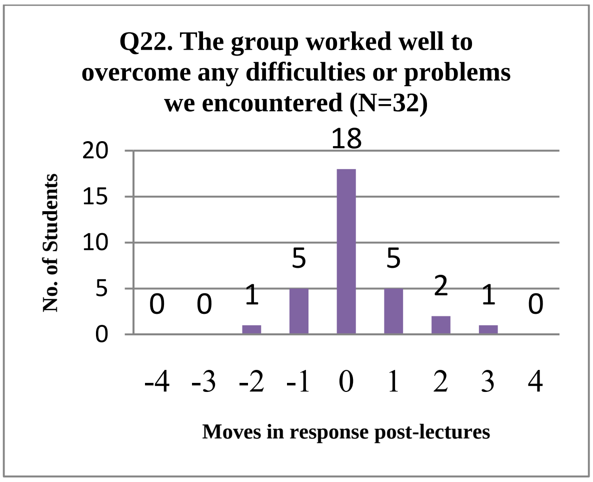


Figure 4.23: Moves in students' responses from Figure 4.22.

The students' responses to the three questions are generally consistent, with Figure 4.18 showing less of a positive response than Figures 4.20 and 4.22. In general, however, students' responses to the statements were positive (Figures 4.18, 4.20 and 4.22). The most positive response was given to the question of whether the students' "group worked well as a team" (Figure 4.20), whereas on the issue of "interpersonal difficulties" the responses were noticeably more negative (Figure 4.18). 88% of students responded "Agree" or "Strongly Agree" post-lectures to the statements indicated in Figures 4.20 and 4.22 (albeit with a difference in distribution). However, in Figure 4.18 this number is reduced to 55%. There are no major shifts in students' responses from mid-EBL to post-lectures, although in Figures 4.21 and 4.23 there are one or two students who have moved from the "Disagree" category to the "Strongly Agree" category (three positive moves).

The issue of group work also arose as a major theme from the short answer questions. Over half of the responding students commented upon group work, in some form, in one of the four short answer questions, both in the mid-EBL (74% of responding students) and post-lectures (60% of responding students) questionnaires. In the mid-EBL questionnaire 59% (16) of students commented upon group work in a positive light. Students responded that they appreciated the opportunity to improve their team working skills and receive help from their peers on the problems.

> *"It's a very good opportunity to meet people who otherwise I probably would not have spoke to. Working in a group means that we can look at the task and explain what we think to others – with feedback."*

Post-lectures, 50% (10) of students who responded commented upon group work as being a positive aspect of the EBL, and again students seemed to appreciate the opportunity to work in a group, even if they would not have chosen to initially. In both questionnaires there are fewer negative comments involving group work (26% (7) of respondents mid-EBL, and 20% (4) of respondents post-lectures).

The focus group with the first year students indicated that students liked working in groups, noting that it was a good way of getting to know people. However, students experienced considerable frustration with unequal participation in the groups.

> *"I don't know, 'cause some people in my group who didn't pull their weight and they were supposed to so it led to a couple of us doing the work and others who weren't and considering that was some of our mark is based on that I didn't think it was fair…"*

> *"… intergroup relationships and stuff like that, but [laughs] I particularly liked it 'cause I wasn't here for Welcome Week and that was probably like the first time I got to know a few people in Chemistry as opposed to like random people in labs, you got to sit down and speak to them, which was good, which formed a foundation for getting to know other people, doing the communication thing with the answers"*

These comments are consistent with the findings from the questionnaires. Three students commented on the questionnaire upon being able to new meet new people through EBL, but, arguably, these could be the same students who participated in the focus group. Unfortunately, there is no way to check this information. The opportunity for students to “meet new people” was enhanced by not allowing student to select their own groups

Despite the generally positive response to whether the students’ groups worked well as a team, there were a few negative responses concerning group work in the short answer questions, both, mid-EBL and post-lectures. In the mid-EBL questionnaire, 33% of respondents (9 students) commented on some aspect of their group work in a negative manner. Interestingly, five of these nine students also commented upon some aspect of their group in a positive manner.

In the mid-EBL short answer questions, four students’ responses (15%) commented negatively on the running of their group, with those students commenting upon the unequal sharing of the work load, personal frictions, and one student commenting that she was “left behind”.

> *“Some people can end up doing all the work, and others very little.”*

In the post-lectures questionnaire, five students (25%) also commented negatively in the area of work distribution. However, only two of these five students commented negatively in the mid-EBL questionnaire. The main two issues for these students was a lack of co-operation within the groups and splitting the work equally (as in the mid-EBL responses).

> *“EBL didn’t work as well as I would have liked as there wasn’t as much co-operation within the group, which meant that there was little helping one another.”*

A number of students experienced unequal participation in their groups, as suggested by the focus group and short answer responses – this is consistent with the suggestion that EBL may lead to unequal participation in group work (Hospitality, Leisure, Sport and Tourism Network, 2009). The perceived unequal participation in the groups by some members may be due to the group size. It was suggested that a group size of no more than five is desirable for floating facilitation, and that this would encourage student accountability (Raine and Symons, 2005). However, due to large number of students within the cohort, group sizes of six with floating facilitation were used.

Another issue that was highlighted by the mid-EBL questionnaire was that 19% of respondents commented on the assessment in a negative light. The students seemed to have concerns over the group marking aspects of the EBL sessions (both the group reports and the peer assessment). One student suggested that this could be rectified by including some form of individual assessment, though this was actually already included at a later stage.

> *"May end up with students who bring your own mark down due to group work."*
>
> *"Try and include an individual assessment (not the peer assessment) that judges everyone's work in the group."*

Assessment appears to have been an issue for students in the mid-EBL questionnaire which may have been down to the use of group reports, with all students receiving the same mark for this component of assessment. It was perceived that facilitation (Section 2.5) would reduce this problem, but group sizes were larger than was recommended by Raine and Symons (2005). Peer assessment was also used in an attempt to promote collaboration (as discussed by Kahn and O'Rourke (2004)), but the only comment regarding its use was that a student was concerned that other students would mark them down in the peer assessment.

In the post-lectures questionnaire, there were no negative responses concerning assessment. Two students commented upon ways of improving the assessment of the course, but these were unrelated comments. Neither of these students had commented on the assessment of the EBL in the mid-EBL questionnaire.

> *"Perhaps give a list of things we need to know and give small tests on different topics to check we have learnt them."*

> *"With the assessed worksheets to perhaps have a mixture of compounds to be found and compounds already found and determining which spectra belongs to it."*

This lack of negative responses in the post-lectures questionnaire may well be accounted for by the fact that the final scenario was individually assessed, but students had not completed this scenario at the time they completed the mid-EBL questionnaire. Consequently, this final assessment may have gone some way to appease some of their concerns.

Despite the lack of comments relating to assessment in the post-lectures questionnaire, the issue did arise in the focus group carried out post-lectures. Although students said the assessment of the scenarios was good practice for them, students thought that they took up too much of their time considering the marks allocated to the assessments.

> *"one thing I didn't like though like the assessment we had was like 6 different assignments and they were like 40%, 20%, we had 2 EBLs assessments at 40% altogether, but that was 40% of 25%, which we do quite a lot of work for it and don't think we get enough marks for the amount we do"*

The results from the remaining questionnaire questions, concerning group work, along with moves in student responses, are presented in Figure 4.24 to Figure 4.33.

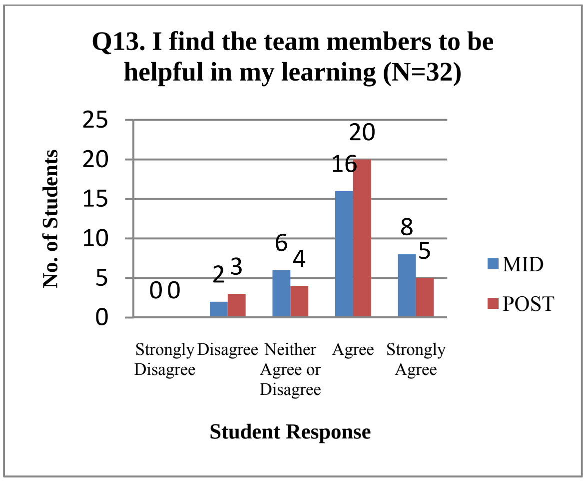


Figure 4.24: Feedback on other team members.

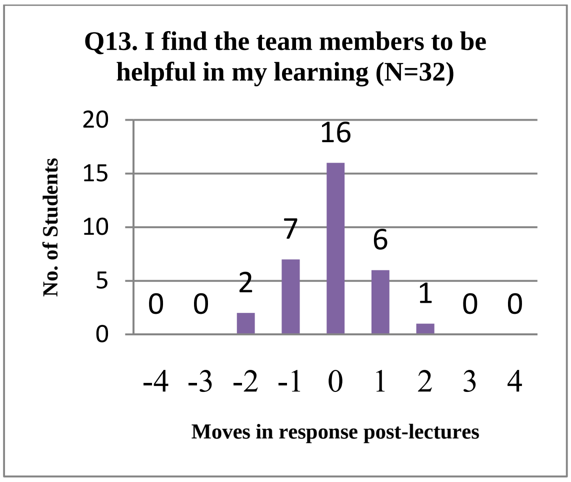


Figure 4.25: Moves in students' responses from Figure 4.24.

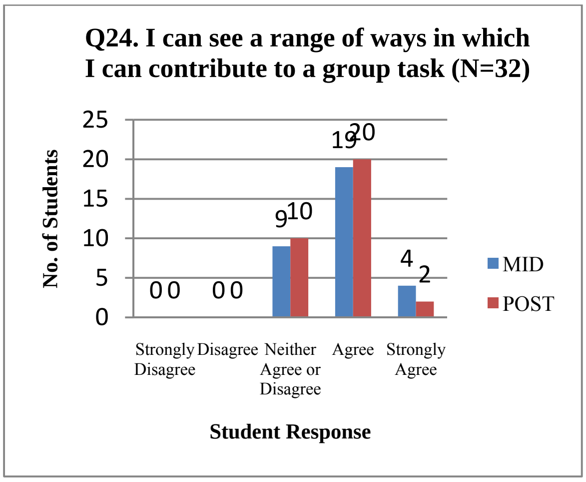


Figure 4.26: Feedback on contributions to a group task.

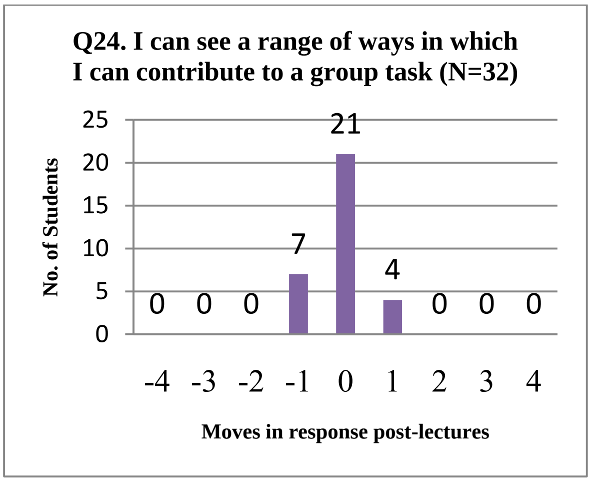


Figure 4.27: Moves in students' responses from Figure 4.26.

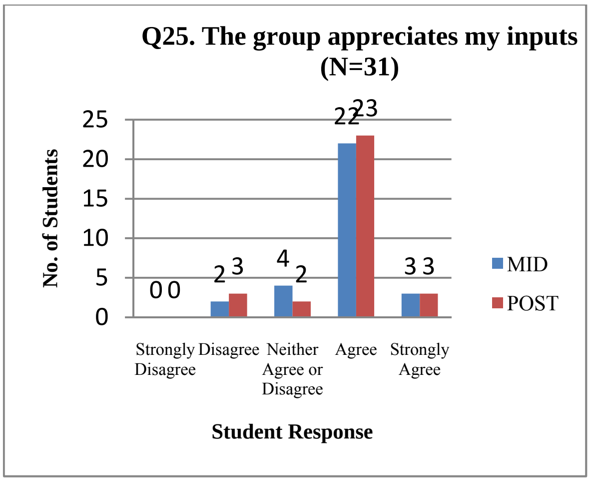


Figure 4.28: Feedback on group appreciation of inputs.

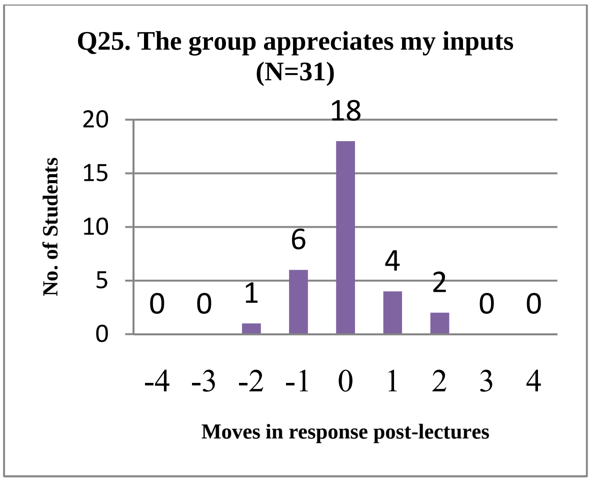


Figure 4.29: Moves in students' responses from Figure 4.28.

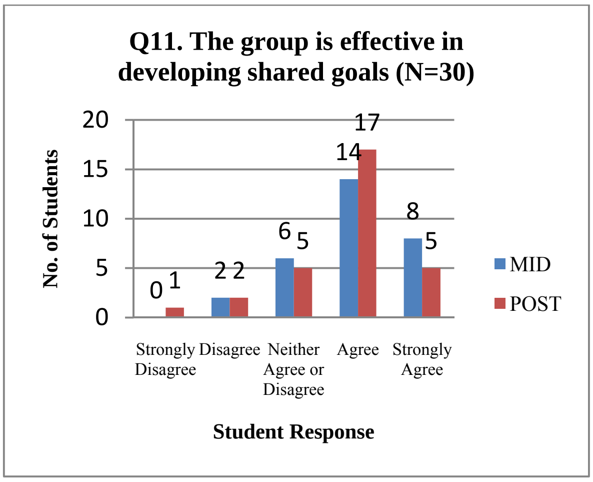


Figure 4.30: Feedback on developing shared goals.

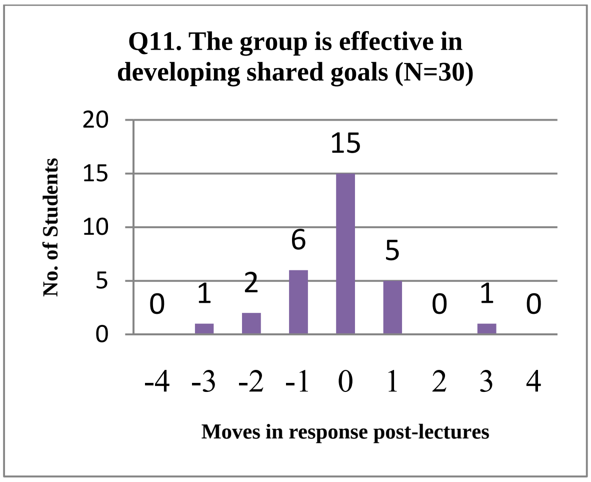


Figure 4.31: Moves in students' responses from Figure 4.30.

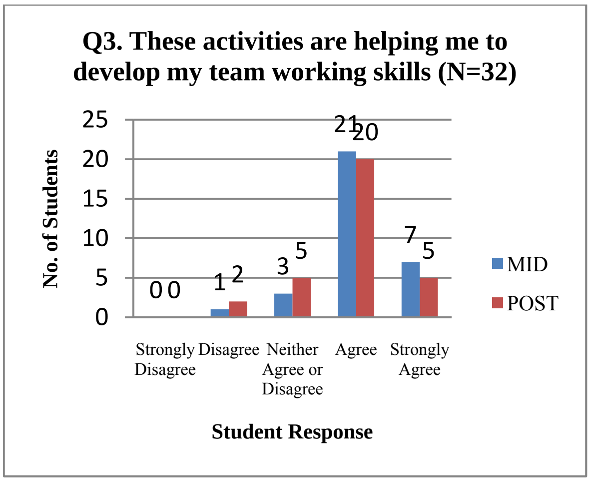


Figure 4.32: Feedback on team working skills.

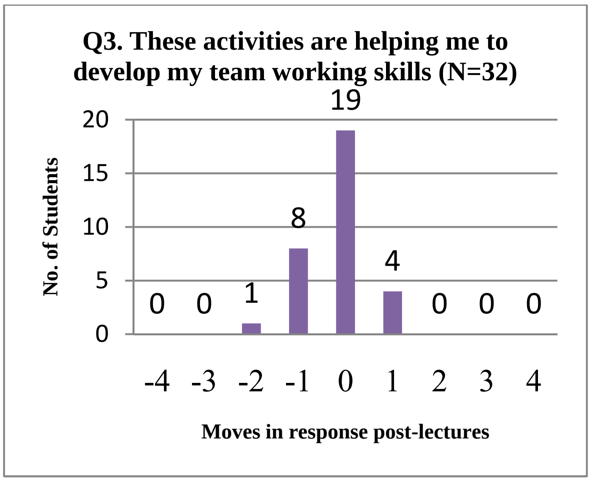


Figure 4.33: Moves in students' responses from Figure 4.32.

The feedback regarding the students' experience of working in groups is mainly positive. There are very few negative responses to the statements, either in the mid-EBL or post-lecture data, with no negative responses at all to the statement "I can see a range of ways in which I can contribute to a group task" (Figure 4.26). Students, on the whole, appeared to have appreciated the collaborative learning aspect of the sessions (Figure 4.24). There is also a large positive response to the statement "These activities are helping me to develop my team working skills" (Figure 4.32), with 78% of students responding "Agree" or "Strongly Agree" to this statement, post-lectures. This also correlates with the findings from the short answer questions, both, pre- and post-lectures. This is consistent with the findings of Dunlap (2005), and Barrows and Kelson (1993), that EBL can develop team working skills, although it should be noted that it is only students' perceptions which are being considered.

Although there is some variation in student responses to both questionnaires, there are no major moves in responses. In general, there is a very slight negative shift in students' responses to all questions in the post-lecture questionnaire.

The focus group and questionnaire indicate that, on the whole, students' attitudes towards their EBL group was positive, with students appreciating the opportunity to collaborate with peers. A few students did experience the problem of unequal participation in their groups, as was indicated by the short answer responses and the focus group. The individual assessment included in the final scenario appears to have appeased students concerns over the group assessment. Coupled with these negative responses, there were negative responses to all but one of the Likert-style statements concerning group work. There, a few negative responses appear to contradict the student response as whole. There will almost always be students who prefer to work on their own, and being forced to work in a group situation may have been an unfamiliar approach to learning, thus leading to such contradictions (OIRA, 2007).

4.2.2 Other Transferable Skills

In addition to group work, data were obtained regarding other transferable skills which students had the potential to develop during the EBL process. The data relating to these questions are presented in Figures 4.34 to 4.45.

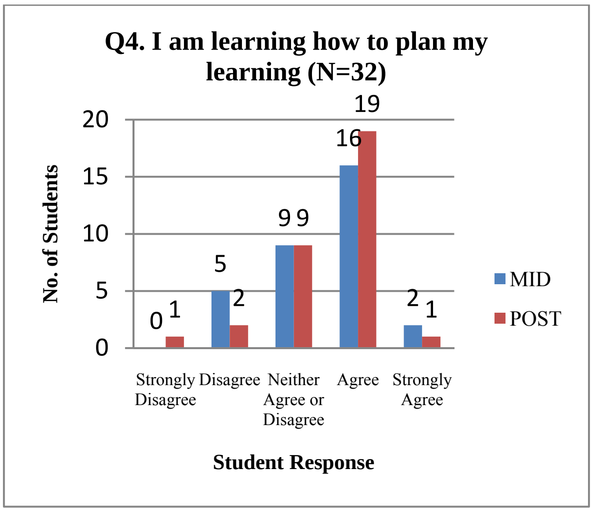


Figure 4.34: Feedback on planning learning.

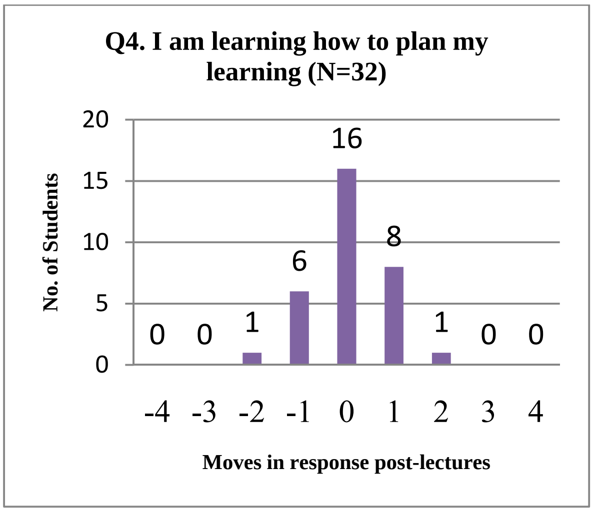


Figure 4.35: Moves in students' responses from Figure 4.34.

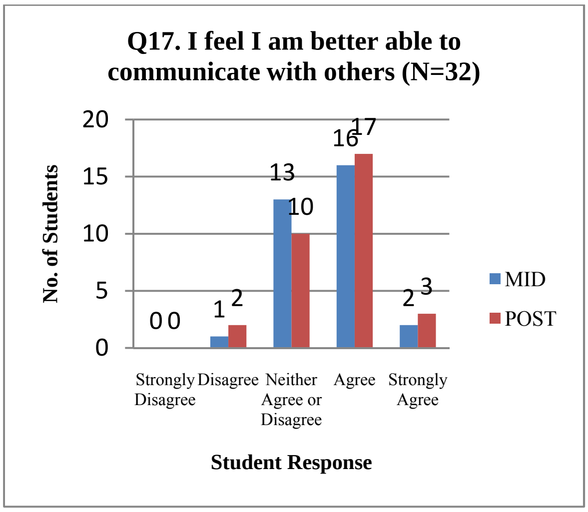


Figure 4.36: Feedback on communication skills.

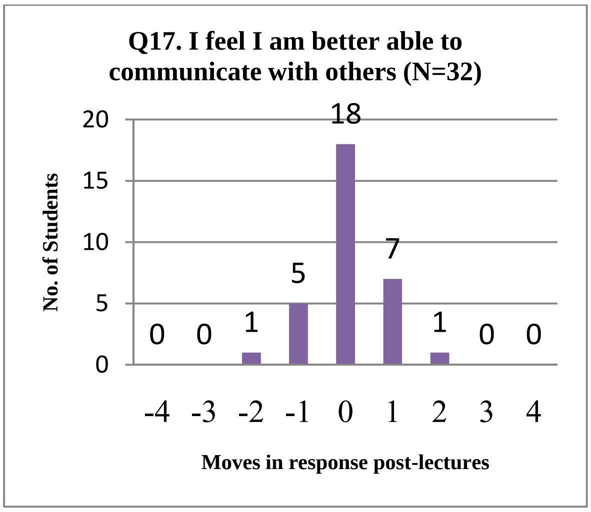


Figure 4.37: Moves in students' responses from Figure 4.36.

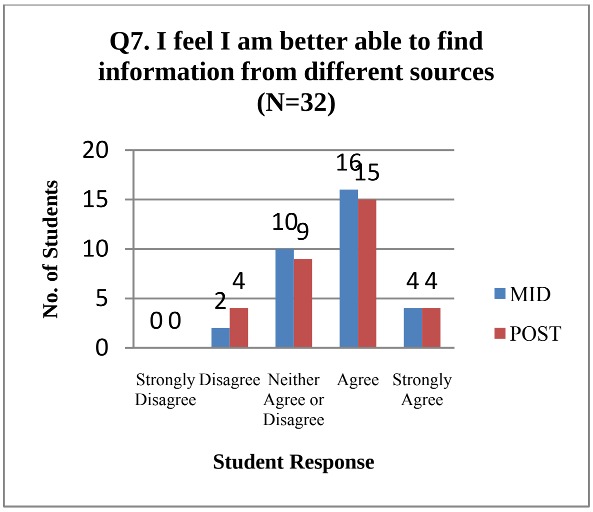


Figure 4.38: Feedback on finding information.

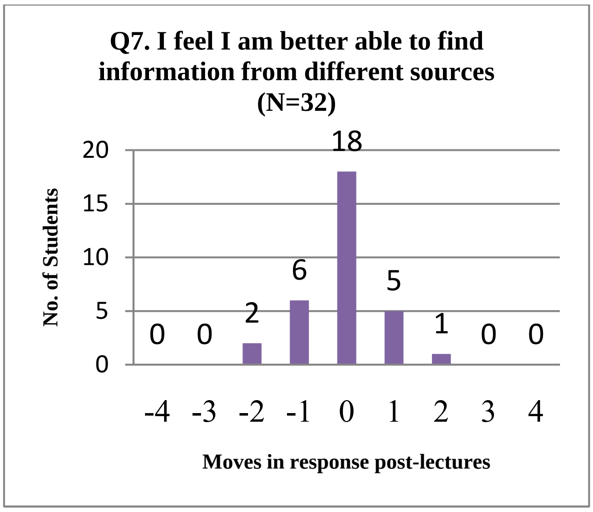


Figure 4.39: Moves in students' responses from Figure 4.38.

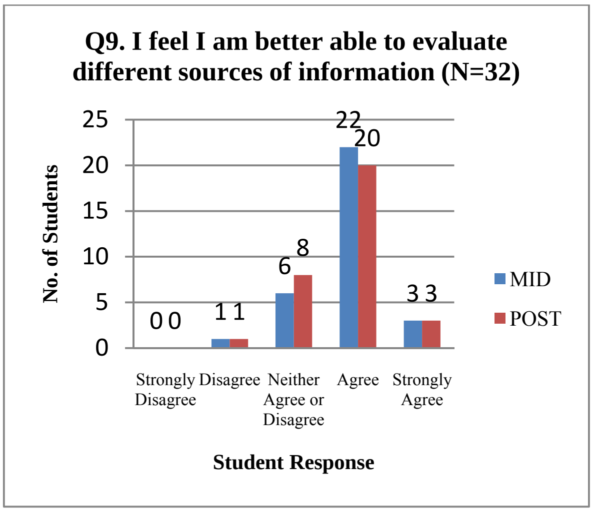


Figure 4.40: Feedback on evaluating sources of information.

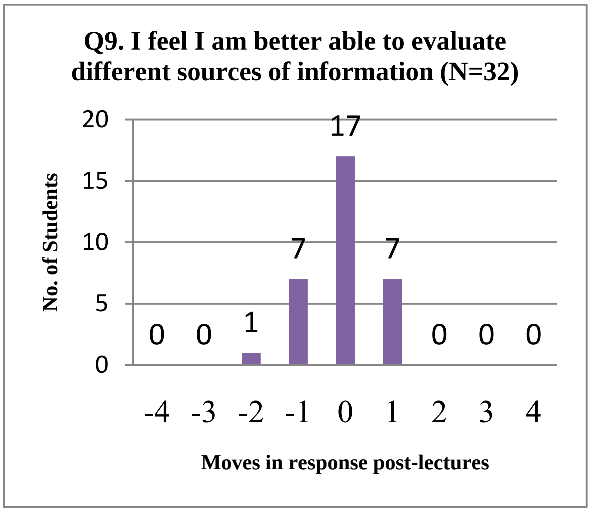


Figure 4.41: Moves in students' responses from Figure 4.40.

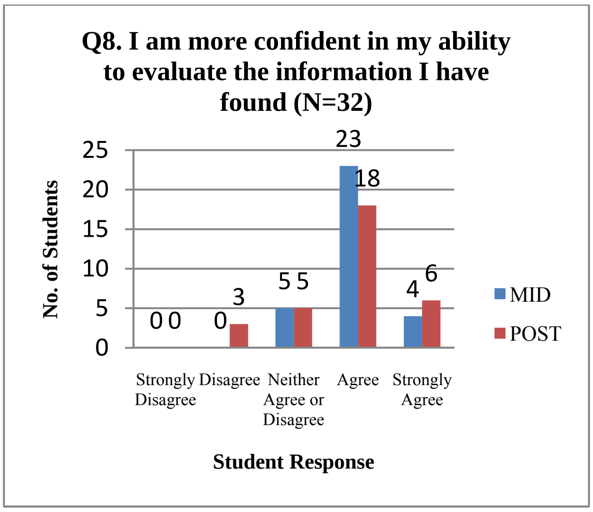


Figure 4.42: Feedback on evaluating information.

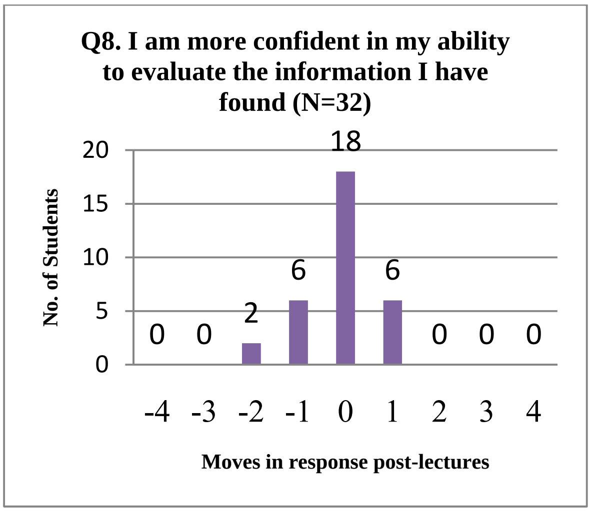


Figure 4.43: Moves in students' responses from Figure 4.42.

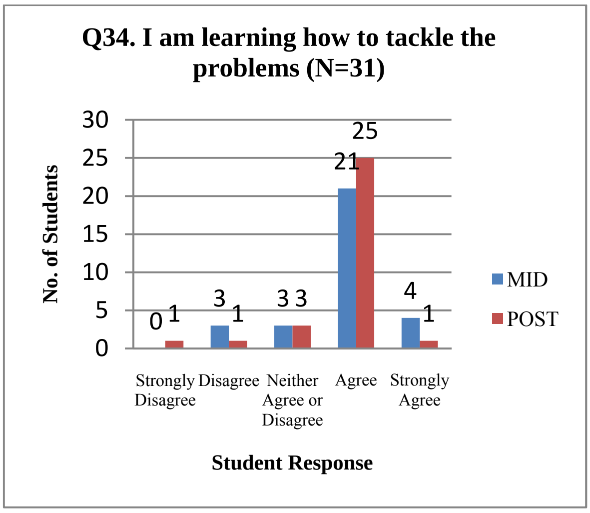


Figure 4.44: Feedback on tackling problems.

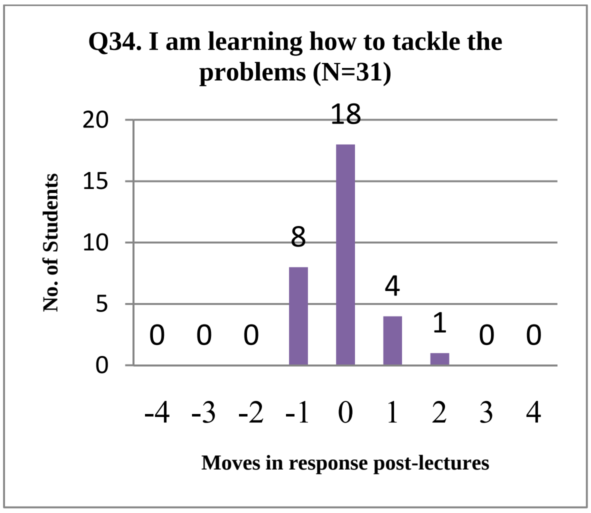


Figure 4.45: Moves in students' responses from Figure 4.44.

Figures 4.34, 4.36, 4.38, 4.42, 4.44 and 4.50, indicate that students, when surveyed after the lectures with regards to the EBL sessions, responded that they believed that they had gained transferable skills. Feedback to all five statements is very positive, both in the mid-EBL and post-lecture data sets. Student responses seem broadly consistent in this area between both questionnaires, with few moves of greater than one (Figures 4.37, 4.39, 4.41, 4.43 and 4.45). In each of these figures, over half the students show no move in response between questionnaires.

In the short answer questions in the mid-EBL questionnaire, 26% (7) of the responding students commented upon gaining other transferable skills in a positive manner, and only one student commented in a negative manner. Three of the seven students mentioned that problem solving was a benefit of EBL, and three also mentioned that developing communication skills was another positive aspect of the course.

> ***What are the positive things about the course?***
>
> ***"****Working as part of team – developing communication skills. Problem solving individually as part of a team."*

In the post-lecture questionnaire, only two students commented on transferable skills, although both were in a positive light.

Interestingly, in the mid-EBL short answer responses, the word "skill(s)" was used by the students in relation to the question "what are the positive things about the course?" by a total of nine (33%) students. It should be noted that the specific mention of the word skill was only used once in the post-lectures responses. These references to skills referred to all transferable skills (including group work).

Again, feedback in this area is mainly positive. Students perceived that they had learnt how tackle the problems (Figure 4.44), and the mid-EBL short answer responses suggest that they also felt that they had developed some degree of problem solving skills. 63% of students (post-lectures) also indicated that they had developed communication skills (Figure 4.36), which was also alluded to by the mid-EBL short answer responses. These results appear to agree with Ward and Lee's (2002) suggestion that problem solving skills and communication skills can be developed by means of an EBL approach. Feedback on students' planning of their learning (Figure 4.34), and literature searching skills (Figures 4.38, 4.40 and 4.20), suggests that students perceived that there were a wide range of transferable skills that they developed through the EBL sessions. These findings are also consistent with those of Kahn and O'Rouke (2004), and the findings of previous studies (Martin, Bill, and West, 2006).

4.2.3 The Activities

Linked questions were included in the area of activities, to test the consistency of response in the paper-based questionnaires. The data for these are presented in Figures 4.46 to 4.49.

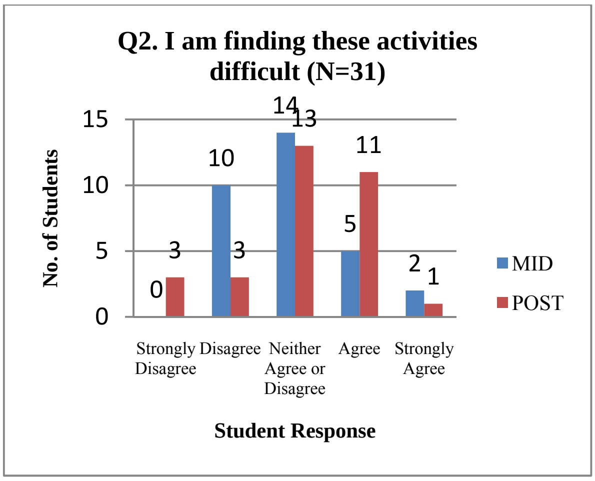


Figure 4.46: Feedback on how difficult students found the activities.

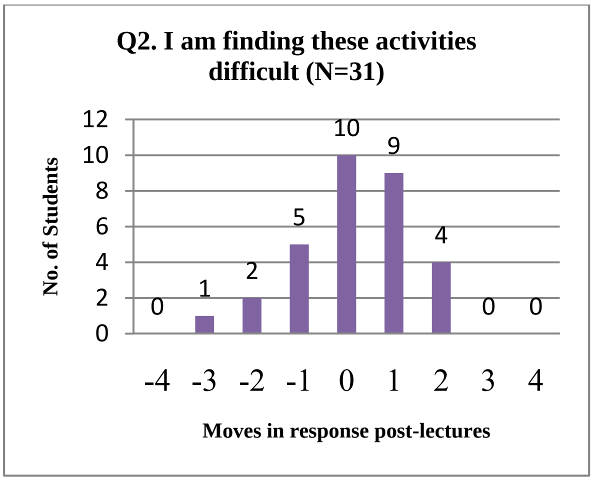


Figure 4.47: Moves in students' responses from Figure 4.46.

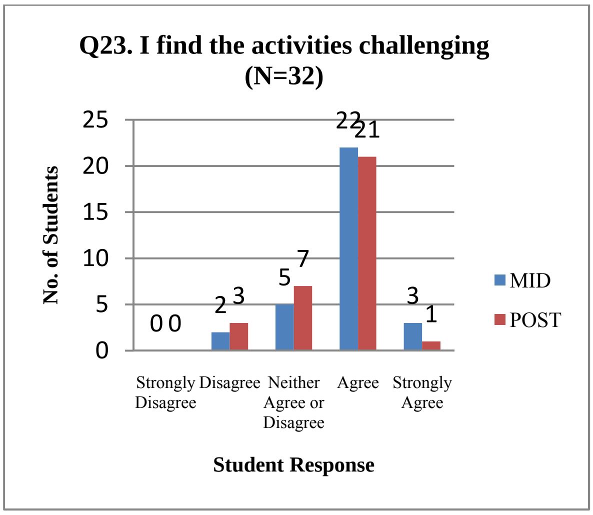


Figure 4.48: Feedback on how challenging students found the activities.

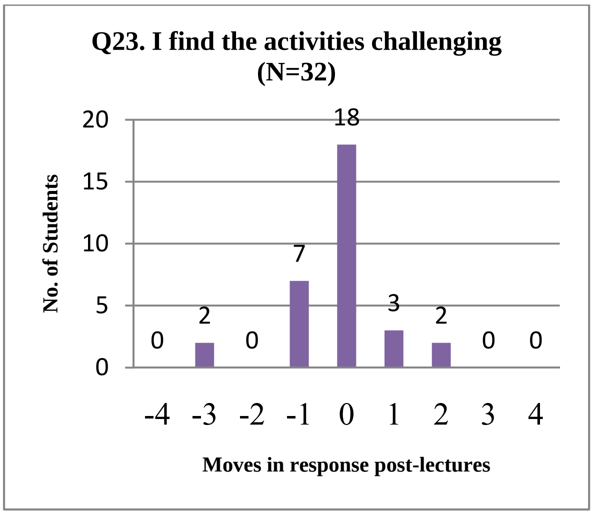


Figure 4.49: Moves in students' responses from Figure 4.48.

Students indicated that they found the activities challenging (Figure 4.48), but the responses as to whether the students found the activities difficult are less conclusive (Figure 4.46). There is a lot of variation in response to the issue of the difficulty of the activities mid-EBL to post-lectures (Figure 4.47). Seven students (23%) changed category (two moves and above) post-lectures, which represents the largest percentage of category changes for all the Likert-type statements in Section 4.2. Although 42% of students showed a positive move post-lectures, there were 26% students whose responses moved negatively post-lectures. Only 39% responded that they found the activities "difficult" to some degree post-lectures, which can be contrasted with 69% of students who suggested they found the activities "challenging" to some extent mid-EBL.

There is an obvious difference between students' responses to these two questions, despite, at first glance, the questions appearing to be asking a similar, if not identical thing. However, the opportunity arose to question the students further on this matter in the form of an additional focus group. The focus group took place approximately a year after the students had completed the post-lectures questionnaire.

After being shown the original questionnaire to help to refresh the students' memories, all of the students who took part in the repeat focus group said that they had completed both the mid-EBL and post-lectures questionnaire originally. Students were asked how they would define "difficult" and "challenging". Students asked for clarification that the question was not referring specifically about a chemical context, but they were told it was not.

Students perceived "difficult" as being a more negative term that "challenging", and "difficult" was defined by the students as being something that they hadn't done before, that requires a lot of time, and that they may need some help with. It was suggested by the students that the complexity of something could make it more difficult.

"Challenging" was perceived as something that requires some thought, but something that could be done. An example suggested was applying a formula to a new situation. It was also suggested that something that was challenging could be fun and satisfying.

> *"Difficult sounds sort of more negative than challenging so challenging would be something that you enjoy working out, rather than difficult would be something that you just find hard"*
>
> *"I say challenging you're sort of testing yourself, seeing what you can do and you have to see how far you can stretch yourself. Whereas difficult is something you struggle with more and so they are similar "*

It was suggested, however, that the terms could go hand in hand, and that when something was too challenging, it also became difficult. Students said something has to be difficult to be challenging, for example, if something was not difficult then it was not challenging. Difficult was seen as something that you struggle with:

> *"Something has to be difficult to be challenging to some extent. So if something is too easy it's not difficult and therefore it's not challenging because it doesn't require any thought process behind it or you're not getting any form of satisfaction out of achieving something"*

> *"I mean challenging in a labs context. Challenging is standing in a lab for whole day, trying to synthesise some little white powder at the end of it. But then difficult might be if you're having to do it for six days without any breaks. To endure it"*

Despite the students' recognizing the similarity between the terms, it is apparent that they do regard the terms "difficult" and "challenging" as possessing two different, albeit closely related meanings. This may account for the discrepancy between the two questions from the questionnaires regarding the how difficult and how challenging the tasks were. The pilot study (Section 3.3) did not highlight any major differences between students' responses to this question, but this may be as a result of the very small sample size. These terms are somewhat ambiguous with respect to one other. Peterson (2000) suggested that words with alternative meanings should be excluded from the design of any questionnaire. In hindsight, it would have perhaps been suitable to remove one of these questions from the questionnaire to prevent confusion in the analysis of the responses.

Further data from the paper-based questionnaire in relation to the tasks the students undertook are presented in Figures 4.50 to 4.57.

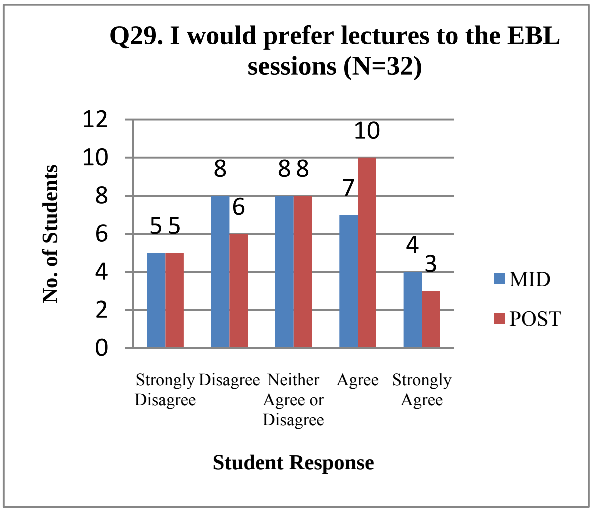


Figure 4.50: Feedback on the preference for lectures.

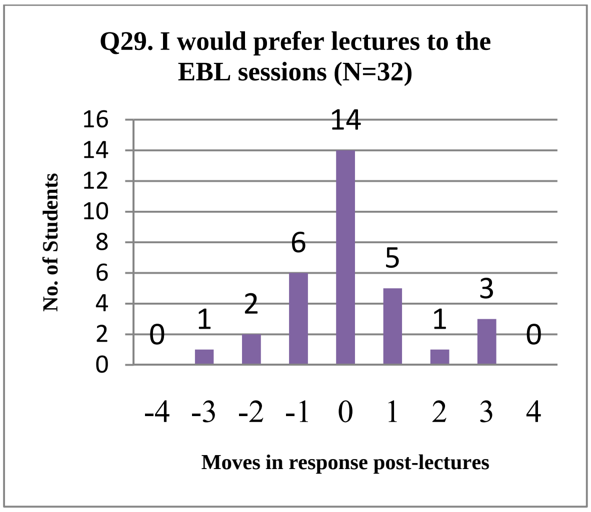


Figure 4.51: Moves in students' responses from Figure 4.50.

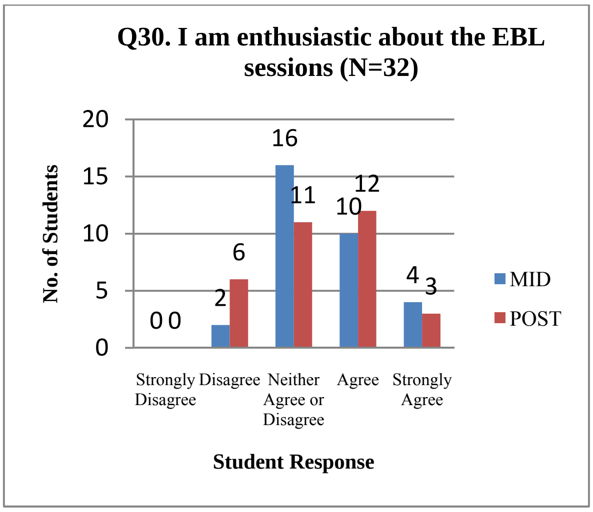


Figure 4.52: Feedback on student enthusiasm.

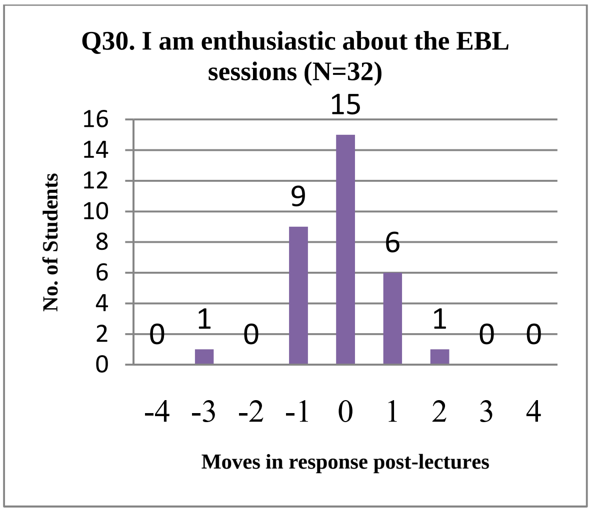


Figure 4.53: Moves in students' responses from Figure 4.52.

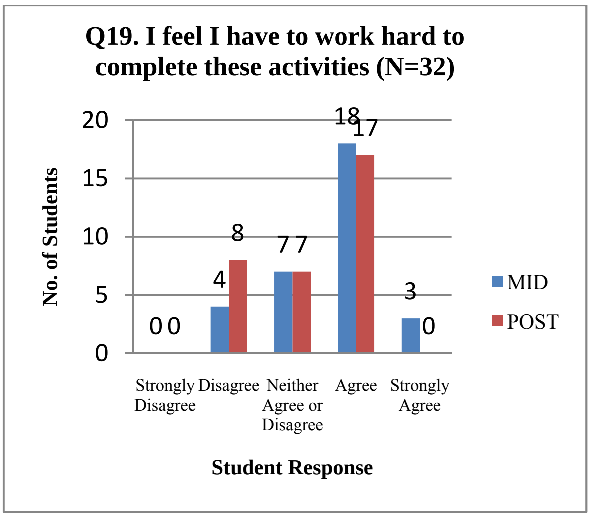


Figure 4.54: Feedback on how hard students felt they

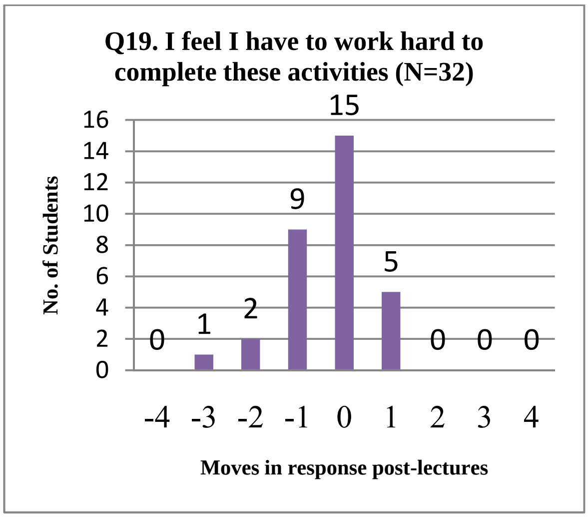


Figure 4.55: Moves in students' responses from Figure 4.54.

worked.

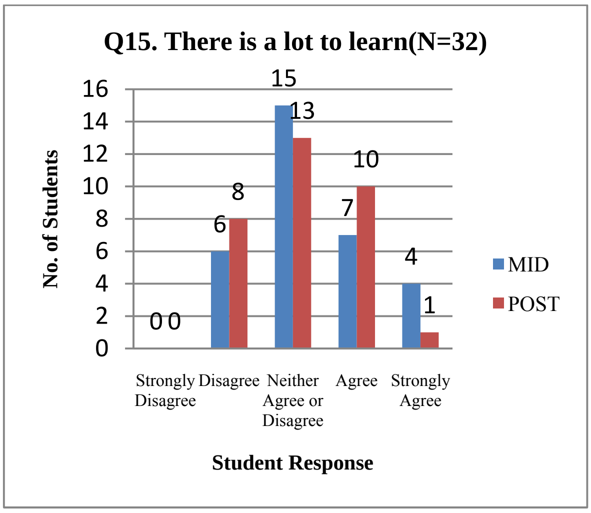


Figure 4.56: Feedback on how much students felt there was to learn.

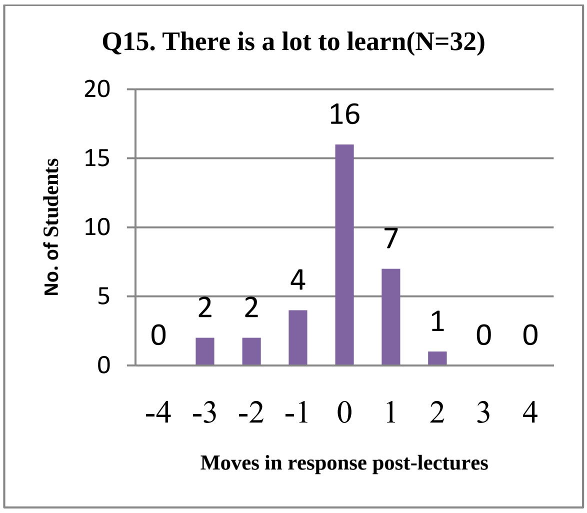


Figure 4.57: Moves in students' responses from Figure 4.57.

There is mixed feedback as to whether students would prefer lectures to EBL sessions (Figure 4.50), and, although the graphs look very similar, only 44% of students responded identically mid-EBL and post-lectures (Figure 4.51). Despite this fluctuation, there is no overall shift in student responses. The issue regarding the placement of the lectures (which were timetabled after the EBL sessions) appears to have been a concern with students in the post-lecture questionnaire, with 30% of respondents (6) commenting that the lectures should have occurred prior to the EBL sessions.

What are the negative things about the course?

"I would have found the theory first more useful."

Of the thirteen responses to the question "What suggestions would you make to improve the course?" four of these responses suggested having the lectures before the EBL sessions. In the mid-EBL questionnaire there were only three respondents (9%) who commented that they would prefer lectures before the EBL sessions. Interestingly, only one of these students commented on the placement of the lecture in the post-lecture questionnaire.

What suggestions would you make to improve the course?

> *"Perhaps have a couple of lectures about analysing the techniques in between the workshops, so that everyone develops a basic understanding of each technique before tackling the problems."*

The issue surrounding the placement of the lectures was also highlighted by the focus group. Students felt that the combination of EBL and lectures was important. As one student noted, "*with EBL we are learning to read spectra, but with the lectures we learnt about the background knowledge and how they work*". Students suggested having some lectures before the EBL sessions, to give them some background information which they could use in these sessions. The findings of the focus group, regarding the placement of lectures, appear to correlate with some of the comments from the short answer questions.

> *"…at the beginning, we should have the lectures before we did the thing, but when we had the lectures I didn't think we learnt – it was just background basically – you learnt about vibrations in IR which you didn't need to know …."*

Students commented that they enjoyed the EBL sessions more than the Spectroscopy lectures, however, because they could interact with each other rather than just being 'spoon fed'. They felt that learning how to work answers out for themselves was useful, and was helpful to them if similar questions/problems arose later on during their course.

> *"definitely more interesting than lectures – you're in a group, you're interacting, you've got the postgrads there"*

It was perceived that students would cover the vast majority of material presented to them in the lectures during their EBL activities. It is clear, however, that students appreciated the inclusion of lectures after the EBL sessions, even though the original intention was for the lectures to be removed completely. Students did, however, indicate that they would have preferred to receive the lectures before the EBL sessions. It is unclear to what extent the course would retain its "enquiry-based" approach if this were to happen, with students being provided with large amounts of information in a traditional lecture-based approach before undertaking the EBL sessions. Despite this, the focus group indicated students enjoyed the EBL sessions more than lectures, due to not being spoon fed, and being given responsibility to work out problems for themselves.

The majority of students post-lectures agreed that they had to work hard to complete the tasks (53%), and there is a minor overall negative shift in responses post-lectures (Figure 4.61).

There were few negative responses as to whether students were enthusiastic about the EBL sessions either mid-EBL or post-lectures (Figure 4.52). Generally the feedback is positive in this area. Again there is a minor overall negative shift in responses post-lectures in comparison with responses mid-EBL (Figure 4.53).

The focus group indicated that the students felt that the scenarios were too repetitive, and suggested presenting them in a different format each week to make them more interesting. Although one or two students commented upon this in the short answer questions, the Likert-style questions in the questionnaire did not give scope for students to give feedback on this issue. The students suggested maybe focusing on different parts for different weeks, *e.g.* one week was Mass Spectrometry, another week was IR Spectroscopy, instead of using all four techniques in the scenarios every week. As has already been mentioned in Section 3.4.2, the first two scenarios, "Down the Drain" and "Waste Disposal", only differed in the context of the scenario and the molecules that students were asked to identify. All of the scenarios required students to use all four techniques to identify unknown compounds. This may have been perceived as being repetitive by the student, but is closer to real-life.

Students did suggest that the EBL scenarios were 'good practice' in helping them to recognise things without referring to their notes or textbooks.

> *"I think they'd focus on different parts for different weeks – like one week was mass, another was IR and the other week was … instead of doing the same, all four in one week, it's very repetitive."*

Despite a few students criticising the scenarios, just under half of the students said that they were enthusiastic about the EBL sessions, with most of the other students responding "Neither Agree or Disagree" (Figure 4.52). Kennedy and Navey-Davis (2004) suggest that students become more enthusiastic for EBL courses due to them becoming engaged in the EBL process. Post-lectures, there are no major moves in student responses to the issue of how enthusiastic they considered themselves to be towards EBL. If anything, there is a slight decrease in student enthusiasm about the EBL sessions.

4.2.4 Rote Learning

The issue of rote learning through simple memorisation was examined in the paper-based questionnaire, and the data from this are presented in Figures 4.58 to 4.63. These questions are also linked questions to examine the validity of the questionnaire.

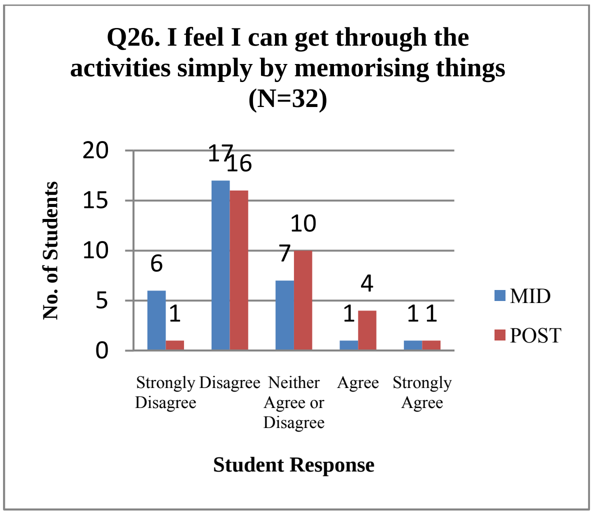


Figure 4.58: Feedback on the use of memorisation.

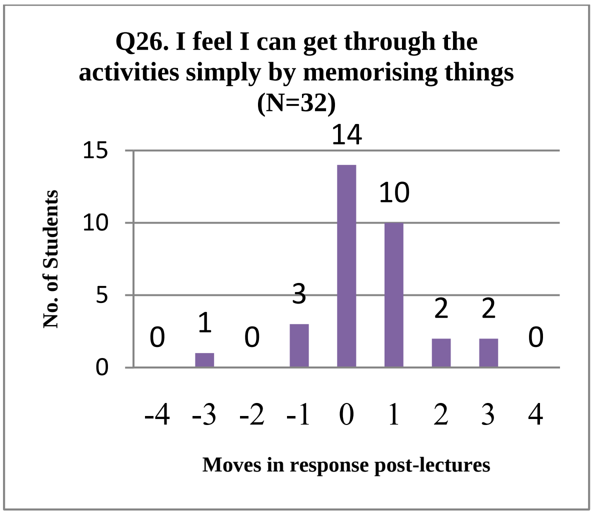


Figure 4.59: Moves in students' responses from Figure 4.58.

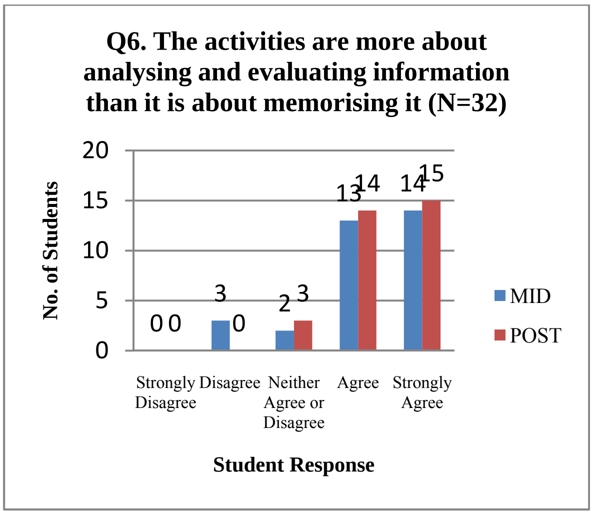


Figure 4.60: Feedback on the activities encouraging analysing and evaluation of information.

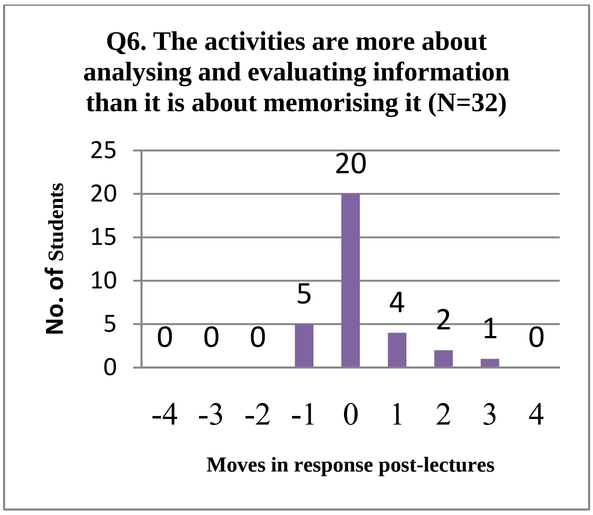


Figure 4.61: moves in students' responses from Figure 4.68.

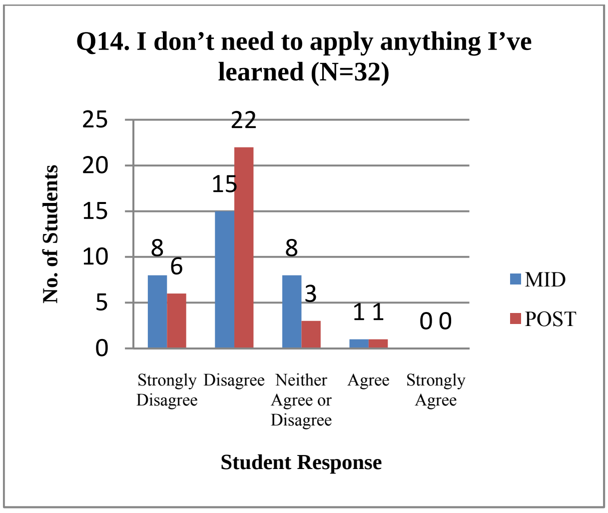


Figure 4.62: Feedback on the application of knowledge.

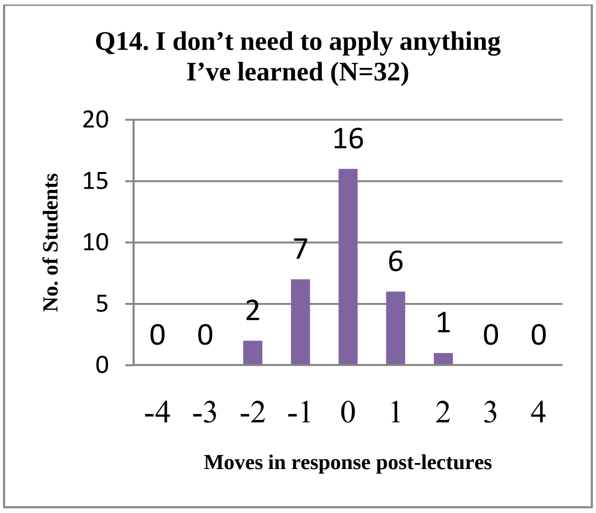


Figure 4.63: Moves in students' responses from Figure 4.70.

The feedback in this area is very positive. It is possible that the activities encouraged "meaningful learning", as defined by Mayer (2002). Students felt that they had to apply their new knowledge (Figure 4.62), not simply remember it. Post-lectures, 91% of students (29) responded, either "Strongly Agree" or "Agree" to the statement, "*The activities are more about analysing and evaluating information than it is about memorising it*" (Figure 4.60). Post-lectures there are also no students who respond at the negative end of the scale (Figure 4.60), which is encouraging from a teaching perspective. There is no major shift in student response in the post-lectures questionnaire to this statement, with 63% of students showing no change on the rating scale post-lectures (Figure 4.61). Feedback on the issue as to whether the students could "get through the activities simply by memorizing things" (Figure 4.58) is not as conclusive, but, the responses seem largely to agree with Figure 4.60, albeit different ends of the rating scales are being examined for these questions. There are positive moves in students' responses post-lectures in the data presented in Figure 4.59. Figure 4.61 shows that 44% of students (14) shifted towards the positive end of the scale post-lectures, suggesting that students thought that they could get through the activities by memorising things to a greater extent post-lectures. It is unclear if the lectures influenced students' response to this issue.

The issue of rote learning did not appear in the short answer questions, on either the mid-EBL or post-lectures questionnaire.

4.2.5 The Learning Process

As questions 15 and 37 were identical, results from both can be compared to test the consistency of response in both questionnaires (mid-EBL and post-lectures). Linked question data with regards to students' enjoyment of the EBL sessions are presented in Figures 4.64 to 4.69.

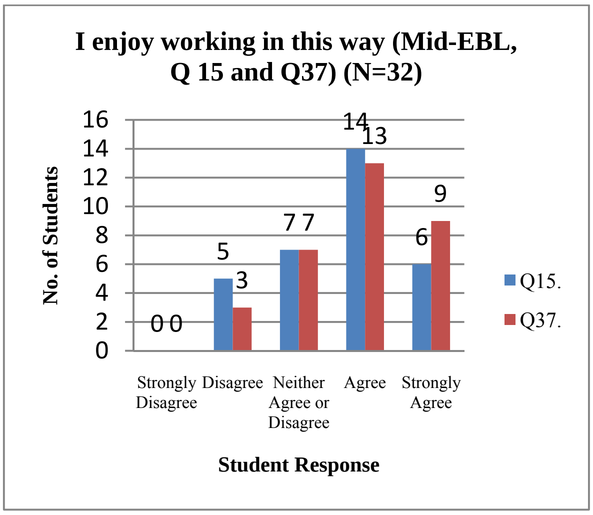


Figure 4.64: Feedback on student enjoyment (mid-EBL).

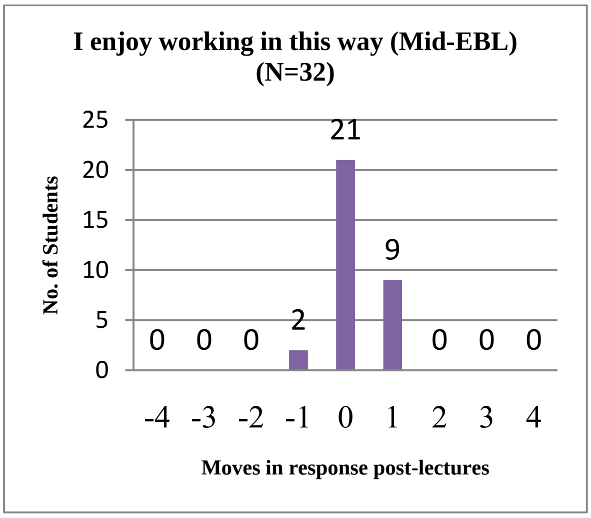


Figure 4.65: Shifts in students' responses from Figure 4.64.

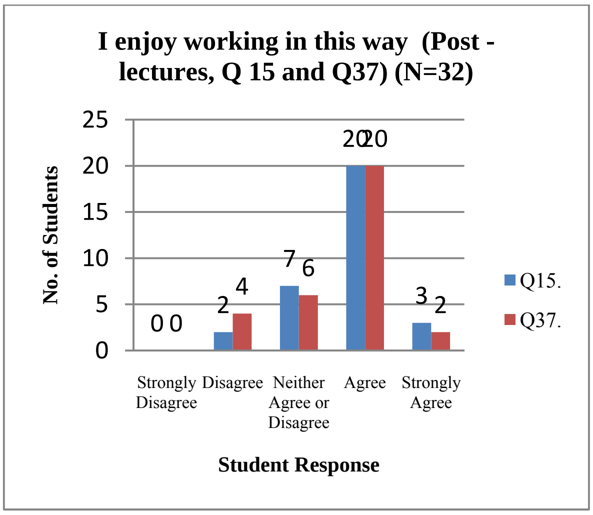


Figure 4.66: Feedback on student enjoyment (post-lectures).

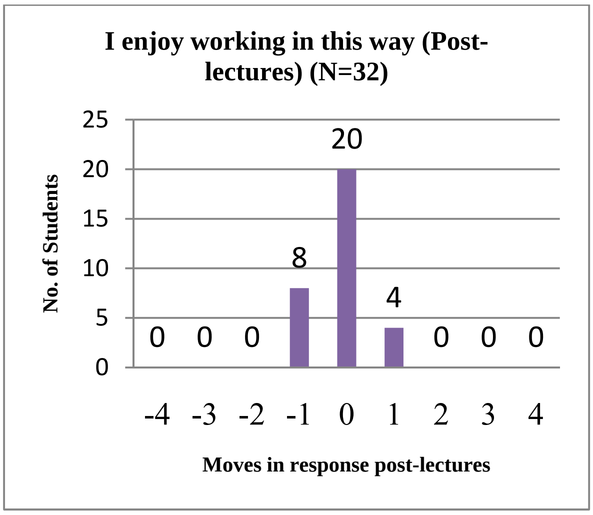


Figure 4.67: Shifts in students' responses from Figure 4.66.

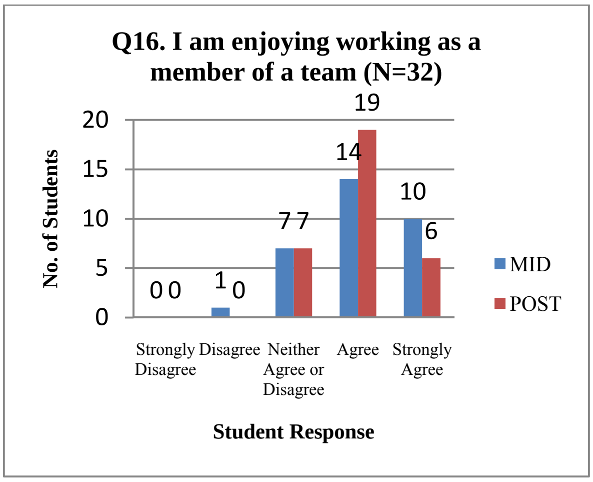


Figure 4.68: Feedback on student enjoyment of team work.

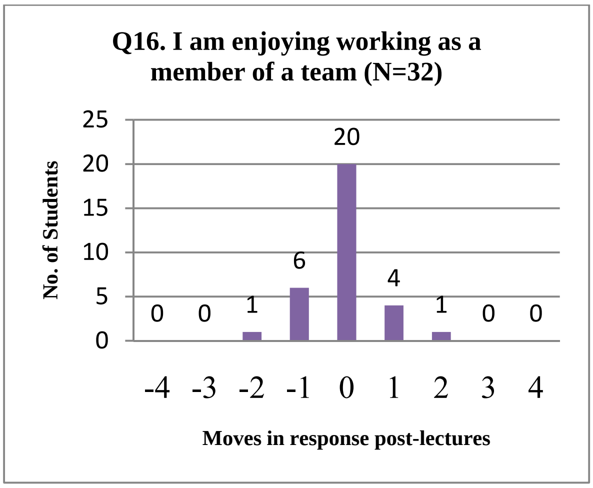


Figure 4.69: Shifts in students' responses from Figure 4.68.

Responses remain generally consistent from question to question, and, overall, the feedback is very positive with respect to student enjoyment of EBL, with *ca.* 63% (20) students showing no moves in response between the two questionnaires (Figures 4.65, 4.67 and 4.69). Despite this, the total number of students responding in the positive category to their enjoyment of EBL (either "Strongly Agree" or "Agree") remains consistent in both questionnaires (*ca.* 22 students). The consistency between responses between these two questions in both mid-EBL and post-EBL questionnaires suggests some degree of validity of the questionnaire.

The comparison of the results for each individual question (*i.e.* question 15 post-lectures compared with question 15 mid-EBL) from both questionnaires is presented in Figures 4.70 to 4.73.

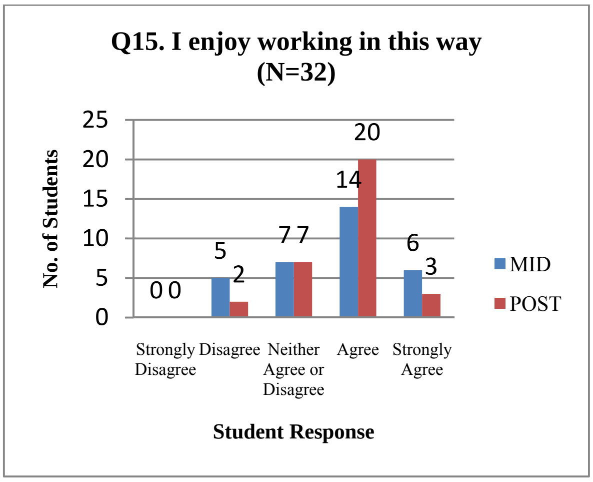


Figure 4.70: Responses to question 15 (mid-EBL and post-lectures).

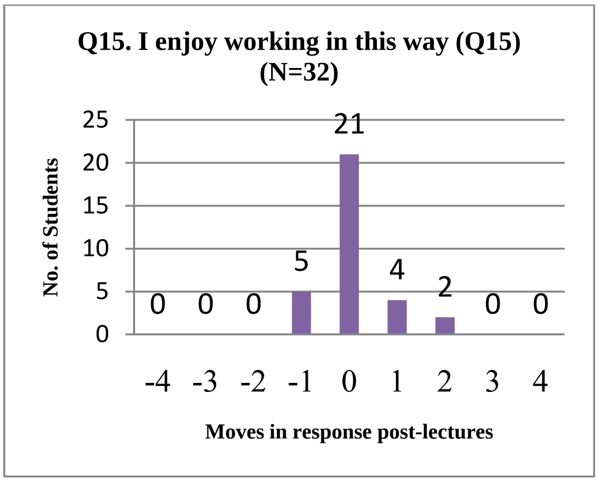


Figure 4.71: Moves in students' responses from Figure 4.70.

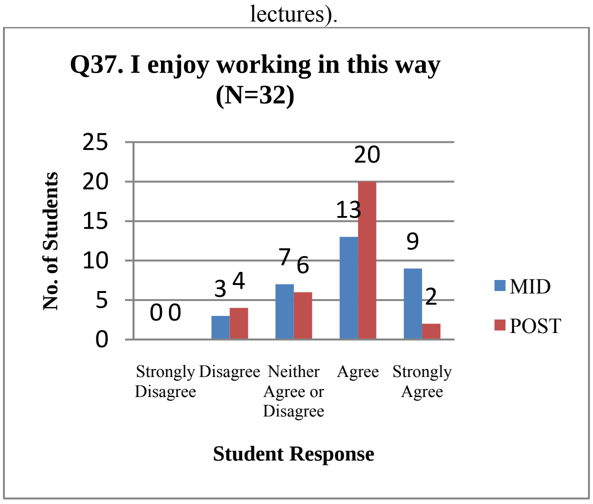


Figure 4.72: Responses to question 37 (mid-EBL and post-lectures).

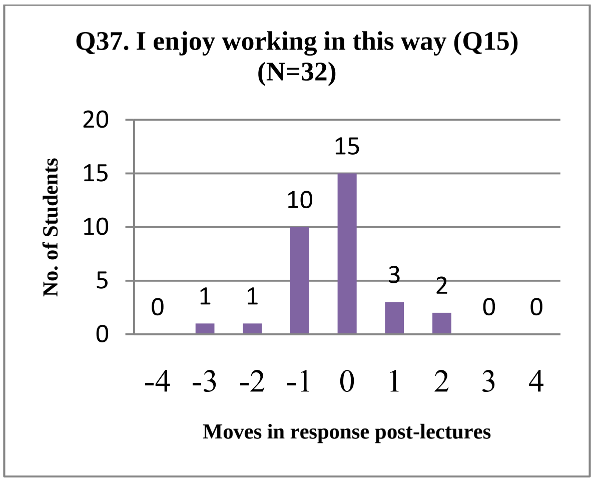


Figure 4.73: Moves in students' responses from Figure 4.72.

Responses to question 15 (Figure 4.70) are similar between mid-EBL and post-lectures questionnaires, with 66% (21) students showing no shift on the rating scale post-lectures (Figure 4.71). This represents the most consistent response, in terms of percentages, to all of the Likert-style statements presented in Section 4.2. Responses are not as constant for question 37 (Figure 4.72), however, with only 47% of students showing no change on the rating scale post-lectures (Figure 4.73). There is a general negative shift in student responses, with 38% (12) of students showing negative moves on the rating scale (Figure 4.73).

The issue of student enjoyment did not arise as a theme from the short answer questions on either mid-EBL, or post-lectures questionnaires. Despite this, three students (9%) did mention that they enjoyed some aspect of the EBL course in the mid-EBL questionnaire (none in the post-lectures questionnaire).

Any other Comments?

> *"I enjoy working like this and feel I am more able to tackle the task when in a team situation because if I get stuck there is always someone to help."*

It is apparent that students enjoyed working in an EBL approach, which is consistent with the literature findings (Pawson, Fournier, Haigh, Muniz, Trafford, and Vajoczki, 2006) (Kennedy and Navey-Davis, 2004) (Duncan, Lyons, and Al-Nakeeb, 2007). This is encouraging from a teaching perspective because, as previously mentioned (Section 2.7.4), the University's Learning and Teaching Strategy suggests that students should enjoy their work (Randall, 2007).

Other issues connected to the learning process that students had undertaken are presented in Figures 4.74 to 4.81.

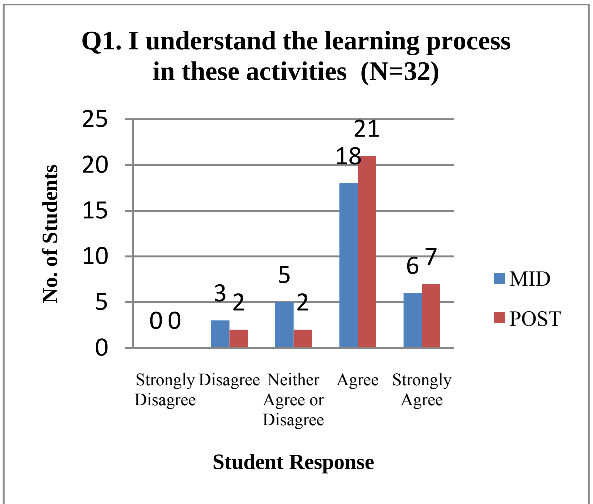


Figure 4.74: Feedback on the learning process.

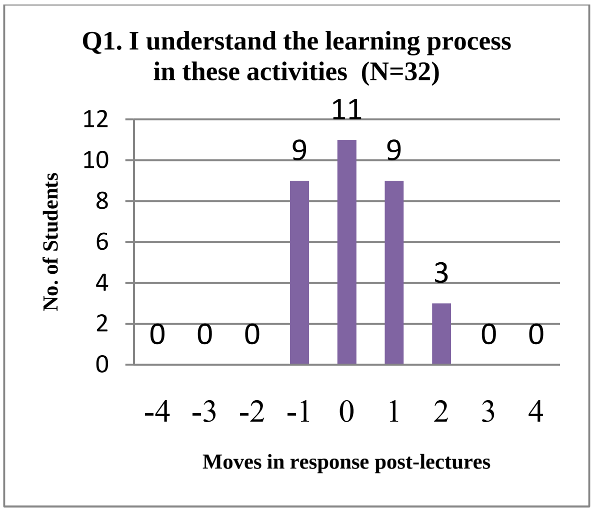


Figure 4.75: Moves in students' responses from Figure 4.74.

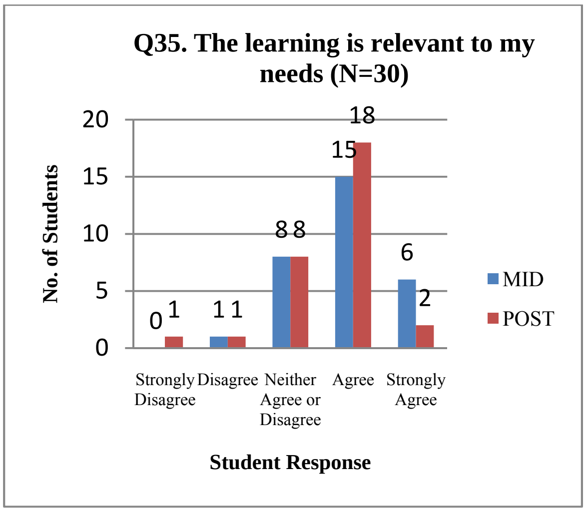


Figure 4.76: Feedback on the relevance of learning.

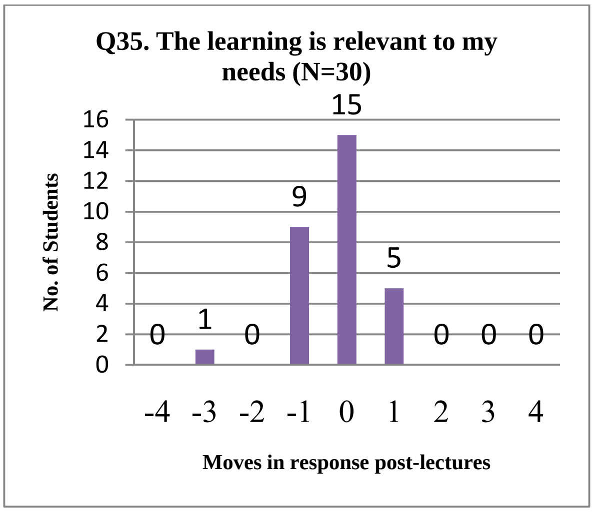


Figure 4.77: Moves in students' responses from Figure 4.76.

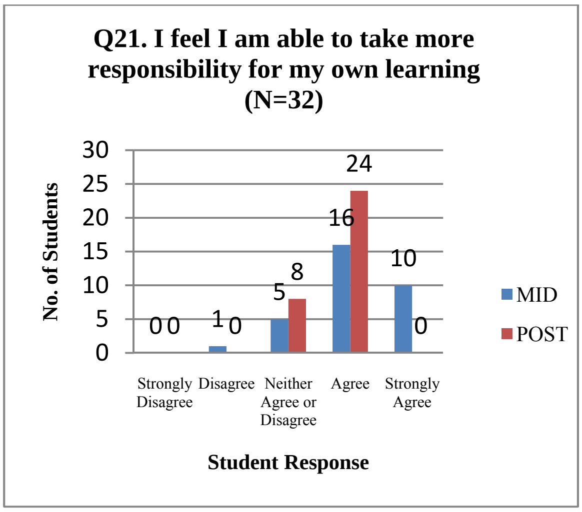


Figure 4.78: Feedback on taking responsibility.

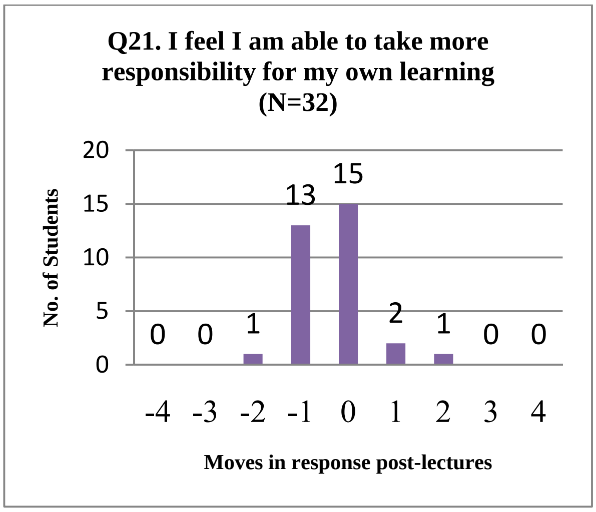


Figure 4.79: Moves in students' responses from Figure 4.78.

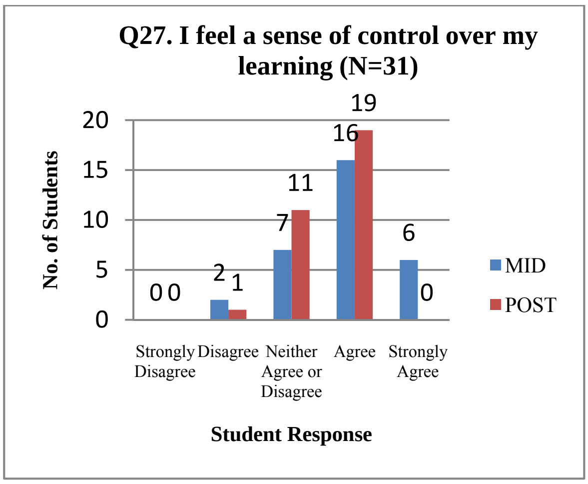


Figure 4.80: Feedback on the feeling of control of learning.

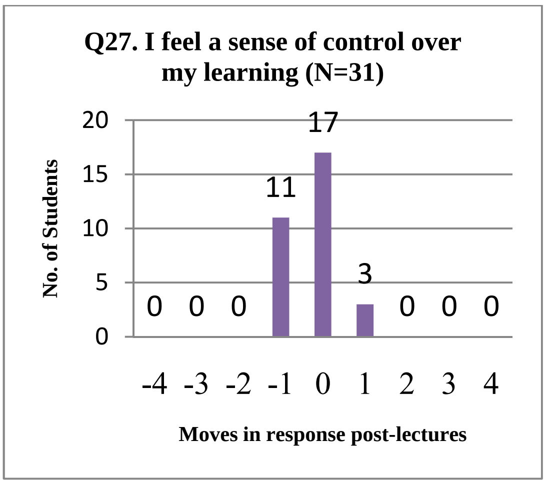


Figure 4.81: Moves in students' responses from Figure 4.78.

Students appear to have understood the learning process in the EBL approach (Figure 4.74). The graphs look similar in Figure 4.74, although there is a degree of variation in student responses between mid-EBL and post-lectures questionnaires, with 66% of students (21) responding differently in the post-lectures questionnaire than they did in the mid-EBL questionnaire (Figure 4.75). Despite this, there are major differences in student responses to this question, with the majority of students only moving by one on the rating scale.

Feedback with respect to "learner independence" also seems generally positive, with only a few negative responses (Figure 4.78 and 4.80). This is as predicted, as Savin-Baden and Major (2004) suggested that PBL allows students to formulate their own learning objectives, and partake in independent study. Post-lectures, there is a negative shift overall in student response in relation to whether they felt a sense of control over their learning (35% of students, seen in Figure 4.81), and if they felt they were more able to take more responsibility for their own learning (44% of students**,** seen in Figure 4.79). In both cases all the "Strongly Agree" responses observed mid-EBL to both statements, are no longer present in the post-lectures data (Figures 4.78 and 4.80). It is not clear if receiving lectures on Spectroscopy lead to these changes in student responses.

The issue of learner independence was a theme that arose from the short answer questions from the mid-EBL and post-lectures questionnaires. In the mid-EBL questionnaire, 52% of respondents commented on the issue of independent learning, although in the post-lectures questionnaire, this was reduced to 19% of respondents.

In the mid-EBL questionnaire 30% of respondents commented that learner independence was a positive aspect of the EBL sessions, with 19% of the total respondents referring to taking responsibility for their own learning as being positive.

"What are the positive things about the course?"

"Learning is your own responsibility." *"Taking responsibility for my learning."*

These examples of positive comments are typical of the post-lectures short answer questions. None of the three students who commented on some aspect of learner independence as being a positive outcome of the EBL course, post-lectures, commented on it being a positive outcome in the mid-EBL questionnaire. Interestingly, in the mid-EBL questionnaire, one student specifically mentioned that being responsible for their own learning was a negative aspect of the EBL course.

The negative comments concerning learner independence appear to focus around a lack of information given to students at the start of the EBL regarding appropriate resources, although it should be noted that only three of the twenty seven (11%) commented on this in the mid-EBL questionnaire (two students post-lectures).

> *"It (EBL) does not give all the information needed leaving people to find out for themselves however with no official reading list finding relevant books for the entire course is challenging."*

Two students commented that the course had not provided them with lecture notes to revise from in the mid-EBL questionnaire, but, as would be expected, no comments were made about the lack of notes in the post-lectures questionnaire. Students appeared to appreciate being given responsibility for their own learning, as outlined in the short answer questions.

One of the aims of the Learning and Teaching Strategy is to foster independent learning and the apparent perception that their EBL activities fostered learning independence within students is consistent with other studies (Oliver and McLoughlin, 1999). The negative responses in the area of learner independence may be down to the suggestion by Wood (2003), *i.e.* some students may struggle to adapt to an independent approach to learning.

4.2.6 Staff

The results from the questions on staff from the paper-based questionnaires (Appendices 11 and 12) are presented in Figures 4.82 to 4.96.

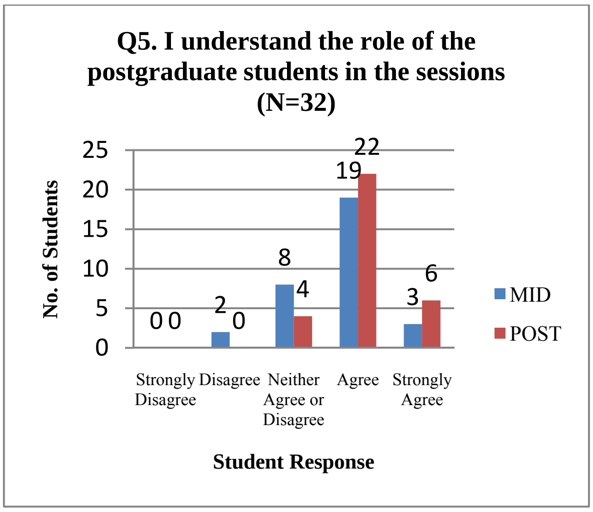


Figure 4.82: Feedback on the role of postgraduate students.

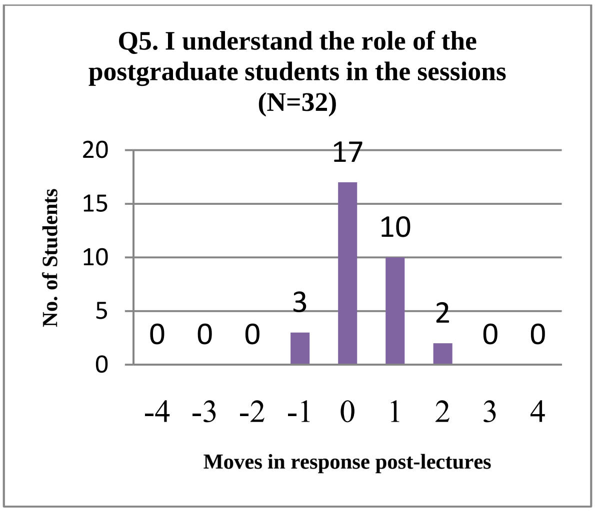


Figure 4.83: Moves in students' responses from Figure 4.82.

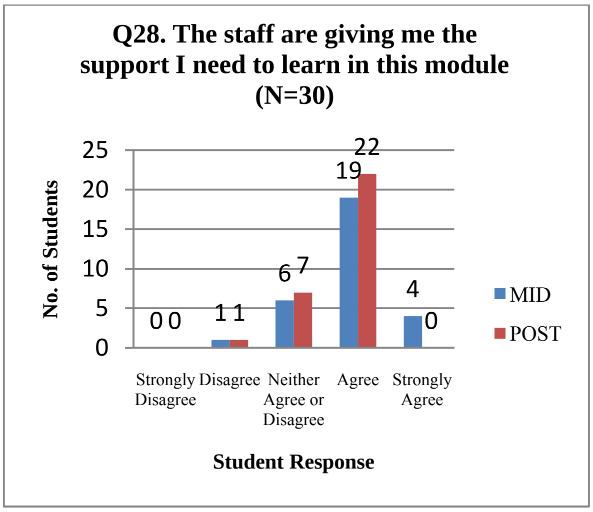


Figure 4.84: Feedback on staff support received.

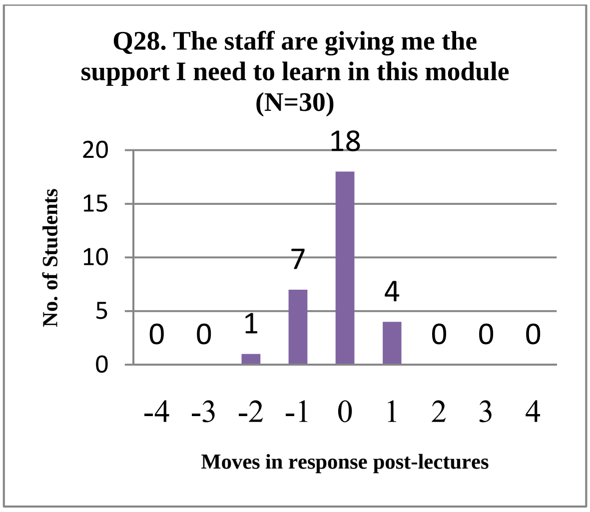


Figure 4.85: Moves in students' responses from Figure 4.84.

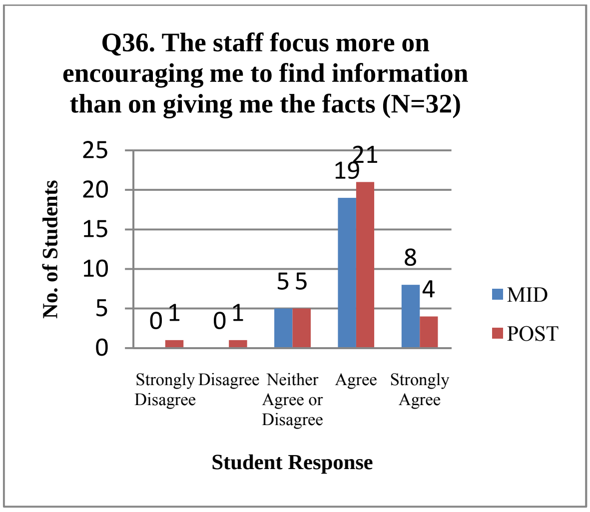


Figure 4.86: Feedback on staff encouragement.

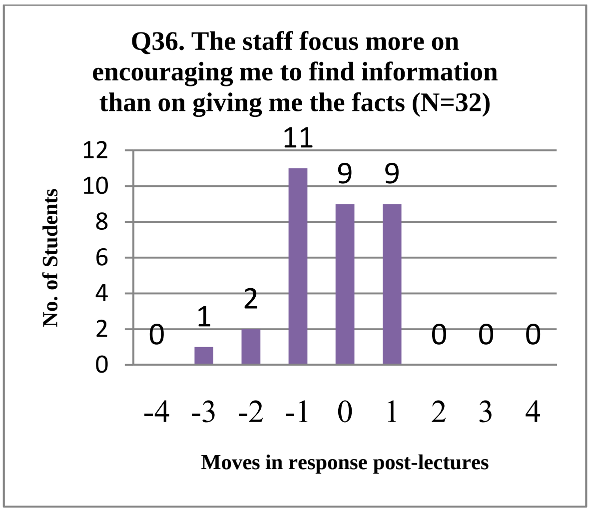


Figure 4.87: Moves in students' responses from Figure 4.86.

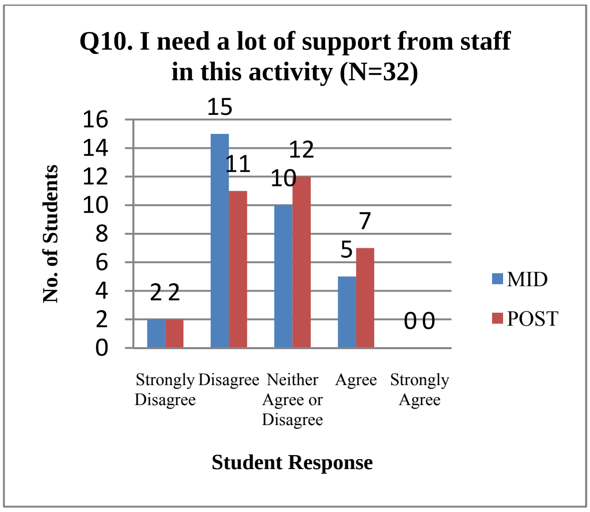


Figure 4.88: Feedback on staff support needed.

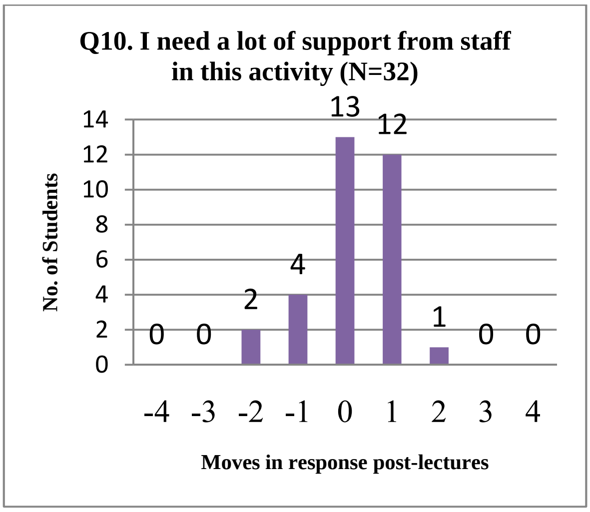


Figure 4.89: Moves in students' responses from Figure 4.88.

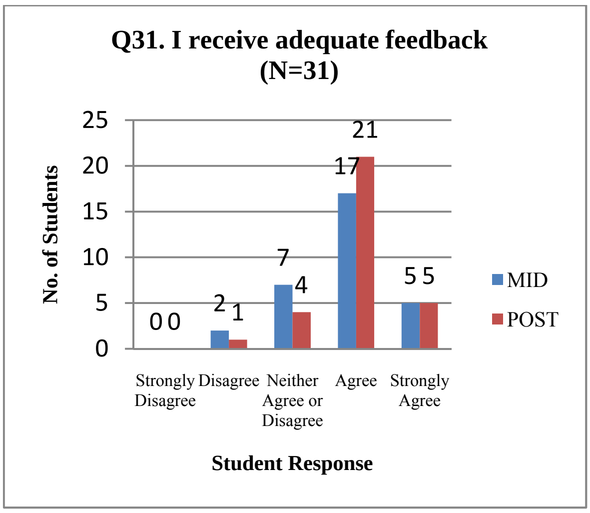


Figure 4.90: Feedback on receiving adequate feedback.

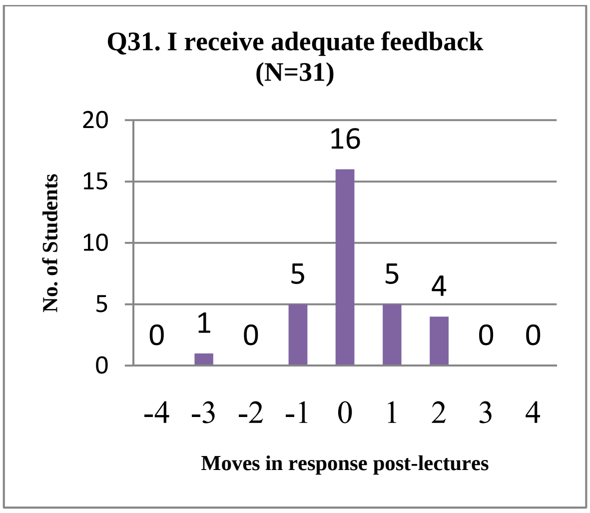


Figure 4.91: Moves in students' responses from Figure 4.90.

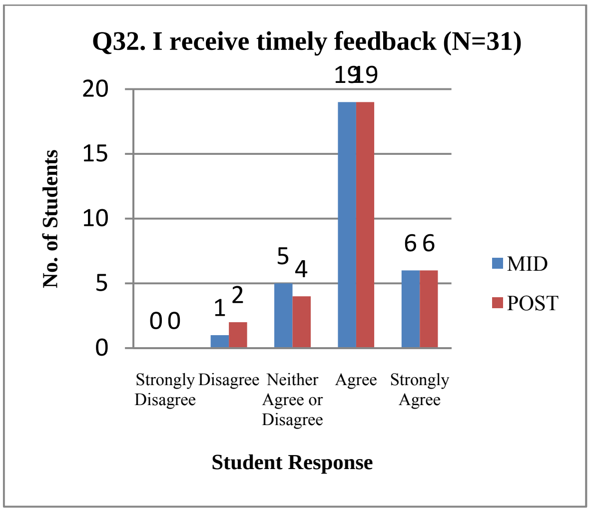


Figure 4.92: Feedback on receiving timely feedback.

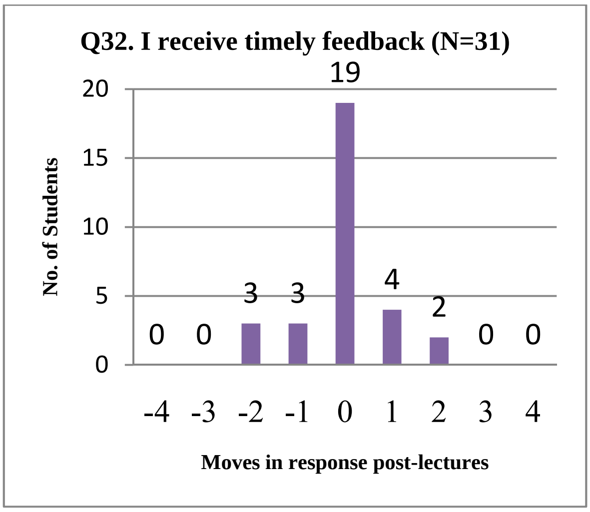


Figure 4.93: Moves in students’ responses from Figure 4.92.

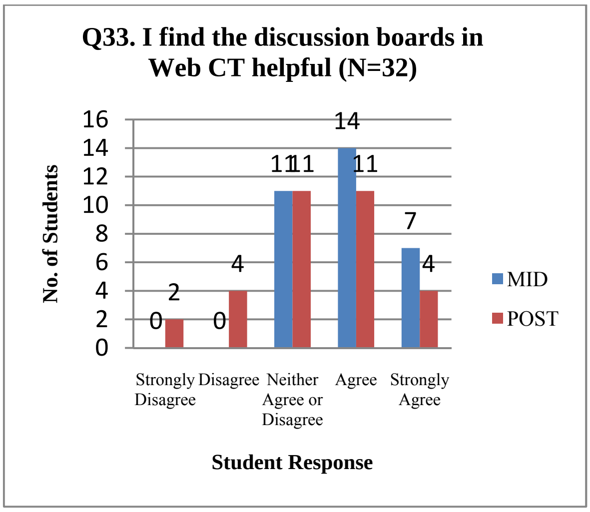


Figure 4.94: Feedback on WebCT discussion boards.

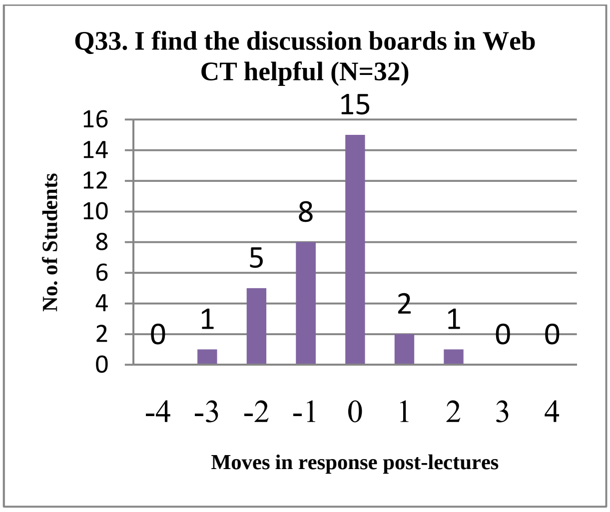


Figure 4.95: Moves in students’ responses from Figure 4.94.

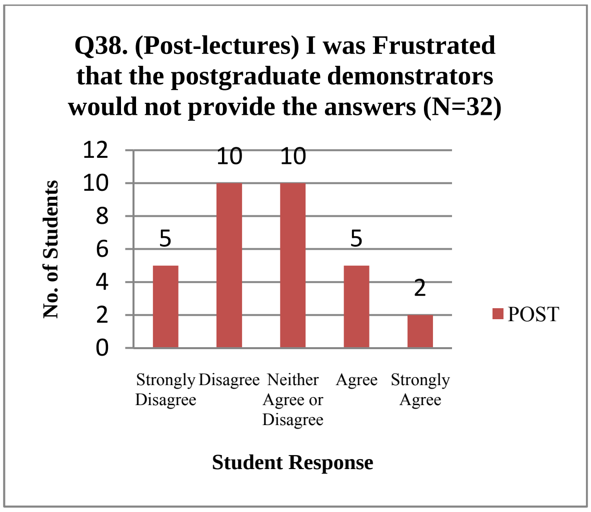


Figure 4.96: Feedback on facilitation.

Students apparently understood the role of the postgraduate facilitators in the EBL sessions, and accepted that the facilitators would not provide them with “the answers” (Figures 4.82 and 4.86). Post-lectures, 43% of students showed a negative move on the rating scale in relation to the issue of staff giving them the answers, despite the mid-EBL and post-lectures graphs looking similar (Figure 4.87). Only 22% of students suggested they were “frustrated” with this (Figure 4.96). 22% students also suggested that they needed a lot of support from staff (Figure 4.88), but the majority of students thought that they did get the required support (Figure 4.84). Post-lectures, 41% of the students showed a positive move on the rating scale regarding the issue of needing support from staff, which suggests that students felt that they needed more support from staff compared to their responses mid-EBL. Only 28% of students showed no move in response post-lectures, which is the lowest percentage of non-movers in all the Likert-type responses.

The majority of students suggested they received timely and adequate feedback (Figures 4.90 and 4.92).

The focus group indicated that students thought that the Postgraduate students were generally very helpful. One student noted that ‘*one postgrad was giving us clues, he wouldn’t just give us the answers, which I thought was quite good...*’ This view would appear to be consistent with the students’ responses in Figure 4.86.

> *“I think it’s better when someone gives you the answers in a way that you’re actually learning from it rather than ‘this is wrong, that’s the answer’. I personally like to know how I got to that answer, so that’s quite a good way.”*

Although the feedback from the focus group on the issue of whether the students were frustrated with the postgraduates indicated that they appreciated this style of facilitation, it is clear from Figure 4.94 that this was not the case for every student.

Feedback on the WebCT Discussion boards is positive in general, but 19% of students suggested, post-lectures, that they did not find them useful (Figure 4.94). Post-lectures there is a general negative shift on the rating scale (Figure 4.95) with responses to “Strongly Disagree” and “Disagree”, which were not present mid-EBL. The focus group indicated that students had mixed views about putting work into WebCT. Students did not find the discussion boards in WebCT particularly useful, as they either saw each other every day anyway, or contacted each other by mobile phones. One student suggested that it was a good exercise to familiarise themselves with the process (required for laboratory reports later on), but another student argued that the extra work involved in doing so was pointless as students met together anyway. A few students reported not putting any work on WebCT. The focus group would appear to disagree with the findings from Figures 4.94, especially as only six students (19%) of students responded either “strongly disagree” or “disagree” to the statement in Figure 4.94.

> *“STUDENT X: we used to exchange mobile phone numbers and you were more likely to get a response if you phoned someone up, rather than if you just leave a message that they may or may not check. We actually went onto the WebCT discussion board when we were in our group just to make it look like we were on there*
>
> *STUDENT Y: yea, that’s what we did because we thought we’d get marked in WebCT!”*

The usefulness of the discussion boards in WebCT is questionable, with students giving mixed opinions on the issue of their use. It is likely that some students only used the discussion boards because they thought that they would gain credit for using them (as was indicated by the focus group). Despite these attitudes towards the discussion boards, students generally responded that they received adequate and timely feedback, which was often given through the discussion boards. As was mentioned earlier (Section 3.4.3) the discussion boards were made available in an attempt to promote group work. However, it is clear that some students prefer to discuss issues face to face or by mobile phones. This is not a major concern, as the discussion boards were there for students to use if they wanted, and their use was not compulsory.

The interviewer from the Learning Development Unit also conducted a one-to-one interview with one of the postgraduate demonstrators who had experience both of demonstrating traditional approaches and in facilitating EBL approaches. The interviewer produced a summary of the interview which is seen below.

Q. Do you feel that you had adequate training for facilitating the EBL sessions?

Facilitating the EBL sessions was more difficult than normal demonstrating as the approach was very different. The demonstrator commented that '*I felt like I was sitting at a loose end and there wasn't much I could be doing'* as students had to work out the answers for themselves. The demonstrator facilitated the sessions by asking students what they thought the answers were and encouraging them to interact with each other more.

The demonstrator found that first year students were frustrated with the EBL sessions due to an unfamiliarity with the format and preferring to be 'spoon fed' the information. They were also frustrated when they could not work things out for themselves, which the demonstrator suggested was due to '*trying to rush through it rather than thinking it out properly'*. First year students found the real spectra of compounds more 'tricky' to analyse, but became used to it by the end of the sessions.

The demonstrator did not enjoy facilitating the EBL sessions as much as demonstrating, but felt that the sessions were 'good practice' for students in learning techniques for solving problems in the future.

Q. Was the concept of EBL explained enough so you knew what to expect?

The demonstrator was satisfied with the explanations given about what to expect, although he did not know what the students had been taught previously or what level they were at.

Q. What do you think of the concept of EBL as a way of learning compared to more traditional approaches?

The demonstrator thought that EBL was a 'very good idea' even though there will always be resistance from some students towards it. Part of the resistance is shaped by student expectations of science degrees, which have traditionally been taught in a more didactic way. Starting with first year students is always the best place to begin because they do not know what to expect when they enter university. Students also do not always see the benefits of different approaches until later on. There will always be some students who really enjoy new approaches to learning and others who don't.

Q. How do you feel the students found the EBL sessions compared to previous workshops?

Students still received the same information base as they had lectures after the sessions. The sessions were very much based on what they did at A level, so the sessions were not all about 'learning' *per se*. Students already knew some of the information and did not have to work things out for themselves. However, students have such a wide range of different A level syllabuses, it would be almost impossible to address this.

It is difficult to say if EBL is better than another method of learning. Exam results may provide an indication to this.

Q. Suggested improvements

- Have one or two more workshops after the sessions.
- The student culture tends to be geared towards passing exams, so changes to EBL sessions may not be necessary. Students have to learn that they have to work problems out and not just learn actual Chemistry to pass an exam.

Students' attitudes towards facilitation were, overall, positive. Students appeared to appreciate that they would not be given the answers to questions, but rather guidance towards the correct answer from the point at which they found themselves. The postgraduate facilitator interviewed suggested that students were frustrated by the facilitation. However, this is not represented in the students' responses in Figure 4.96 (despite 22% students suggesting this was the case). It is clear that a number of students did find not being giving the answers "frustrating", but this view does not appear to represent that of the whole year group, indeed the focus group findings also suggest that this attitude is not common.

The interview with the facilitator suggests that they found it hard to adjust to the facilitation process, as was suggested by Kahn and O'Rourke (2004), but it is clear that the facilitator understood the new role and the EBL process in general.

4.2.7 Timetabling and Room Issues

An issue which arose from the focus group was that of when and where the EBL sessions were timetabled (4-6 pm on a Friday afternoon). Students indicated that they found the 4 pm to 6 pm time slot, after two hours of lectures (2 pm to 4 pm) difficult, and that having the sessions in a less crowded room would have helped them to concentrate better.

“..and it gets hot and stuffy on a Friday afternoon and no one wants to be there.”

Although neither of these issues arose as major themes in the short answer responses, mid- and post-lectures, there were four students (13%) who commented upon the timetable slot in a negative light in the mid-EBL questionnaire. None of these students commented on this issue on the post-lectures questionnaire. In the post-lectures questionnaire, only one student highlighted the timetable slot as an issue.

The Friday afternoon timeslot was not very popular with the students. This negative attitude towards the timeslot for the EBL sessions could have had an impact on students overall attitudes towards the EBL sessions. This would have been compounded if students held the perception that they would not have had anything timetabled 4 till 6pm otherwise. It is not clear if this was the case.

Unfortunately, this timetabling was out of our control, as if there had not been EBL sessions in this timeslot, there would have been lectures instead, a fact that was perhaps lost on some students. Despite the criticism of the timeslot, students in the session mostly remained till 6 pm, and one week students had to be asked to leave at 6.30 pm. It could be argued that EBL sessions promoted active learning, which was more suitable for this time slot than a further two hours of lectures.

4.2.8 General Changes in Attitudes Post-Lectures

As part of the research questions presented in Section 1.3, an investigation into how students' attitudes changed through the course is necessary. Giving students a mid-EBL questionnaire after a few sessions enabled an investigation into changes in students' attitudes towards various issues. Table 4.4 explores the average moves in students' responses (in both positive and negative directions) to all the thirty seven Likert-type statements.

Move in response post-lectures	**No. of students (%)**	**Standard Deviation**	**High (%)**	**Low (%)**
0	*52*	*8.84*	*66*	*28*
1	*39*	*7.98*	*63*	*22*
2	*7*	*4.58*	*19*	*0*
>2	*2*	*3.06*	*12.5*	*0*

Table 4.4: Moves in student responses to the Likert-type statements.

It should be highlighted, that, as these are average values, there may be some variation in individual responses to statements. Also, the moves shown in Table 4.5 could be in either direction (positive or negative). Table 4.5 does suggest that, on average, there are no major changes in students' responses to the Likert-type statements, with the majority of students showing no moves in their responses post-lectures. Only 9% of students exhibited more than one move in their responses post-lectures. However, there were some differences between the short answer responses in the mid-EBL and post-lectures questionnaires. For example, the issue of assessment only appeared as a major theme in the mid-EBL questionnaire (Section 4.2.1). On the whole, responses to the short answer questions of the questionnaire post-lectures were much reduced in comparison with the mid-EBL assessment. Students may have felt that they would have been simply repeating information given in the mid-EBL questionnaire. Students may have felt that comments in the mid-EBL would have a direct impact on future EBL sessions, thus encouraging students to respond.

In conclusion, it would appear that, with certain exceptions (discussed throughout Section 4.2), the attitudes towards various aspects of EBL that students held three sessions into the course were maintained through to the end of the course (post-lectures). This stability of attitudes was suggested by Reid (2006a), and the findings in Table 4.5 appear to agree with this observation. In most cases, the final EBL sessions and the lecture course appear to have had no major affect on student attitudes towards most of the issues explored. Students commented that they had appreciated the inclusion of lectures post-EBL. It should be highlighted that they would have had no experience of the Spectroscopy lecture course in the mid-EBL assessment. Despite this, it is likely that students knew what to expect on this lecture course as they had experience of other lecture courses, and possessed, from the outset, detailed information on what the material would be covered during the Spectroscopy lecture course.

CHAPTER 5

CONCLUSIONS AND LIMITATIONS OF STUDY

5.1 Conclusions

The University of Birmingham updated its Learning and Teaching strategy approximately five years ago, and now promotes the implementation of an "enquiry-based" learning approach. As a result of this change, several Learner Independence Projects were established, to support the new vision for learning at the University. A new enquiry-based learning course was designed and incorporated within the first year undergraduate Chemistry curriculum at the University of Birmingham. A traditional course in Spectroscopy was adapted to embrace the enquiry-based approach to learning. EBL scenarios and research tools were developed through the use of a pilot study. The main study saw first year Chemistry students complete an EBL course in Spectroscopy in the 07/08 academic year. In order to answer the research questions of this study, students' attitudes towards the processes of EBL and their perceived confidences in Spectroscopy were investigated by various commonly used research methods at different points in the Spectroscopy course.

Students' perceived confidence in Spectroscopy, and how this changed as a result of the students' EBL activities, was investigated by means of questionnaire. Students' attitudes towards various aspects of the EBL implementation were also assessed using a questionnaire, and these were supplemented by two focus groups and an individual interview. The interviews added depth to the information obtained from questionnaires, providing further insight into students' attitudes towards various issues. This work was carried out in order to address the research questions of this study. These can now be considered in light of the findings presented in Chapter 4.

"What are the students' attitudes towards the processes of EBL and how do these attitudes change through the course?"

The first sub-question investigates what the student's attitudes are and how they change. The question does not consider why they possess the attitudes that they do, as this would be a much more complicated question to answer. This sub-question was dealt with in Section 4.2. Students were mainly positive towards the various processes of EBL examined in this study, and attitudes remained comparatively stable between the two data points. There were very few (if any) noticeable overall moves in students' responses between mid-EBL and post-lectures questionnaires. This suggests that attitudes formed in the first three EBL sessions were then relatively stable throughout the remaining parts of the course.

The positive and negative attitudes students held towards EBL are consistent with those identified in the literature. The majority of students appreciated working in their groups, and being given the opportunity to interact with their peers. As was suggested in the literature (Section 2.7.1.2) there were some students who were frustrated with unequal participation in their groups at certain points. Students additionally felt that they had developed other transferable skills and had developed some degree of learner independence. Importantly, students understood the EBL process, including the role of staff, and indicated that they enjoyed their EBL sessions. There was, however, a contradiction between responses from a facilitator and the students regarding the issue of how frustrated students were at not being given direct answers. It is unclear if the facilitator held a misconception, or perhaps there was an issue with the validity of the research methods. Of course, students may not have been responding truthfully.

The scenarios were criticised by students for being repetitive, which is an important issue in PBL as the problems themselves drive the learning process.

As would be expected, not all students responded positively to the EBL course, with some negative responses observed in almost all of the Likert-style statements from the questionnaires. A minority of students' responded that they would have preferred to work individually, and a few also commented that they struggled with learning independently. As students possess various learning styles, it is unlikely that "all the students can be pleased, all of the time". A degree should attempt to cater for these various learning styles by incorporating varying approaches to learning, whether it be through lectures, laboratories, tutorials, or EBL sessions. It is unclear to what extent the timeslot for the EBL session affected the students' attitudes towards the EBL sessions. It is, however, clear that the 4 till 6 pm timeslot was not popular among students.

"How does student perceived confidence (in handling the subject matter and in their learning) change, if at all, as a result of their experience in using EBL in the Spectroscopy course?"

This research sub question was addressed in Section 4.1. There are definite increases in confidence, post-EBL, in the various aspects of Spectroscopy examined in this research. Most increases are subtle due to students possessing a fair degree of confidence in the spectroscopic techniques before taking the first year Spectroscopy course. Pre-EBL the majority of students lacked confidence in understanding how ^{13}C NMR Spectroscopy works and in interpreting ^{13}C NMR spectra, but there was a marked increase in confidence post-EBL. Students who perceived themselves as possessing the least confidence in their knowledge of the theory behind the techniques pre-EBL, were confident post-EBL.

It was also of interest to note that a number of students apparently decreased in confidence after completing the EBL course. With the data collected in relation to student confidence, it is not possible to attribute this decrease in confidence to any one cause. It is possible that students were over confident in various areas pre-EBL or that students would have preferred an approach to learning that was more familiar to them. This however, is purely speculation.

For each technique, the majority of students responded that their confidence was the same, both in understanding the theory behind each technique, and in interpreting the spectra of each technique. It was perceived that these two features are interconnected, and the students' responses indicate that this was the case.

It is clear that EBL has the potential to increase a student's perceived confidence in Spectroscopy to varying degrees. At the same time, there is also the potential for some students' perceived confidence to drop in all of the areas examined in this research. The number of students who increased in perceived confidence, however, outweighs the number of students who decreased in perceived confidence. Indeed, the decreased confidence may simply reflect greater awareness of reality.

"What are the experiences of first year Chemistry students of a new EBL approach to teaching Spectroscopy?"

Now that the research sub-questions have been considered, it is important to reflect on the main research question as whole. It is clear that the majority of students had a positive experience of the EBL course, albeit with a few negative attitudes towards some areas. The majority of students were confident in the various areas of the Spectroscopy course post-EBL, with it being shown that EBL has the potential to increase students' perceived confidence in

Spectroscopy, particularly within those students who are the least confident before the EBL sessions. Some students lost confidence in some of the techniques post-EBL, but this may arise as increased experience makes them more aware of the reality of the difficulties.

5.2 Limitations of Study

The attitudes and confidences investigated in this thesis are all latent constructs, and, as a result, it not possible to measure them directly. This is a limitation of any research that investigates attitudes or confidence. However, it is possible to incorporate checks for validity and reliability into the research design, and the evidence offered here is encouraging in that a fairly consistent picture emerged of student experiences with EBL.

The focus group and interview with the postgraduate demonstrator were carried out after Christmas, hence a considerable time after the EBL sessions. This may have resulted in a reduced ability to recall some of the details of these sessions. For similar reasons, the focus group, run approximately a year after the Spectroscopy course had finished, may not have provided an entirely accurate perspective on the students' attitudes at the time of filling out the questionnaire. Despite this, the opinions of the students who completed the questionnaire are, arguably, the most important in this case.

All questionnaires also possessed certain inherent limitations. Well designed questionnaires can offer good reliable pictures (Reid, 2003). The real problem relates to validity in that it is never possible to be certain that the responses reflect reality or what the students would like reality to be. This where the focus groups help and the outcomes do seem to support the validity of the questionnaires.

The sample size for all the data presented in this thesis is very small, and does not represent every student in the year due to a number of non-responding students. This makes reliable analysis of the data difficult, and does not allow the use of any statistical methods normally used in data analysis. The creation of an alternative method aimed to assist here.

There is no comparison of students' attitudes towards the traditional Spectroscopy course, so it is not possible to ascertain how EBL would have affected students' attitudes and confidence in comparison to this. Inevitably, as this was the first year of implementation, the EBL course may have contained flaws that could be improved upon in future years. As a result, it is not possible to ascertain if the negative attitudes that some students possessed could be removed by making improvements to the course.

As a result of this being the first year of the implementation of the EBL course, the enthusiasm of the member of staff who ran the course may have increased. This is often the case with new course designs. It is not clear if this will have affected students' experiences of EBL. More years of data may remove this limitation, however, and also provide a more reliable overview of students' experiences of EBL, as every cohort of students is different.

5.3 Future Work

As the results collected represent only one year of data, it is essential to collect several further years of data before reliable conclusions can be drawn. Improvements could be made to the EBL course, such as improving the EBL scenarios used, for example by including more variety and more true-to-life situations. It would be of interest to investigate if such improvements to the course removed some of the negative attitudes towards areas of the EBL course.

As well as making improvements to the EBL course, the small error in the confidence questionnaires should of course be rectified. This would provide further insight into how students' confidences are affected by the new EBL approach.

In this research, "how" students' confidences are affected by EBL and "what are" students attitudes toward the processes of EBL have been investigated. Future work may consider asking the question "why". This is a lot harder to assess, but would be a valuable investigation in order to explain some of the findings presented in this thesis. A good example of such an investigation may involve an examination as to why some students felt that their confidence decreased post-EBL. Was it because they were overconfident to start with, that the new approach to learning was unfamiliar to them, or for some other unknown reason? Also it may be possible to further probe both the positive and the negative attitudes towards aspects of the EBL process.

5.4 Epilogue

This study aimed to explore the experiences of first year Chemistry students in a new enquiry-based learning approach to teaching Spectroscopy. Working with small numbers, a fairly positive picture has emerged and much is consistent with the findings of others. Given that the aims of Higher Education need to encompass a wider range of skills (such as independent learning, group work, communication skills), then this change in the way Spectroscopy has been presented seems to offer much scope. It is hoped that this will contribute to future developments in an ongoing attempt to make the undergraduate learning experiences in Chemistry at Birmingham richer as a contribution to the goal of educating in and through Chemistry.

REFERENCES

Adams, D., and Hamm, M. (1996). *Cooperative Learning: Critical Thinking and Collaboration Across the Curriculum* (2nd ed.). Springfield: Charles C. Thomas.

AIST. (2009). Retrieved April 6, 2009, from Spectral Database for Organic Compounds, SDBS: http://riodb01.ibase.aist.go.jp/sdbs/cgi-bin/cre_index.cgi?lang=eng

Ajzen, I., and Fishbein, M. (1977). Attitude-Behaviour Relations: A Theoretical Analysis and Review of Empirical Research. *Psychological Bulletin , 54* (5), 88-918.

Antephol, W., and Herzig, S. (1999). Problem-Based Learning Versus Lecture Based Learning in a Course of Basic Pharmacology: a controlled, randomized study. *Medical Education , 33*, 106-113.

Armstrong, E. (1998). A Hybrid Model of Problem-Based Learning. In D. Bould, and G. Feletti, *The Challenge of Problem-Based Learning* (pp. 137-150). London: Routledge.

Barows, H., and Tamblyn, R. (1980). *Problem-based Learning: An Approach to Medical Education.* New York: Springer Pub. Co.

Barrett, T. (2005). Understanding Problem-based Learning. In T. Barret, H. Fallon, and I. Mac Labhrainn (Eds.), *Handbook of Enquiry and Problem-based Learning: Irish Case Studies and International Perspectives.* AISHE and HEA.

Barrows, H. (1980). *Problem-Based Learning, An Approach to Medical Education.* New York: Springer.

Basch, C. (1987). Focus Group Interview: An Underutilized Research Technique for Improving Theory and Practice in Health Education. *Health Education and Behavior , 14* (4), 411-448.

Baume, D. (2001). A Briefing on Assessment of Portfolios. LTSN Generic Centre.

Belt, S., Evans, E., McCreedy, T., Overton, T., and Summerfield, S. (2002). A Problem Based Learning Approach to Analytical and Applied Chemistry. *University Chemistry Education , 6* (2), 65-72.

Benware, C., and Deci, E. (1984). Quality of Learning With an Active Versus Passive Motivational Set. *American Educational Research Journal , 21* (4), 755-765.

Black, T. (1999). *Doing Quantitative Research in the Social Sciences: An Integrated Approach to Research Design, Measurement and Statistics.* Sage.

Bloom, B., Englehart, M., Furst, E., Hill, W., and Krathwohl, D. (1956). *Taxonomy of Educational Objectives: Book 1 Cognitive Domain.* New York: Longman.

Boekaerts, M. (1996). Personality and the Psychology of Learning. *European Journal of Personality , 10* (5), 377-404.

Bonk, C., and Kim, K. (1998). Extending Sociocultural Theory to Adult Learning. In C. Smith, and T. Pourchot, *Adult Learning and Development* (pp. 67-80). New Jersey London: Lawrence Erlbaum Associates.

Braye, S., Lebacq, M., Mann, F., and Midwinter, E. (2003). Learning Social Work Law: An Enquiry-Based Approach to Developing Knowledge and Skills. *The International Journal , 22* (5), 479-492.

Brink, C., Goodney, D., Hudak, N., and Silverstein, T. (1995). A Novel Spiral Approach to Introductory Chemistry Using Case Studies of Chemistry in the Real World (FORUM). *The Journal of Chemical Education , 72* (6), 530-532.

Cheng, W. (1995). An Environmental Curriculum Using Case Studies. *Journal of Chemical Education , 76* (6), 525-527.

CIBL. (2008). *What is Inquiry Based Learning?* . Retrieved September 18, 2008, from Centre for Inquiry-Based Learning: http://www.ciblearning.org/about.inquiry.php

Cohen, L., Manion, L., and Morrison, K. (2000). *Research Methods in Education.* London: Routledge.

Cole, M., and Mattews, A. (1996). *Fitness for Purpose - a Means of Comparing Qualifications.* London: Schools Curriculum and Assessment Authority and the National Council for Vocational Qualifications.

Conner, M., Wright, E., Curry, K., Devries, L., Zeider, C., Wilmsmeyer, D., et al. (1996). Learning: The Critical Technology, A whitepaper on Adult Education in the Information Age. St. Louis.

Cummings, L., Huber, G., and Eugene, A. (1974). Effects of Size and Spatial Arrangements on Group Decision Making. *The Academy of Management Journal , 17* (3), 460-475.

Danili, E., and Reid, N. (2004). Some Strategies to Improve Performance in School Chemistry, Based on Two Cognitive Factors. *Research in Science and Technological Education , 22* (2), 203-226.

Duch, B. (1996). *Problems: A Key Factor in PBL*. Retrieved September 18, 2008, from University of Delaware: http://www.udel.edu/pbl/cte/spr96-phys.html

Duncan, M., Lyons, M., and Al-Nakeeb, Y. (2007). The Impact of Problem-Based Learning on the Student Experience in Sports and Exercise Biomechanics. *Journal of Hospitality, Leisure, Sport and Tourism Education , 6* (1), 71-80.

Dunlap, J. (2005). Problem-Based Learning and Self-Efficacy: How a Capstone Course Prepares students for a profession. *ETRandD , 53* (1), 65-85.

Entwistle, N. (1988). *Styles of Learning and Teaching: An Integrated Outline of Educational Psychology for Students, Teachers and Lecturers.* David Fulton.

Exley, K., and Dennick, R. (2004). *Giving a Lecture: From Presenting to Teaching.* London and New York: Routledge.

Fetherston, T. (2001). Pedagogical Challenges for the World Wide Web. *AACE , 9* (1), 25-32.

Ford, J., Prudente, C., and Newton, A. (2008). A model of Incorporating Research into the First-Year Chemistry Curriculum. *The Journal of Chemical Education , 85* (7), 929-933.

Glasersfeld. (1991). Questions and Answers About Radical Constructivism. In M. Pearsall, *Scope, Sequence, and Coordination of Secondary School Science, Vol. II: Relevant Research* (pp. 169-182). Washington, D.C: The National Science Teachers Association.

Guttman, L. (1944). A basis for scaling qualitative data. *American Sociological Review , 9*, 139-150.

Hamachek. (1990). *Psychology in Teaching, Learning and Growth.* Boston: Allyn and Bacon.

Heise, D. (1970). Validity, invalidity, and reliability. In E. Borgatta, and G. Bohrnstedt (Eds.), *Sociological Methodology.* San Francisco: Jossey-Bass.

Heller, P., Keith, R., and Anderson, S. (1992). Teaching Problem Solving Through Cooperative Grouping. Part 1: Group Versus Individual Problem Solving. *American Journal of Physics , 60* (7), 627-636.

Hospitality, Leisure, Sport and Tourism Network. (2009). Subject Specific Guides: Problem Based Learning in Sport Leisure and Social Sciences.

Hutchings, B. (2006). Principles of Enquiry-Based Learning. Centre for Excellence in Enquiry-Based Learning.

Huxham, M., and Land, R. (2000). Assigning Students in Group Work Projects. Can We Do Better than Random. *Innovations in Education and Training International , 37* (1), 17-22.

Johnstone. (1997). Chemistry Teaching - Science or Alchemy? *Journal of Chemical Education , 74* (3), 7.

Johnstone, A., and El-Banna, H. (1986). Capacities, Demands and Processes: A Predictive Model for Science Education, Education in Chemistry. *Education in Chemistry , 23* (3), 80-84.

Johnstone, A., and El-Banna, H. (1989). Understand Learning Difficulties - A Predictive Research Model. *Studies in Higher Education , 14* (2), 159-68.

Kahn, P., and O'Rourke, K. (2004). Guide to Curriculum Design: Enquiry-Based Learning. The Higher Education Academy.

Kahn, P., and O'Rourke, K. (2005). Understanding Enquiry-based Learning (EBL). In T. Barret, I. Labhrainn, and H. Fallon (Eds.), *Handbook of Enquiry and Problem-based Learning: Irish Case Studies and International Perspectives.* Galway: CELT.

Kandel, M., and Tonge, P. (2001). Personalized Combined Organic Spectroscopy Problems - Online and in the Lab. *Journal of Chemical Education , 78* (9), 1208-1209.

Kennedy, A., and Navey-Davis, S. (2004). Inquiry-Guided Learning and the Foreign Language Classroom. In V. Lee, *Teaching and Learning Through Inquiry: A Guidebook for Institutions and Instructors* (pp. 71-80). Sterling: VA: Stylus.

Kennesaw State University. (2005). *General Chemistry Case Studies*. Retrieved May 15, 2009, from http://chemcases.com/

Kirschner, P., Sweller, J., and Clark, R. (2006). Why Minimal Guidance During Instruction Does Not Work: An Analysis of the Failure of Constructivist, Discovery, Problem-Based, Experiential, and Inquiry-Based Teaching. *Educational Psychologist , 41* (2), 75-86.

Knowles, M. (1990). *The Adult Learner: A Neglected Species* (4 ed.). Houston: Gulf Publishing Co.

Könings, K., Wiers, R., Wiel, M., and Schmidt, H. (2005). Problem-Based Learning as a Valuable Educational Method for Physically Disabled Teenagers? The Discrepancy Between Theory and Practice. *Journal of Developmental and Physical Disabilities , 17* (2), 107-117.

Kreuger, R. (1988). *Focus groups: A Practical Guide for Applied Research.* London: Sage.

Likert, R. (1932). *A Technique for Measurement of Attitudes.* New York: Coloumbia University Press.

Loftus, E. (1975). Leading Questions and the Eyewitness Report. *Cognitive Psychology , 7*, 550-572.

Lumsden, J., and Morgan, W. (2005). Online-Questionnaire Design: Establishing Guidelines and Evaluating Existing Support. *Annual International Conference of the Information Resources Management Association.* San Diego: National Research Council of Canada.

Macdonald, R. (2005). Assessment Strategies for Enquiry-Based and Problem-Based Learning. In T. Barret, H. Fallon, and I. Mac Labhrainn (Eds.), *Handbook of Enquiry and Problem-Based Learning: Irish Case Studies* (pp. 4-12). Galway: CELT.

Martin, L., Bill, K., and West, J. (2006). Incorporating Problem-Based Learning Strategies to Develop Learner Autonomy in Sports Science Undergraduates. Worcester.

Mayer, R. (2002). Rote Versus Meaningful Learning. *Theory into Practice , 41* (4), 226-232.

Moore, I. (2007). *An Evaluation Survey for EBL.* Retrieved April 6, 2009, from CEEBL: http://www.campus.manchester.ac.uk/ceebl/resources/evaluation/evaluation_survey.rtf

Moore, I. (2006). towards an evaluation strategy: Frameworks for evaluating the impact of the CEEBL. University of Manchester: Centre for Excellence in Enquiry-Based Learning.

Muller, T. (2007). Assigning Students to Groups for Class Projects: An Exploratory Test of Two Methods. *Decision Sciences , 20* (3), 623-634.

OIRA. (2007). Interpreting and Using Student Ratings of Teaching Effectiveness. Syracuse.

O'Kelly, J. (2005). Designing a Hybrid Problem-Based Learning (PBL) Course: A Case Study of First Year Computer Science in NUI, Maynooth. In T. Barret, I. Labhrainn, and H. Fallon, *Handbook of Enquiry and Problem-based Learning: Irish Case Studies and International Perspectives* (pp. 45-53). Galway: Centre for Excellence in Learning and Teaching.

Oliver, R., and McLoughlin, C. (1999). *Using Web and problem-Based Learning Environments to Support the Development of Key Skills.* Retrieved April 6, 2009, from http://www.heacademy.ac.uk/assets/hlst/documents/projects/round_5/r5_martin_report.pdf

Oppenheim, A. (1998). *Questionnaire Design, Interviewing and Attitude Measurement.* Guilford: Biddles Ltd.

Osgood, C., Suci, G., and Tannenbaum, P. (1957). *The Measurement of Meaning.* Urbana: University of Illinois.

Oxford University Press. (2008). *Oxford English Dictionary*. Retrieved July 9, 2008, from Oxford English Dictionary: http://dictionary.oed.com/

Pawson, D., Fournier, E., Haigh, M., Muniz, O., Trafford, J., and Vajoczki, S. (2006). Problem-Based Learning in Geography: Towards a Critical Assessment of its Purposes, Benefits and Risks,. *Journal of Geography in Higher Education , 30* (1), 103-116.

Peterson, R. (2000). *Constructing Effective Questionnaires.* Sage Publications, Inc.

Piaget, J. (1962/1945). *Play, Dreams and Imitation in Childhood.* New York: Norton.

Powell, N., Peaker, A., William, T., Hicks, P., and Canavan, B. (2007). Seeding Enquiry-Based Learning in Electrical and Electronic Engineering: Case Study 1 – Optoelectronics. *International Conference on Engineering Education.* Coimbra, Portugal.

Problem Based Learning Initiative. (2008). *Generic Problem-based Learning Essentials*. Retrieved September 18, 2008, from Problem Based Learning Initiative: www.pbli.org/pbl/generic_pbl.htm

QAA. (2007). *Subject Benchmark Statements, Chemistry.* Quality Assurance Agency for Higher Education.

Qin, Z., Johnson, D., and Johnson, R. (1995). Cooperative Versus Competitive Efforts and Problem Solving. *Review of Educational Research , 65* (2), 129-143.

Raine, D., and Symons, S. (2005). *PossiBiLities: A practical guide to Problem-based Learning in Physics and Astronomy.* (D. Raine, and S. Symons, Eds.) Hull: The Higher Education Academy Physical Sciences Centre.

Ram, P. (1991). Problem-Based Learning in Undergraduate Education. *Journal of Chemical Education , 78* (8), 1222-1126.

Randall, A. (2007). *University of Birmingham: Learning and Teaching Strategy 2007-2009.* Retrieved September 10, 2008, from https://www.intranet.bham.ac.uk/landt/documents/landtstrat5dec07whole.pdf

Rau, W., and Heyl, S. (1990). Humanizing the College Classroom: Collaborative Learning and Social Organization Among Students. *Teaching Sociology , 18* (2), 141-155.

Rees, J., Atkin, R., and Zimmerman, W. (2005). On the Use of Audio-Tapes for Teaching Vector Analysis to Engineering Undergraduates. *International Journal of Mechanical Engineering Education , 33* (4), 358-367.

Reid, N. (2006b). *Getting Started in Pedagogical Research in the Physical Sciences.* Higher Education Academy Physical Sciences Centre.

Reid, N. (2006a). Thoughts on Attitude Measurement. *Research in Science and Technological Education , 24* (1), 3-27.

Savery, J. (2006). Overview of Problem-Based Learning: Definitions and Distinctions. *The Interdisciplinary Journal of Problem-based Learning , 1* (1), 9-20.

Savin-Baden, M., and Major, C. (2004). *Foundations of Problem-based Learning* (1st ed.). Open University Press.

Schmidt, H. (1983). Problem-Based Learning: Rationale and Description. *Medical Education , 17* (1), 11-16.

Seddigi, Z., and Overton, T. (2003). How Students Perceive Group Problem Solving: The case of a Non-Specialised Chemistry Class. *Chemistry Education: Research and Practice , 4* (3), 387-395.

Simmel, G. (1950). *The Sociology of Georg Simmel*. New York: Free Press.

Slavin, R. (1989). Research on Cooperative Learning. *Scandinavian Journal of Educational Research , 33* (4), 231-243.

Stewart, D., and Shamdasani, P. (1990). *Focus Groups: Theory and Practice*. London: Sage.

Stuart, J., and Rutherford, R. (1978). Medical Student Concentration During Lectures. *lancet. , 2* (2), 514-516.

The National Center for Case Study Teaching in Science. (2008). *Case collection*. Retrieved May 15, 2009, from The National Center for Case Study Teaching in Science: http://ublib.buffalo.edu/libraries/projects/cases/ubcase.htm

Thurstone, L. (1928). Attitudes Can Be Measured. *American Journal of Sociology , 33* (4), 529-554.

Thurstone, L., and Chave, E. (1929). *The Measurement of Attitudes.* Chicago: Univ. Chicago.

Tourangeau, R., and Rasinski, K. (1988). Cognitive Processes Underlying Context Effects in Attitude Measurement. *Psychological Bulletin , 103* (3), 229-314.

Vaughn, L., and Baker, R. (2001). Teaching in the Medical Setting: Balancing Teaching Styles, Learning Styles and Teaching Methods. *Medical Teacher , 23* (6), 610-612.

Waite, W., Jackson, M., and Diwan, A. (2003). The Conversational Classroom. *34th SIGCSE Technical Symposium on Computer Science Education* (pp. 127-131). New York: ACM.

Ward, J., and Lee, C. (2002). A Review of Problem-Based Learning. *Journal of Family and Consumer Sciences Education , 20* (1), 16-26.

Wee, K., Kek, Y., and Sim, H. (2001). Crafting Effective Problems for Problem-based Learning. *PBL Conference.* Yeppoon.

Wilson, N., and McLean, S. (1994). *Questionnaire Design: A Practical Introduction.* Newton Abbey: University of Ulster Press.

Wood, D. (2003). ABC of Learning and Teaching in Medicine. *BMJ , 326* (7383), 328-330.

Appendices

APPENDIX DESCRIPTION

1. The learning objectives from the traditional spectroscopy course.
2. A typical set of lecture notes from the traditional spectroscopy course.
3. A handout given to students in one of the traditional workshops.
4. The original CEEBL questionnaire
5. The 37 remaining Likert-Statements
6. The Likert statements for the pilot study
7. A report produced by Question Mark Perception
8. Handouts given to students in the pilot study
9. Potential molecules for use in the pilot study
10. Results from the online Questionnaire
11. The final Attitudes Questionnaire (Mid-EBL).
12. Post-lectures questionnaire.
13. Students confidences Pre-EBL questionnaire
14. Student confidences Post-EBL questionnaire
15. Transcript of the first focus group
16. Transcript of interview
17. Transcript of second focus group
18. Handout for waste disposal.
19. The sixteen solvents used
20. The sixteen molecules used in down the drain
21. Handout used in the “down the drain” scenario.
22. Molecules used in the “carbonyl conundrum” scenario.
23. Handout for “Carbonyl Conundrum”
24. Initial spectra provided for the “Reaction Dilemma” scenario

25. Second step in the “Reaction Dilemma” scenario

26. Final step in the “Reaction Dilemma” scenario

27. Facilitators guide to EBL

28. Ice Breaker

29. Introduction to EBL handout

30. Screen shot of discussion boards

31. Mid-EBL short answer responses

32. Post-lecture EBL responses

33. Exam results for spectral interpretation questions 2007 and 2008

APPENDIX 1

Module CHM1C1	10 Credits	Semester 1	Banner Code: 03 21400

Core Chemistry — Structure, Isomerism and Bonding

Lectures	16 hours
Tutorials/Workshops	2 hours [embedded in timetabled classes]
Spectroscopy Workshops	12hours
Continuous Assessment	Spectroscopy Worksheet (Weighting 25%)
Examinations	May/June a single 1.5-hour exam paper (Weighting 75%)

This module aims to provide a basic introduction to the 3D representation of structures, and to various types of isomerism. An introduction to the interpretation of spectra will also be provided.

Lecturer: Dr NM Rowley (16 Lectures)

Learning Outcomes:- ***by the end of this course students should be able to***

- Recognise *constitutional*, *configurational*, and *conformational* isomers;
- Draw accurate line formulae;
- Use systematic nomenclature;
- Know the correct symbols to depict electron movement and various reaction types;
- Recognise *enantiomers*, *diastereoisomers*, and *meso compounds;*
- Assign *R*, *S* and *E*, *Z* nomenclature using the Cahn-Ingold-Prelog priority system;
- Use the *dotted line / wedge* system to depict configurational isomers;
- Use *Newman projections* to depict conformations;
- Sketch appropriate energy / torsion angle diagrams for simple alkyl systems;
- Draw accurate *chair* and *boat* conformations of cyclohexanes;
- Recognise *axial* and *equatorial* substituents in cyclohexanes;
- Interpret simple *mass, infrared*, ^{13}C and ^{1}H *NMR* spectra.

Lectures	Contents
1 - 2	***Constitutional Isomerism and Representation of Structure.*** Overview of constitution, configuration, and conformation as a hierarchy of structural detail. Constitution and constitutional isomerism, connectivity. Line formulae conventions and usage. **Nomenclature.** Systematic nomenclature *(particularly of functional groups).*
3 - 5	***Configuration and Configurational Isomerism.*** Representation of 3D structures using dotted line / wedge representations. Enantiomers and diastereoisomers. *Terminology*: chiral, achiral, stereogenic, racemic, and meso structures. Cahn-Ingold-Prelog priority system: *R* and *S*, *E* and *Z* nomenclature.
6 - 7	***Conformation and Conformational Isomerism.*** Newman projections: energy barriers in ethane, propane, and butane. Cyclohexane ring systems as an example of conformational restraint - axial and equatorial substituents. Energy

barriers to interconversion. Configurational isomerism in substituted cyclohexanes.

8 - 9 **Class Workshops**

10 - 16 **Spectroscopy.** Mass spectrometry, electromagnetic spectrum, IR spectroscopy, NMR spectroscopy (^{13}C and ^{1}H), elemental analysis, UV-Visible spectroscopy, and integrated problem solving.

Recommended Texts:

Organic Chemistry 3rd Edition by Maitland Jones, Jr

APPENDIX 2

CHM1C1: Infrared Spectroscopy

- Infrared spectroscopy provides the best means of identifying the functional groups present in a molecule

- The absorption by a substance of radiation in the region of 4000 to approximately 400 cm^{-1} is measured (note the unusual units - $\mathbf{cm^{-1}}$)

Frequency (ν)/Hz	**Wavelength (λ)/m**	**Wavenumber/cm^{-1}**	**Energy/$kJmol^{-1}$**
1.20×10^{13}	2.50×10^{-5}	400	4.79×10^{3}
1.20×10^{14}	2.50×10^{-6}	4000	4.79×10^{4}

Frequency, wavelength and energy are interrelated: $\mathbf{c = \nu\lambda}$

Where c = velocity of light (3.00×10^{8} ms^{-1}), ν = frequency (Hz), λ = wavelength (m)

and $\mathbf{E} = \boldsymbol{h\nu}$

E = energy and h = Planck constant (6.63×10^{-34} Js)

- Within a molecule every bond vibrates, giving rise to a change in its dipole moment. It is this *change* in dipole moment which provides a mechanism for the absorption of radiation

- The vibrational energy is such that radiation is absorbed in the *infrared* region (*i.e.*, at a lower frequency and hence lower energy than visible light)

- As a consequence, every bond in a molecule has an absorption peak either in the infrared spectrum or in the Raman spectrum of the molecule

- Consequently, every substance has its own unique infrared spectrum, so an organic material can be identified by comparing its infrared spectrum to that of a known sample

- In addition, each different functional group, such as O-H, C-H or C=C, absorbs within a narrow range of frequencies. Therefore, a functional group can be identified in a molecule by the presence of an absorption band in a particular range of the infrared spectrum

- The frequency at which a bond absorbs radiation is dependent upon the masses of the atoms which form the bond

- Bonds which absorb radiation at the upper end of the frequency range are those involving a light atom, hydrogen, with a heavier atom, *e.g.* carbon, nitrogen or oxygen. Hydrogen, being light, vibrates strongly and rapidly, so a strong, high energy absorption is seen

- Vibrations of two heavier atoms, *e.g.* C-C, C-N, C-O can be seen at lower frequencies

- Vibrations of the heavier atoms bonded to very heavy atoms, *e.g.* C-Cl, C-Br, C-I are found at the lowest energies

- Within this general trend, it is also useful to note that multiple bonds absorb higher energy radiation than single bonds, and so the C≡C bond absorbs at higher frequency than the C=C bond

Infrared spectrometers:

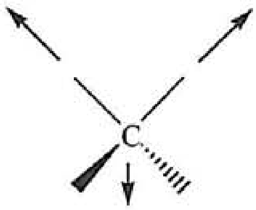
- Conventional infrared spectrometers use two beams of radiation: one of which passes through the sample, and the other passes through a reference cell. A monochromator is used to select radiation of only one frequency at a time (monochromatic radiation)

- Fourier Transform Infra Red (FTIR) spectrometers use just one beam. Consequently, all of the required frequencies pass through the instrument simultaneously. A computer is then used to interpret the resulting information (by a mathematical treatment known as Fourier transformation) to give the infrared spectrum

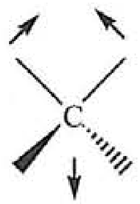
Sample preparation:

- Samples can be prepared in a number of different ways:
    - As a gas (need special cell)
    - As a pure liquid
    - As a mull (*e.g.* Nujol - long-chain hydrocarbon)
    - As a KBr disc
    - Using a solvent

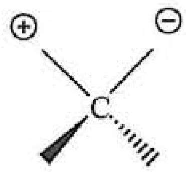
Examples of some modes of vibration:



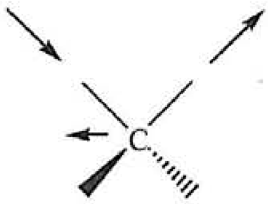
Symmetrical stretching



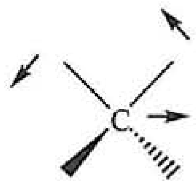
Bending or Scissoring



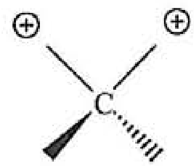
Twisting or out-of-plane bending



Asymmetrical stretching



Rocking or in plane bending



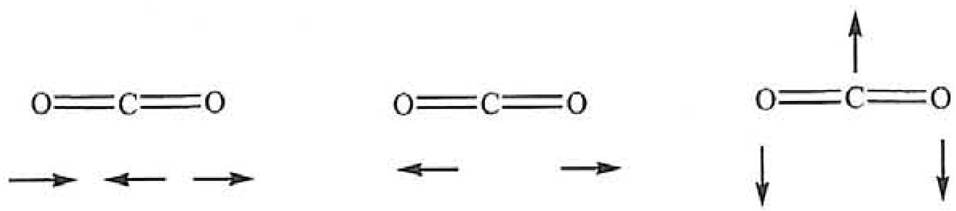
Wagging or out-of-plane bending

$\oplus$ and $\ominus$ denote movement out of and into the plane of paper respectively

- Only those vibrations which result in a *change* in dipole moment, and having resonant frequencies in the infrared region of the spectrum, will absorb infrared radiation

- Simple gas molecules such as H_2, Cl_2 and O_2 do not therefore have infrared spectra (as they do not have dipoles)

- The CO_2 molecule has a number of ways of absorbing energy and vibrating:



Asymmetrical stretch	Symmetrical stretch	Bending: 2 modes at right angles to each other
2360 cm^{-1}	inactive in IR	670 cm^{-1}

- Note that the symmetrical stretch shown above does not involve a *change* in the dipole of the molecule. This mode would not therefore be expected to absorb radiation (this mode is said to be *inactive*). The other modes shown do change the dipole of the molecule and therefore absorb infrared radiation (they are said to be *active* modes)

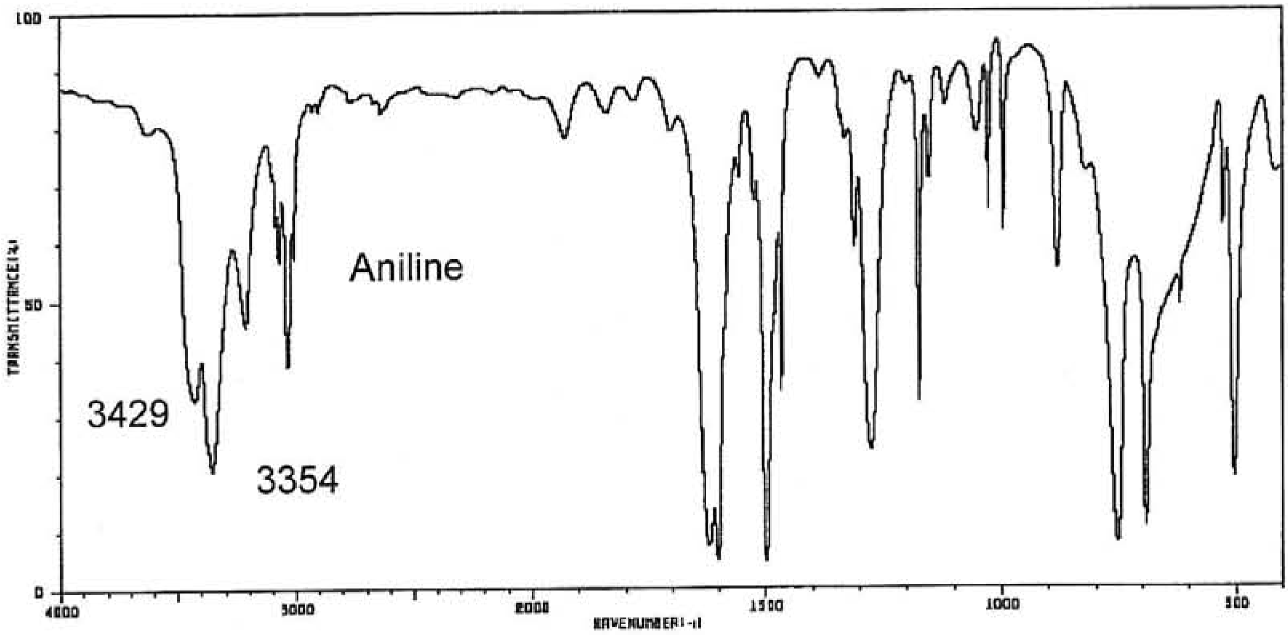
Interpretation of spectra

The infrared spectrum can conveniently be split into four regions for interpretation:

- **4000-2500 cm^{-1}**: absorption of single bonds to hydrogen, *e.g.* C-H, O-H, N-H
- **2500-2000 cm^{-1}**: absorption of triple bonds, *e.g.* C≡C, C≡N
- **2000-1500 cm^{-1}**: absorption of double bonds, *e.g.* C=C, C=O
- **1500-400 cm^{-1}**: absorption due to other bond deformations, *e.g.* rotating, scissoring, bending

4000-2500 cm^{-1}:

The high frequency is explained by the low mass of the hydrogen atom. A different spectrum is produced if deuterium (^2H) is present – the C-H stretch of $CHCl_3$ (3020 cm^{-1}) is at a higher frequency than the C-D stretch of $CDCl_3$ (2260 cm^{-1})



N.B. The spectrum records the amount of radiation transmitted at each frequency, so the maximum absorption occurs when the least light is transmitted (at the bottom of the spectrum)

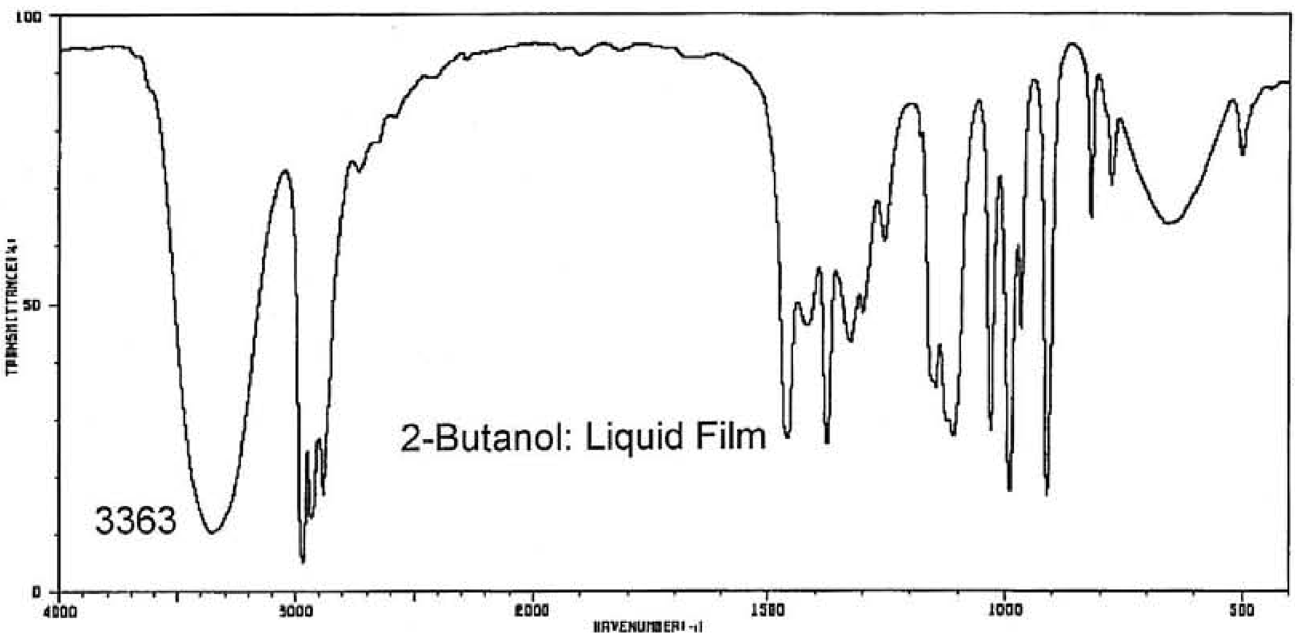
e.g. Aniline (phenylamine) – has an NH_2 group, which characteristically absorbs in the region between 3500-3250 cm^{-1}. The spectrum has two peaks (at 3429 and 3354 cm^{-1})

- The two peaks do NOT represent one peak for each of the N-H bonds. The N-H bonds are indistinguishable, and therefore must have identical absorption frequencies. The two peaks result from the in-phase and out-of phase vibrations of the N-H bonds:

In-phase or symmetric vibration **Out-of-phase or antisymmetric vibration**

- O-H bond absorbs between 3700-3200 cm^{-1}

*e.g.*2-Butanol*:* O-H bond absorbs at 3363 cm^{-1}

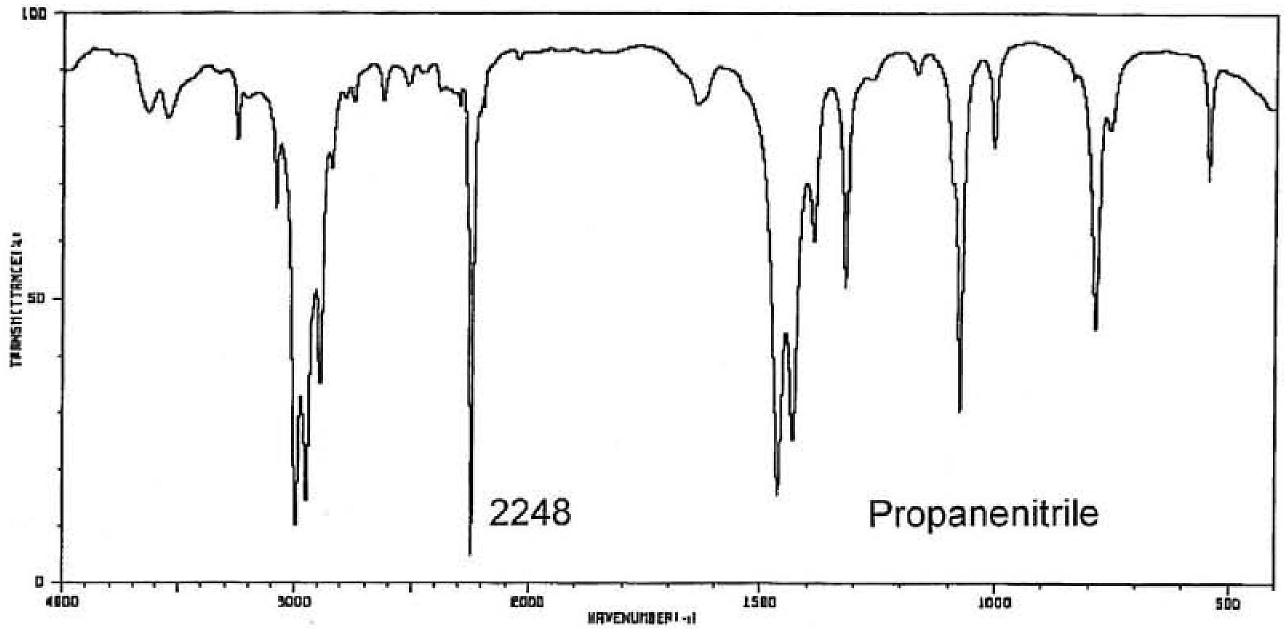


$2500\text{-}2000\ cm^{-1}$:

Relatively high frequencies are required to provide the high energies necessary to make the strong triple bonds vibrate

- C≡N absorbs 2300 – 2200 cm^{-1}
- C≡C absorbs 2250 – 2100 cm^{-1} (particularly weak if neither carbon atom is bonded to hydrogen)

e.g. Propanenitrile: C≡N bond absorbs at 2248 cm^{-1}

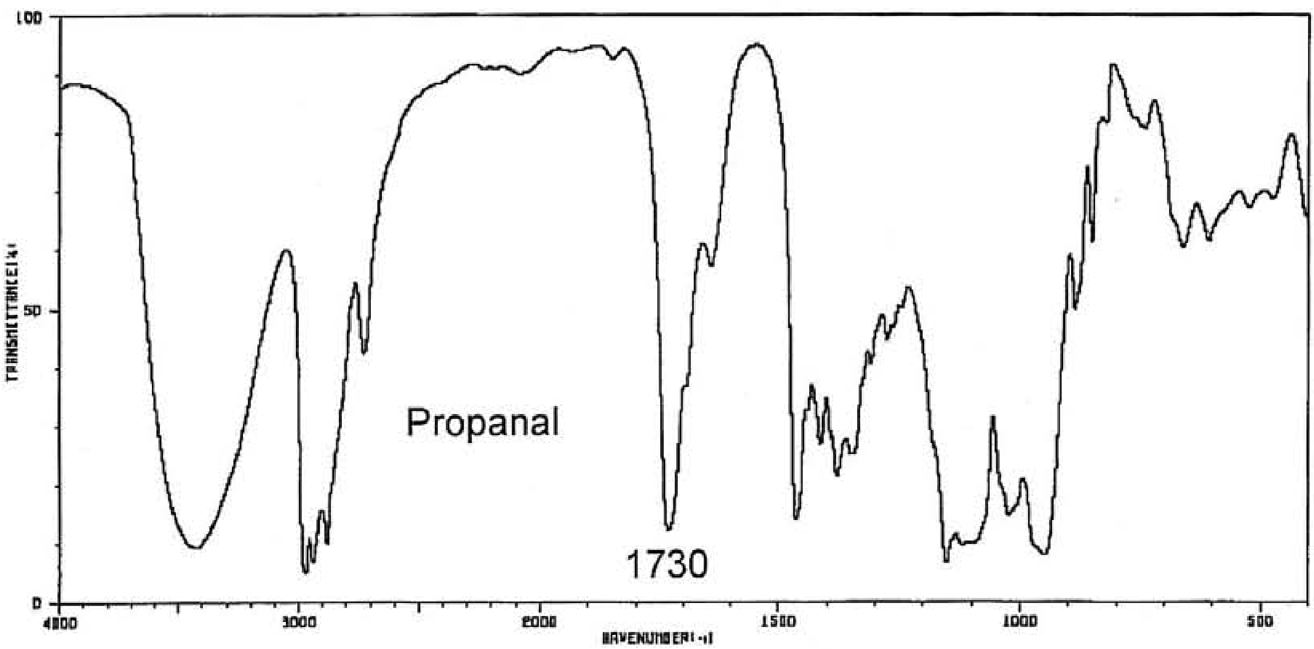


2000-1500 cm^{-1}:

Double bonds generally absorb in this region (C=O, C=C, C=N)

- C=O: 1850-1640 cm^{-1}, unusually wide range - variation in position useful diagnostically

e.g. Propanal: C=O bond absorbs at 1730 cm^{-1}



- C=C :
  - o 1680-1620 cm^{-1} in unconjugated systems
  - o can be as low as 1590 cm^{-1} in conjugated systems

- Note that C=C absorptions are often weak, especially when they are fully substituted and they are then easily missed

- In aromatic systems, C-C bonds usually have two or three absorption peaks between *ca.* 1600 and 1500 cm^{-1}, usually with the strongest peak at *ca.* 1500 cm^{-1}

1500-400 cm^{-1} (Fingerprint region):

- Absorptions in this region are due to deformations such as rotating, scissoring, and some bending and depend on the combination of bonds in the molecule

- This part of spectrum is unique to each compound, and so is known as the "fingerprint" region

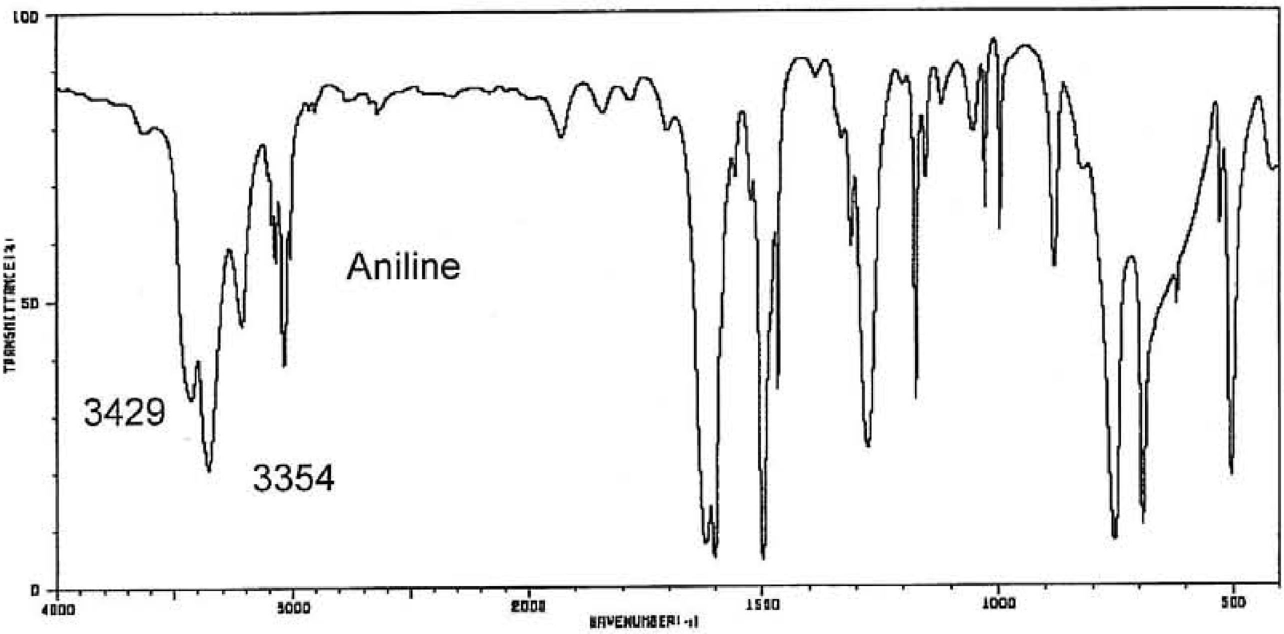
- This region is rarely used for identifying particular functional groups, but some generalisations can be made:

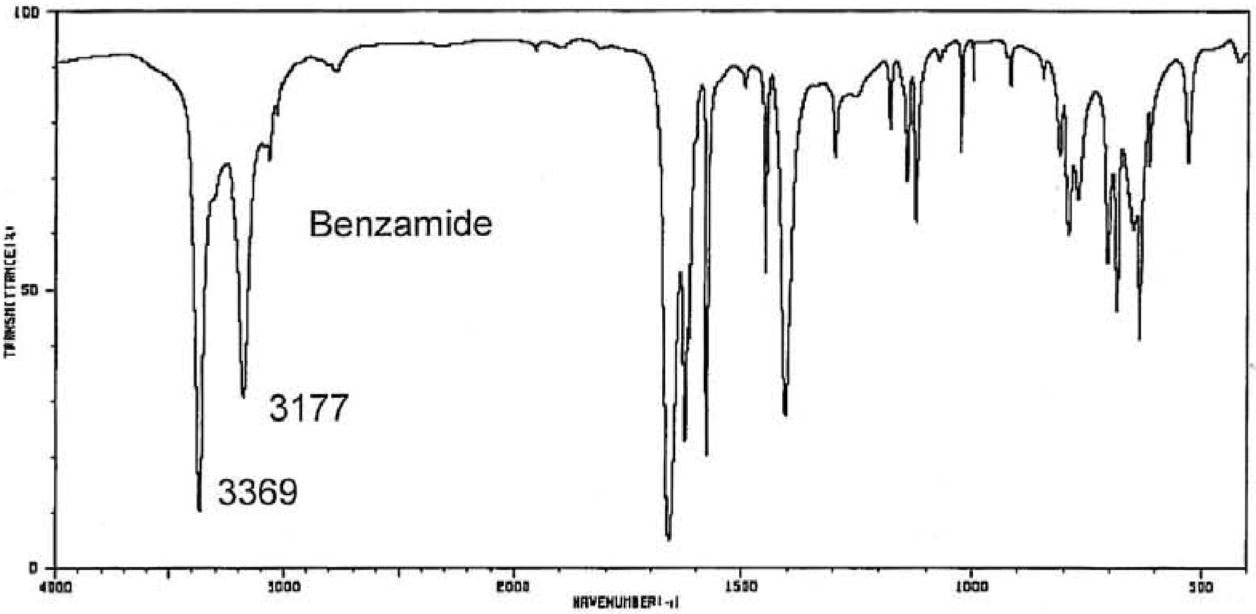
  - e.g. C-O absorbs at 1300-1020 cm^{-1}, however absorption here is not exclusive to C-O

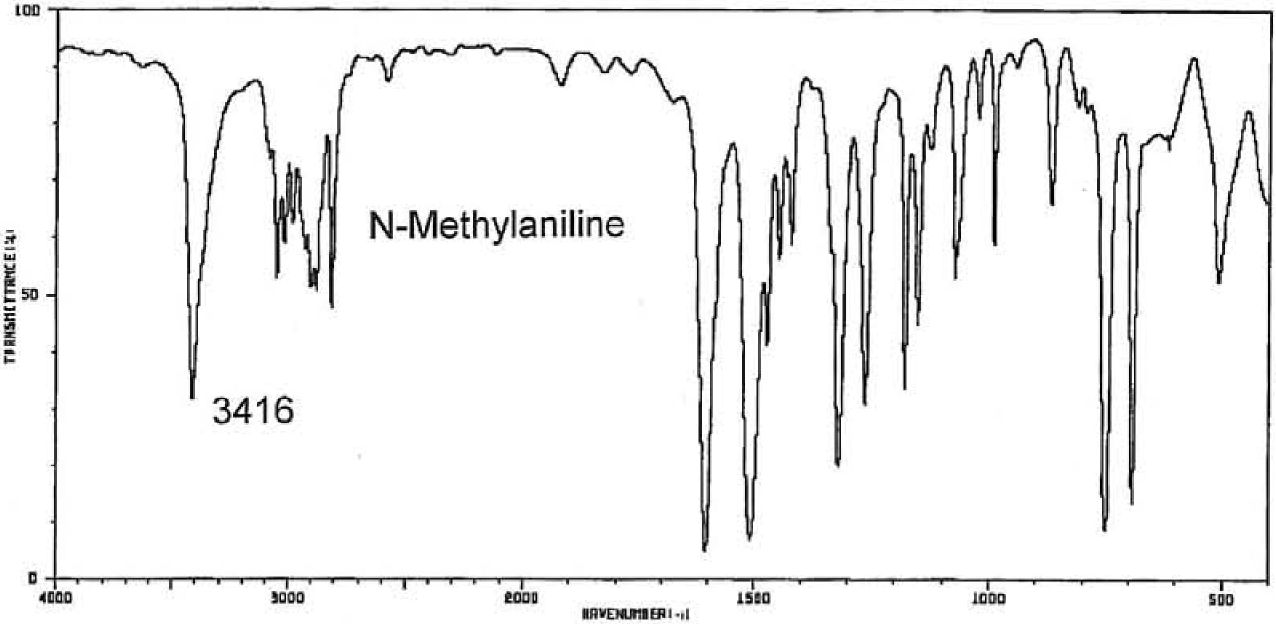
  - C-Cl bond absorption between 800-400 cm^{-1}. Note that C-Br and C-I bonds usually absorb at too low a frequency for most spectrometers.

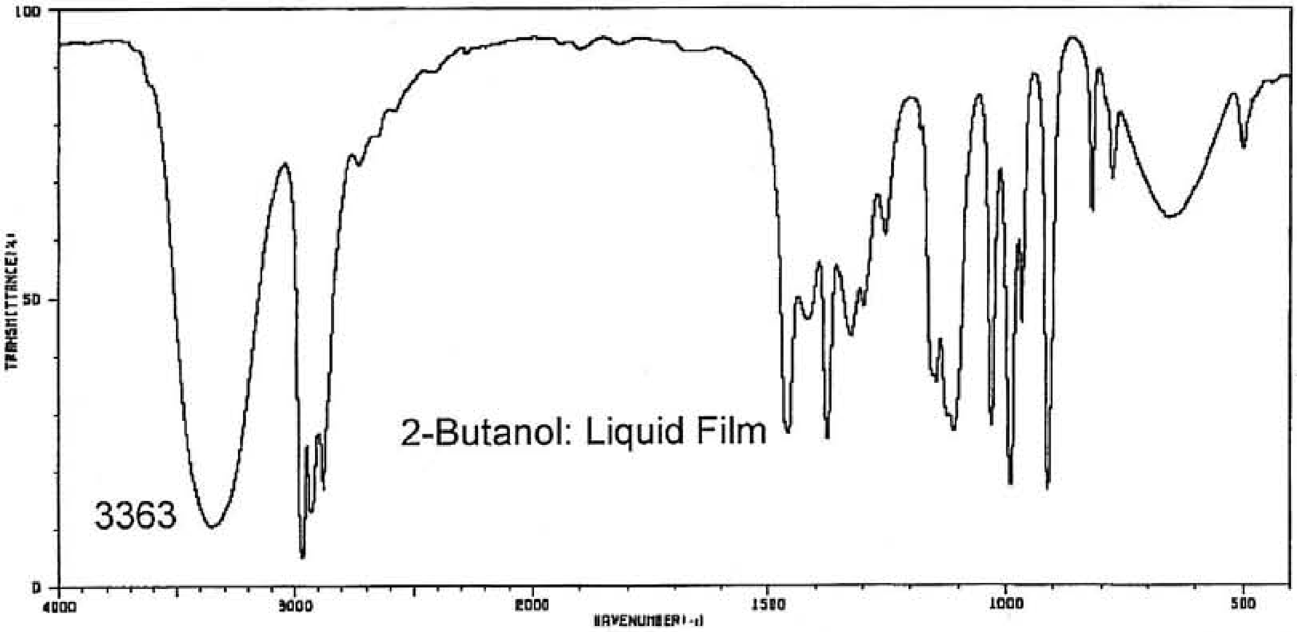
Infrared absorption frequencies of some common functional groups	
Functional group	**Approx. Absorption range / cm^{-1}**
N-H	3500 - 3250
CON-H	3500 - 3000
O-H	3700 - 3200
COO-H	3200 - 2200
C-H	3100 - 2700
C≡N	2300 - 2200
C≡C	2250 - 2100
C=O	1850 - 1640
C=C (unconjugated)	1680 - 1620
C=C (conjugated)	Can be as low as 1590
C-C Aromatic	1600-1500
C-Cl	800 - 400

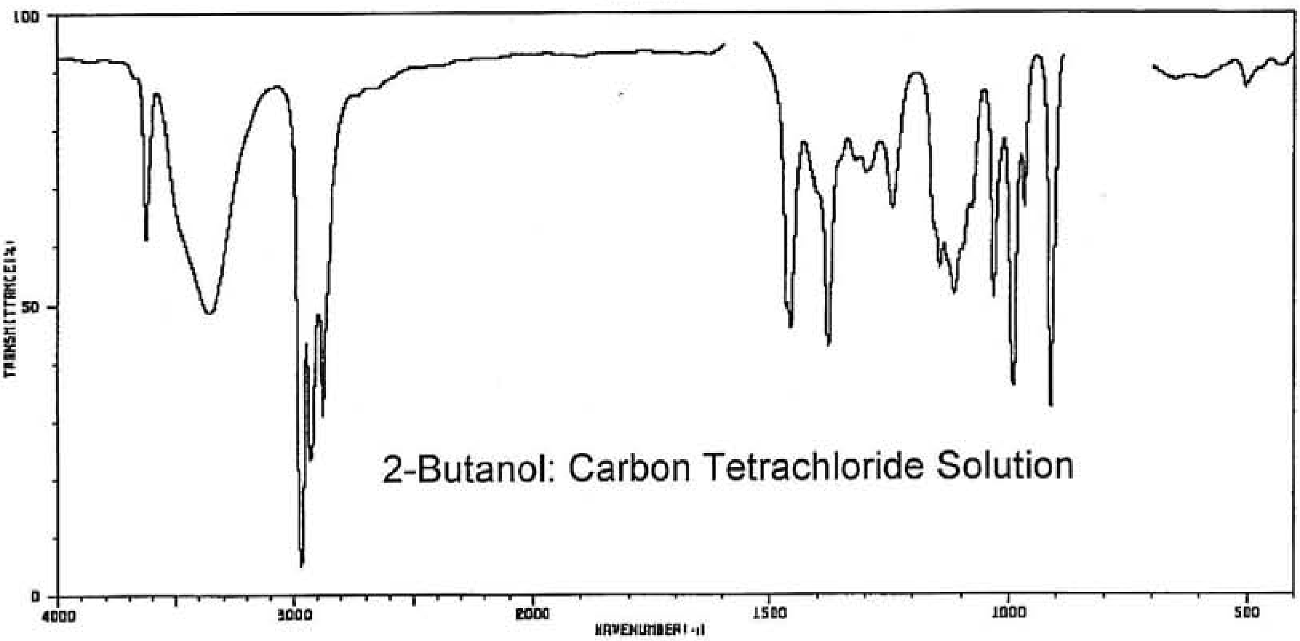
Further Examples:

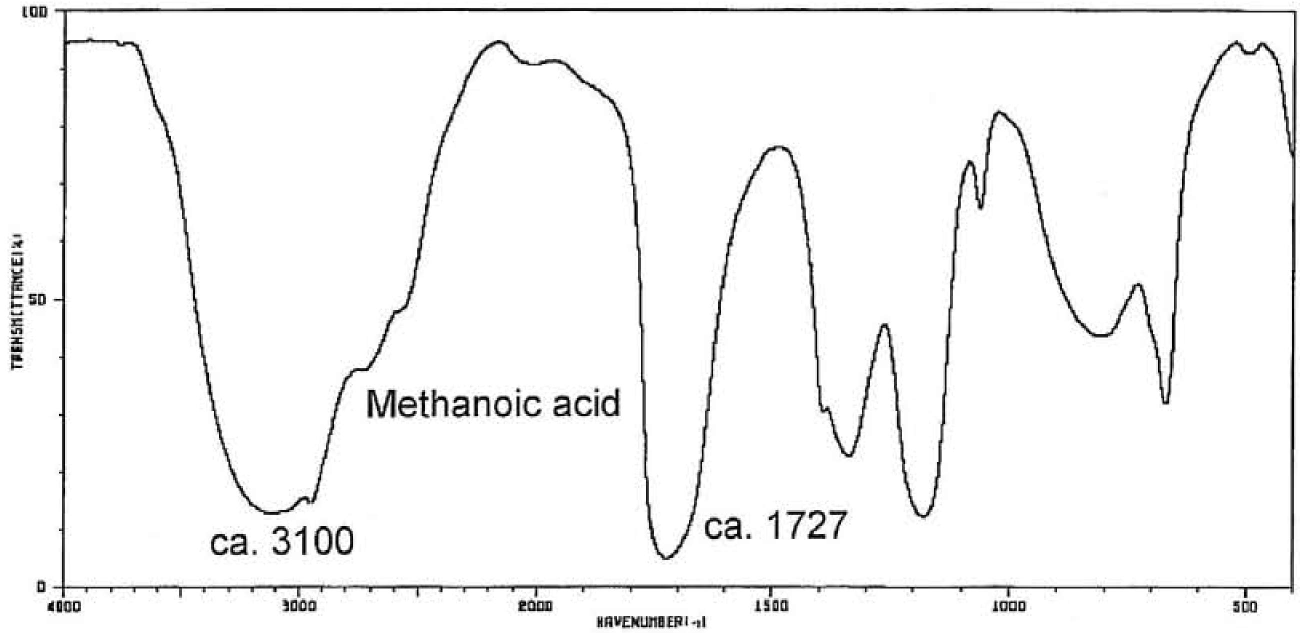


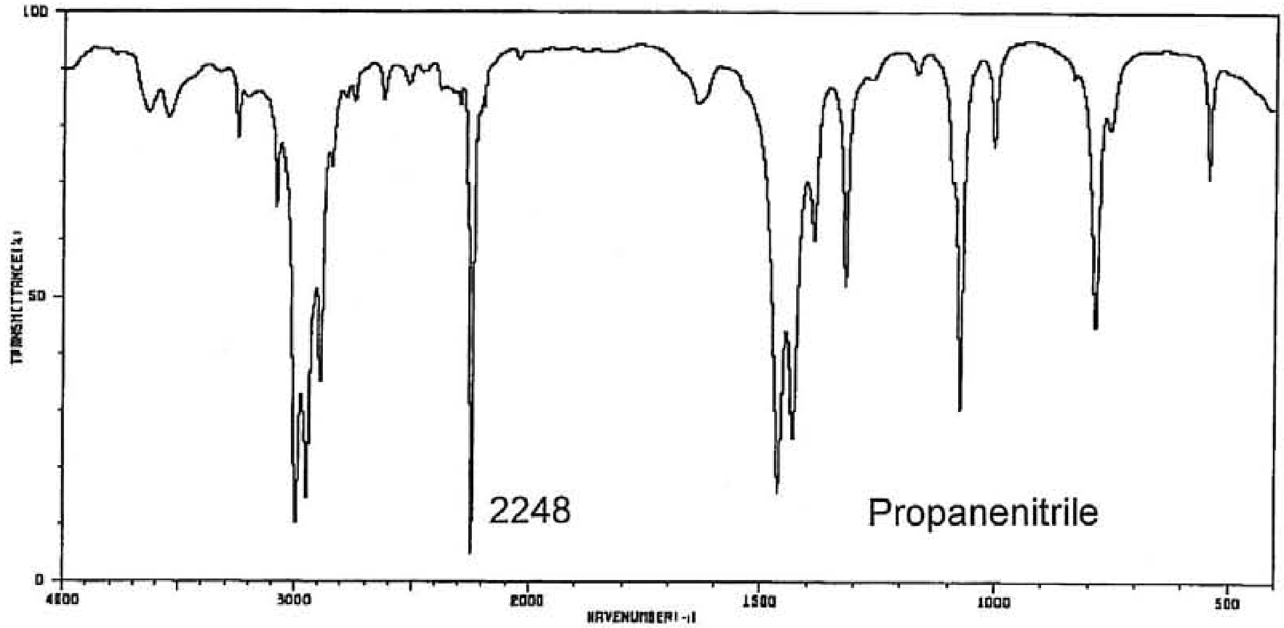


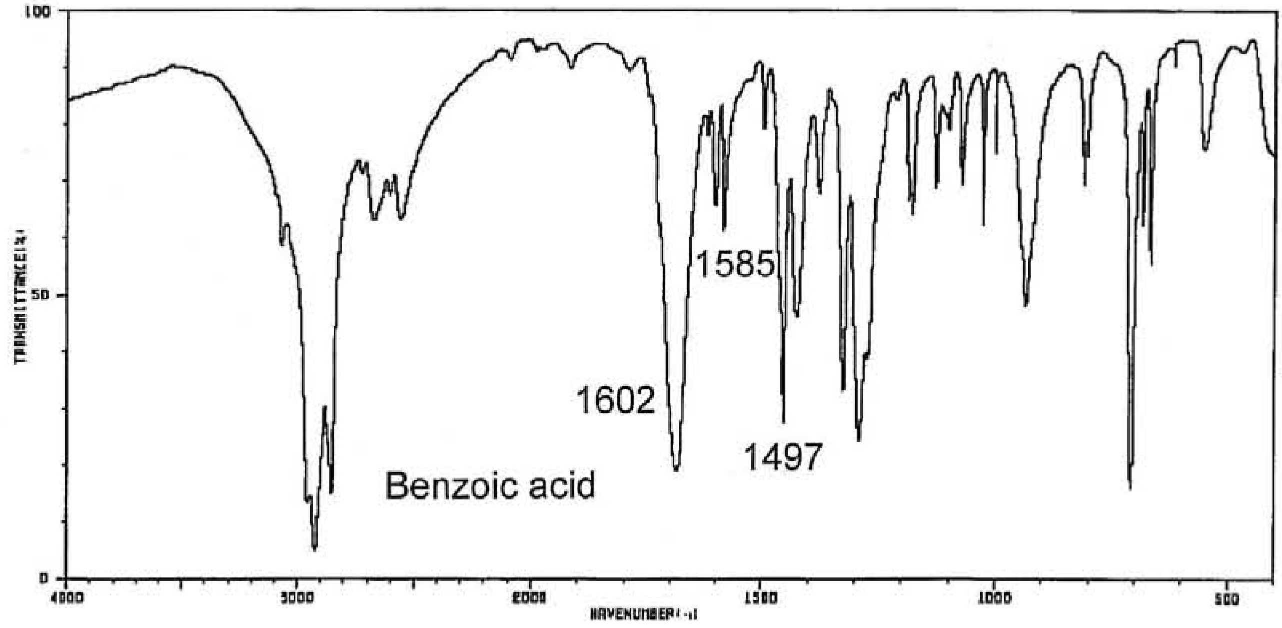

N-Methylaniline
3416
TRANSMITTANCE(%)
WAVENUMBER(-1)

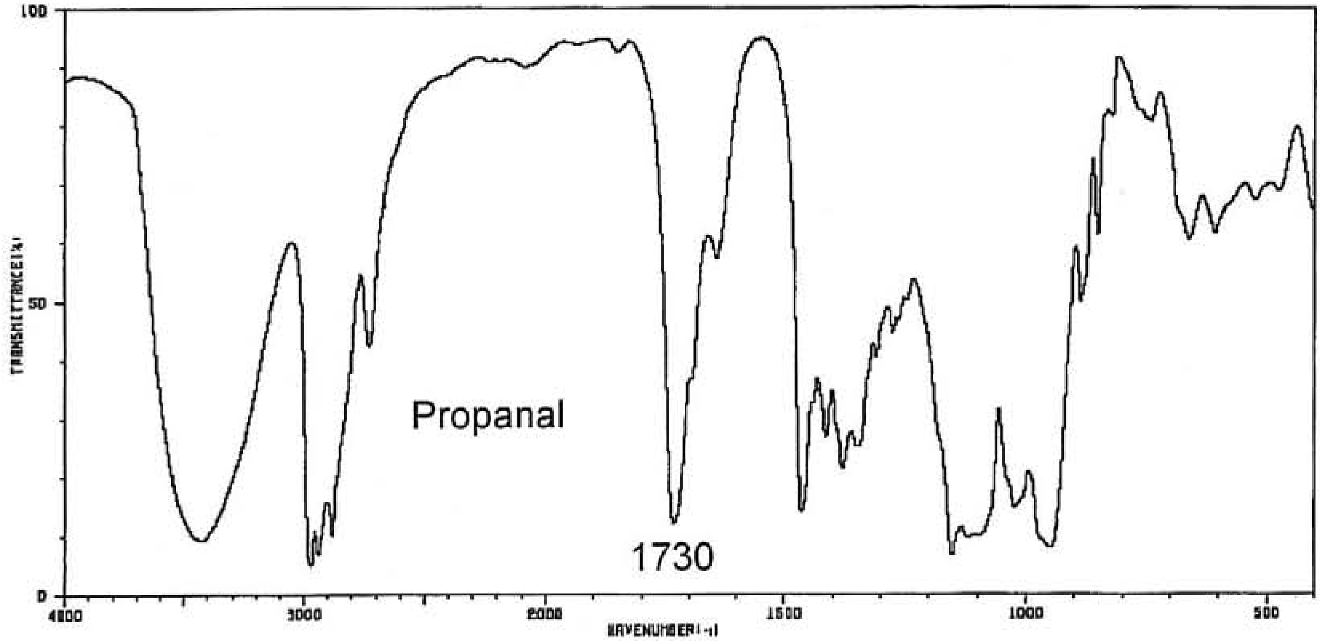

2-Butanol: Liquid Film
3363
TRANSMITTANCE(%)
WAVENUMBER(-1)

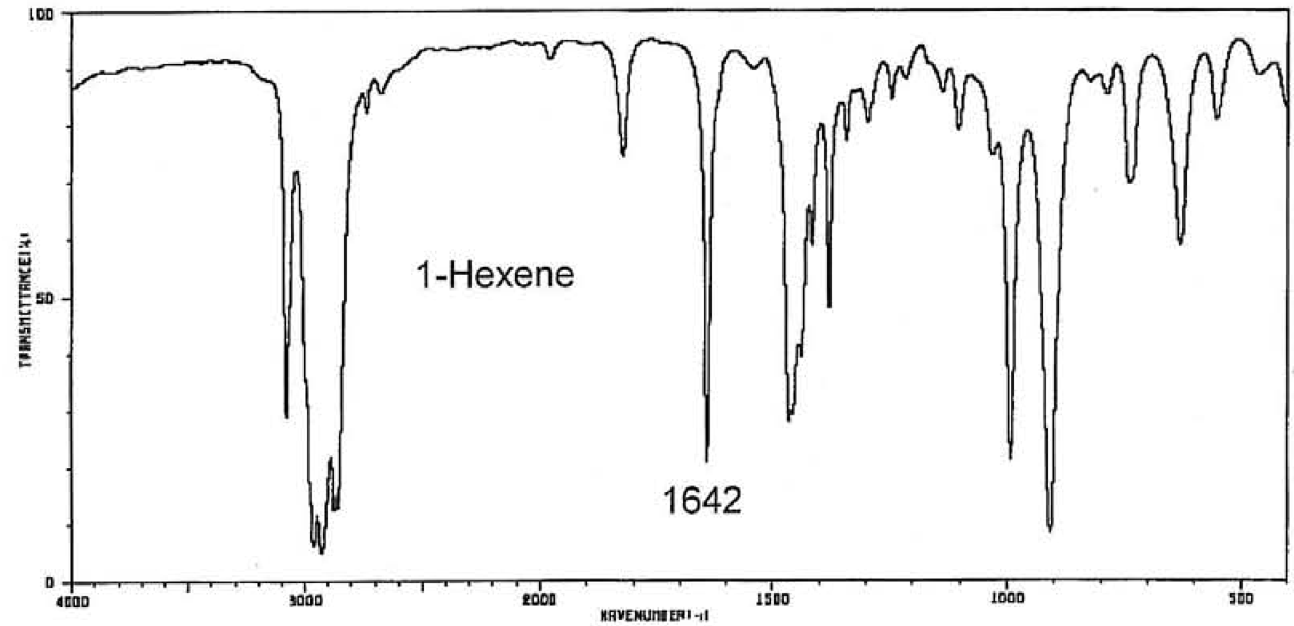

2-Butanol: Carbon Tetrachloride Solution
TRANSMITTANCE(%)
WAVENUMBER(-1)

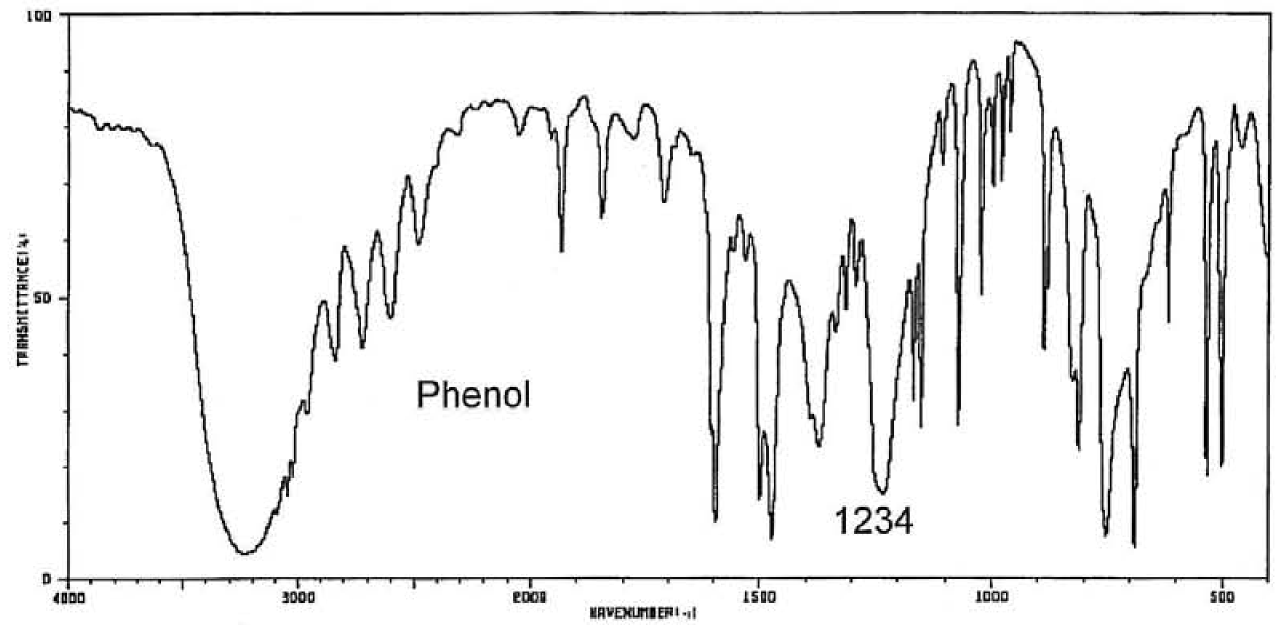

TRANSMITTANCE(%)
Methanoic acid
ca. 3100
ca. 1727
WAVENUMBER(-1)


TRANSMITTANCE(%)
2248
Propanenitrile
WAVENUMBER(-1)


TRANSMITTANCE(%)
1585
1602
1497
Benzoic acid
WAVENUMBER(-1)


100
50
0
4000
3000
2000
1500
1000
500
Propanal
1730


100
50
0
4000
3000
2000
1500
1000
500
1-Hexene
1642


100
50
0
4000
3000
2000
1500
1000
500
Phenol
1234

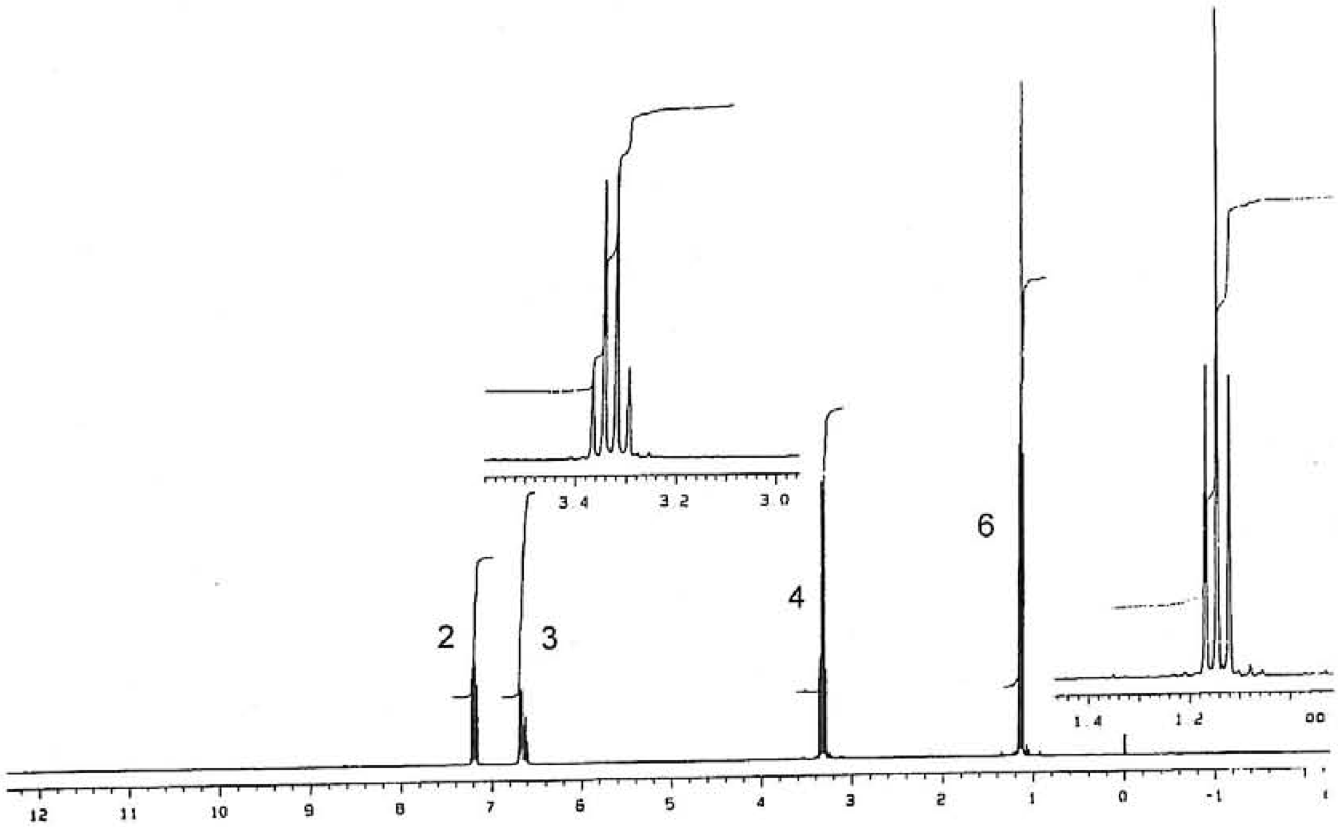
APPENDIX 3

CHM1C1
Spectroscopy

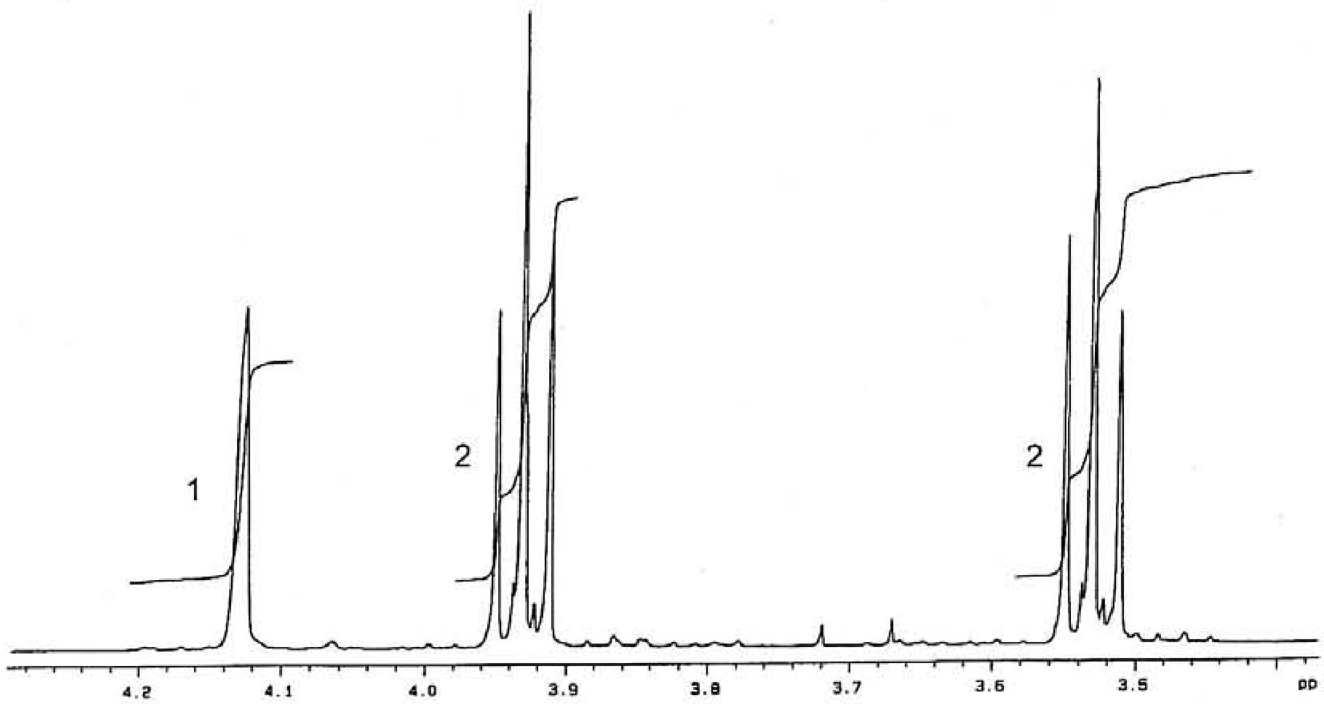
Workshop 4

Use the spectra provided to determine the identity of compounds 1-8. Try to use all of the spectra provided for each compound to justify your decision

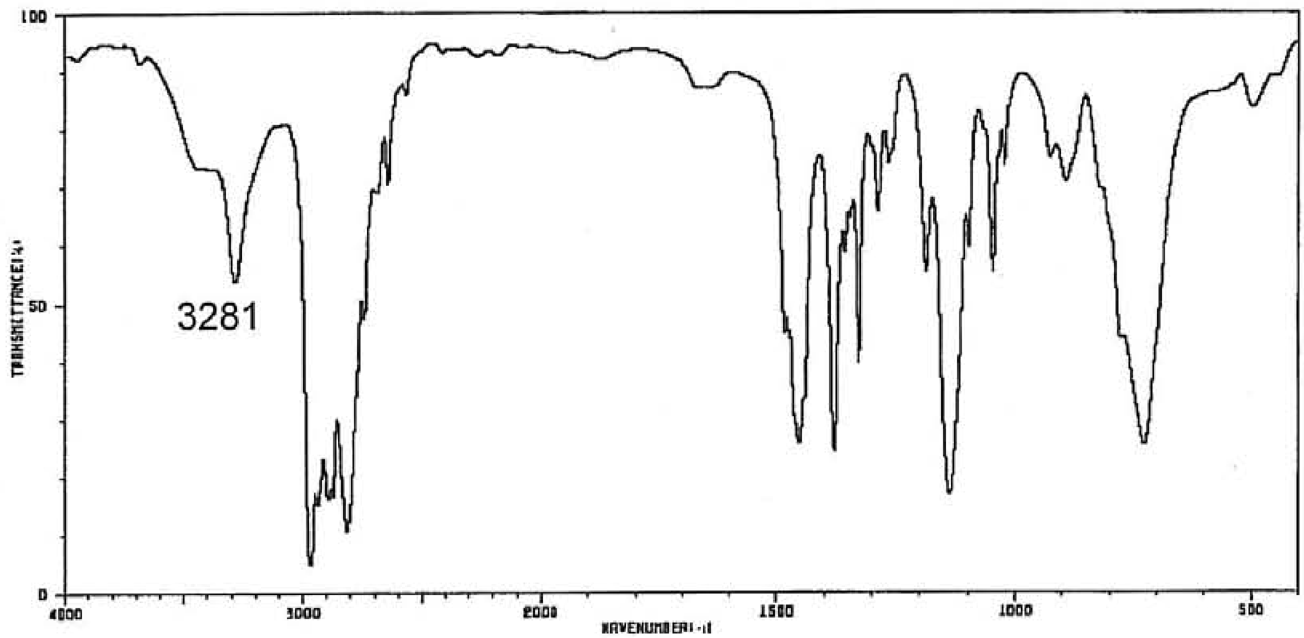
1 $C_{10}H_{15}N$



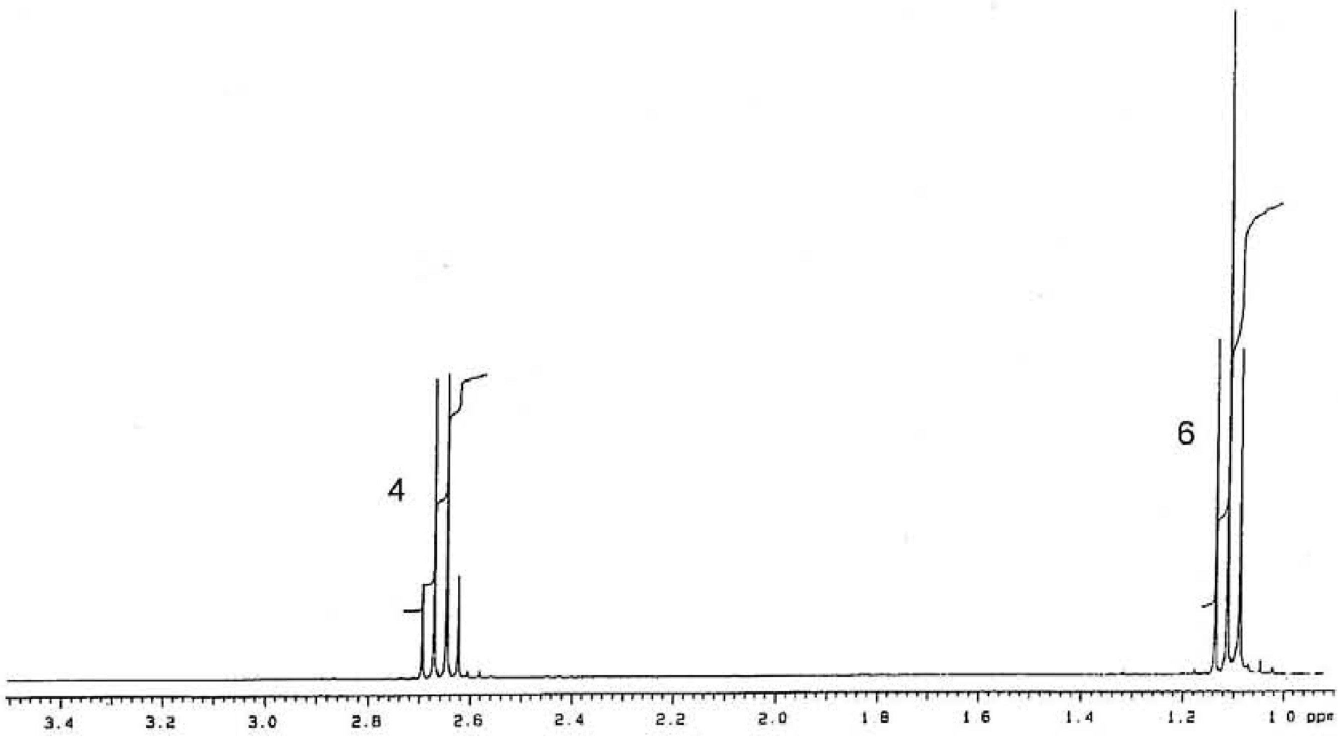
2 C_2H_5OBr



3 $C_4H_{11}N$

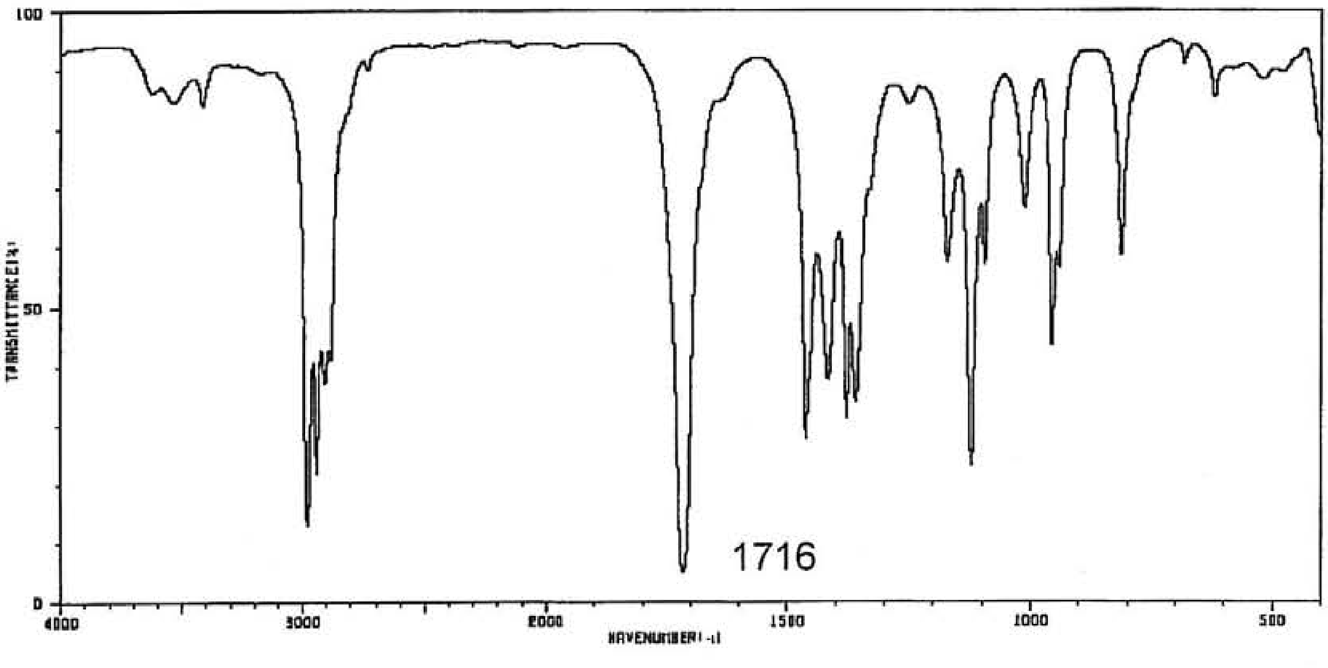


100
50
0
TRANSMITTANCE(%)
3281
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)

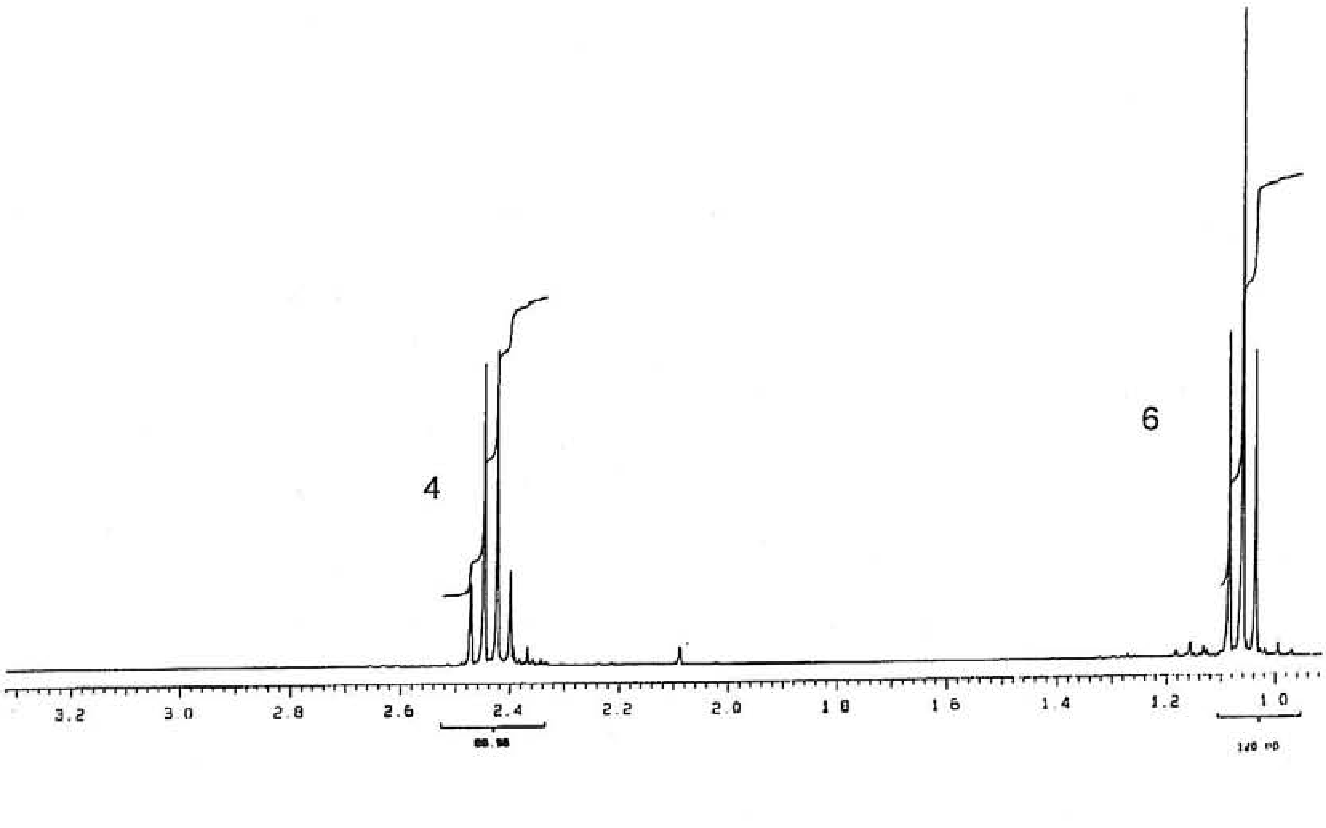


4
6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0 ppm

4 $C_5H_{10}O$

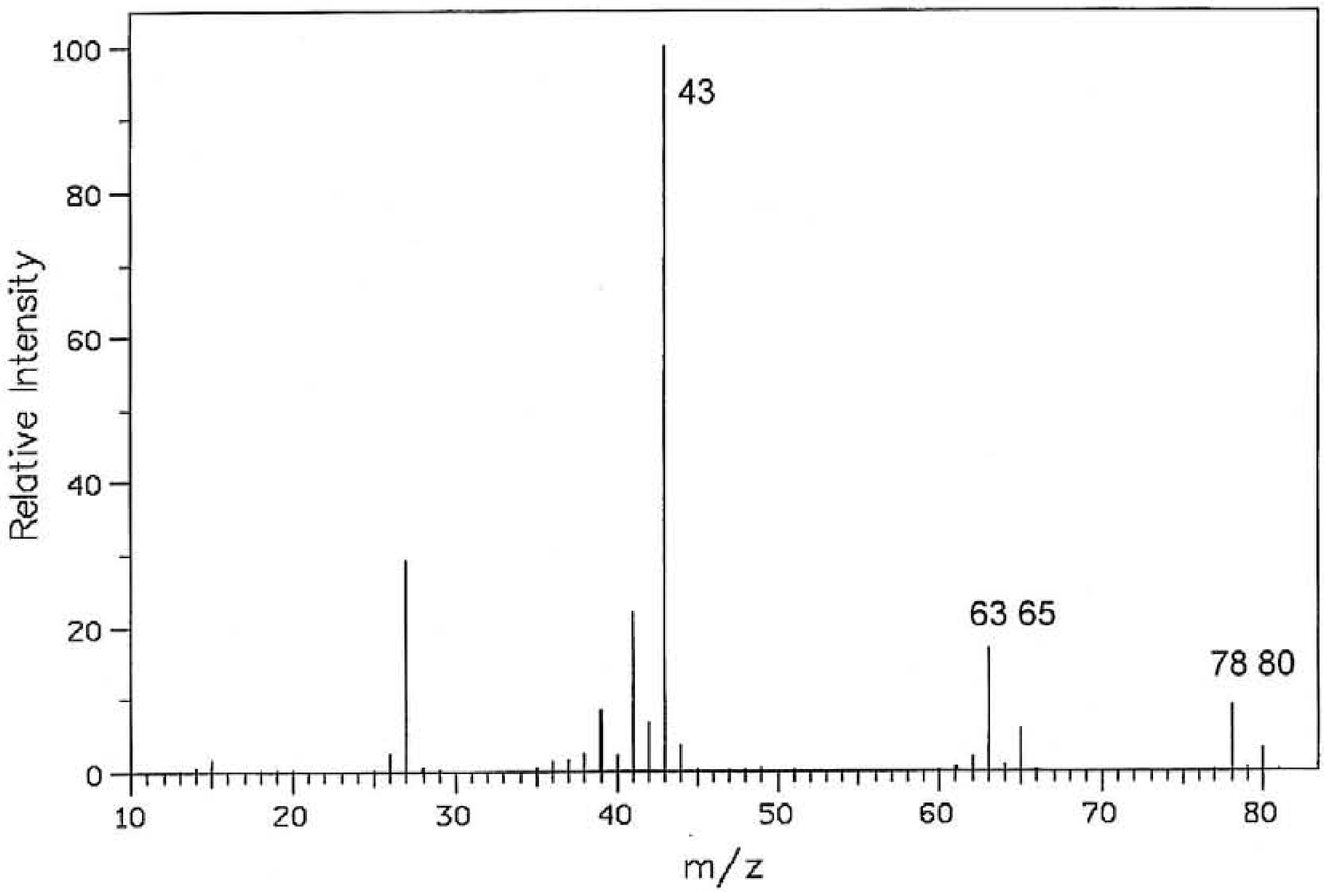


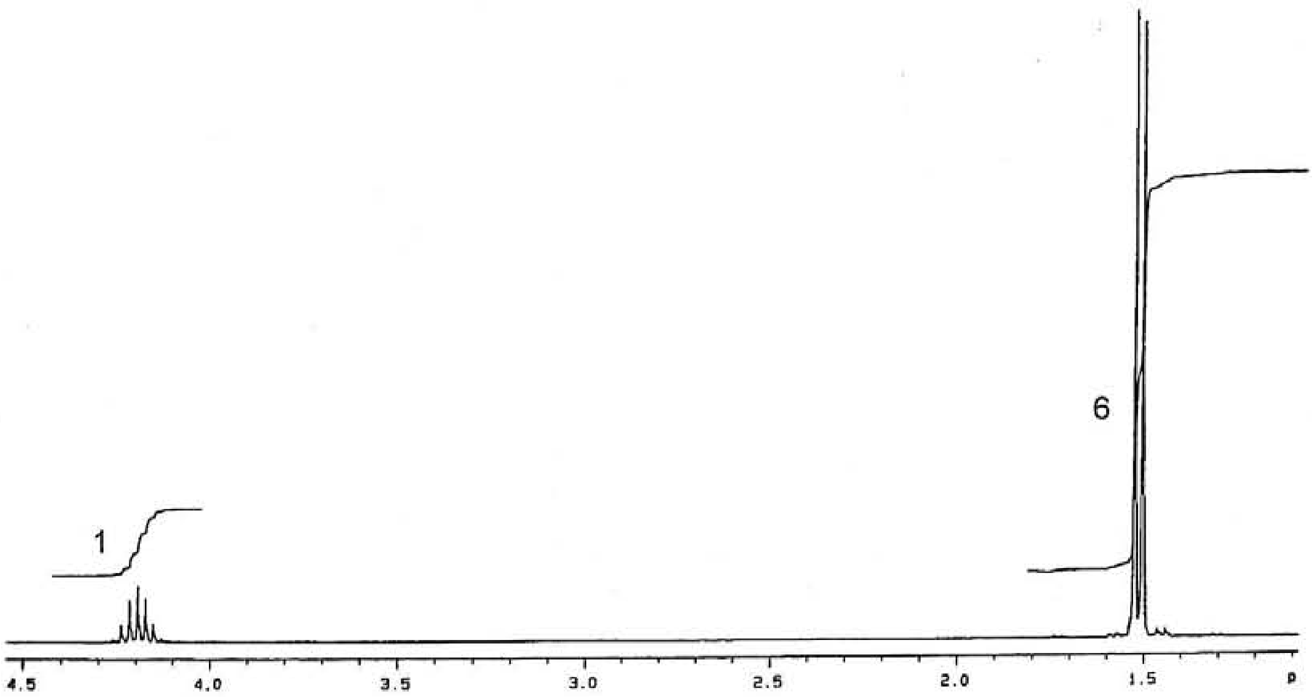
100
50
0
TRANSMITTANCE(%)
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)
1716



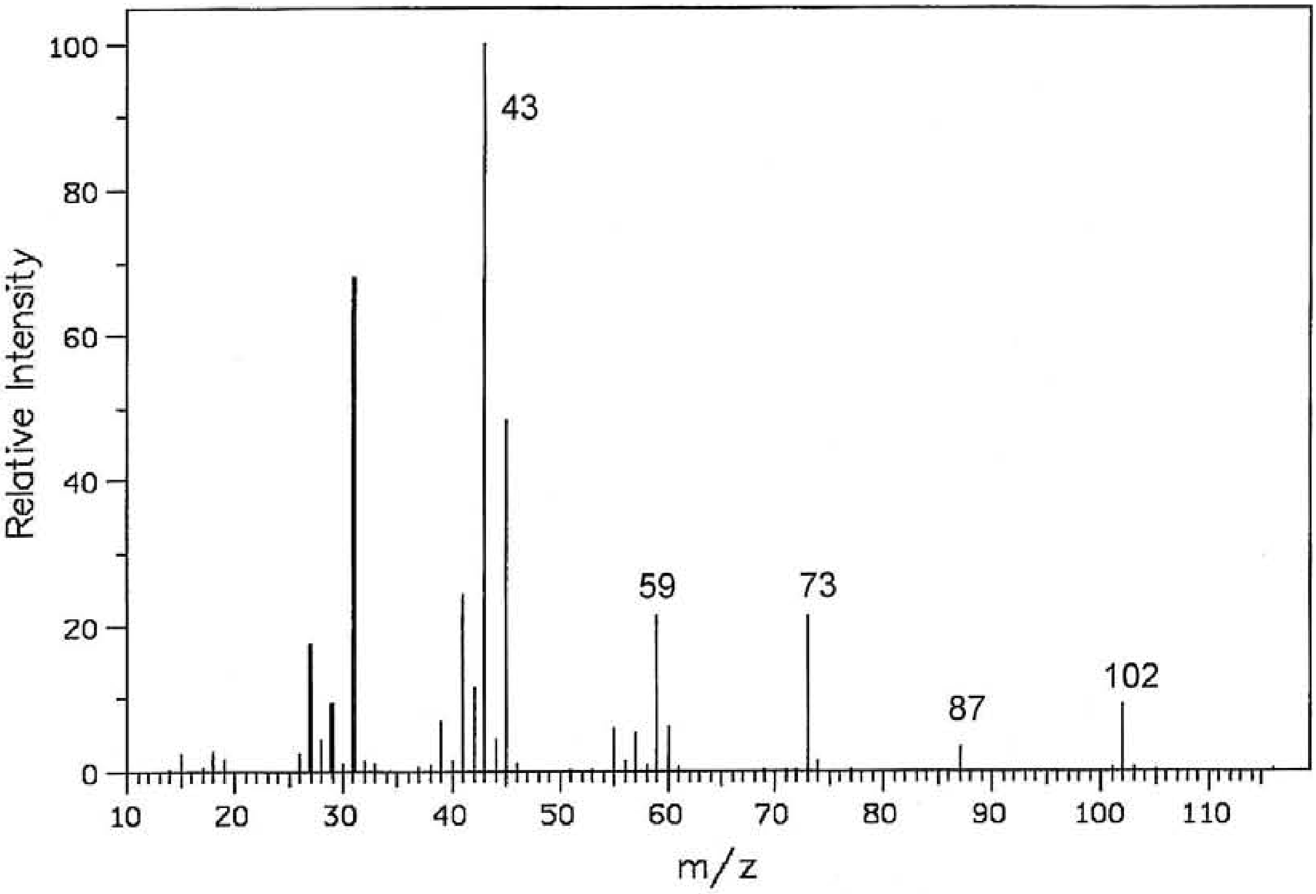
4
6
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0

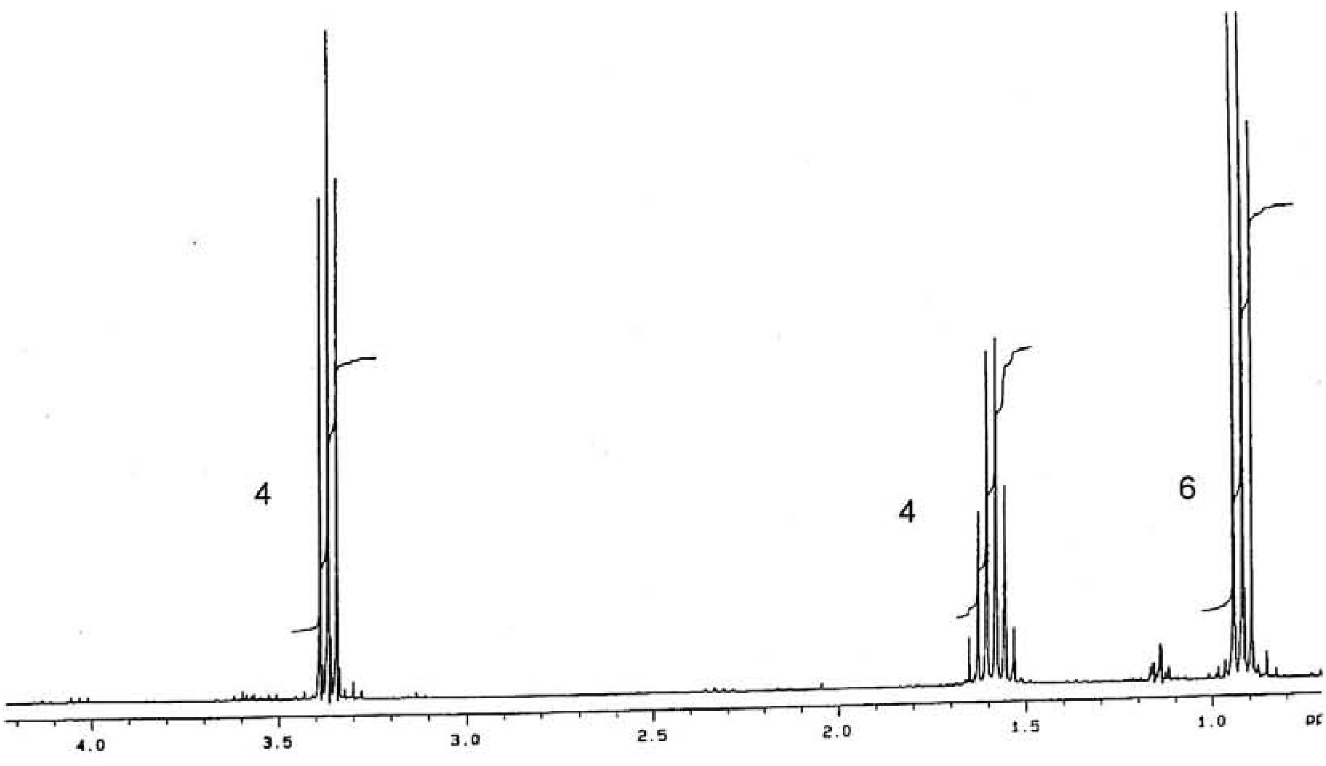
5 Molecular weight: 78



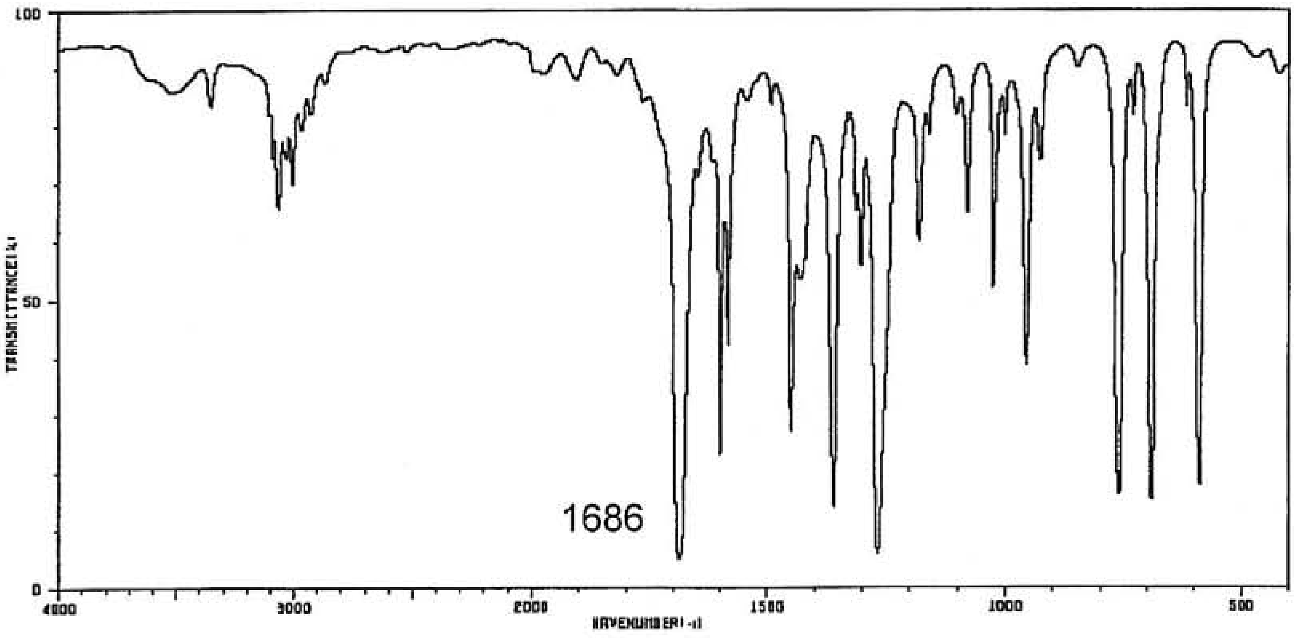


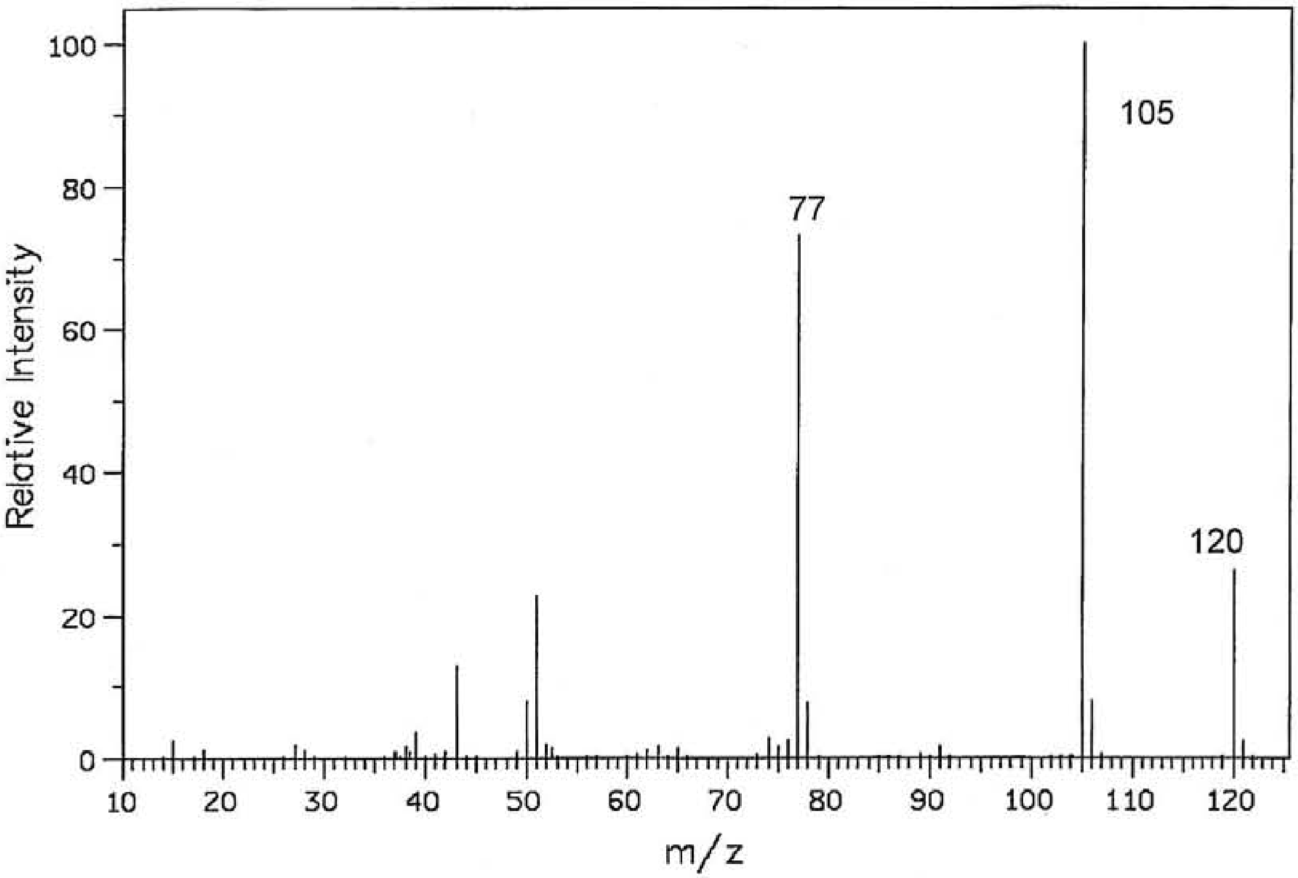
6 Molecular weight: 102

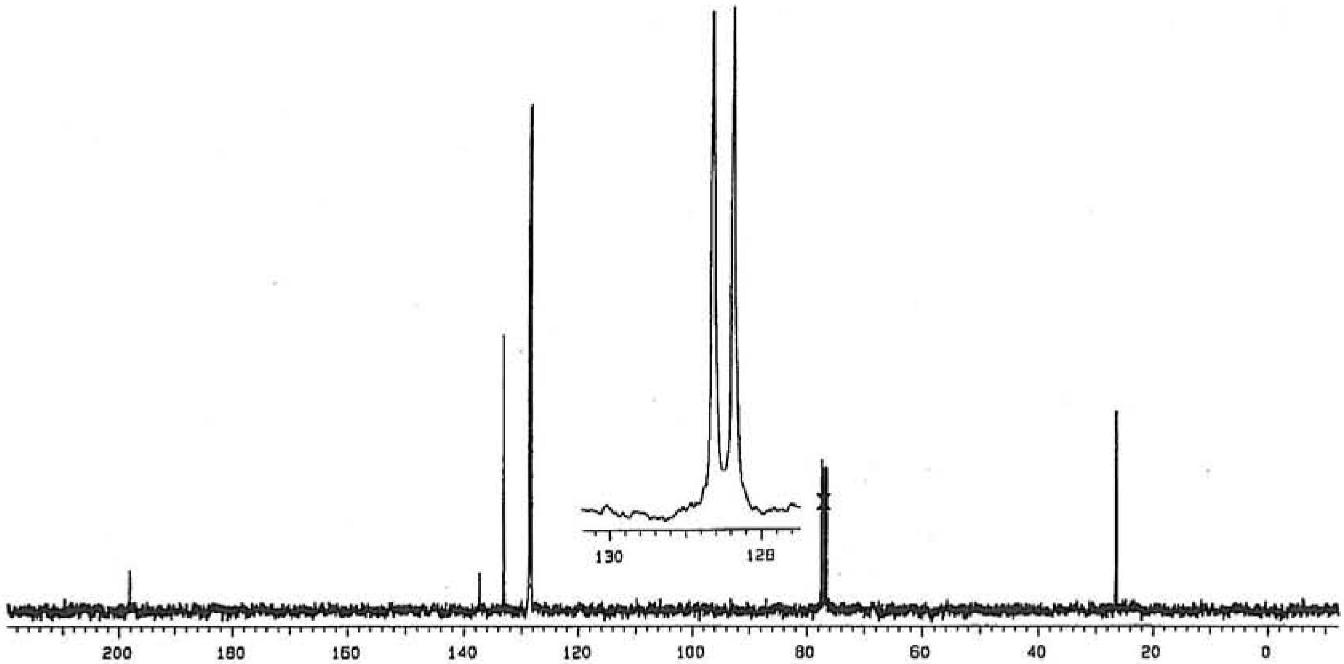




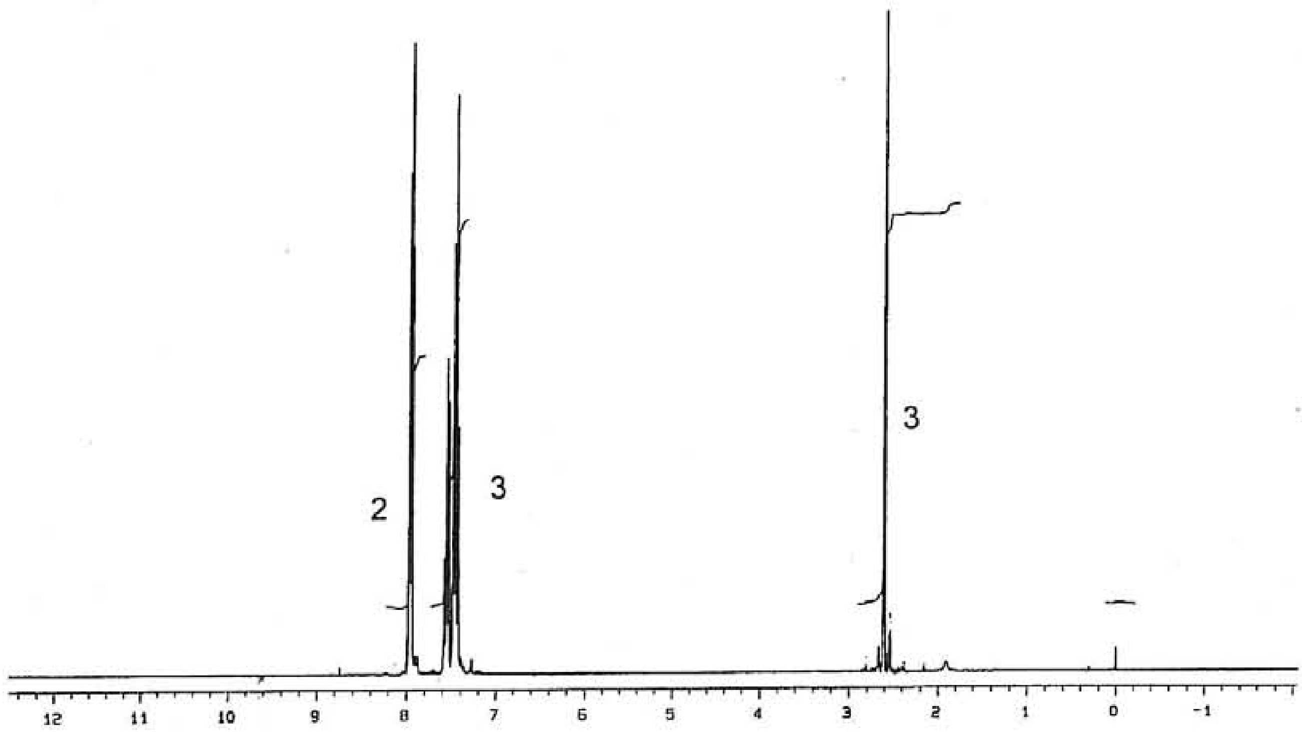
7 Molecular weight: 120





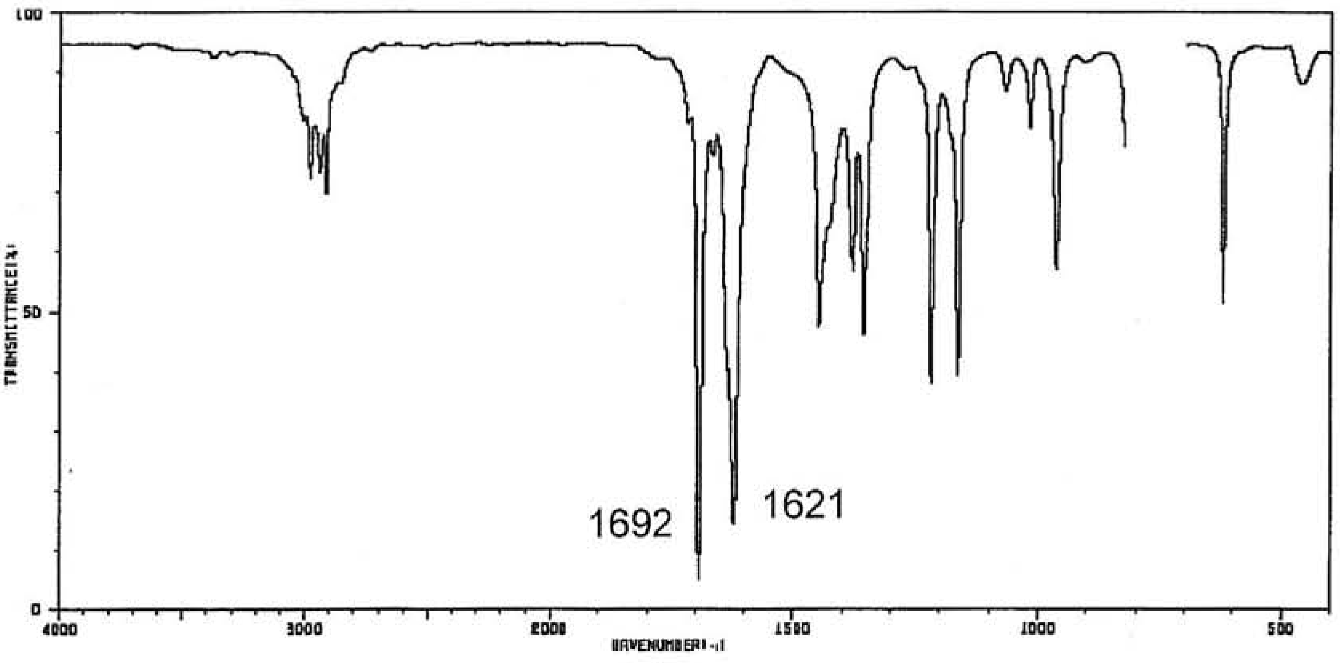


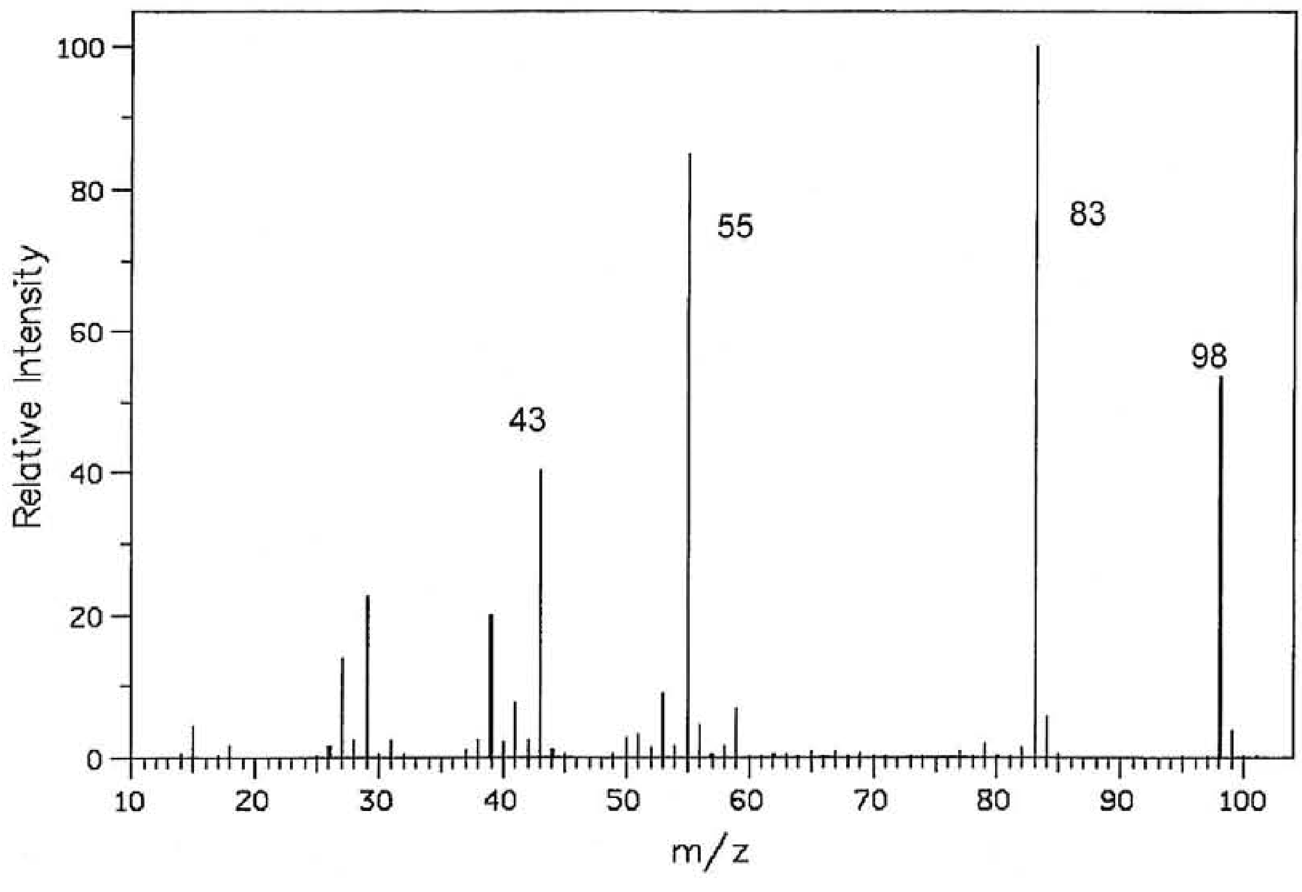
130
128
200
180
160
140
120
100
80
60
40
20
0

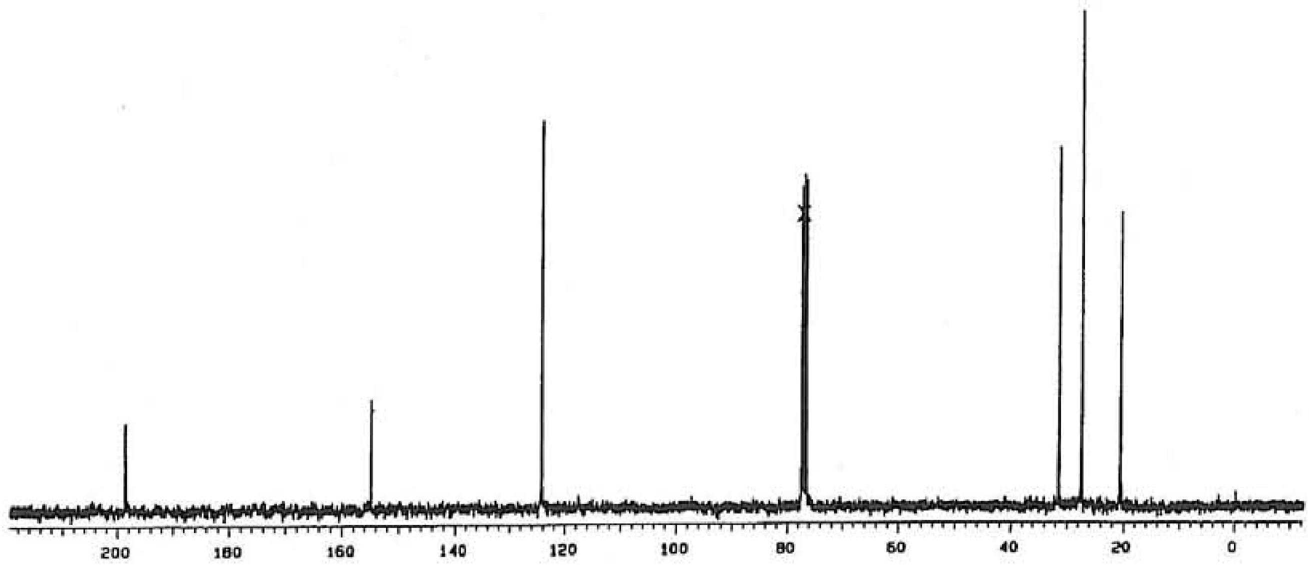


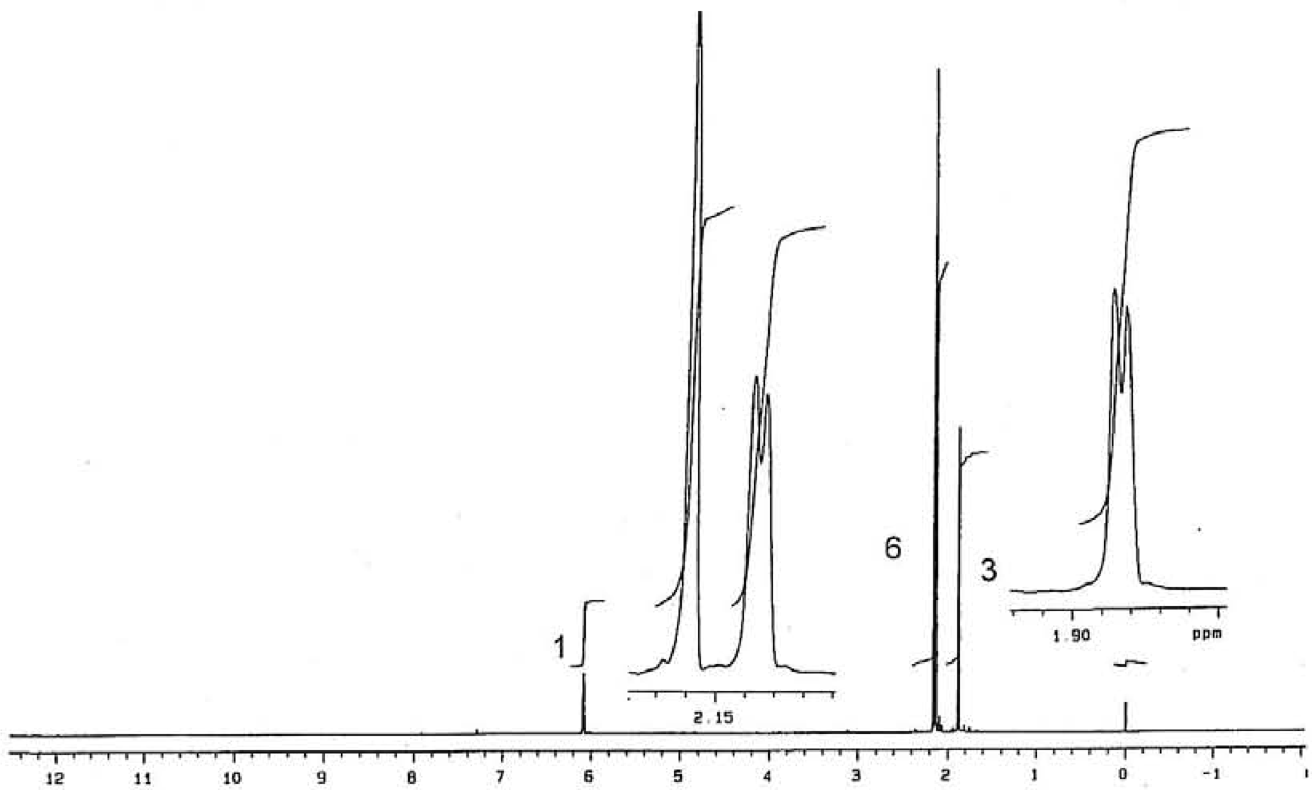
2
3
3
12
11
10
9
8
7
6
5
4
3
2
1
0
-1

8 Molecular weight: 98






200
180
160
140
120
100
80
60
40
20
0


1
6
3
2.15
1.90
ppm
12
11
10
9
8
7
6
5
4
3
2
1
0
-1

APPENDIX 4

An Evaluation Survey for EBL

Sections 1 and 2 of this evaluation refer to the part of your module where you were learning through Enquiry Based Learning[1]. For the purposes of this evaluation questionnaire, we will refer to it as 'the activity'.

Section 1

For each statement, tick one box to indicate your response as follows:

- **1 = strongly disagree**
- **2 = disagree**
- **3 = neither agree or disagree**
- **4 = agree**
- **5 = strongly agree**

	Statement		1	2	3	4	5
1	I felt that I understood the learning process in this activity						
2	I learned about how to present my findings to an audience						
3	I found this activity difficult						
4	This activity helped me to develop my team working skills						
5	I learned how to plan my learning						
6	During the module, I was given opportunities to establish my own research questions						
7	The staff focused more on encouraging me to find information than on giving me the facts						
8	The activity was more about analysing and evaluating information than it was about memorising it						
9	I feel I am better able to find information from different sources						
10	I am more confident in my ability to evaluate the information I have found						
11	I feel I am better able to evaluate different sources of information						
12	I needed a lot of support from staff in this activity						
13	This activity helped me to discover what was expected of me as a learner						
14	The group was effective in developing shared goals						
15	I enjoyed working in this way						

[1] Evaluators might wish to replace 'Enquiry Based Learning' with some other term that is understood by the students, e.g. Design exercise, Problem Based Learning, an investigative study etc.

16	I needed support in establishing my own questions to research						
17	I found the team members to be helpful in my learning						
18	I didn't need to apply anything I learned						
19	I had opportunities to lead the group						
20	I feel that I am better able to make an oral presentation						
21	There was a lot to learn						
22	I enjoyed working as a member of a team						
23	I feel I am better able to communicate with others						
24	Any interpersonal difficulties were cleared up in a positive manner						
25	I felt I had to work hard to complete this activity						
26	My group worked well as a team						
27	I felt I was able to take more responsibility for my own learning						
28	As a result of this activity, I am now more confident about my ability to establish my own research questions						
29	The group worked well to overcome any difficulties or problems we encountered						
30	I found the activity challenging						
31	I can see a range of ways in which I can contribute to a group task						
32	I feel more confident in my ability to solve problems						
33	The group appreciated my inputs						
34	I felt I could get through the activity simply by memorising things						
35	I felt a sense of control over my learning						
36	I feel I am better able to present my findings						
37	The staff gave me the support I needed to learn in this module						
38	I developed an understanding of technical processes through working with my group						
39	I was able to see good ways of presenting information						

Section 2

Please add a comment to follow the introductory statement

During the activity

1	The thing I found most helpful was.....
2	The most useful thing/skill I learned was.....
3	The thing that most changed the way I learned was......
4	What made learning most effective for me was....
5	The thing I found most difficult was....
6	To help me to improve as a learner, what I need to work on is....
7	What I need to stop doing, which hinders my learning, is...
8	To help me improve as a learner, I would like my tutor to: Stop.... Start... Continue....

Section 3

This section refers to the whole of your year's study so far; not just the activity or even the module, but to all of the modules you are studying on your course.

So far this year

1	**What is helping me most to develop my team working skills is....**
2	**I have been developing information skills by....**
3	**The most useful learning experience for me has been....**
4	**I have spent most time learning....**
5	**I have learned about doing research by....**
6	**The best thing about this course is....**
7	**I have gained most confidence as a learner through....**

APPENDIX 5

The 37 Likert-Style Statements of Potential Use in the Questionnaires

I felt that I understood the learning process in this activity

I found this activity difficult

This activity helped me to develop my team working skills

I learned how to plan my learning

The activity was more about analysing and evaluating information than it was about memorising it

I feel I am better able to find information from different sources

I am more confident in my ability to evaluate the information I have found

I feel I am better able to evaluate different sources of information

I needed a lot of support from staff in this activity

The group was effective in developing shared goals

I enjoyed working in this way

I found the team members to be helpful in my learning

I didn't need to apply anything I learned

There was a lot to learn

I enjoyed working as a member of a team

I feel I am better able to communicate with others

Any interpersonal difficulties were cleared up in a positive manner

I felt I had to work hard to complete this activity

My group worked well as a team

I felt I was able to take more responsibility for my own learning

The group worked well to overcome any difficulties or problems we encountered

I found the activity challenging

I can see a range of ways in which I can contribute to a group task

I feel more confident in my ability to solve problems

The group appreciated my inputs

I felt I could get through the activity simply by memorising things

I felt a sense of control over my learning

The staff gave me the support I needed to learn in this module

I developed an understanding of technical processes through working with my group

The staff focused more on encouraging me to find information than on giving me the facts

I would prefer lectures to the EBL sessions.

I am enthusiastic about the EBL sessions.

I receive adequate feedback.

I receive timely feedback.

I find the discussion boards in WebCT helpful.

I understand the role of the postgraduate students in the sessions

The learning was relevant to my needs

APPENDIX 6

Statements Used in the Online Questionnaire

1. I felt that I understood the learning process in this activity
2. I found this activity difficult
3. This activity helped me to develop my team working skills
4. The activity was more about analysing and evaluating information than it was about memorising it
5. I feel I am better able to find information from different sources
6. I needed a lot of support from staff in this activity
7. The group was effective in developing shared goals
8. I enjoyed working in this way
9. I found the team members to be helpful in my learning
10. I didn't need to apply anything I learned
11. There was a lot to learn
12. I enjoyed working as a member of a team
13. I feel I am better able to communicate with others
14. I felt I had to work hard to complete this activity
15. My group worked well as a team
16. I felt I was able to take more responsibility for my own learning
17. The group worked well to overcome any difficulties or problems we encountered
18. I found the activity challenging
19. I can see a range of ways in which I can contribute to a group task
20. I feel more confident in my ability to solve problems
21. The group appreciated my inputs
22. I felt I could get through the activity simply by memorising things

23. I felt a sense of control over my learning

24. The staff gave me the support I needed to learn in this module

25. I developed an understanding of technical processes through working with my group

26. The staff focused more on encouraging me to find information than on giving me the facts

APPENDIX 7

Please wait
Your report is being generated
...

Questionmark

Question statistics report

Back Home

Assessment: Experience of Learning
Report generated: April 3, 2007 - 14:00

No filters specified

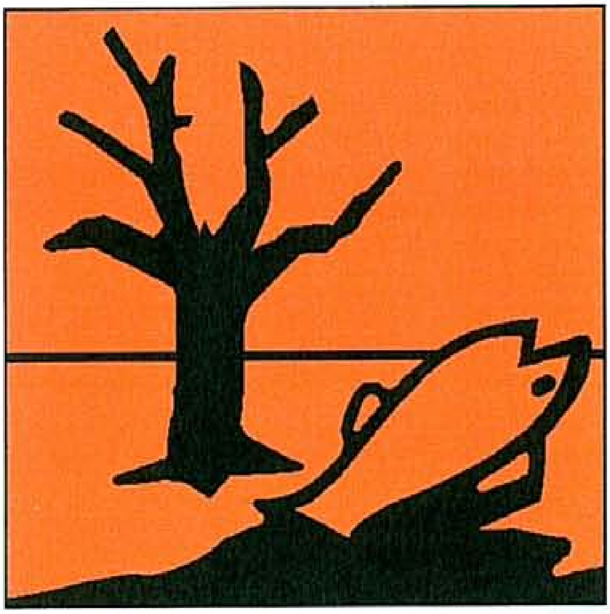
Question description	I can see a range of ways in which I can contribute to a group task.
Question wording	I can see a range of ways in which I can contribute to a group task.
Topic	rowleynm\EBL\Experience
Question type	Multiple Choice
Times presented	9
Times answered	9
When last presented	March 29, 2007 - 11:47
Maximum score	5
Mean score	3.889
Standard deviation of score	0.601
Difficulty	0.778
Correlation	0.896
Significance of correlation	1%

Outcome analysis

Outcome name	Times answered	Percentage of times answered	Mean for outcome
* 0 Strongly Agree	1	11%	82.00%
1 Agree	6	67%	72.83%
2 Neither Agree or Disagree	2	22%	65.00%
3 Disagree	0		-
4 Strongly Disagree	0		-

APPENDIX 8

DOWN THE DRAIN



Pilot Study 22 March 2007

Down the Drain

An Environmental Scientist working for the Environmental Science Department has recently sampled waste water from the Chemistry Department at the University of Rummidge, after some dead fish were discovered in the river that the waste water runs into. Relatively large concentrations of eight molecules have been discovered in the waste water. The spectra of these have already been produced, from ^{1}H NMR, ^{13}C NMR, IR Spectroscopy and Mass Spectrometry, by a colleague in the Analytical Department.

You are a graduate Chemist and have been assigned the task of analysing which molecules are present in the water sample. The Environmental Scientist that undertook the sampling is new to the job and has asked your company, Rummidge Laboratories, for further information on how the analytical techniques actually work.

Things to consider

- How each spectroscopic technique works?
- What molecules are present in analysis?

Memorandum

TO: Frank, Analytical Department
FROM: Dave Carew, CEO
DATE: 22/3/07
SUBJECT: Environmental Science Department Sample Analysis

Dear Frank

The Environmental Science Department has now completed the collection of samples from the river near the University of Rummidge. They have requested a report on the compounds that have been isolated from the water sample they have provided us.

Tim has analysed the compounds, found in the water sample, by ^{13}C NMR, ^{1}H NMR, and IR spectroscopy and also by Mass Spectrometry (spectra attached).

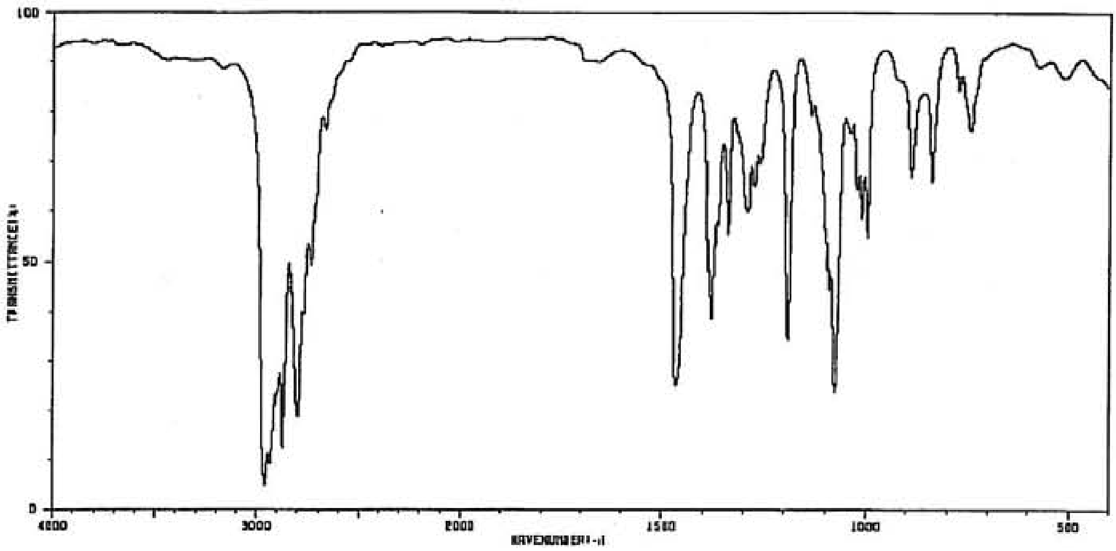
Please can you use your chemical expertise to interpret the spectra. This must include identification of the compounds present, and assignment of the key peaks in the spectra provided.

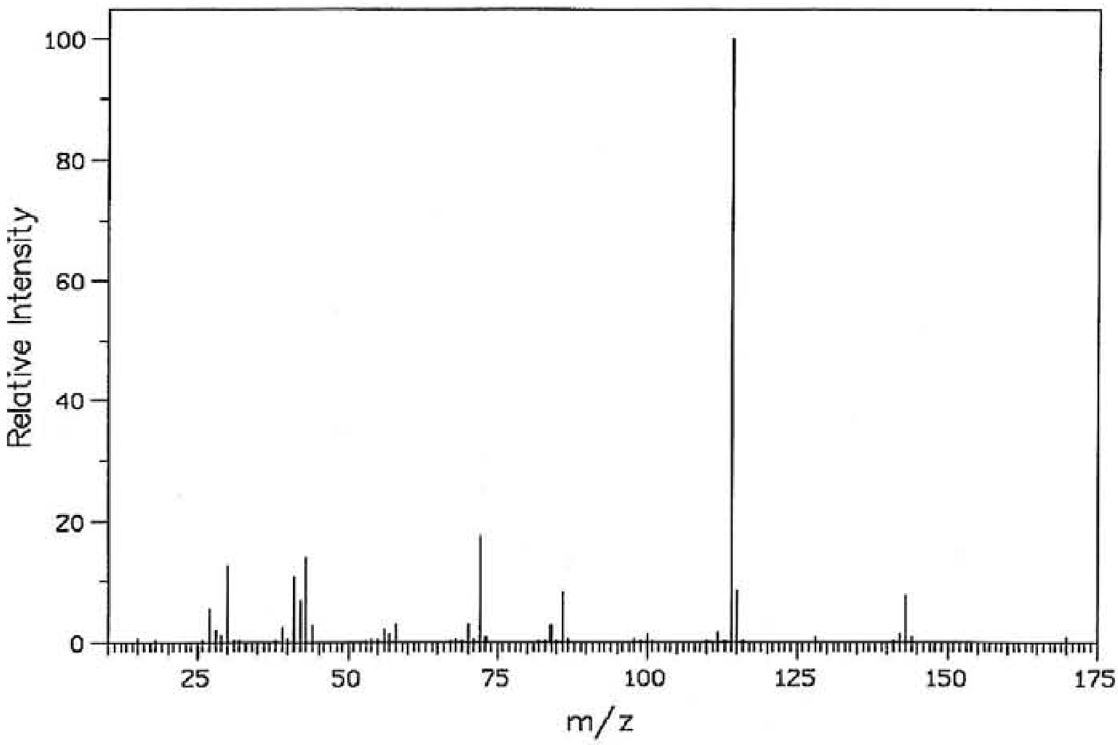
I look forward to seeing your analysis report and subsequent briefing paper.

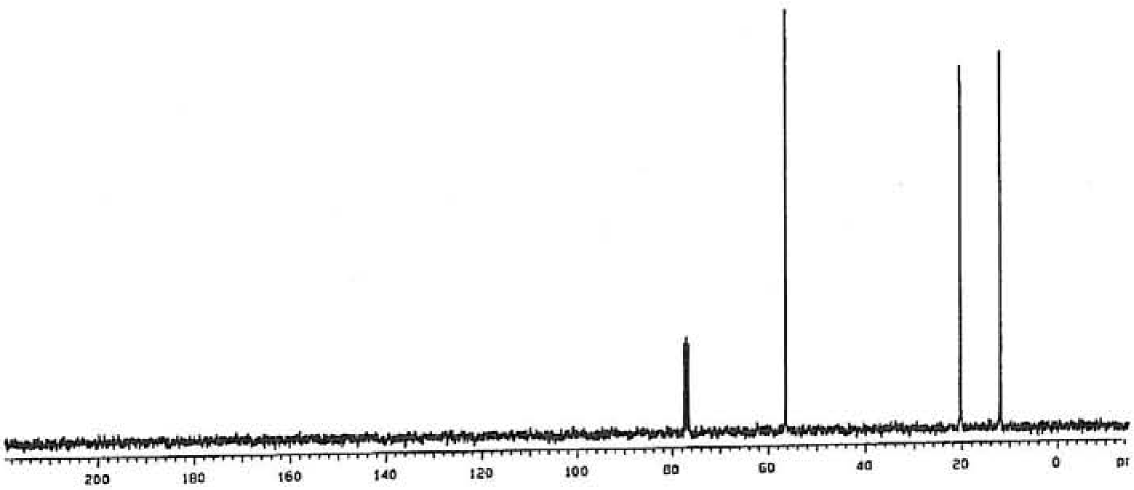
Many Thanks,

Dave Carew
Chief Executive Officer

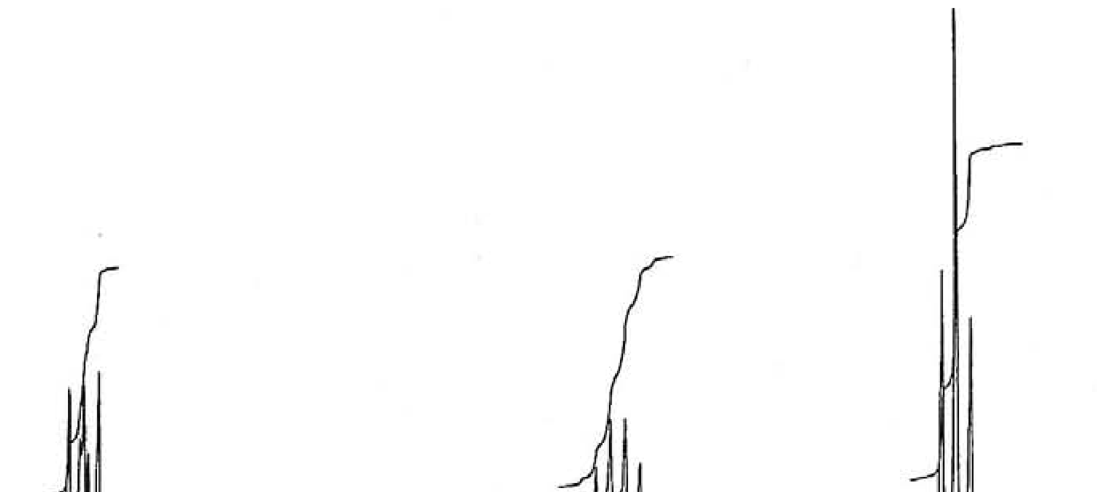
A


100
50
0
4000
3000
2000
1500
1000
500


100
80
60
40
20
0
Relative Intensity
25
50
75
100
125
150
175
m/z

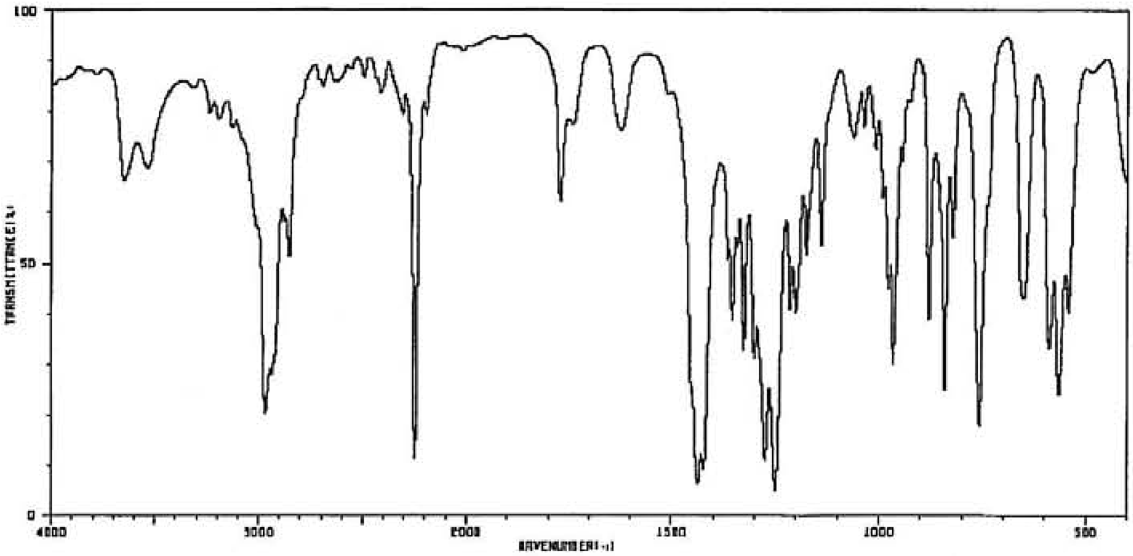


200
180
160
140
120
100
80
60
40
20
0
pr

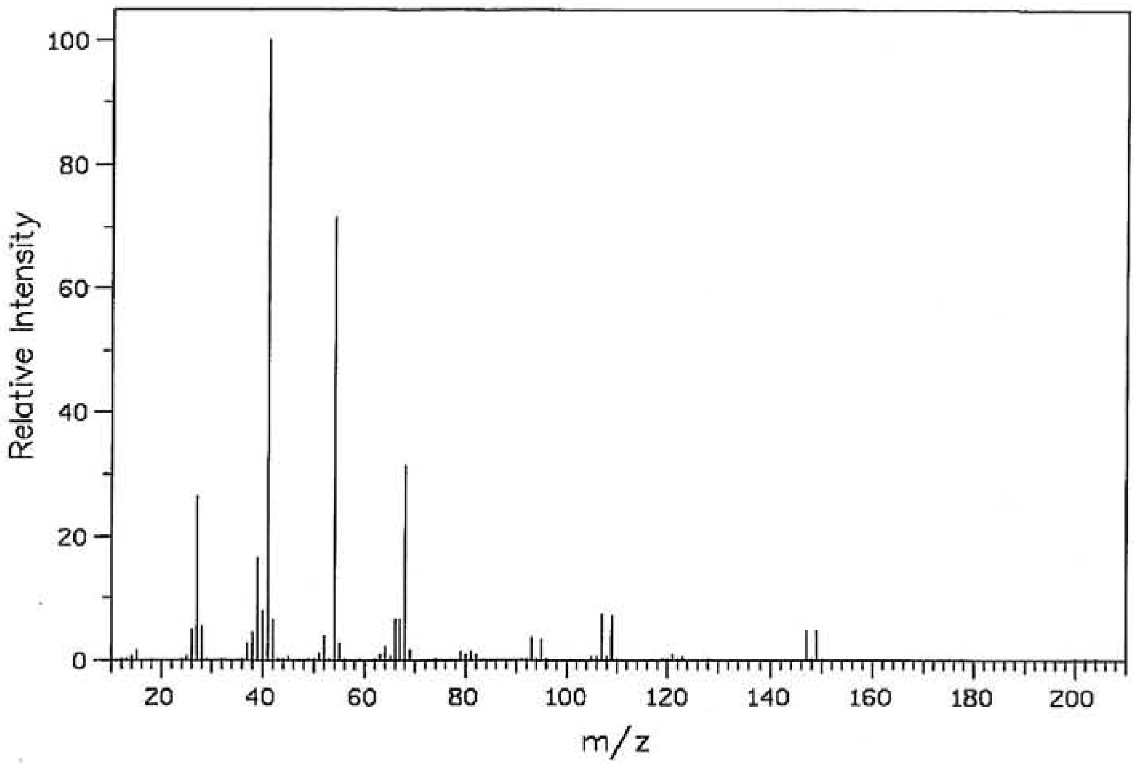


2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
pp

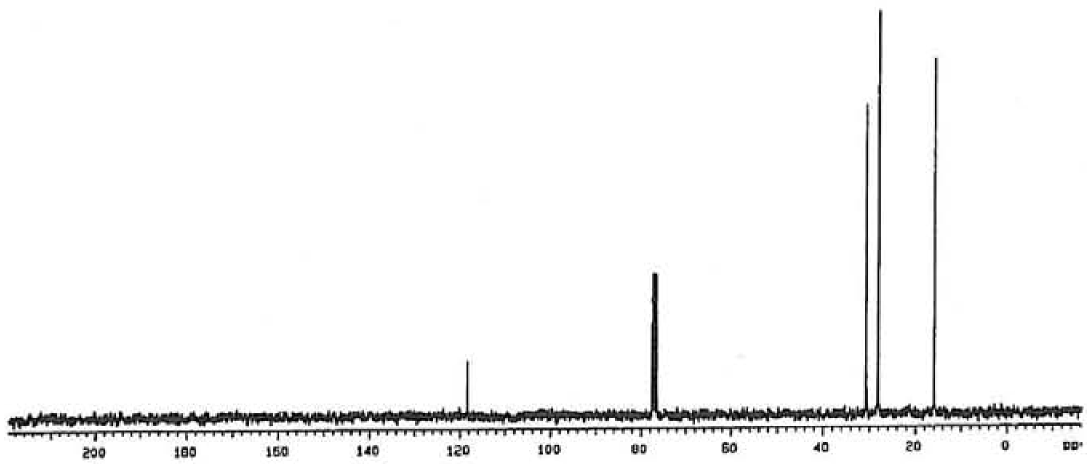
B

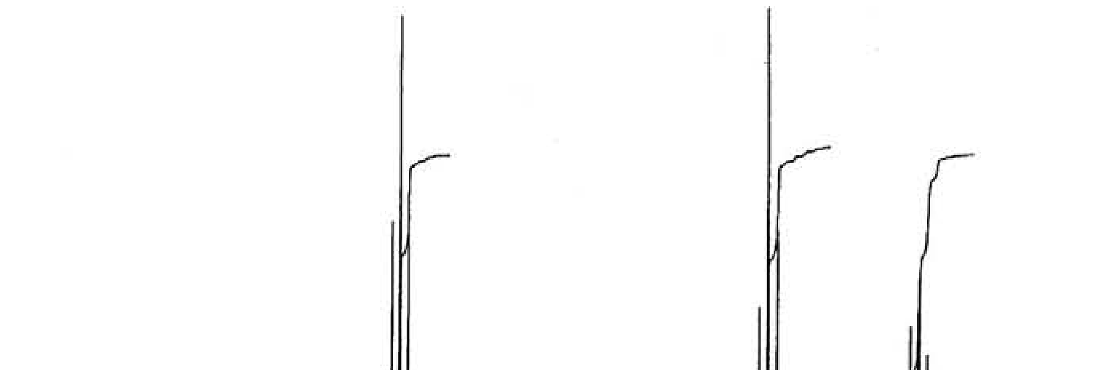


100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]

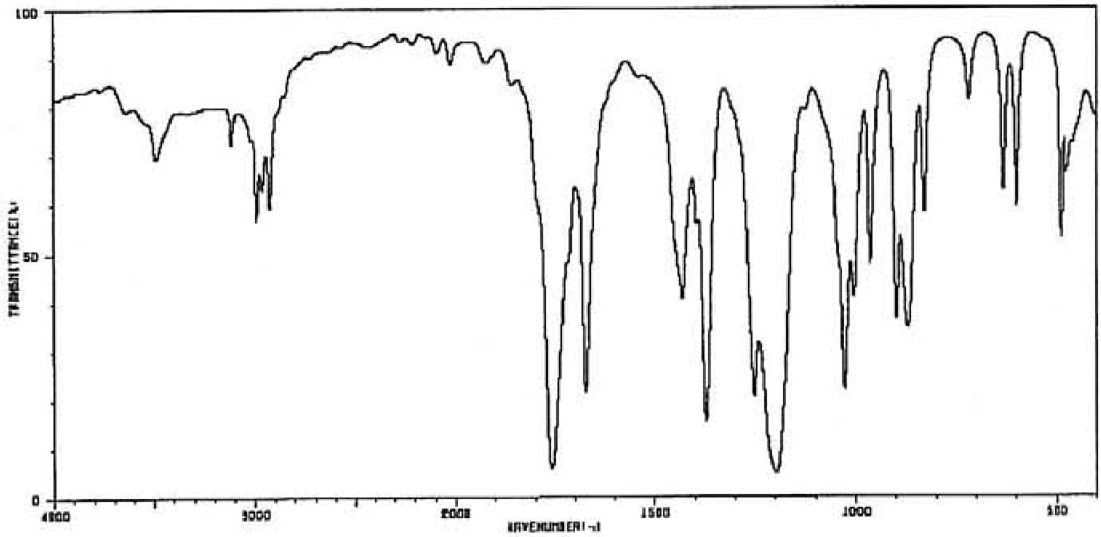


100
80
60
40
20
0
Relative Intensity
20
40
60
80
100
120
140
160
180
200
m/z

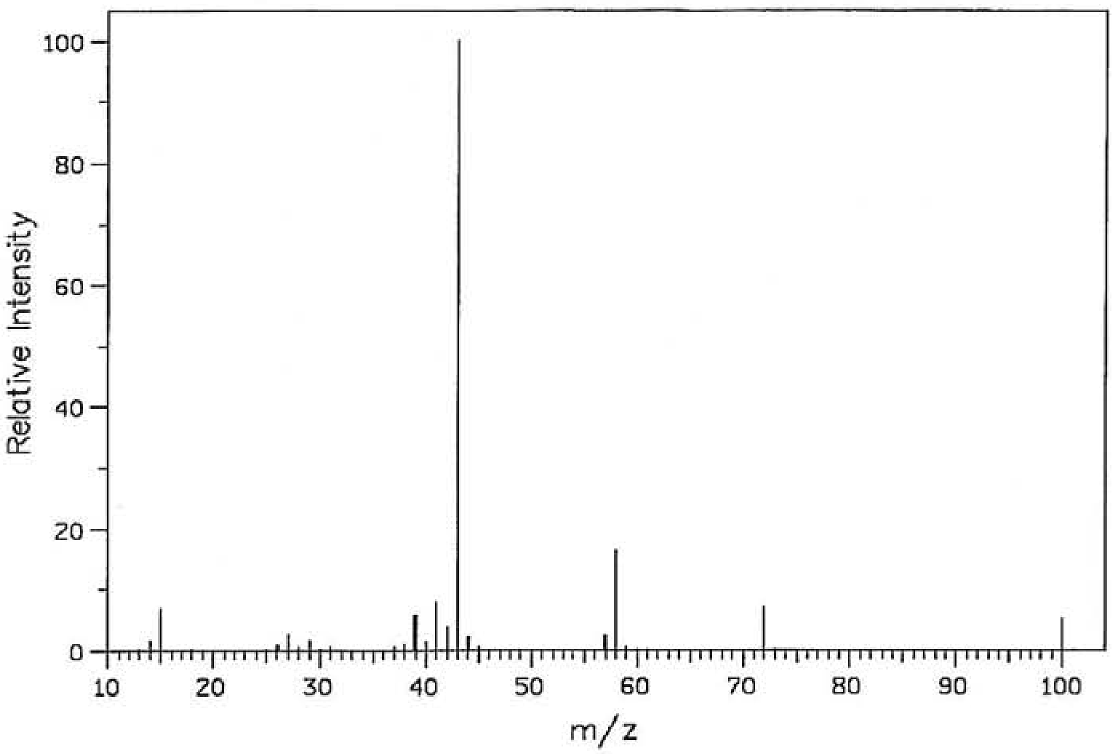

200
180
160
140
120
100
80
60
40
20
0
ppm


4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
ppm

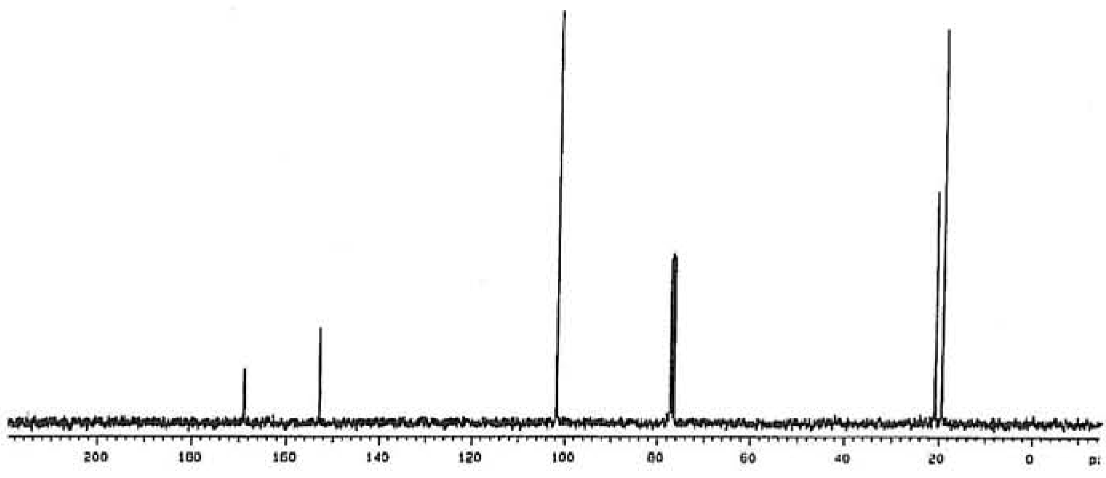
C

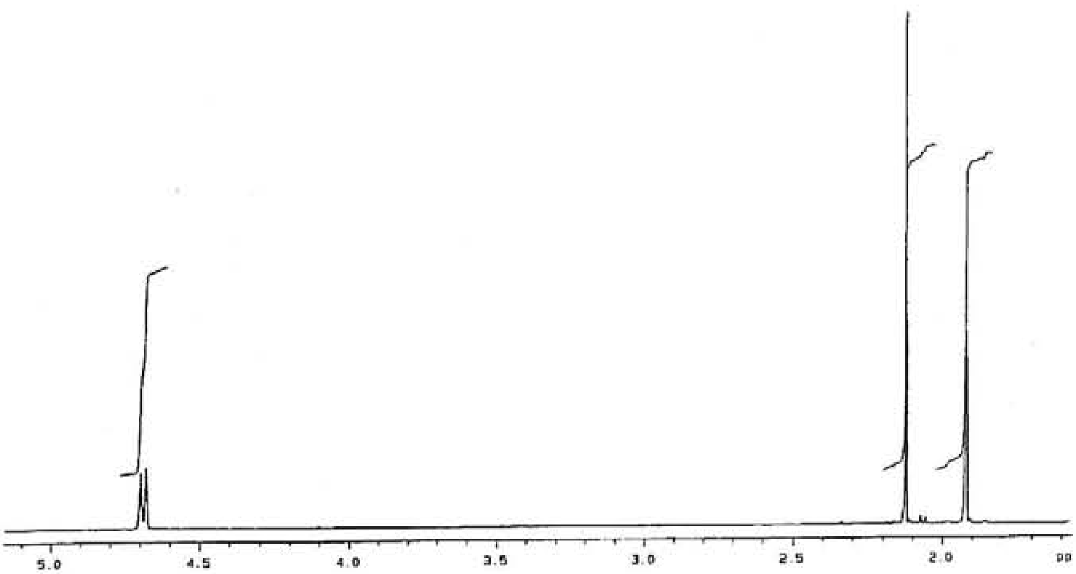


100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]

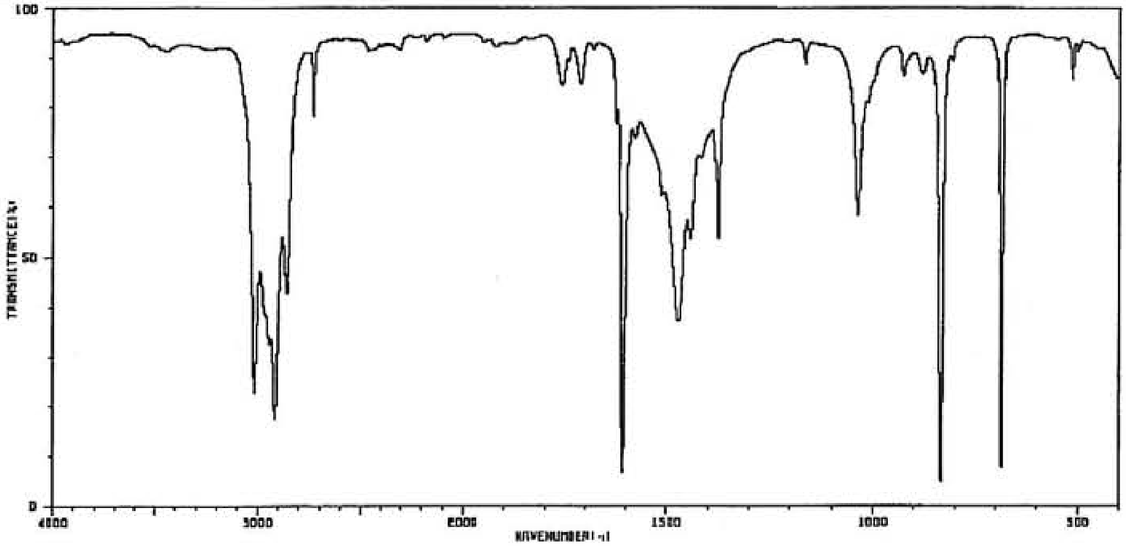


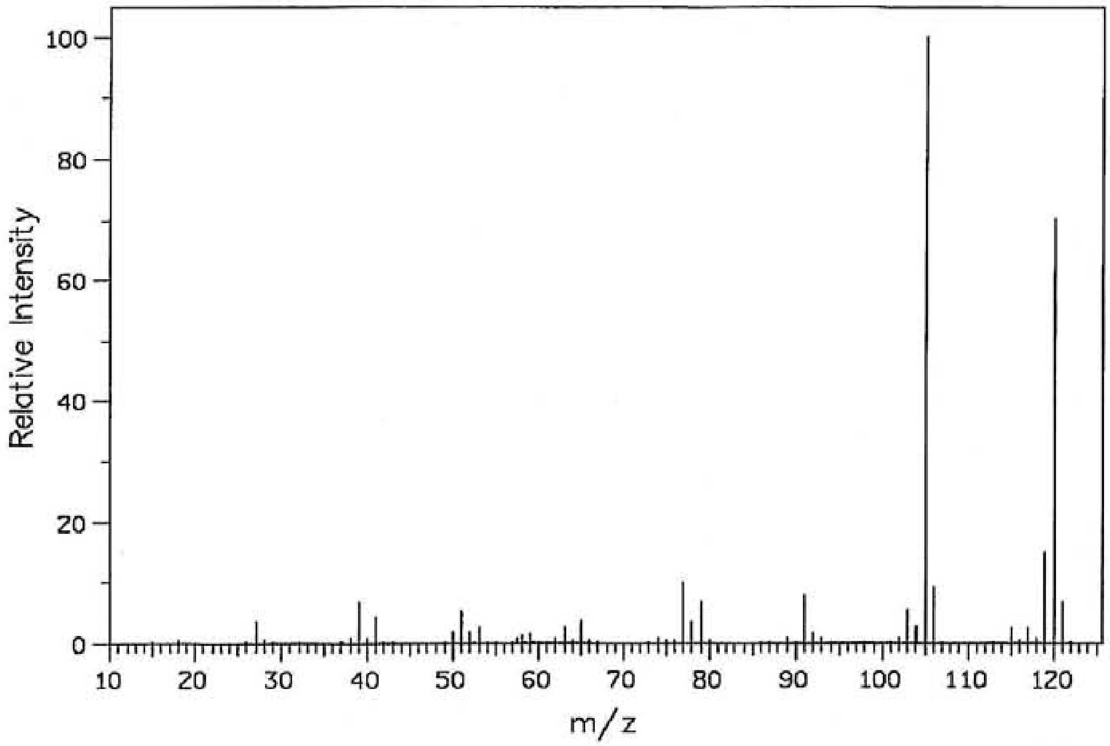
100
80
60
40
20
0
Relative Intensity
10
20
30
40
50
60
70
80
90
100
m/z

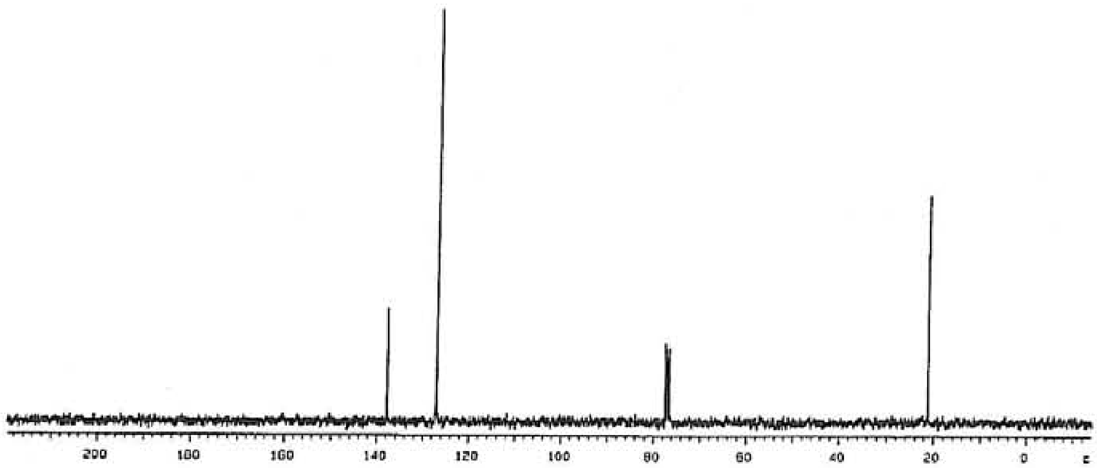

200
180
160
140
120
100
80
60
40
20
0

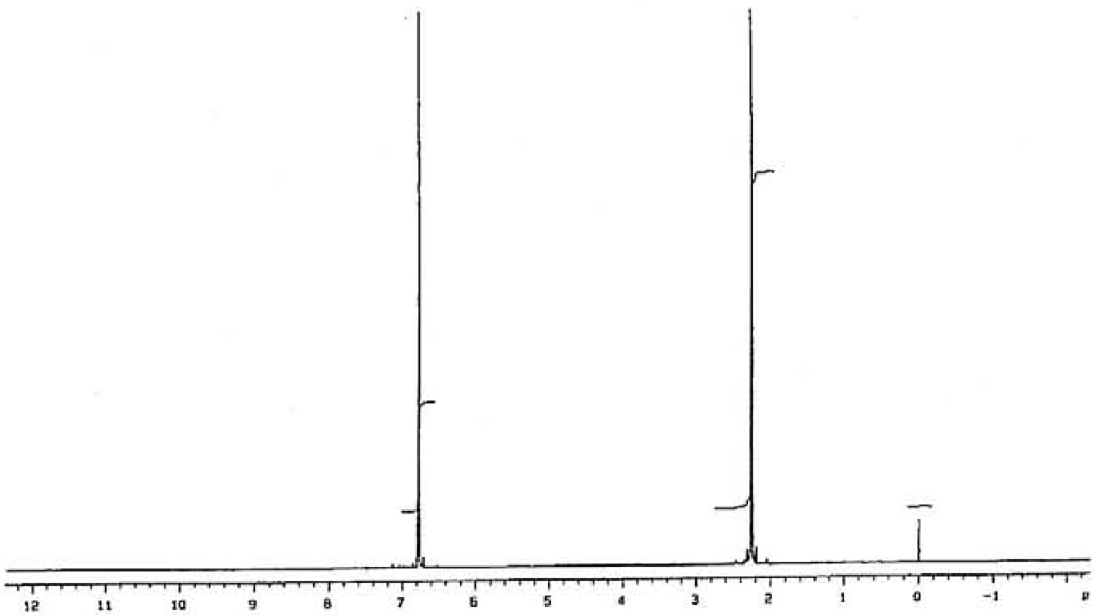

5.0
4.5
4.0
3.5
3.0
2.5
2.0
pp

D

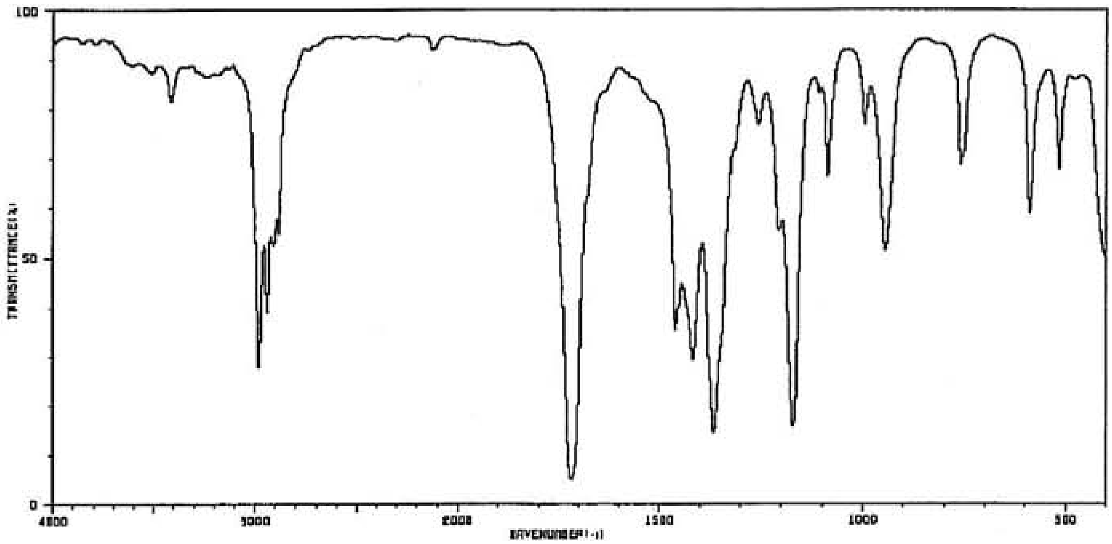

100
50
0
4000
3000
2000
1500
1000
500

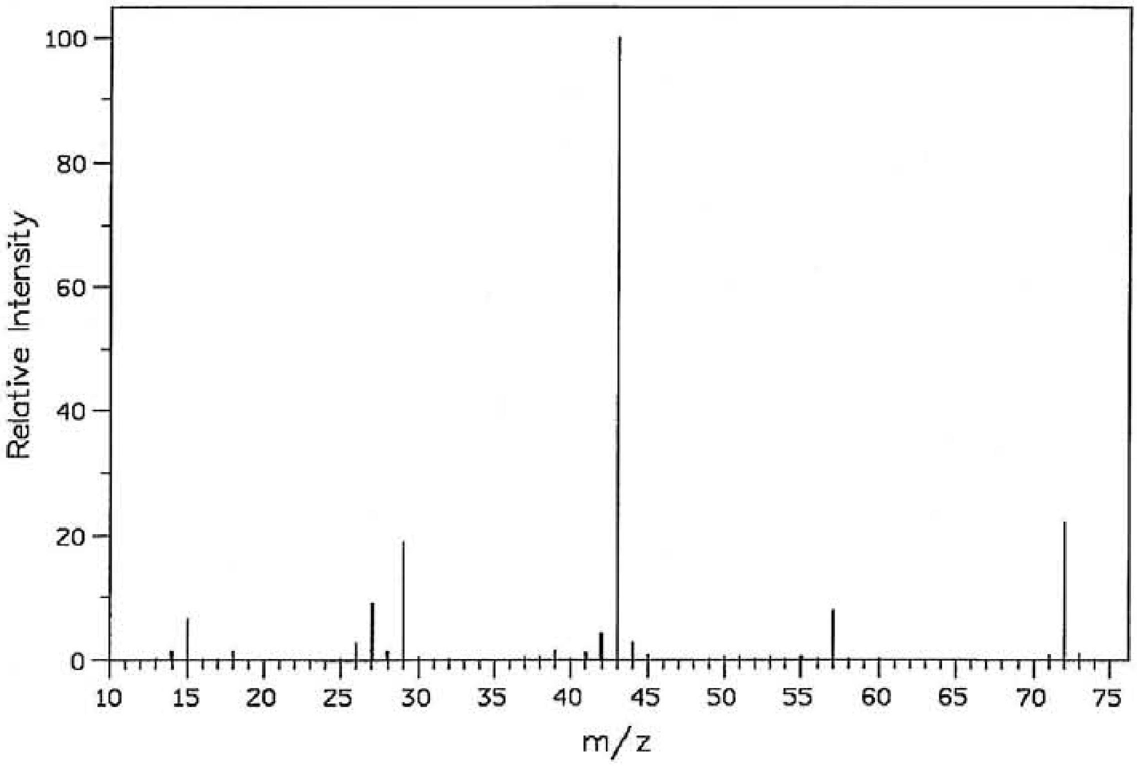

Relative Intensity
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
100
110
120
m/z

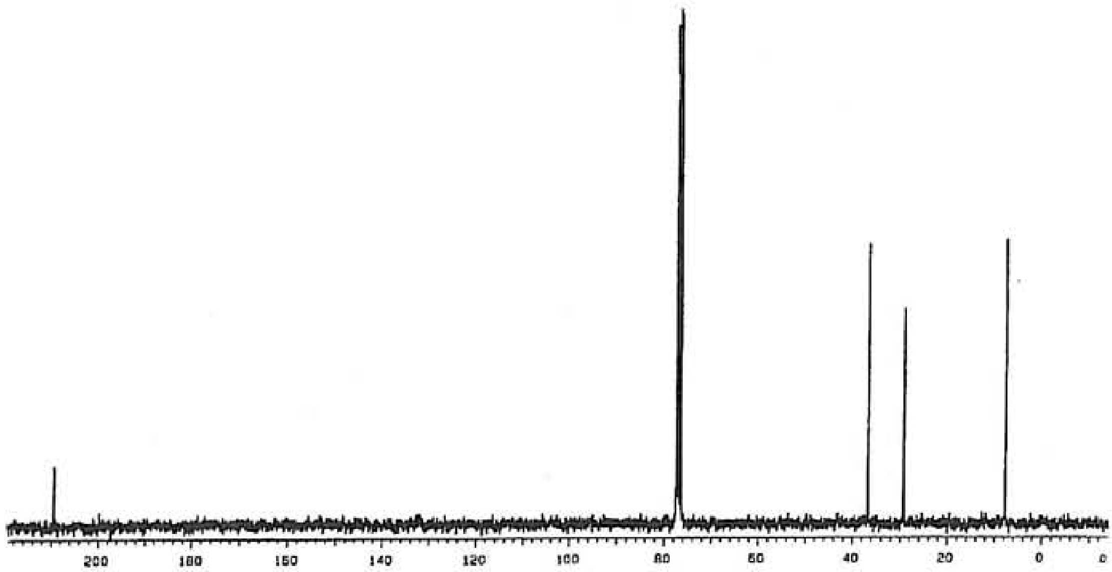

200
180
160
140
120
100
80
60
40
20
0


12
11
10
9
8
7
6
5
4
3
2
1
0
-1

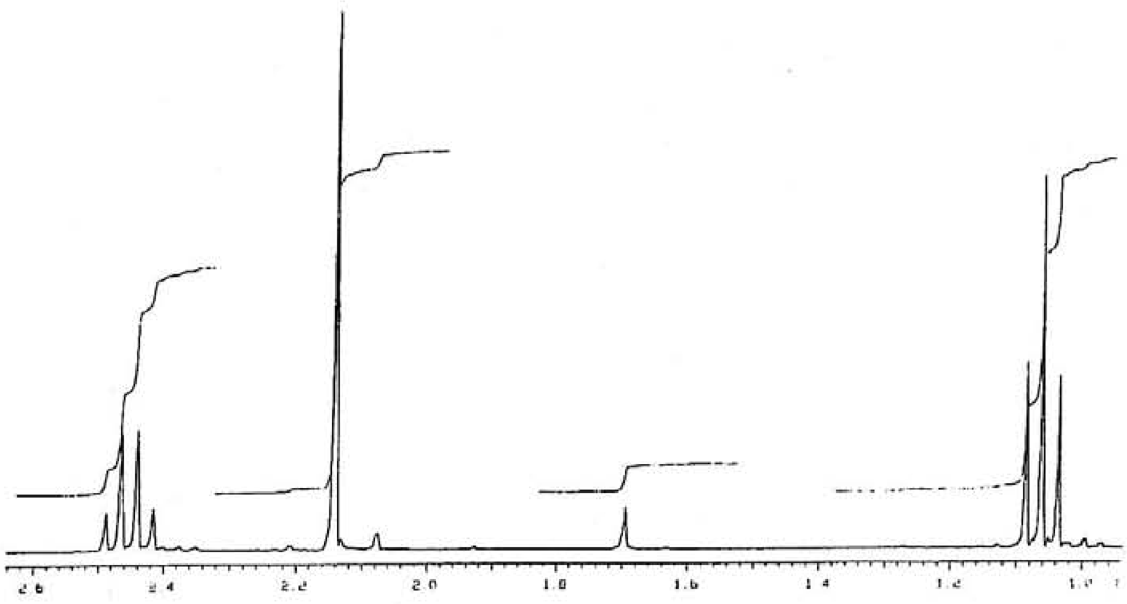
1


100
50
0
4000
3000
2000
1500
1000
500


Relative Intensity
0
20
40
60
80
100
10
15
20
25
30
35
40
45
50
55
60
65
70
75
m/z

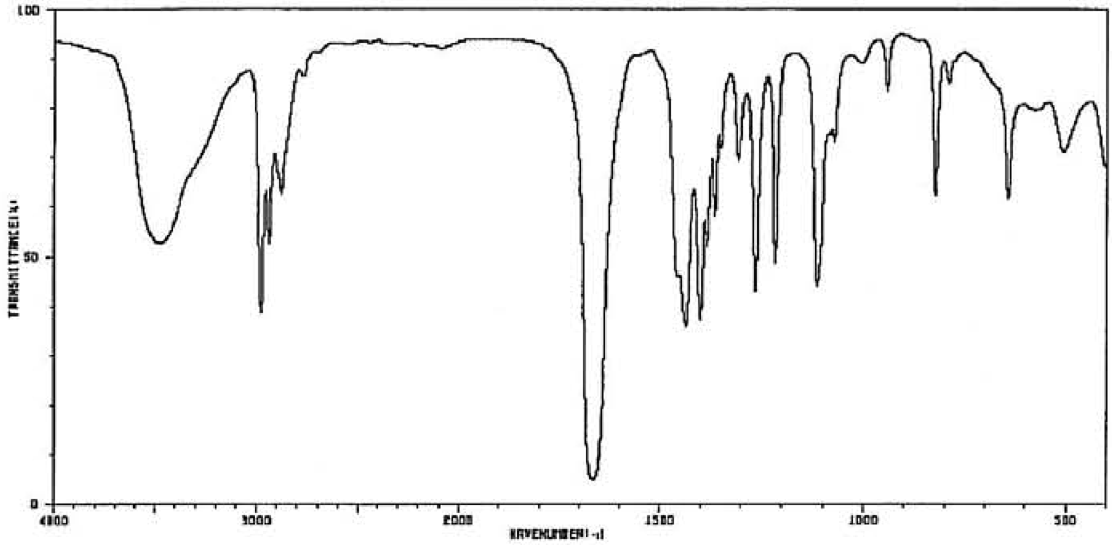


200
180
160
140
120
100
80
60
40
20
0

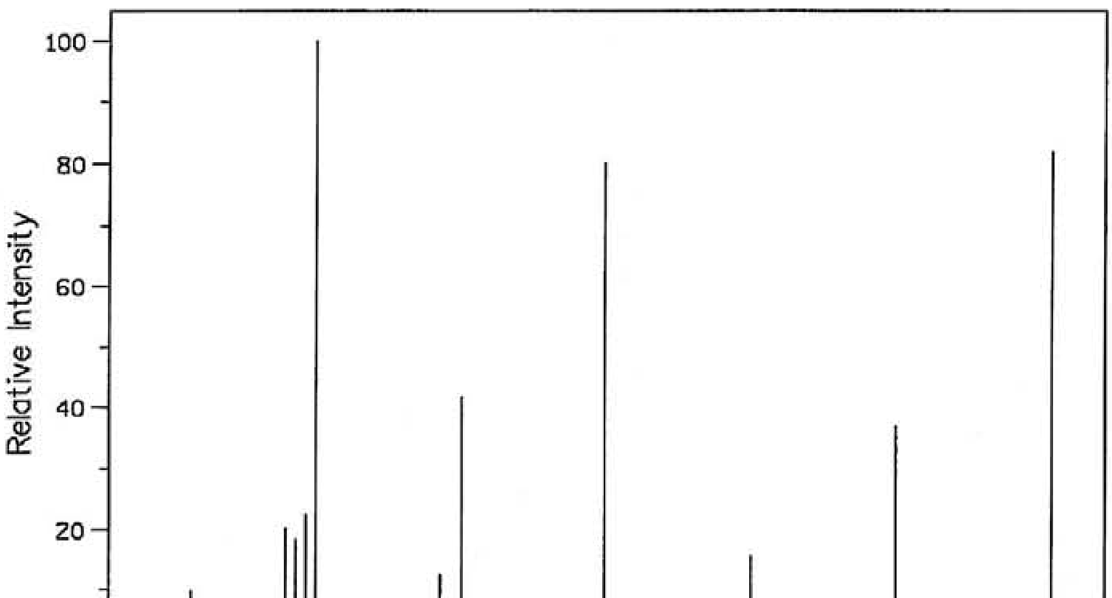


2.4
2.2
2.0
1.8
1.6
1.4
1.2

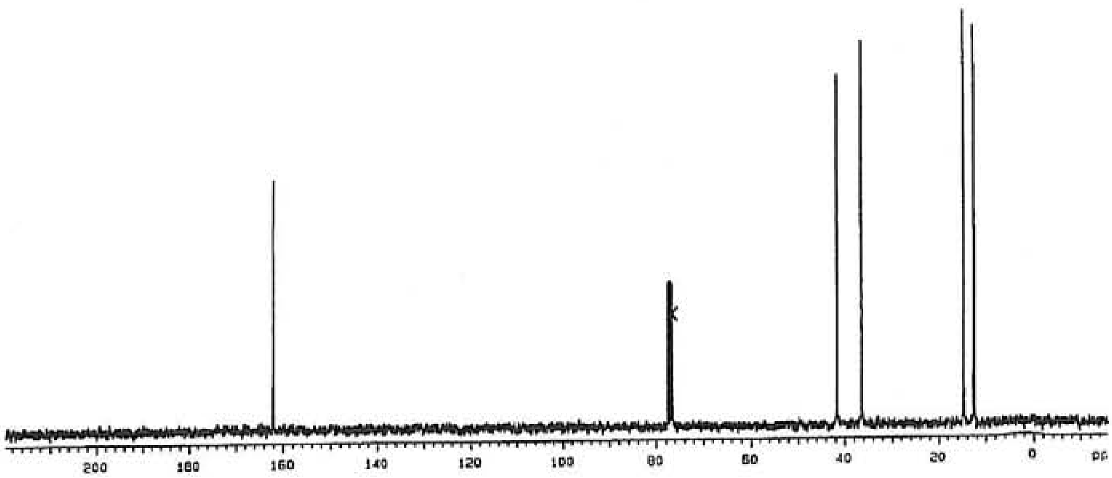
2

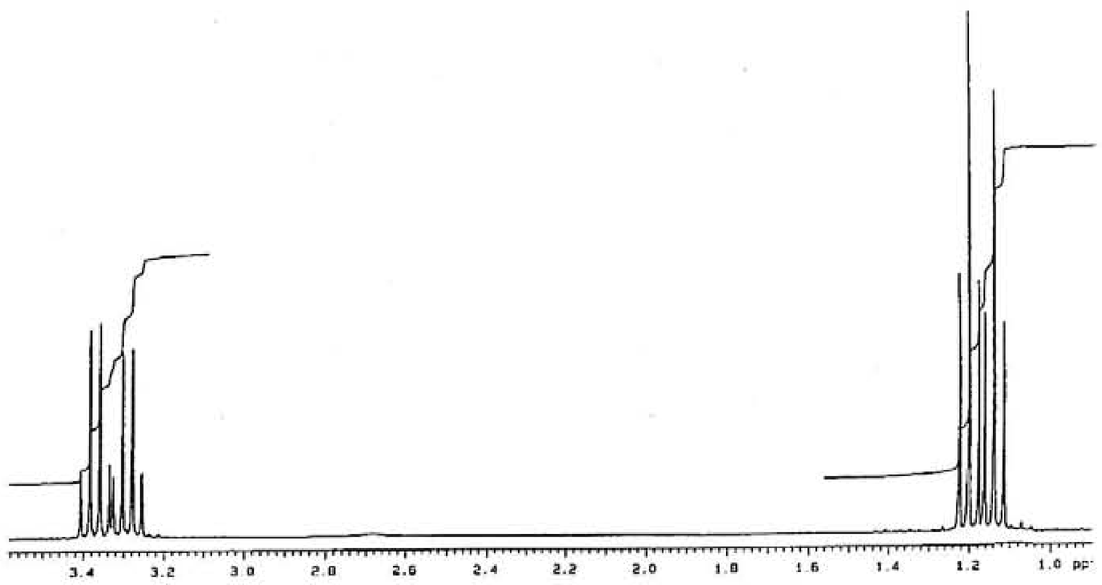


100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]

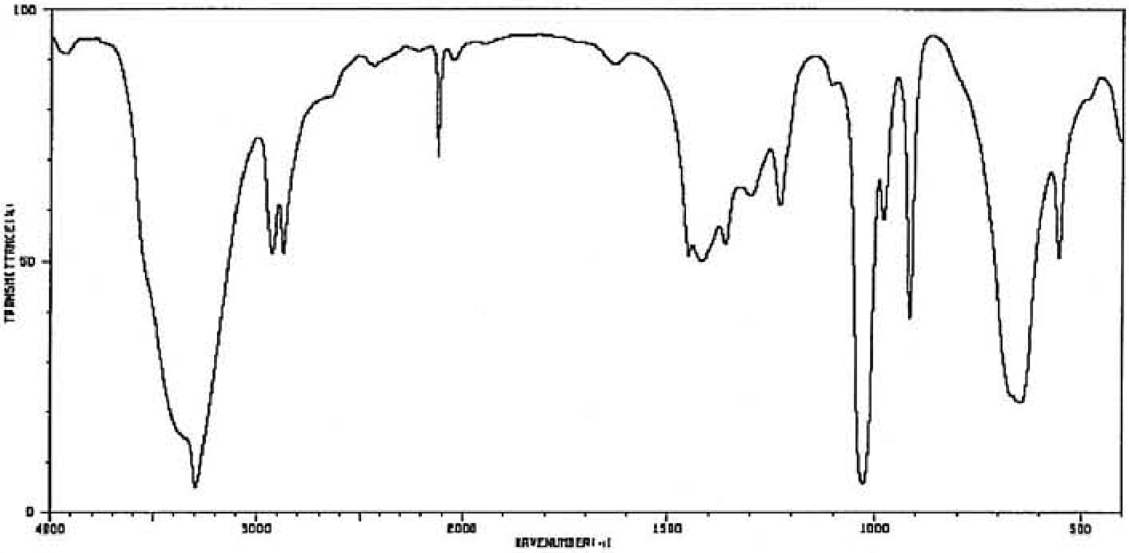


Relative Intensity
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
100
m/z

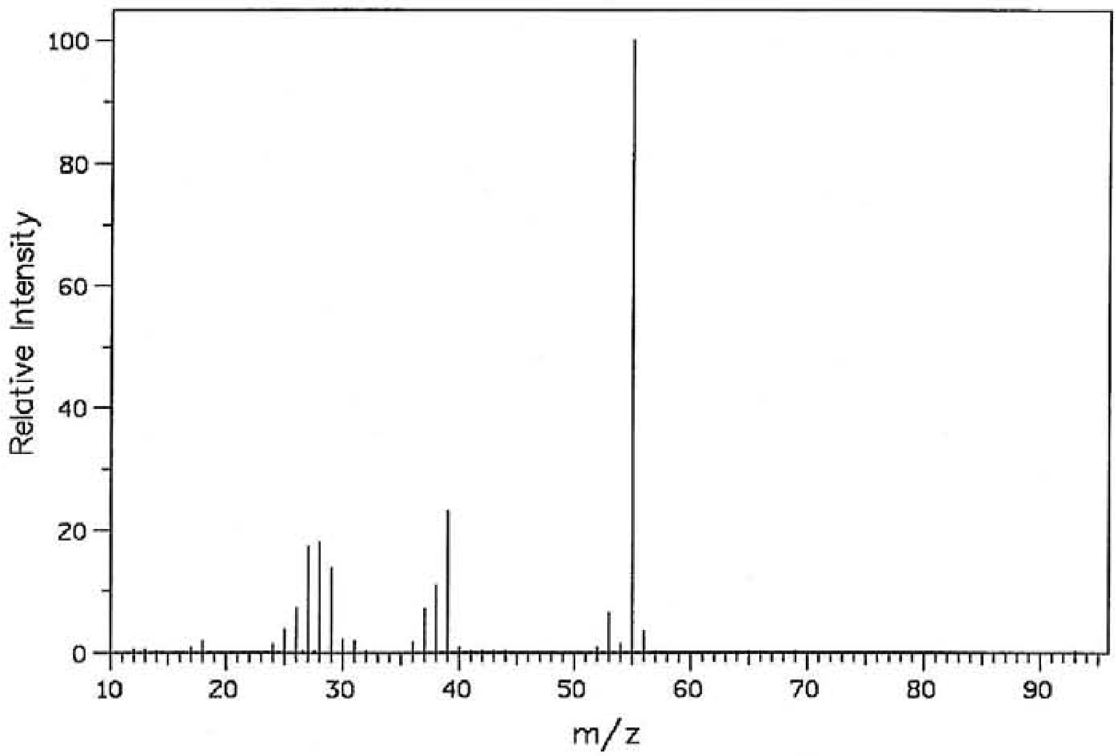

200
180
160
140
120
100
80
60
40
20
0
pp


3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0 pp

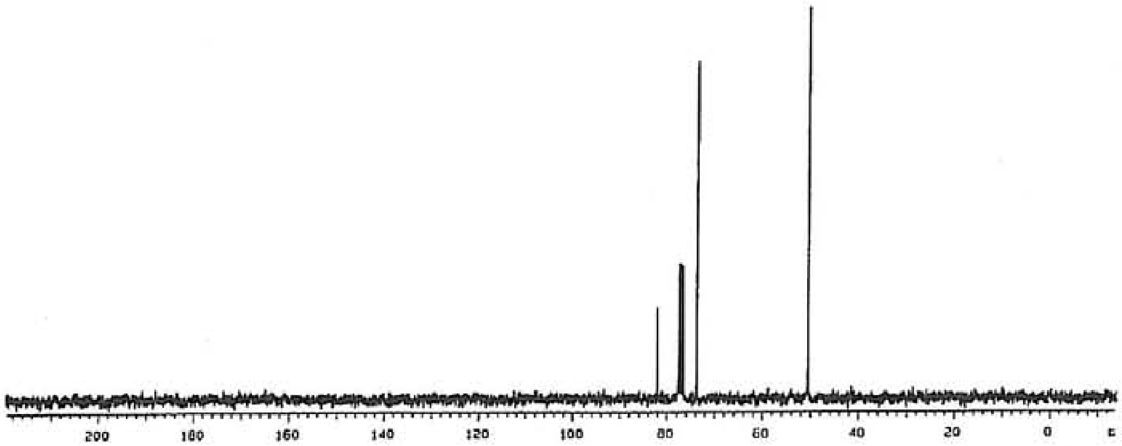
3

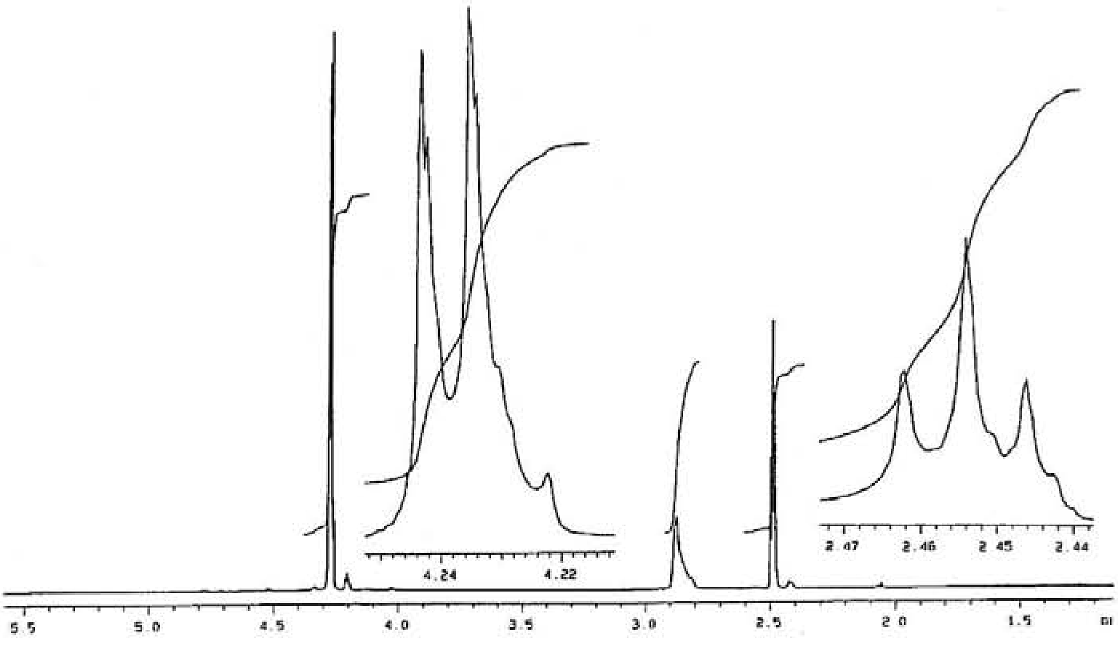


100
50
0
4000
3000
2000
1500
1000
500

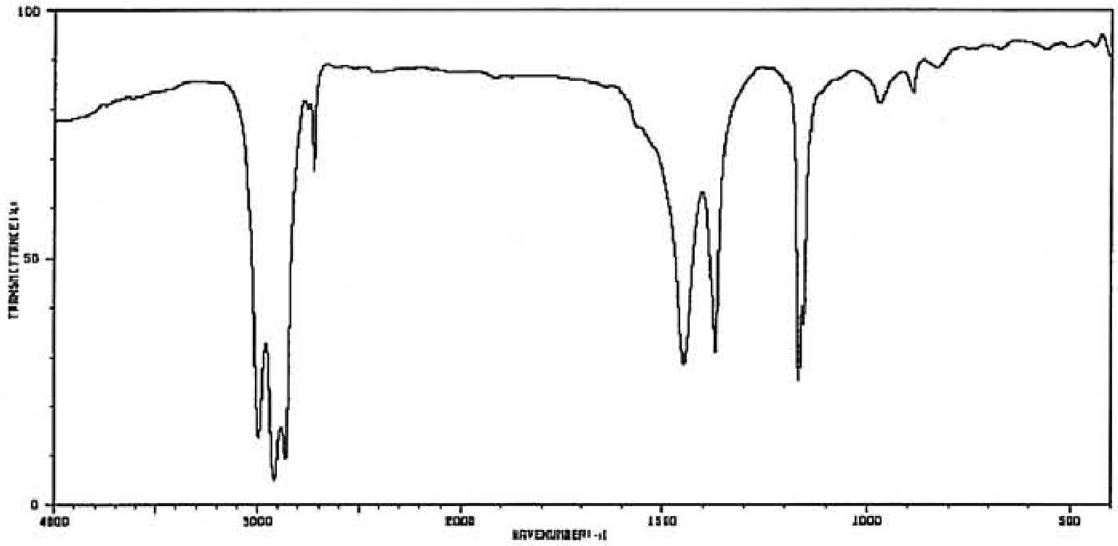


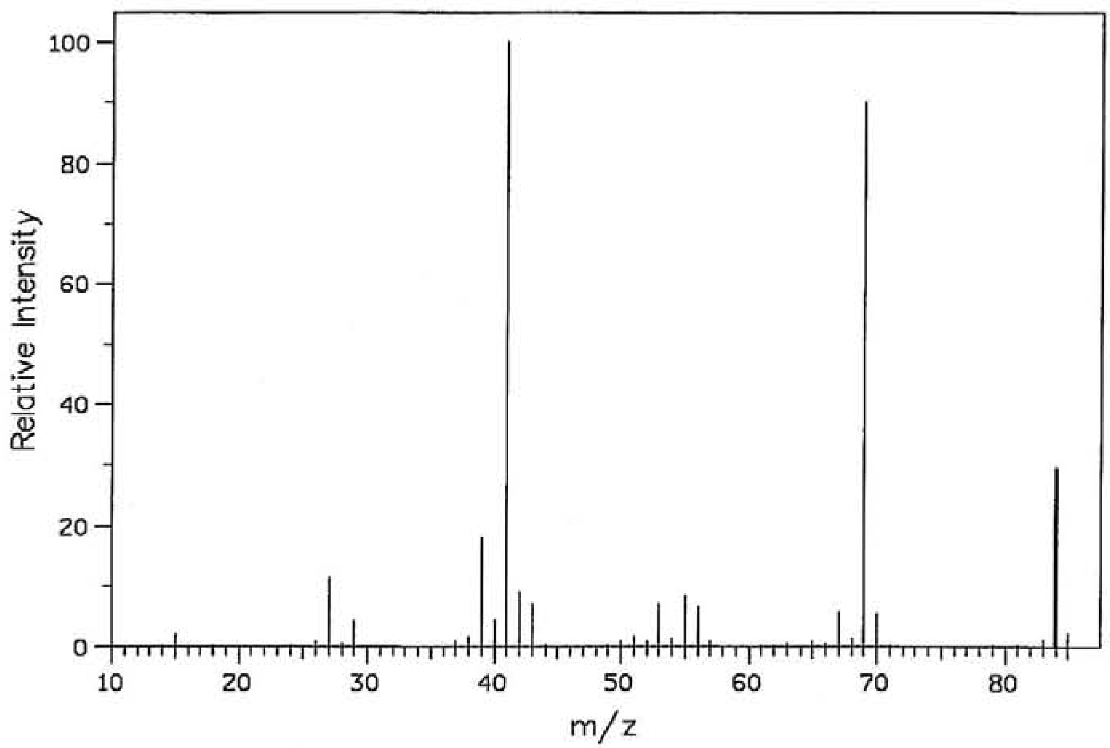
Relative Intensity
m/z
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90

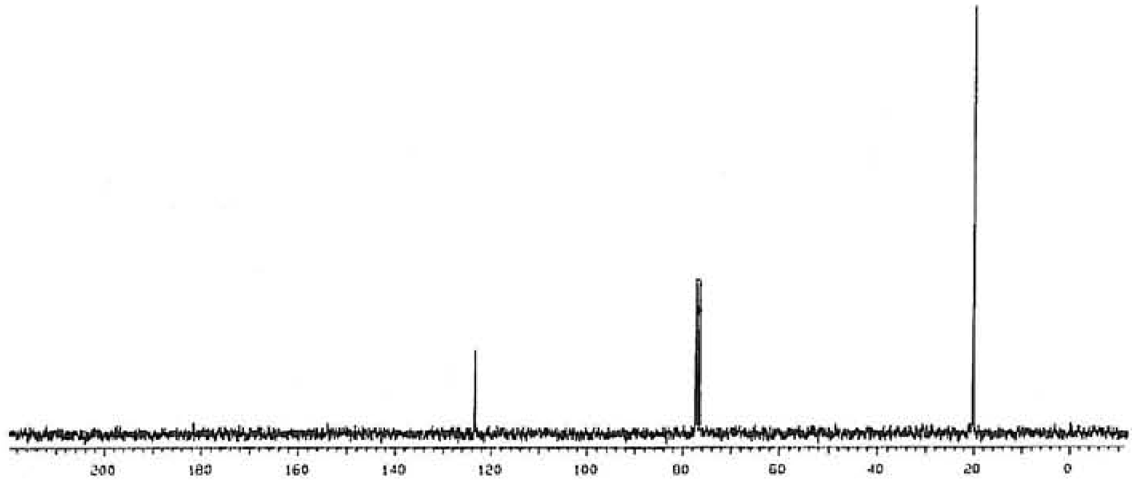

200 180 160 140 120 100 80 60 40 20 0


4.24 4.22
2.47 2.46 2.45 2.44
5.5 5.0 4.5 4.0 3.5 3.0 2.5 2.0 1.5

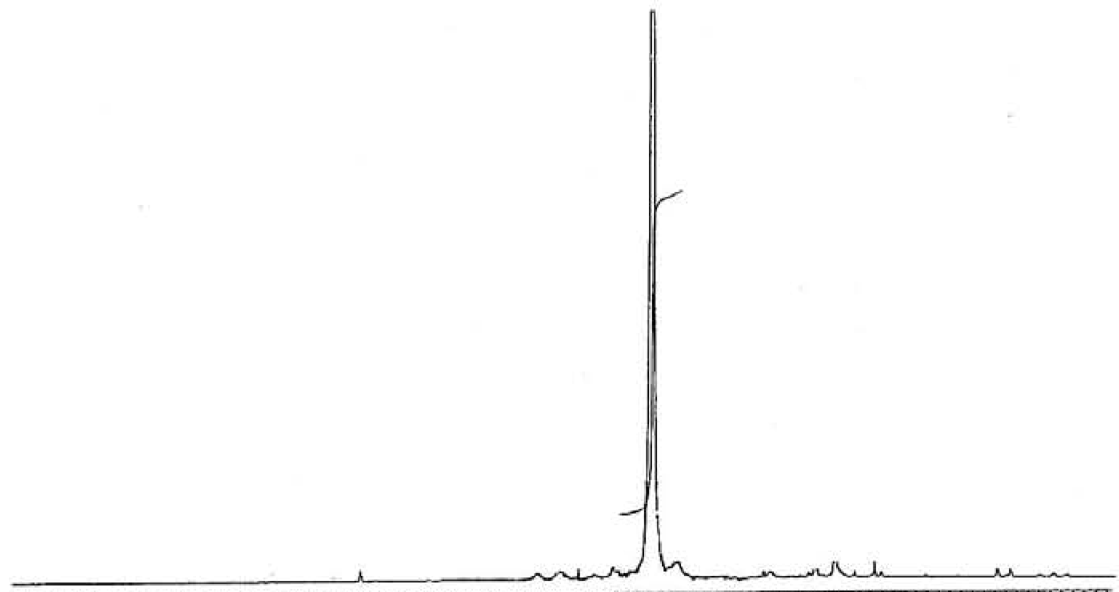
4


100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]


100
80
60
40
20
0
Relative Intensity
10
20
30
40
50
60
70
80
m/z



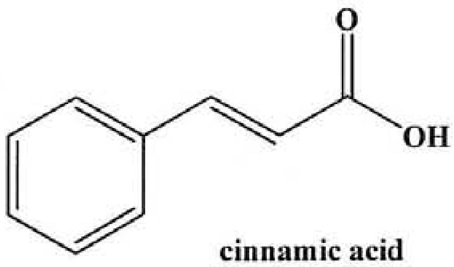
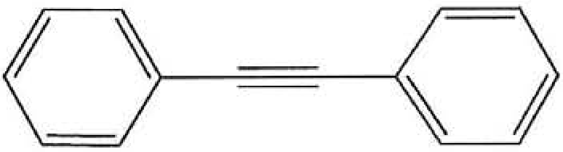
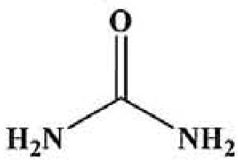
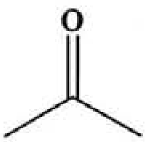
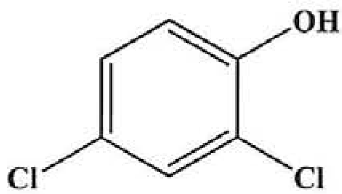
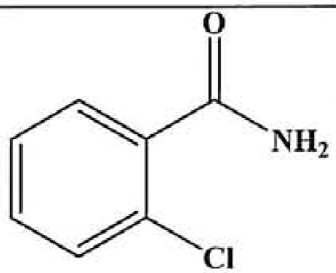
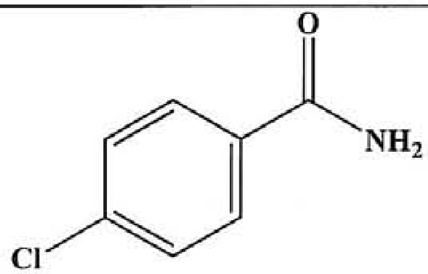
200
180
160
140
120
100
80
60
40
20
0



2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0

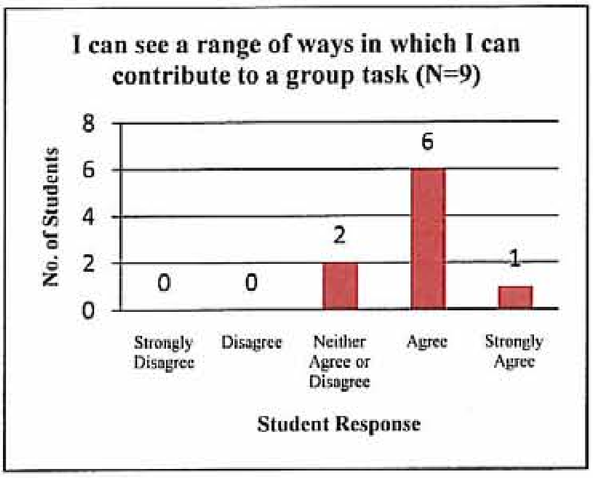
APPENDIX 9

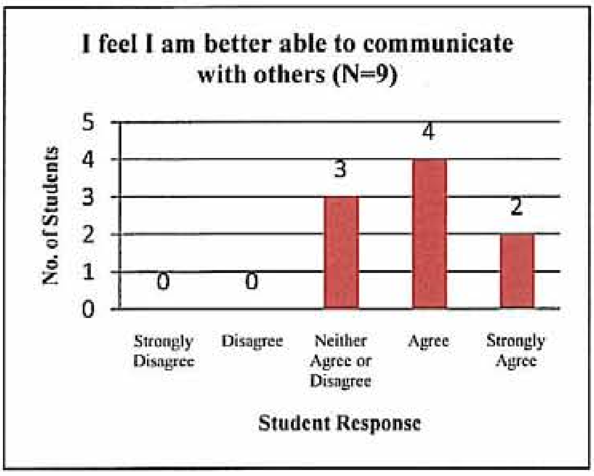
Potential Molecules for Use in the Pilot Study

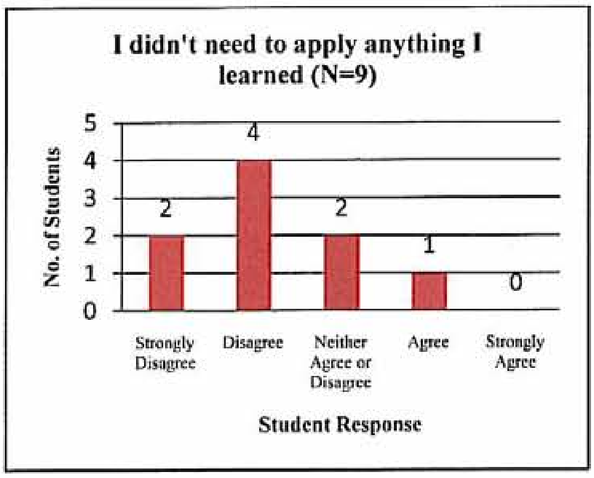
 cinnamic acid	 hexane
 diphenylacetylene	 urea
 acetone	 2,4-dichlorophenol
 o-chlorobenzamide	 p-chlorobenzamide

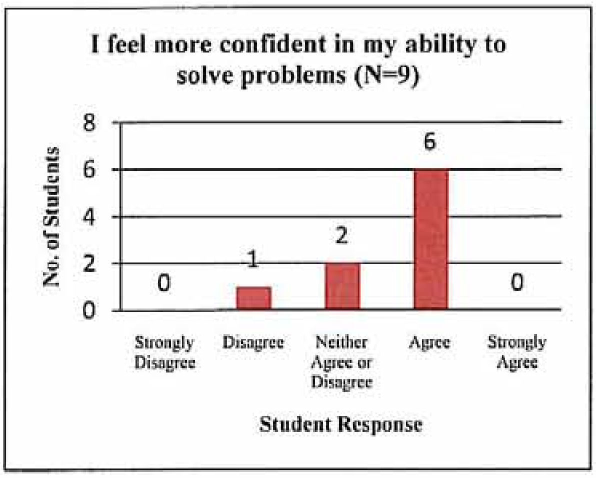
APPENDIX 10

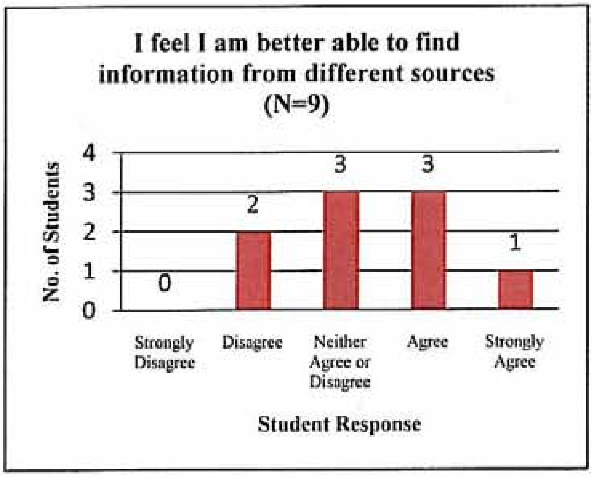
Pilot Study Questionnaire Data

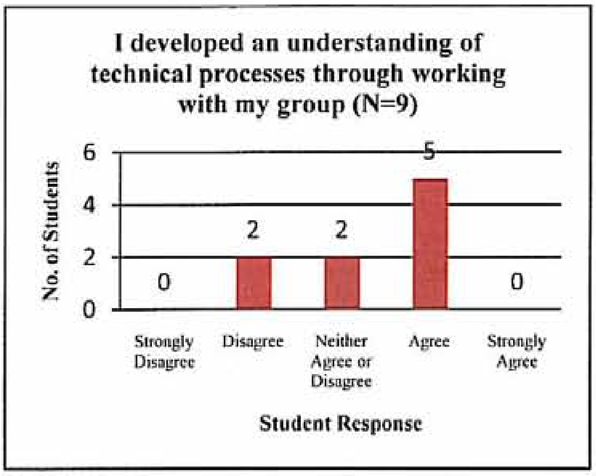


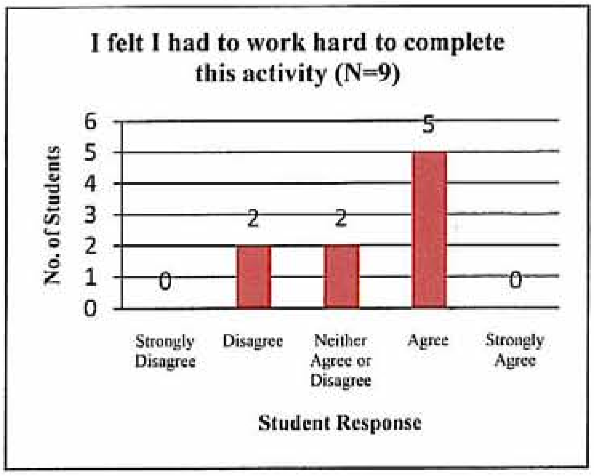


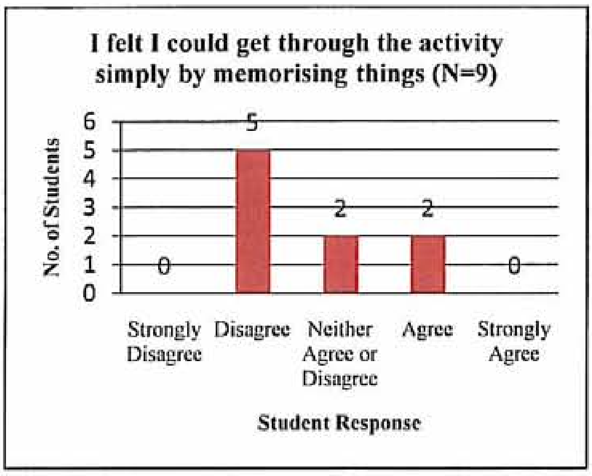


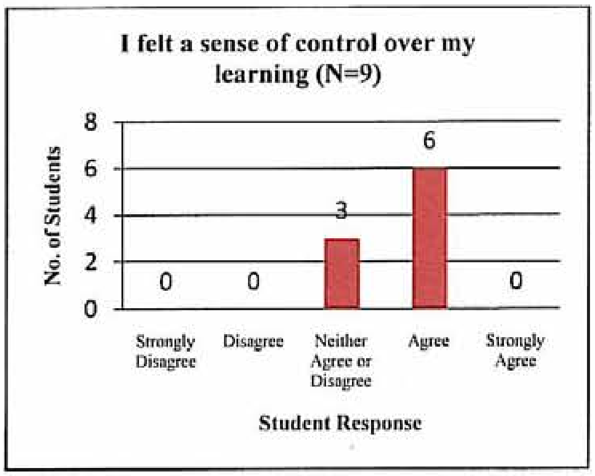


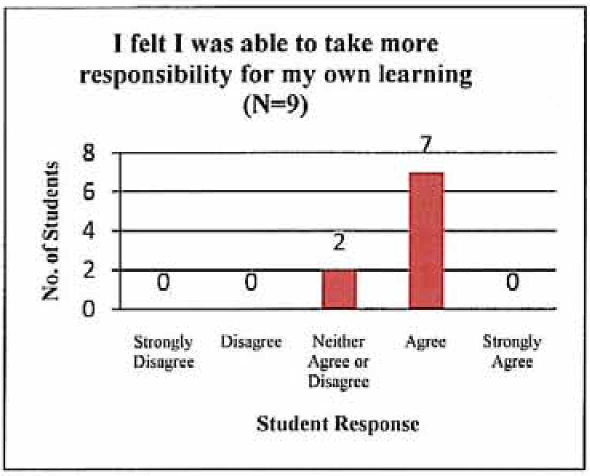


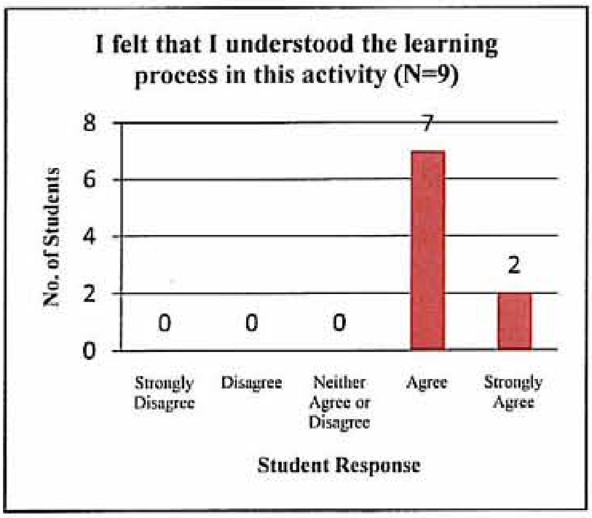


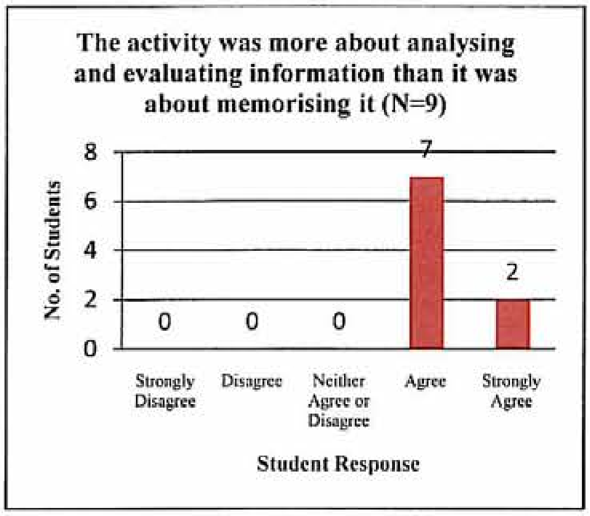

I felt I had to work hard to complete this activity (N=9)
No. of Students
Student Response
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
0
2
2
5
0

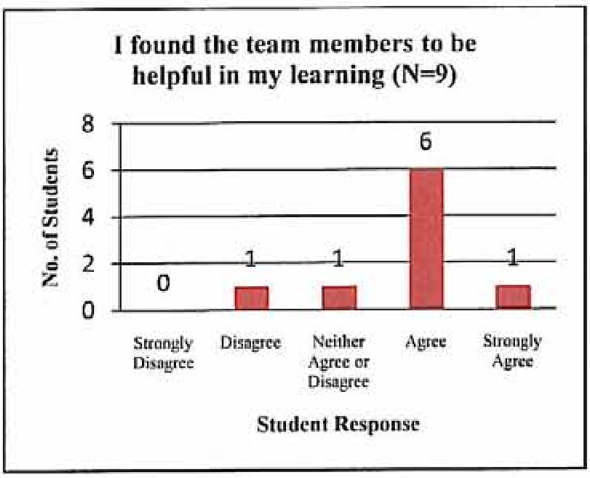

I felt I could get through the activity simply by memorising things (N=9)
No. of Students
Student Response
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
0
5
2
2
0

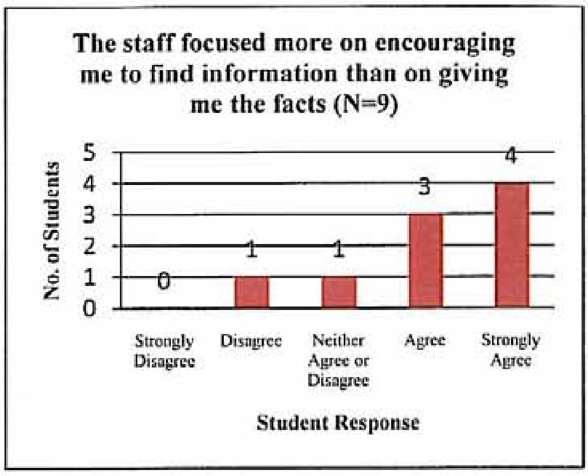

I felt a sense of control over my learning (N=9)
No. of Students
Student Response
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
0
0
3
6
0

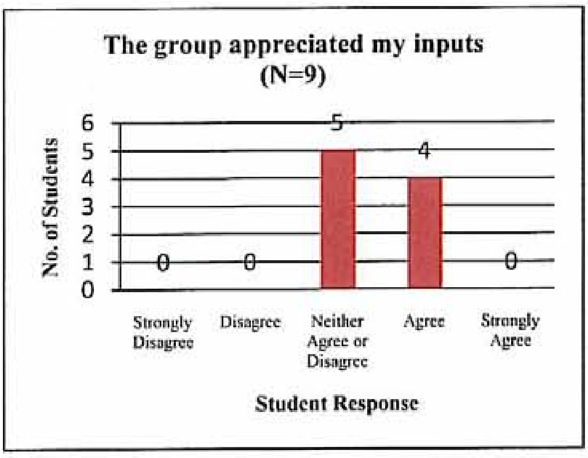

I felt I was able to take more responsibility for my own learning (N=9)
No. of Students
Student Response
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
0
0
2
7
0

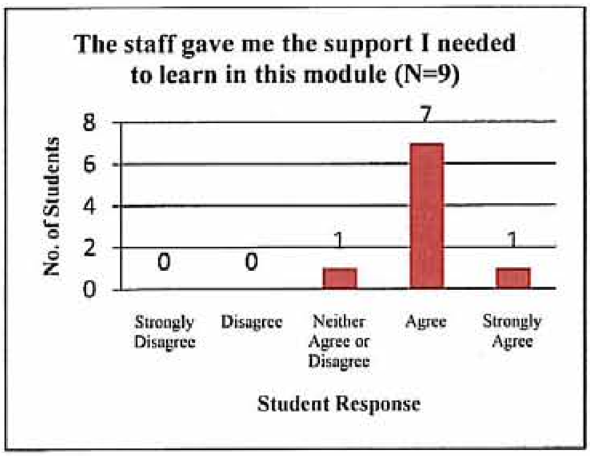

I felt that I understood the learning process in this activity (N=9)
No. of Students
Student Response
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
0
0
0
7
2

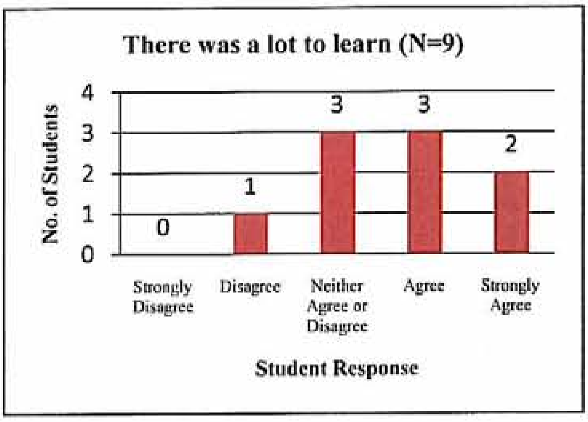

The activity was more about analysing and evaluating information than it was about memorising it (N=9)
No. of Students
Student Response
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
0
0
0
7
2

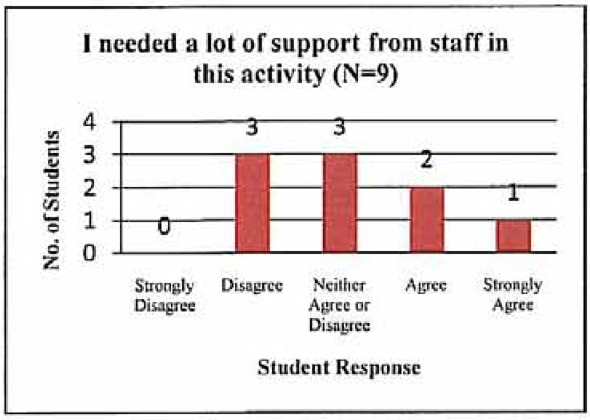

I found the team members to be helpful in my learning (N=9)
No. of Students
8
6
4
2
0
0
1
1
6
1
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
Student Response

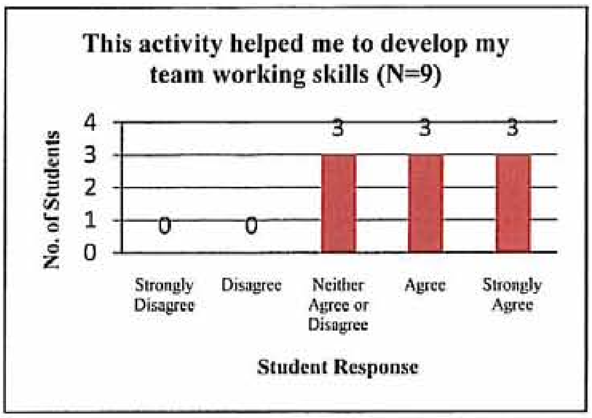

The staff focused more on encouraging me to find information than on giving me the facts (N=9)
No. of Students
5
4
3
2
1
0
0
1
1
3
4
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
Student Response


The group appreciated my inputs (N=9)
No. of Students
6
5
4
3
2
1
0
0
0
5
4
0
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
Student Response


The staff gave me the support I needed to learn in this module (N=9)
No. of Students
8
6
4
2
0
0
0
1
7
1
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
Student Response


There was a lot to learn (N=9)
No. of Students
4
3
2
1
0
0
1
3
3
2
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
Student Response


I needed a lot of support from staff in this activity (N=9)
No. of Students
4
3
2
1
0
0
3
3
2
1
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
Student Response


This activity helped me to develop my team working skills (N=9)
No. of Students
4
3
2
1
0
0
0
3
3
3
Strongly Disagree
Disagree
Neither Agree or Disagree
Agree
Strongly Agree
Student Response

APPENDIX 11

ID Number

Mid-EBL Sessions Evaluation

As part of our teaching and research we would appreciate it if you could fill out this questionnaire about the spectroscopy EBL sessions you are currently undertaking on Fridays.

For each statement, tick one box to indicate your response as follows:

- **1 = strongly agree**
- **2 = agree**
- **3 = neither agree or disagree**
- **4 = disagree**
- **5 = strongly disagree**

	Statement		1	2	3	4	5
1	I understand the learning process in these activities						
2	I am finding these activities difficult						
3	These activities are helping me to develop my team working skills						
4	I am learning how to plan my learning						
5	I understand the role of the postgraduate students in the sessions						
6	The activities are more about analysing and evaluating information than it is about memorising it						
7	I feel I am better able to find information from different sources						
8	I am more confident in my ability to evaluate the information I have found						
9	I feel I am better able to evaluate different sources of information						
10	I need a lot of support from staff in this activity						
11	The group is effective in developing shared goals						
12	I enjoy working in this way						
13	I find the team members to be helpful in my learning						
14	I don't need to apply anything I've learned						
15	There is a lot to learn						

	Statement		1	2	3	4	5
16	I am enjoying working as a member of a team						
17	I feel I am better able to communicate with others						
18	Any interpersonal difficulties have been cleared up in a positive manner						
19	I feel I have to work hard to complete these activities						
20	My group work well as a team						
21	I feel I am able to take more responsibility for my own learning						
22	The group worked well to overcome any difficulties or problems we encountered						
23	I find the activities challenging						
24	I can see a range of ways in which I can contribute to a group task						
25	The group appreciates my inputs						
26	I feel I can get through the activities simply by memorising things						
27	I feel a sense of control over my learning						
28	The staff are giving me the support I need to learn in this module						
29	I would prefer lectures to the EBL sessions						
30	I an enthusiastic about the EBL sessions						
31	I receive adequate feedback						
32	I receive timely feedback						
33	I find the discussion boards in Web CT helpful						
34	I am learning how to tackle the problems						
35	The learning is relevant to my needs						
36	The staff focus more on encouraging me to find information than on giving me the facts						
37	I enjoy working in this way						

What are the positive things about the course?

What are the negative things about the course?

What suggestions would you make to improve the course?

Any other comments

APPENDIX 12

ID Number:

Post-EBL Sessions Evaluation

As part of our teaching and research we would appreciate it if you could fill out this questionnaire about the spectroscopy EBL sessions you have undertaking on Fridays.

For each statement, tick one box to indicate your response as follows:

- **1 = strongly agree**
- **2 = agree**
- **3 = neither agree or disagree**
- **4 = disagree**
- **5 = strongly disagree**

	Statement		1	2	3	4	5
1	I understood the learning process in these activities						
2	I found these activities difficult						
3	These activities helped me to develop my team working skills						
4	I learnt how to plan my learning						
5	I understood the role of the postgraduate students in the sessions						
6	The activities were more about analysing and evaluating information than they are about memorising it						
7	I feel I am better able to find information from different sources						
8	I am more confident in my ability to evaluate the information I have found						
9	I feel I am better able to evaluate different sources of information						
10	I needed a lot of support from staff in this activity						
11	The group was effective in developing shared goals						
12	I enjoyed working in this way						
13	I found the team members to be helpful in my learning						
14	I didn't need to apply anything I'd learned						
15	There was a lot to learn						

	Statement		1	2	3	4	5
16	I enjoyed working as a member of a team						
17	I feel I am better able to communicate with others						
18	Any interpersonal difficulties were cleared up in a positive manner						
19	I felt I have to work hard to complete these activities						
20	My group worked well as a team						
21	I feel I am able to take more responsibility for my own learning						
22	The group worked well to overcome any difficulties or problems we encounter						
23	I found the activities challenging						
24	I could see a range of ways in which I could contribute to a group task						
25	The group appreciated my inputs						
26	I felt I can get through the activities simply by memorising things						
27	I felt a sense of control over my learning						
28	The staff gave me the support I need to learn in this module						
29	I would have prefer lectures to the EBL sessions						
30	I was enthusiastic about the EBL sessions						
31	I received adequate feedback						
32	I received timely feedback						
33	I found the discussion boards in WebCT helpful						
34	I learnt how to tackle the problems						
35	The learning was relevant to my needs						
36	The staff focused more on encouraging me to find information than on giving me the facts						
37	I enjoyed working in this way						
38	I was frustrated that the postgraduate demonstrators would not provide the answers						

What are the positive things about the course?

What are the negative things about the course?

What suggestions would you make to improve the course?

Any other comments

APPENDIX 13

Spectroscopy Questionnaire

Name:

Which of the following techniques have you learnt about before? (Please tick as appropriate)

Mass Spectrometry	
IR Spectroscopy	
^{13}C NMR Spectroscopy	
^{1}H NMR Spectroscopy	

Please rate your current knowledge of these techniques:

I understand how Mass Spectrometry works	SA	A	N	A	SA	I don't understand how Mass Spectrometry works
I understand how IR Spectroscopy works	SA	A	N	A	SA	I don't understand how IR Spectroscopy works
I understand how ^{13}C NMR Spectroscopy works	SA	A	N	A	SA	I don't understand how ^{13}C NMR Spectroscopy works
I understand how ^{1}H NMR Spectroscopy works	SA	A	N	A	SA	I understand how ^{1}H NMR Spectroscopy works

SA = Strongly Agree, A = Agree, N = Neutral

Please rate your confidence of these interpreting the spectra from these techniques:

I am good at interpreting Mass Spectra	SA	A	N	A	SA	I am poor at interpreting Mass Spectra
I am good at interpreting IR Spectra	SA	A	N	A	SA	I am poor at interpreting IR Spectra
I am good at interpreting ^{13}C NMR Spectra	SA	A	N	A	SA	I am poor at interpreting ^{13}C NMR Spectra
I am good at interpreting ^{1}H NMR Spectra	SA	A	N	A	SA	I am poor at interpreting ^{1}H NMR Spectra

SA = Strongly Agree, A = Agree, N = Neutral

APPENDIX 14

Spectroscopy Questionnaire

Name:

Please rate your current knowledge of these techniques:

I understand how Mass Spectrometry works	SA	A	N	A	SA	I don't understand how Mass Spectrometry works
I understand how IR Spectroscopy works	SA	A	N	A	SA	I don't understand how IR Spectroscopy works
I understand how ^{13}C NMR Spectroscopy works	SA	A	N	A	SA	I don't understand how ^{13}C NMR Spectroscopy works
I understand how ^{1}H NMR Spectroscopy works	SA	A	N	A	SA	I understand how ^{1}H NMR Spectroscopy works

SA = Strongly Agree, A = Agree, N = Neutral

Please rate your confidence of these interpreting the spectra from these techniques:

I am good at interpreting Mass Spectra	SA	A	N	A	SA	I am poor at interpreting Mass Spectra
I am good at interpreting IR Spectra	SA	A	N	A	SA	I am poor at interpreting IR Spectra
I am good at interpreting ^{13}C NMR Spectra	SA	A	N	A	SA	I am poor at interpreting ^{13}C NMR Spectra
I am good at interpreting ^{1}H NMR Spectra	SA	A	N	A	SA	I am poor at interpreting ^{1}H NMR Spectra

SA = Strongly Agree, A = Agree, N = Neutral

APPENDIX 15

Focus Group Year 1 Chemistry Students (EBL)

AD: [Explains who she is and why we are running focus group]

[AD asks questions of induction material, not transcribed here]

Spectroscopy EBL

AD: How did you find working in groups

[thumbs up from everyone]

F1: I don't know, 'cause some people in my group who didn't pull their weight and they were supposed to so it led to a couple of us doing the work and others who weren't and considering that was some of our mark is based on that I didn't think it was fair…

M1: …but you do get chance to kind of mark…

F2: ….you do get to mark your peer assessments as well so you can mark everyone in your group how they did as a percentage and that goes towards their mark

F3: I liked it, I liked our group, our group really did pull their weight, they shared

[everyone starts to talk at once]

AD: sorry, can you speak one at a time!

F3: with us, we shared all our questions and we got 2 each and then we met up during the week on a Wednesday perhaps, and went through the answers, wrote it up, put it up on WebCT, whereas a lot of other groups didn't bother to put anything on WebCT….

M1: we'd pass work down to the next peer along sort of thing – to assess and criticise and they can agree with you, whatever

F1: we found in our group, because we'd met together and we'd already written it up on a piece of paper, putting it up on WebCT didn't seem like any purpose in it. It was just an extra bit of work that you had to write it up again

F3: but it was to familiarise yourself 'cause when you have to do lab reports and stuff, you have to submit them by WebCT, so it was probably giving you good practice to do that

AD: were you in the same group you two?

F1&3: no

M2: I think a lot of groups took it seriously at the start and stuff, we had a really great time, we were messing around all the time – we did the work!

F1: we'd have a balance in between, but at the start

M: in the start, in the first one, you were told to write some rules down, so we put things like 'no sleeping' [lots of talking, hard to pick out], which is pretty standard isn't it!!

F3: black food was one of ours!

M1: our group, we had really silly ones, like we must always be group 12 and whatever

F3: intergroup relationships and stuff like that, but [laughs] I particularly liked it 'cause I wasn't here for welcome week and that was probably like the first time I got to know a few people in chemistry as opposed to like random people in labs, you got to sit down and speak to them, which was good, which formed a foundation for getting to know other people, doing the communication thing with the answers

AD: you were just chatting just then about some people didn't pull their weight in your group – were they a problem then?

F1: at the start – we tried to distribute it like a couple of questions each, and when we came up to meet, some of them sort of said I've looked at it and I can't figure it out', and considering they hadn't even looked at any of them even like the easier spectroscopy, which seemed a bit point- they hadn't pulled any weight and seemed a bit unfair on the rest of us who had done our own and then had to help them with theirs.

AD: Did you find the discussion boards in WebCT useful for preparing your work in groups?

All: No!

F1: it seemed pointless us going onto WebCT

M1: although it's useful for regular meetings

F1: we used to exchange mobile phone numbers and you were more likely to get a response if you phoned someone up, rather than if you just leave a message that they may or may not check. We actually went onto the WebCT discussion board when we were in our group just to make it look like we were on there

F3: yea, that's what we did because we thought we'd get marked in WebCT!

F1: we went on thinking we had to type stuff up – 'do you think this could be this' and ….

F2: ….most people carry their mobile phones around with them, no one checks WebCT that regularly, so to be able to pick it up straight away, so you're just more likely to get in touch with somebody if you phone them

M2: plus you don't really need to discuss them online because you work them out in the meantime, see what you got

F2: plus you see them in lectures every day so

AD: OK then, so what did you think of the EBL scenarios?

M2: It just got a bit repetitive towards the end

F3: [in background] they were good – they tried to look..[?]

M2: they failed – it does get very repetitive towards the end

F2: well they were the same exercises weren't they?

Everyone: yea

F3: it was exactly the same exercise, just different scenarios

F1: just lots of weeks doing the same thing

[everyone talking together now]

M2: I think if they changed the format and they did it one week the way they'd done it, then next week, they made it some way of putting it across but they were still in the same format, that might of made it more interesting

F3: I think they'd focus on different parts for different weeks – like one week was mass, another was IR and the other week was .... instead of doing the same, all four in one week, it's very repetitive

F2: even with the different scenarios, it basically boils down to 'what is it? Work out what it is?'

AD: so do you feel you gained anything from doing it that way

F3: oh definitely

[others murmur positively]

F3: we had to do assessments after that and it really did help because the groups were divided in such a way that we were divided upon our strengths and our weaknesses so, if one person knew say mass spec and someone knew carbon 13, then they were put in the other group rather than all the people who knew every technique and all the people who didn't know any techniques put in groups, so it was all, so everyone in the group knew 3 of the 4 and so when we did the assessments, it got us to practice on the bit we didn't know, which in most cases was the carbon 13

M1: we don't do that at A level

F3: yea, we didn't do it at A level, so when we did the assessments it was quite good, good practise, and she did lectures on each of the things and then we had another assessment just to see where we went wrong

F2: exactly. It's a good idea because even now when, if you're doing IR in the labs, you can look at it and decide roughly what band it is so it's good

F1: it's just a lot of practice, you just get used to – you recognise it. I find I don't have to look it up

F3: and we had lots of postgrads around

F1: they were really helpful

F3: I thought they were really helpful – the demonstrators

M1: some of them were

F3: well yea, some of them!

M2: some of them just gave us the answers, some wouldn't give you the answers

F3: there was one postgrad – X – and he was like, we ran the scenarios, I think it was the Shelley one – so with that one, he was giving us clues, he wouldn't just give us the answers, which I thought was quite good, rather than – you're not going to learn that –

F1: it's just pointing you in the right direction

AD: right, goodo – would you have been happy to have just had the EBL sessions to learn about Spectroscopy, or do you feel that you needed the lectures too?

All: lectures, definitely

M2: lectures beforehand though because

F3: or interspersed [everyone talking again]

M2: with EBL we are learning how to read the spectra but with the lectures we learnt about the background knowledge of how they work

F3: I agree with you at the beginning, we should have the lectures before we did the thing, but when we had the lectures I didn't think we learnt – it was just background basically – you learnt about vibrations in IR which you didn't need to know ....

M1: but there were some key points that not everyone would know – like the nitrogen rules

M2: that would have helped if we knew about that beforehand

F1: I don't think we need the whole lecture course before, but I think if we'd just had a couple – just sort of the basics on each thing just to, 'cause it was like being thrown in at the deep end 'cause I hadn't done any of this for a while and we'd not done it in any particular depth, and then just suddenly being asked to work out what things were and look at these based on what you could remember and what other people could remember

F3: but like she did do a lecture of each of the techniques like one day we did IR, another we did mass specs, but I do agree with x, I think we should have them before the whole EBL thing and then we can use the knowledge from the lectures to actually put it on paper

M1: it does seem to work though because no one knew how to do carbon, but by the end of it we knew how to do it.

F3: and most people did well on the assessments anyway

AD: good, that's positive. Do you feel that with the EBL, you've learnt more, that's included with the lectures, or could you have got away with just the lectures?

M1: no

[lots of voices answering at same time]

F1: EBL is more hands on

F3; to be honest, I thought the EBLs were better than the lectures

M2: it was because spectroscopy is a technique rather than something you just learn

F2: definitely more interesting than lectures – you're in a group, your interacting, you've got the postgrads there

F1: it's more engaging

M1: although we seem to be doing that now – sitting in lectures on a Friday afternoon

AD: how did you find the Friday sessions apart from the 4-6 time, how do you find the style of demonstrating

M1: at the start it was quite interesting because we were given these pads of paper and

F2: sort of given what the rules were

M1: and there was fun quizzes and stuff and towards the end it was just – we weren't really using the resources, we were just doing the quizzes and working out and stuff

F2: there was one point when we had to email, email things and something didn't email and we didn't get an email back in time or it didn't send and it ended up in the session and we were just emailing it just because we had to, to Dr X who was in the same room and it was just, and we were waiting to get an email back even though she was just the other side of the room!! It seemed really pointless and quite unreliable. I mean you weren't learning anything – you were doing it for the sake of getting an email in on time to get a reply so you could finish it

F1: yea, it was sort of, making it more complicated just to fit the scenario and it didn't help very much 'cause we were sitting around waiting for an email back

AD: were you frustrated to be guided by the answers rather than being given them directly?

F3: no, I think it's better when someone gives you the answers in a way that you're actually learning from it rather than 'this is wrong, that's the answer'. I personally like to know how I got to that answer, so that's quite a good way

F2: yea you want to work – if you were presented with the same problem again, you still wouldn't be able to do it

F3: and I suspect we might get loads of them in the exam

AD: these is very encouraging! Have you any suggestions on how to improve year 1 EBL for next year as a sort of summary

F3: I think timetable slot, just because, like the first years had it quite difficult because even in the first and second semesters, we are here the whole of the afternoon until 6 o' clock most Fridays, so I think 4-6 after having two lectures prior to that workshops – students are just like –arrrgh

M2: and maybe a different room as well as it's really crowded

F3: well we were supposed to do it in the Learning Centre but because there were so many people doing chemistry that's why they moved

F2/M1: but it's really cramped as well

M2: groups sharing tables – a lot of cheating!

F2: and it gets hot and stuffy on a Friday afternoon and no one wants to be there.

F3: some demonstrators were really helpful and others weren't, they were like 'no you should know this'

M1: they're just doing it for the money!

F3; [laughs] but most of them were really helpful and like gave you clues rather than spoon feeding you answers. They didn't belittle you, which is a good thing, 'cause obviously you know it and we don't or we don't just yet

M2: change the format every week as well to make it more interesting

F3: so it's not so repetitive

M2: yea, repetitive

F3: but it was a good thing, because we could have had 4-6 lectures like from 4-6, but the fact we're in a reading room kind of, we were still doing work but it was more mellow and we got to socialise as well – that was probably better than being given a lecture

F1; we often left early didn't we? And I think that was because it was the end of the day. I think if it had been earlier they would have got more work out of us because we wouldn't have been so desperate to leave

F3: I don't think they let us leave until we'd finished the work though

F1: but there were times when the rest of the group had left and I'd stayed 'cause I was having a bit of trouble and the demonstrators were really helpful

F3: I think they should assign one demonstrator to a group as well, 'cause some people had like 2 or 3 demonstrators in their one group and others didn't have any walking around. So if they had one demonstrator to one group and then rotated

M1: and rotate yea

F3: and rotate on a weekly basis

M2: the thing was you had to say who was a team leader. That seemed a bit pointless

M1: yea 'cause it didn't work like that at all

F3: yea, that never really happened

[everyone talking at once again]

F1: the only thing with that is some people didn't pull their weight some weeks 'cause they didn't want to be a leader, it would always fall to the same people every week to do it

F3: for us, we actually said 'we don't want a team leader, we don't want a scribe' so your two elements, you put on WebCT, and you write yours on your piece of paper, and you do this, we just separated all the questions and we just wrote our own ones but we did meet up during the week to discuss and we had everyone's input so it wasn't just one person doing all the work

AD: I mean I don't know if it was a time issue that they put it at that time of the week

F3: I think it is a timetable issue

F1: I was talking to my tutor last year, semester and he said it was either lectures plus EBL last thing on a Friday or Labs and honestly I'd rather do EBL at that time

[F3 &M2 mutter agreement]

M1: the computer doesn't really care what time you finish!

F3: and also it clashes with other people 'cause some do major minors, some do straight chem., some do analytical, so it's probably the only free slot. But I think first years have had a really bad timetable issue with a Friday –

F2: I'd rather have it on a Monday morning 'cause you can't really go home very well

F1: I have 9 o'clock starts Monday to Thursdays every single week!

AD: I think there are always going to be timetable issues

F3: I think workshops, we don't any …. With Dr X either,

M1: we don't have …..module

F3: [very quiet] exams – 5%, whereas EBL is worth 25%, whereas everyone else their exams are 65% and 25 is lab and 10 is tutorial

M2: I guess it's a good way of breaking up marks for you, not all down to the exam at the end

F3: one thing I didn't like though like the assessment we had was like 6 different assignments and they were like 40%, 20%, we had 2 EBLs assessments at 40% altogether, but that was 40% of 25%, which we do quite a lot of work for it and don't think we get enough marks for the amount we do

M1: yea, for the amount we do

F3: there were 6 EBL sessions and each of the assignments we did were worth 10%, the second two were 40% and then there was another one where we had to write an essay for and that was worth 20%. So all that 100% of the 25% module….

M1: it's not really worth that divide

[2 others agree]

F3: it takes up a lot of time

F2: a lot of time

F1: yea

F2: a lot of it's in your own time as well, doing it

F3: you do five different questions but each one is explaining the different methods and then finding out what the compound is, so that took ages!

AD: so you'd like more credit for what you do then?

F3: yea, if they make it 65/35 like most modules, 'cause most modules are like 65% exam and 35% other stuff, so if it was all the same

AD: does that put you off that way of learning

F3: well no, yea, I got a good grade, and I realised it was oh, it's 25%,

F2: it puts a dampener on when you get your results and you're thinking 'oh I got 70%'

F3: exactly.

F2: but it's of 25% - a tiny little amount

F3: I didn't know this until I actually looked at my specification in the book we got given

F1: back to induction week, what would have been helpful and I know it's the start of the year and you're not thinking much about exams, but it would have been nice to – I think it was in there with all the module stuff – but just a break down of what exams we would be getting and what they would be worth and where the marks were all coming from. I think we've got the information somewhere but it's buried

[3 others agree]

F3: They don't know it themselves. When we went to the student/staff meeting that's what they were saying – they don't actually know – the first year exams take place in the 3rd-5th week but we don't…but the breakdown they don't know 'cause they don't write the questions

F2: you mean like what percentage goes to what like what you saying before

F3: well they know like 65% is exam, but they don't know where the marks are allocated or how many you have to answer until the questions are written, 'cause we didn't know, there are 6 questions and you have to chose 4

AD: is that because you are all doing different things then or…

F3: no.

AD: I think at this stage in the course it's quite important though to look ahead and see how this is going to provide a basis for when you get to your finals, I mean, I think with what you've said with the EBL and all that you've done, it's most useful phase it's helped you to revise and understand things so you've got some basis from which to move on to the next year – is that fair?

F3: yea. I mean a lot of us didn't know about carbon data, but we can safely say we know that now

F1: it's the kind of thing we're going to use over and over again

M2: yea, it's useful techniques

F1: and it's not even for an exam, you've just got to use it

F3: it's useful in labs as well 'cause the format they show on the piece of paper, they're more like, dummy staff,

F2: yea, they fix it so you can understand it easier, whereas when you get the actual – it's a lot more difficult to understand

F3: and that's another thing that Dr X did, she actually gave us actual spectra data so we knew what to expect in the exam. You're probably going to get a fixed version – a few peaks you're going to have to label, but in real life, we know what they look like

F2: so we're not going to go into a lab next year and think 'arrgh'!!

APPENDIX 16

Chemistry Postgraduate TA Interview: March 2008

Do you feel that you had adequate training for facilitating the EBL sessions as opposed to normal demonstrating?

I did feel a bit kind of lost in it. Demonstrators weren't so important for this, more for the previous style. As it was, I felt like I was sitting at a loose end and there wasn't much I could be doing. Most of the questions students asked I couldn't answer 'cause students had to work them out for themselves. It was just trying to encourage them to work things out for themselves.

How did you go about that then?

I found it quite annoying! Because I know all the stuff and taught this course and the second year course as well in the same kind of thing, and it was very much a taught thing. So not being able to tell them anything was a bit weird. I had the idea of teaching them a bit as we went along to impart some of my knowledge to them, but I'm not allowed to do that this way. So, it was very much 'what do you think the answer is' and getting them to talk to their peers more. It was easier to deal with individuals when they got stuck. When the whole group got stuck, it was more of a problem.

Students also got frustrated with the format. I spoke to a few outside the EBL sessions and found that quite a few weren't getting on with it. They wanted to be spoon fed mostly, which isn't necessarily the best.

First years got annoyed when they couldn't figure things out but this was often due to trying to rush through it rather than sitting and thinking it out properly. It's more theoretical this year

Second years – given more real spectra of compounds so it's more tricky to work out what's what. They always found it more tricky but they got used to it by the end of it.

Did they explain the concept of EBL enough so you knew what to expect and what to do with the sessions?

Yes, that's true. I kind of knew what to expect. I didn't know what they would have been taught or what level they would be at. From what I understood, they were split up into groups according to what they knew – they had one specialist in each field in their group. A lot of the groups had 5 problems with 5 of us, 1 problem each, then they would be able to do their specialisation on the thing and a little bit else, then they'd start getting stuck, everyone would be fine with that and nobody would get anywhere. It was my job to get them to talk to each other!

From your perspective, how did you find facilitating compared to demonstrating?

I think they will get a lot out of it. On a personal level, I didn't enjoy it as much. They found it fairly frustrating but it's good practice for them irrespective of what they've learnt on the course, they'll probably learn techniques for working things out in the future.

What do you think of the concept of EBL as a way of learning and how it compares with the more traditional way of learning?

I do think it's a very good idea, but you are going to get resistance to it! Some of them just want to be taught stuff, but science degrees have always been very much taught and not having to read text books yourself, certainly with what we did, we didn't read much outside what we were given. It's a different mindset, it's something students should be able to do – work things out for themselves.

Do you think they should be prepared a bit more in terms of their expectations – it's all quite new – the first years accepted it more, the second years weren't so sure.

I think that starting in the first year is the best place to start because they don't know what to expect other than it will be different to school. Students don't necessarily appreciate or enjoy things to start with but then see the benefits later on.

How do you feel the students found the EBL sessions compared to the previous workshops?

The first years hadn't done anything like it before, so in comparison to previous years, I think that there will always be some who get on with it and others don't – true for whatever method you use. I would have liked to have seen them after they'd been taught it. I understand they still got the lectures they would have had before after the sessions so they still got the same information base. That's one thing I found – it was very much based on what they did at A level, so it wasn't entirely about learning completely, it was just that some had done huge amounts at A level on the subject, also because they'd already learnt it they weren't working it out for themselves at that point. It's very hard, giving them a few more starting points for working it out, making it something new – but that's going to be impossible because first years have such a wide range of different A level syllabuses!

I'm certain the EBL has improved over before they started it, but I don't know if it's any better than the other method because – you'd have to look at exam results to see. It could be useful to have one or two more workshops – traditional – after they've had all the lectures as well and see how they do in that and see if they can still work it out for themselves. The other method requires quite a different mindset because they know that the maximum they can know about any technique is what they've been taught – they start with each technique and work through it.

Have you got any suggestions how they could improve the sessions from both perspectives?

I don't know. There's nothing that leaps out, other than having another workshop or two after the talk and see how it compares and remind them that it's a similar process. No matter what you do, some will get more out of it than others. When I was an undergraduate there was quite an emphasis on passing exams – from the students – in terms of 'right we've been taught this on the course, we know it's going to be on the exams, this might be on the exams so we'll revise this'. That wasn't the way I personally learnt it, I learnt everything because it was interesting info outside the exams to know.

Did you have that in mind – does your attitude reflect the fact you've gone on to do a PhD?

I did find that I'd learnt all the information, I could add the extra information to the exams and if there was any cross-over from one topic to another I could still talk about it. I think that's where I got higher marks than my colleagues. Flexibility of knowledge. I think the EBL will help them to realise that not everything is as cut and dried as this fits into that module – they'll have to work round problems - they can't work out what they need to learn to pass an exam from the EBL because the skills they are learning are how to get round a problem as much as the actual chemistry they are learning.

What do you think the key factors are in this whole thing of students out to pass to exams – what do you think makes them like this?

I think particularly – I've spoken to a few of my friends, informally – students, since the increase of tuition fees, feel that they're here to get a degree, a lot more than they are used to – they are paying so much money that they have to get value for money out of what they are doing, and so they shouldn't be learning anything that isn't part of their course or exams and that this money is going into getting them a qualification, not into getting them knowledge. So they don't care about the knowledge, they care about passing exams. The extra money is causing them, affecting them badly, it's making them not want to learn anything that isn't part of the course. It's also making them not wanting to spend any time outside of work.

How extensive is this?

I know quite a lot of students from a lot of different departments and I've found this to be the case across the spectrum. Having been involved in societies too, the last couple of years, particularly this year and a bit last year, no one seems interested in doing anything that's not involved in – events during the week they don't attend because they've not got time – they've got to go back and work. It never used to be like this. Fees are the only obvious thing that has changed, but I don't know what else.

It's hard because a lot of them think they are here to get a qualification. Some have optional modules if they want to learn more. Students should maybe attend optional stuff to expand their knowledge.

APPENDIX 17

Spring Term 2009 Focus Group

Interviewer: "Right, erm. This is going to be a really quick discussion and the first thing we want to do..... did you all participate in that mid and post EBL questionnaire. You don't remember?

M: "Erm. If you jog our memories we might have."

SHOWS QUESTIONAIRE

Group "Oh yeah, yes"

Interviewer : "You all did this didn't you?"

S: "Yes. A while ago"

Interviewer: "Can I just ask. If I asked you to define what you class as difficult what would you say?"

S: "In what context? A chemical context?"

Interviewer: "No, no. It could be anything. If I came and said something was difficult and something was challenging, how would you define both terms?"

S: "I think challenging is something you can do but require a bit of thought. And difficult is something you haven't done before so it's getting a grasp, getting used to it, you have to"

Mx: "trying to understand it properly"

A: "Or maybe if you can't do it all and you need extra help. That might be difficult"

L: "You certainly can't do it straight away. You need to spend a lot of time trying. Trying different things probably.

Interviewer: "So that's difficult. So what about challenging."

A: "Something which does require you to think a bit. Apply rules to a new situation that you've never done it before."

Interviewer: "So if you're looking at a chemistry problem then you might..... you know the sort of formula that you apply but you've never done it in that particular way before?"

A: "Yeah or just thinking about the problem from a different direction completely"

M: "Difficult sounds sort of more negative than challenging so challenging would be something that you enjoy working out, rather than difficult would be something that you just find hard and...."

S: "It can go hand in hand but sometimes like you said but sometimes there is not always a positive or negative thing. Difficult, you can hate it because it's so challenging that you can't get your result or complete what you're doing. Challenging can just be that you're doing it for fun or you're enjoying solving something and you do get satisfaction out of achieving what you're going to achieve."

A: "Does anyone else think anything different?"

L: "I say challenging you're sort of testing yourself, seeing what you can do and you have to see how far you can stretch yourself. Whereas difficult is something you struggle with more and so they are similar "

Interviewer: "So that's going to lead onto my question. Do you think that they are the same thing or are they different?"

S: "Something has to be difficult to be challenging to some extent. So if something is too easy it's not difficult and therefore it's not challenging because it doesn't require any thought process behind it or you're not getting any form of satisfaction out of achieving something. If you do something really easy you're not going to get the satisfaction of doing it because you just do it like that *clicks fingers*. It's like doing 2+2 to me ohhhhh I've done it and it equals four. It doesn't mean anything to me. But if you do a complicated sum it can be challenging and getting the right answer at the end can be satisfactory "

A: "I mean challenging in a labs context. Challenging is standing in a lab for whole day, trying to synthesise some little white powder at the end of it. But then difficult might be if you're having to do it for six days without any breaks. To endure it!"

Interviewer:" So you view difficult more as the length of time it takes to do something?"

A+S: "not always"

S: "It could be the complexity "

A: "Yeah complexity as well. Adding more layers of complexity to something would make it more difficult"

Interviewer: "So difficult would be more complex than challenging?"

L: "Yeah difficult is something you probably have more trouble with than challenging where as if it's challenging you find it difficult but you can eventually, probably get the outcome that you want. Whereas difficult could be you're struggling to do it I think. "

S: "For a challenge it's only so far you can push someone before it becomes difficult and obviously that varies from person to person but it's still true."

Interviewer: "that could almost be a motto for everyone"

A: "Anyone else want to add........mx?"

Mx: "No I concur with it"

APPENDIX 18

Memorandum

TO: Staff, Analytical Department
FROM: John Baker, Head of the Analytical Department
DATE: 12/10/07
SUBJECT: Carlton Laboratories Waste Disposal Contract

Dear Graduate Chemist

Recently, Carlton Laboratories employed our company to dispose of chemical waste located in one of their disused laboratories. Unfortunately, some containers of chemicals were not labelled.

In order for us to dispose of these chemicals in the correct manner, the chemicals present must first be identified. Sample collection and spectral analysis have already been performed, and the resulting spectra (^{1}H NMR, ^{13}C NMR, IR Spectroscopy, and Mass Spectrometry) are attached.

Please can you use your chemical expertise to interpret the spectra. This must include identification of the compounds present, and assignment of the key peaks in the spectra provided. This should then enable us to dispose of these chemicals in a safe and environmentally-friendly manner.

Please can you compile a report on your findings, and could you also suggest what the molecules might be used for, and why they are suitable for that use.

Many Thanks,

John Baker
Head of the Analytical Department

Waste Disposal Scenario

Action Plan

	To Do:	Who?
Friday:		
Monday:		
Tuesday:		
Wednesday:		
Thursday:		
Friday:		

Waste Disposal Scenario

Peer Assessment of Group Activity

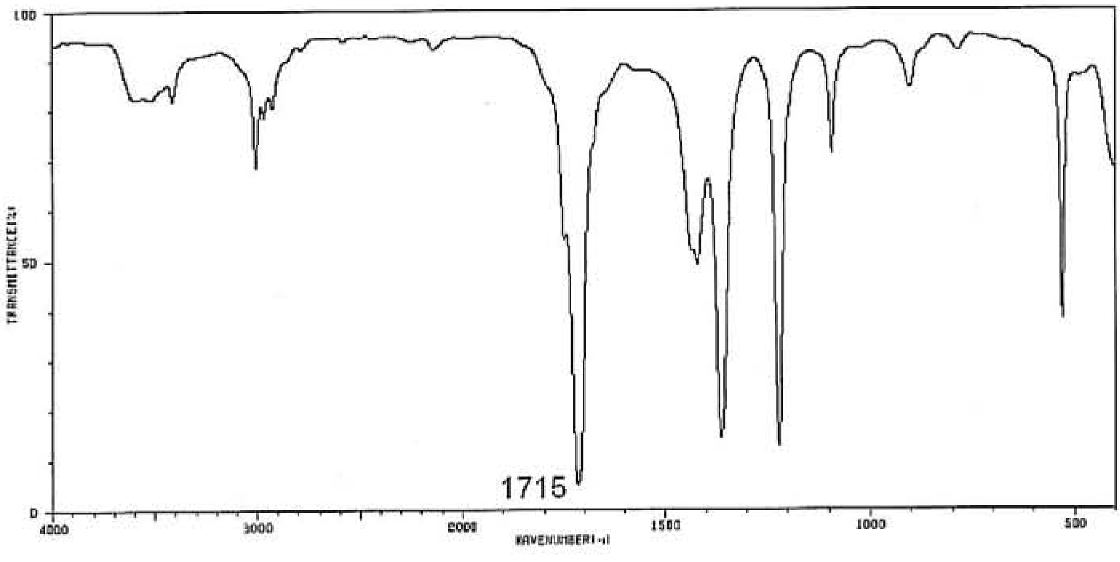
You will each receive group marks for each week's EBL activities as well as marks for your group report. Most of the groups are working together very well, though some are less successful. This is your opportunity to consider whether all of your fellow chemists pulled their weight. Did you feel that everyone contributed equally? Did you feel as if you were carrying anyone?

Consider how your group operated. Then give each team member a score from 0-100 %. If you feel that you all worked well together and made an effective team, then you may give everyone the same score. If the workload was unbalanced, then you may reflect this in your scoring. This assessment is confidential. You will all receive an average score from the rest of the team.

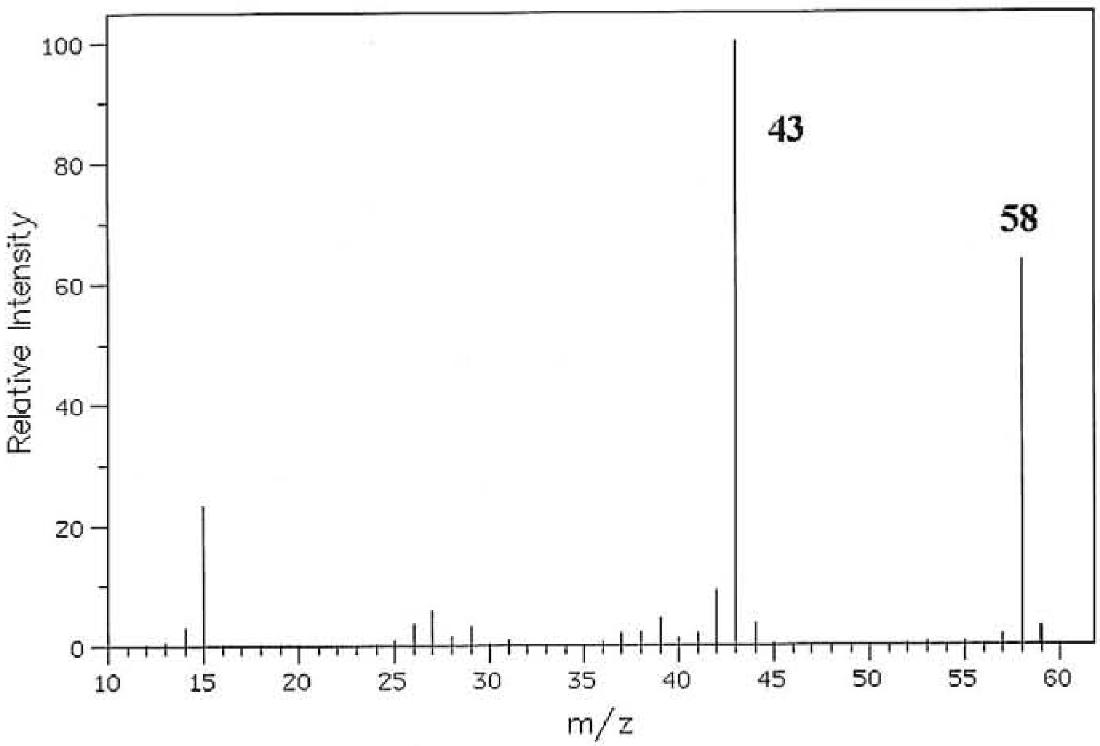
Your name:

Group 1	Score as %	Group 2	Score as %
Group 3	Score as %	Group 4	Score as %
Group 5	Score as %	Group 6	Score as %
Group 7	Score as %	Group 8	Score as %

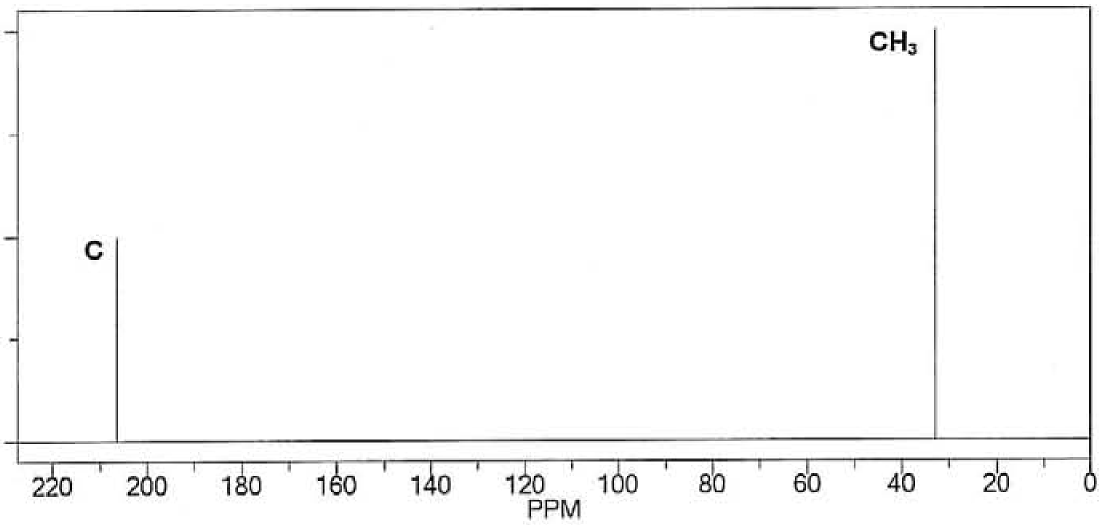
Compound C

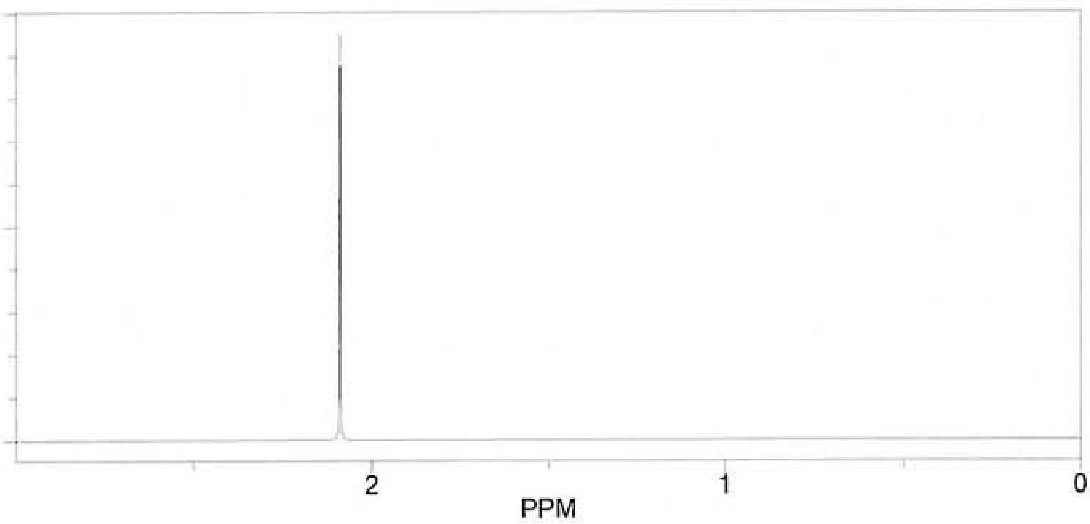


100
50
0
TRANSMITTANCE[%]
1715
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]

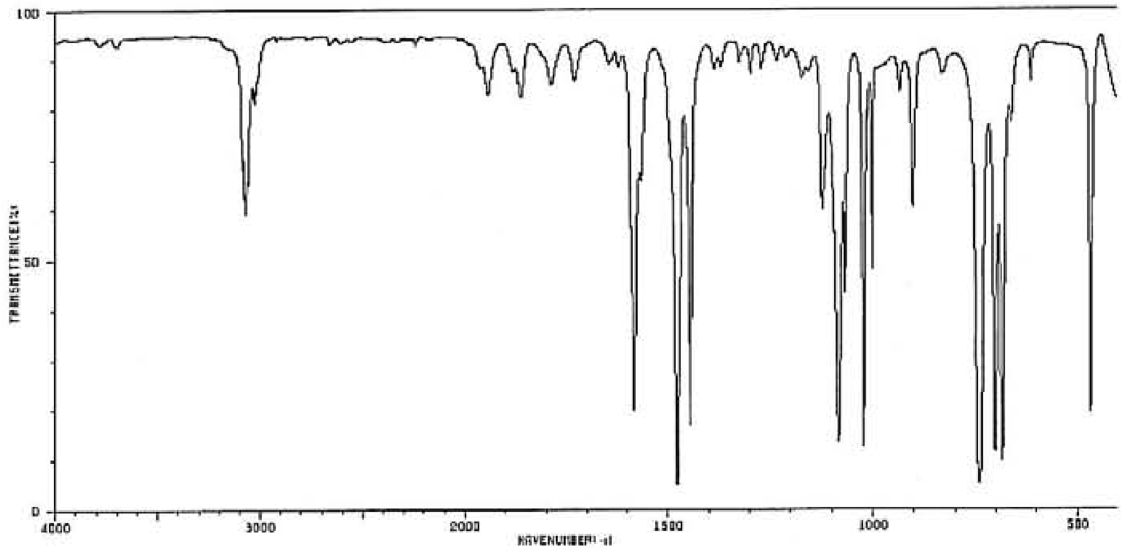


43
58
Relative Intensity
m/z
0
20
40
60
80
100
10
15
20
25
30
35
40
45
50
55
60

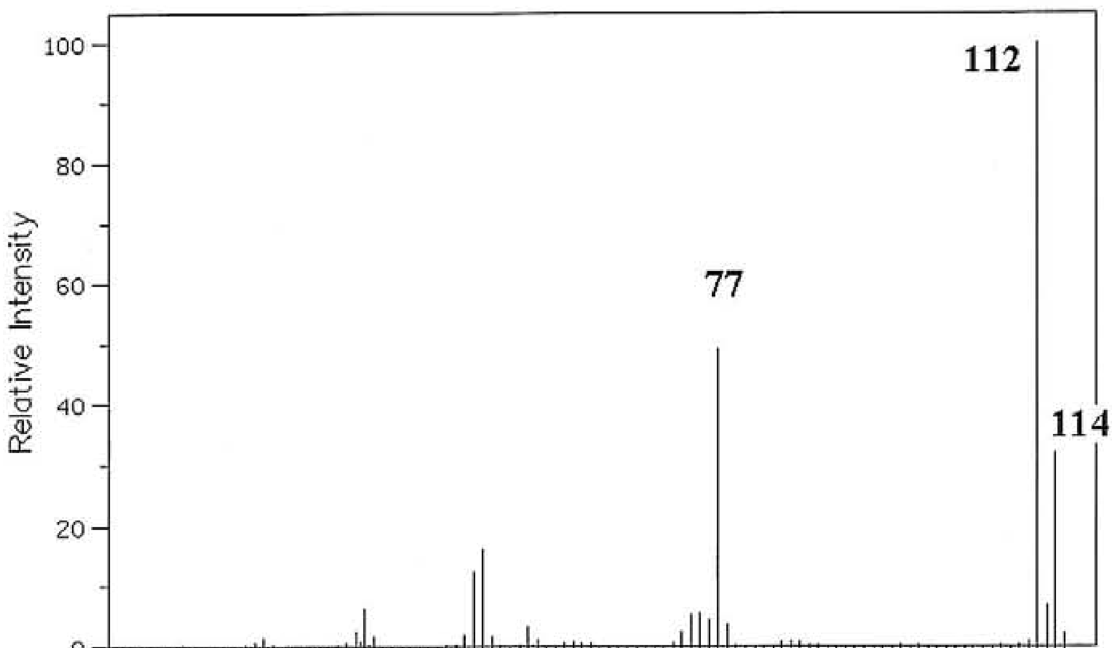

CH₃
C
220 200 180 160 140 120 100 80 60 40 20 0
PPM


2 1 0
PPM

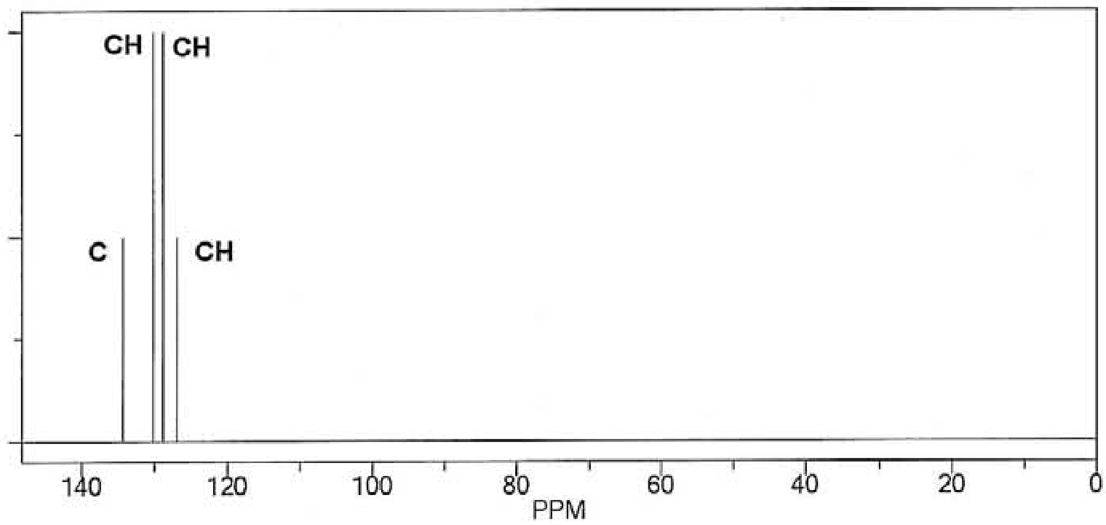
Compound E

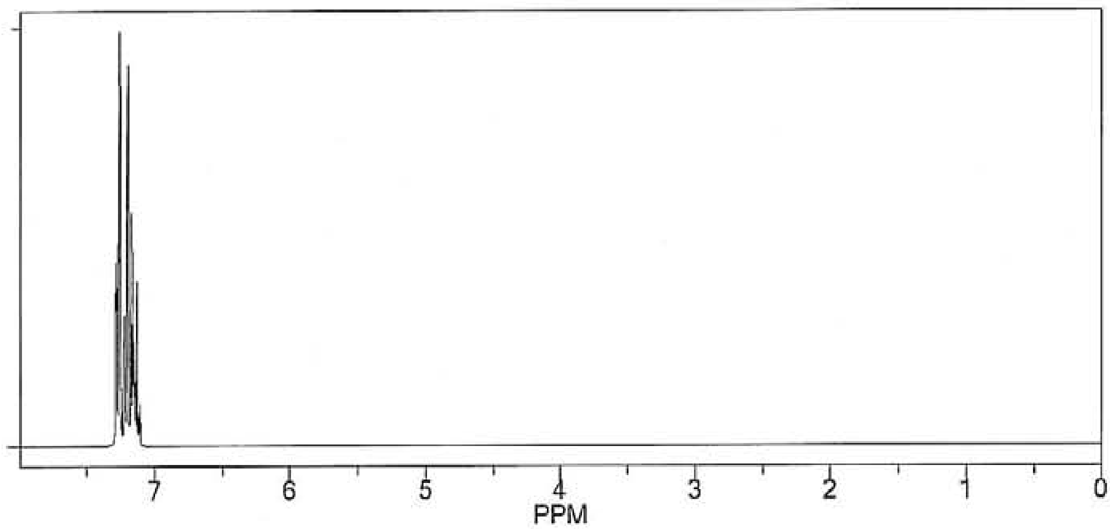


100
50
0
4000
3000
2000
1500
1000
500

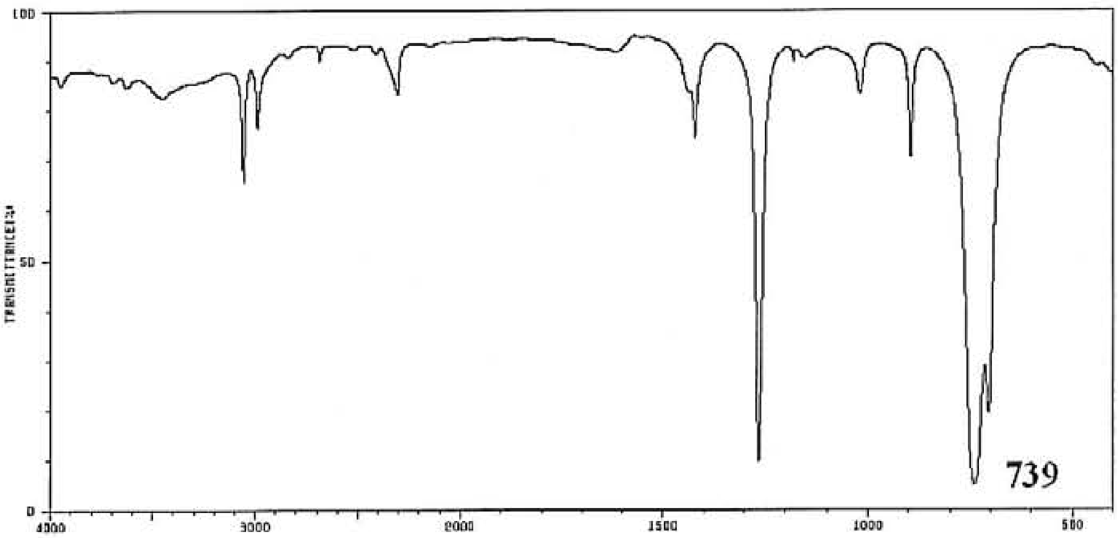


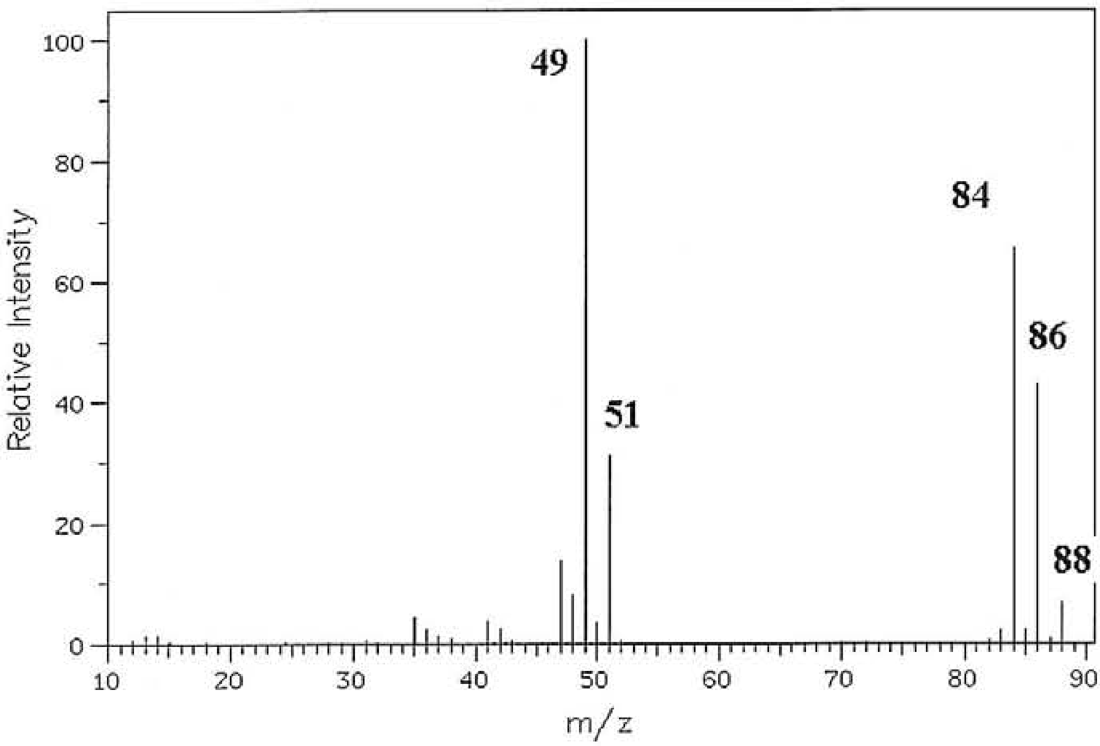
112
77
114
Relative Intensity
m/z

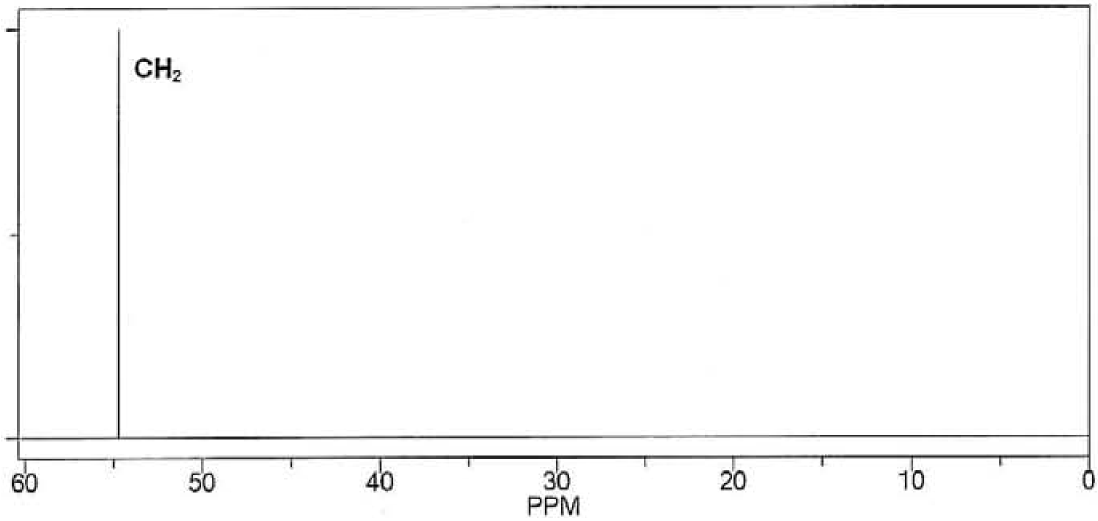

CH
CH
C
CH
140
120
100
80
60
40
20
0
PPM

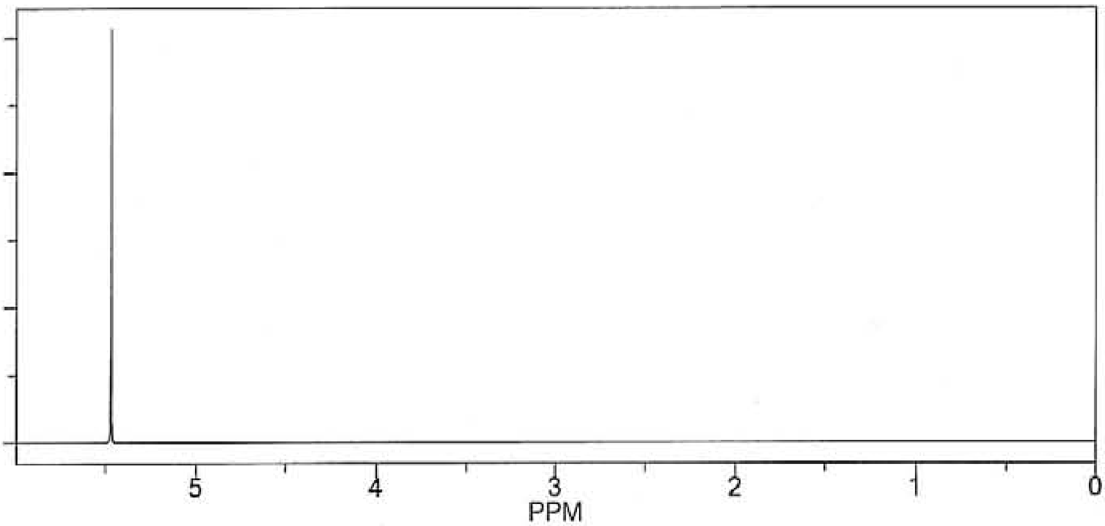

7
6
5
4
3
2
1
0
PPM

Compound H

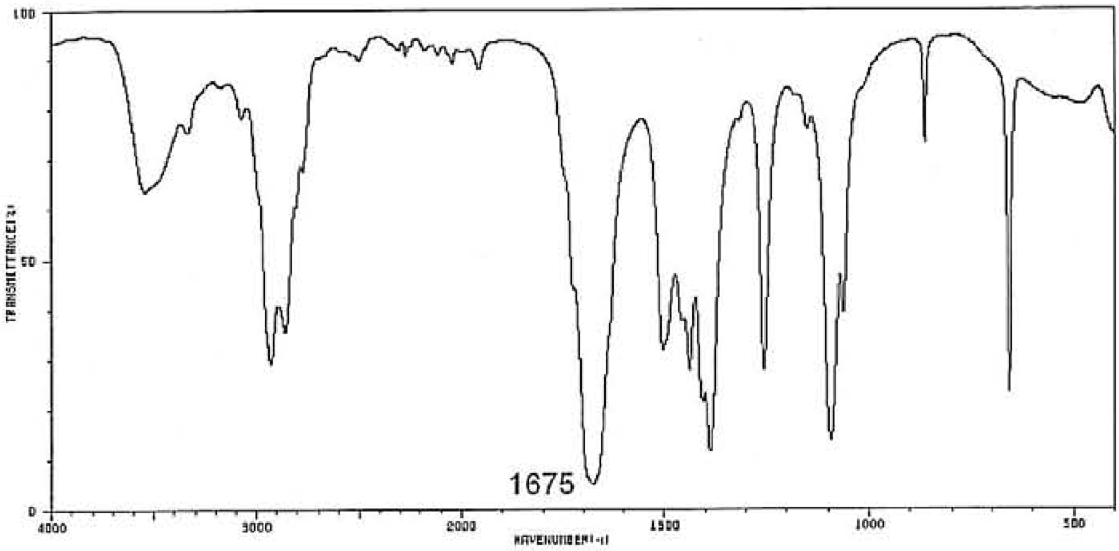

100
50
0
TRANSMITTANCE(%)
739
4000
3000
2000
1500
1000
500


Relative Intensity
m/z
49
51
84
86
88
0
20
40
60
80
100
10
20
30
40
50
60
70
80
90

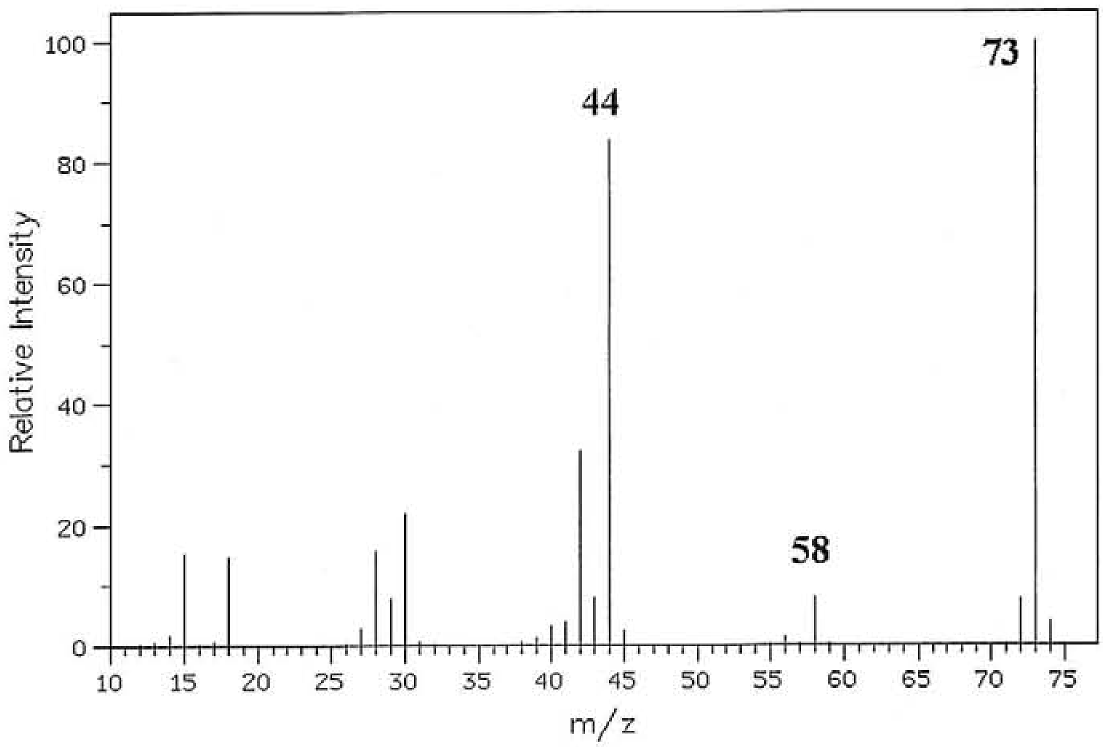

CH$_2$
60
50
40
30
20
10
0
PPM


5
4
3
2
1
0
PPM

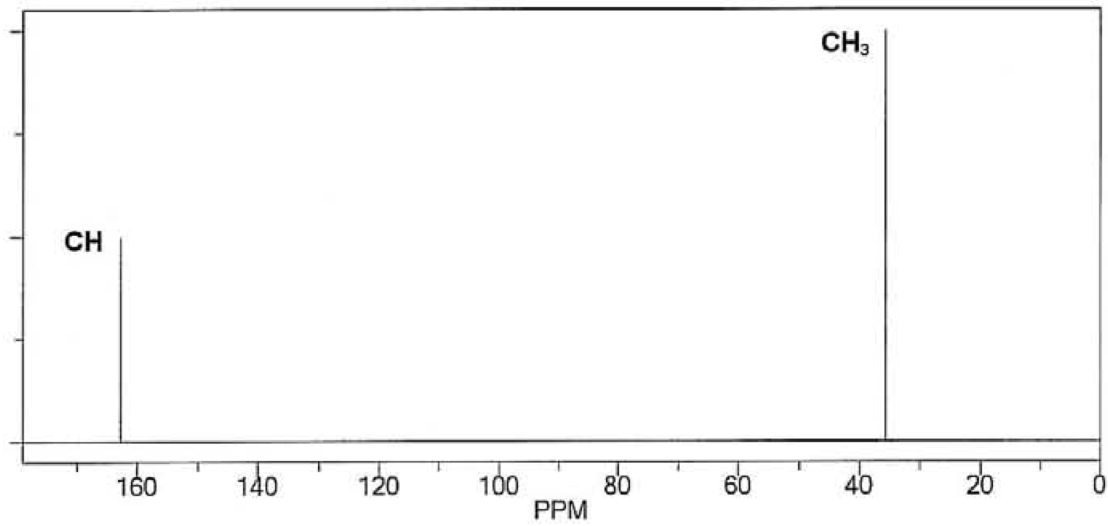
Compound I



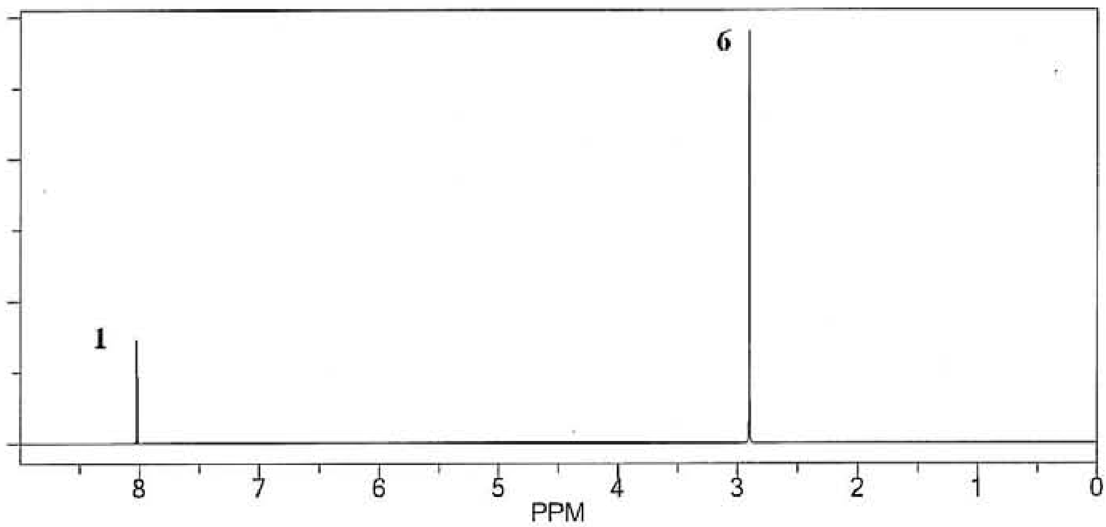
100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]
1675



100
80
60
40
20
0
Relative Intensity
10
15
20
25
30
35
40
45
50
55
60
65
70
75
m/z
73
44
58

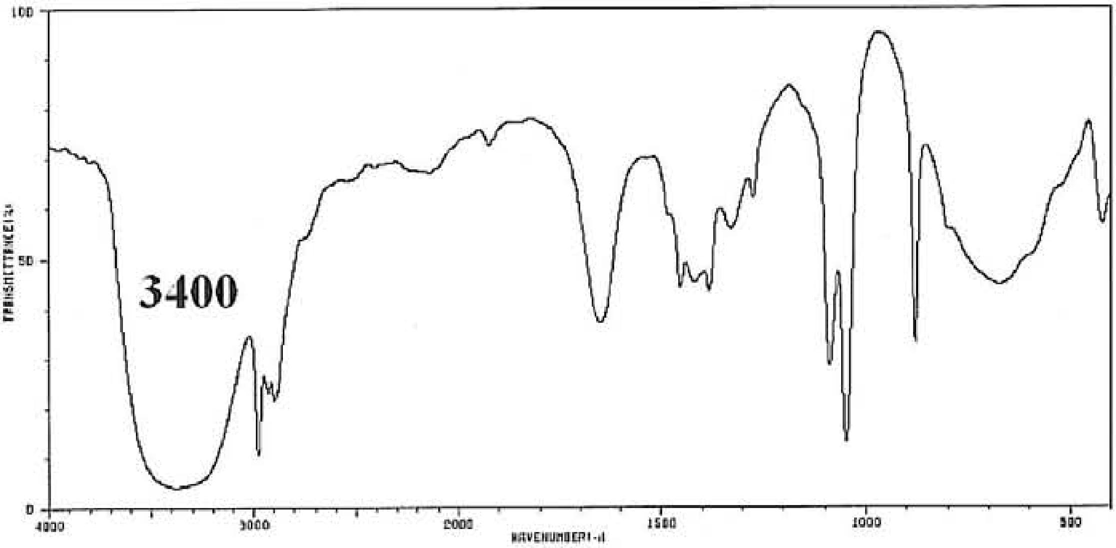


CH
CH3
160
140
120
100
80
60
40
20
0
PPM

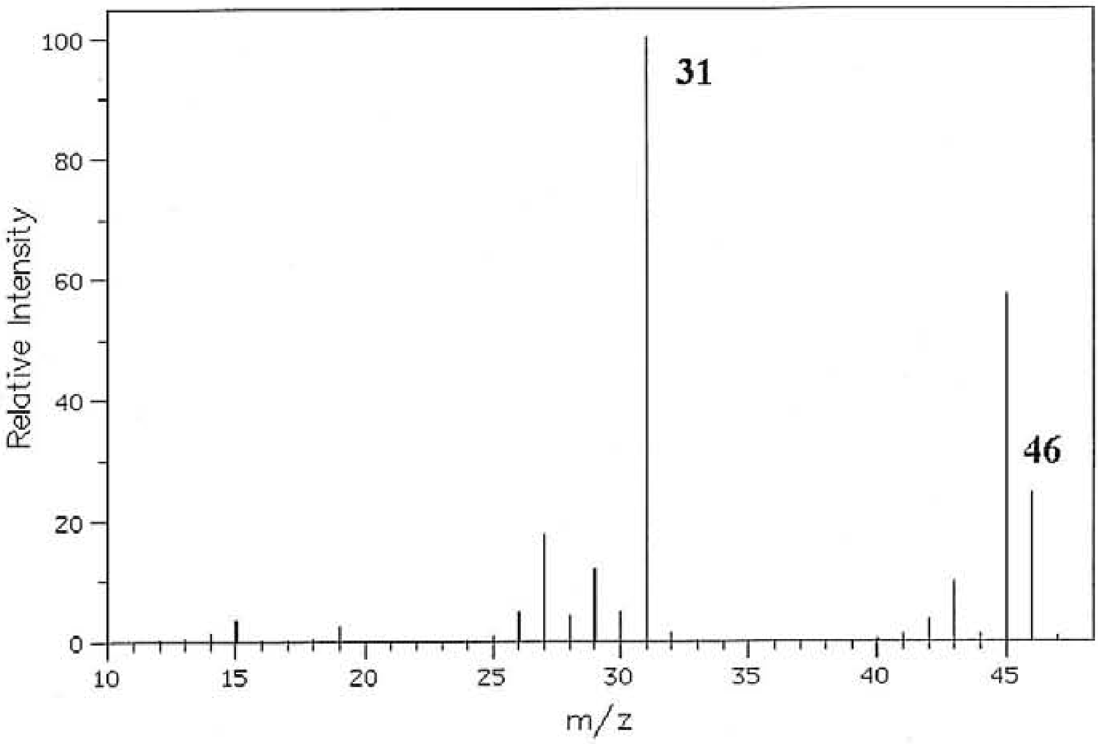


1
6
8
7
6
5
4
3
2
1
0
PPM

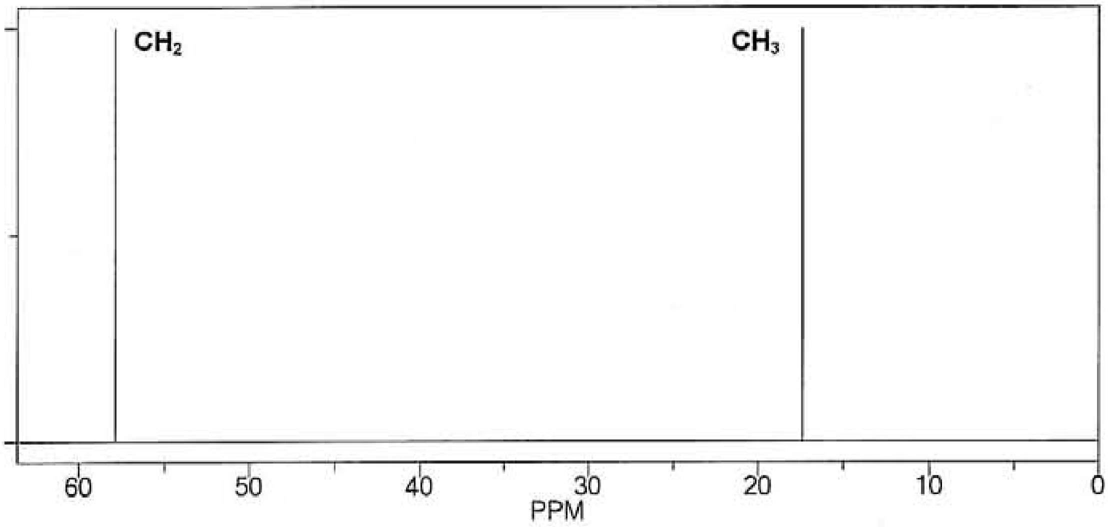
Compound J



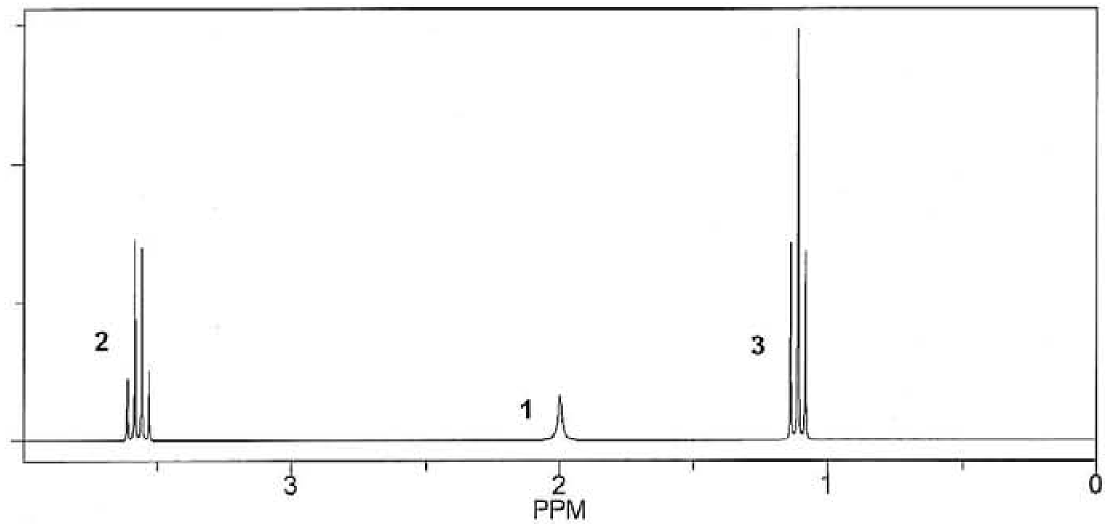
100
50
0
TRANSMITTANCE[%]
3400
4000
3000
2000
1500
1000
500
WAVENUMBER[-cm]



100
80
60
40
20
0
Relative Intensity
31
46
10
15
20
25
30
35
40
45
m/z

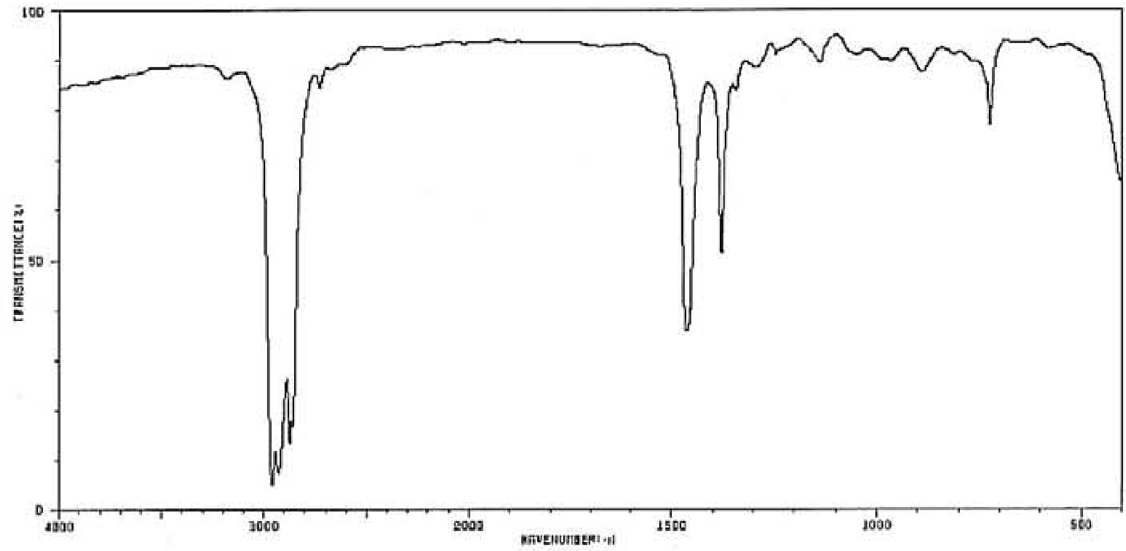


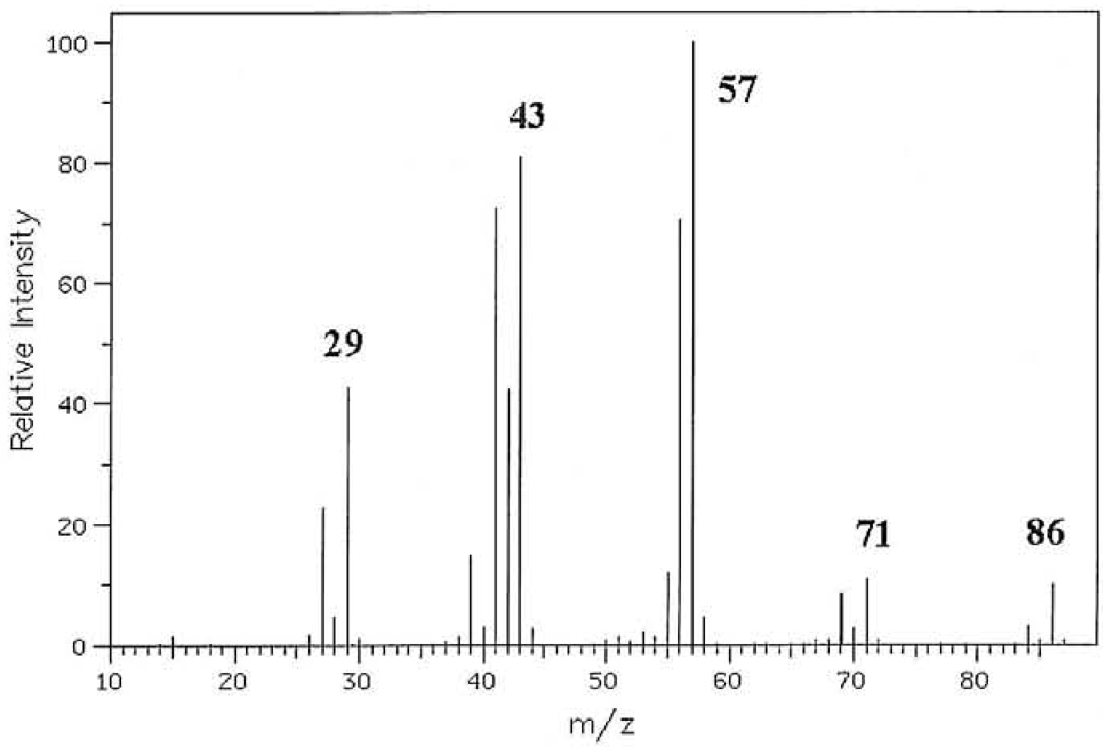
CH$_2$
CH$_3$
60
50
40
30
20
10
0
PPM

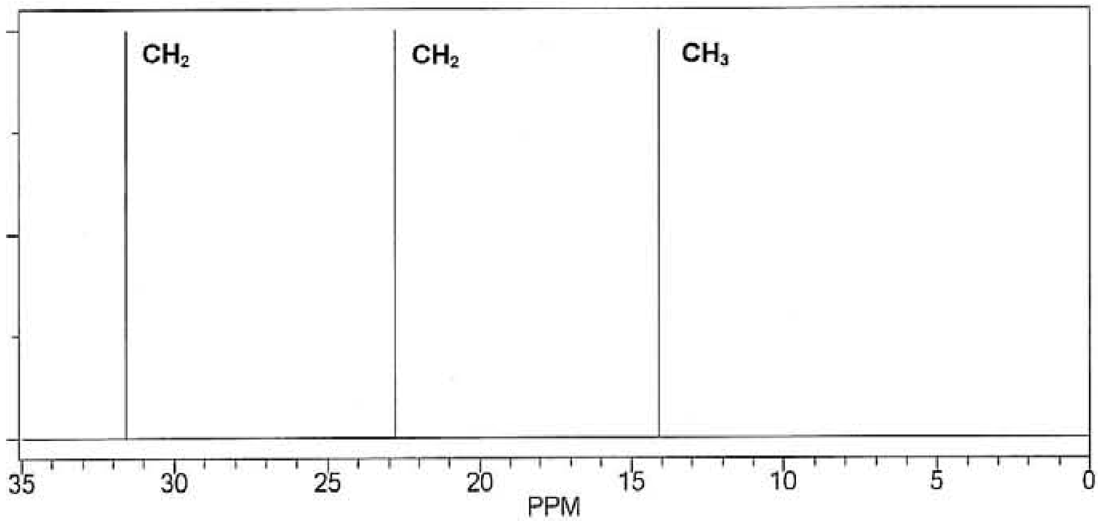


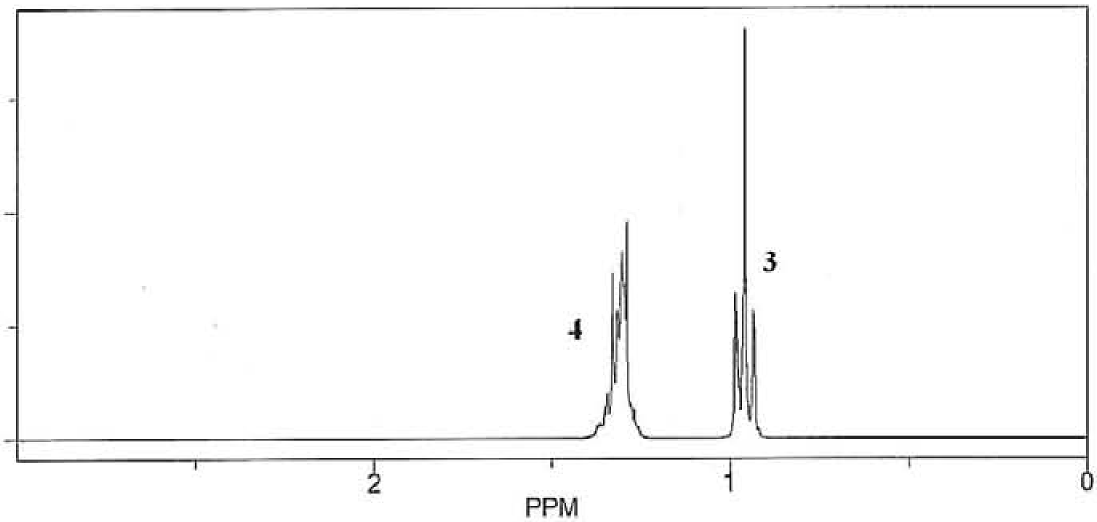
2
1
3
3
2
1
0
PPM

Compound L

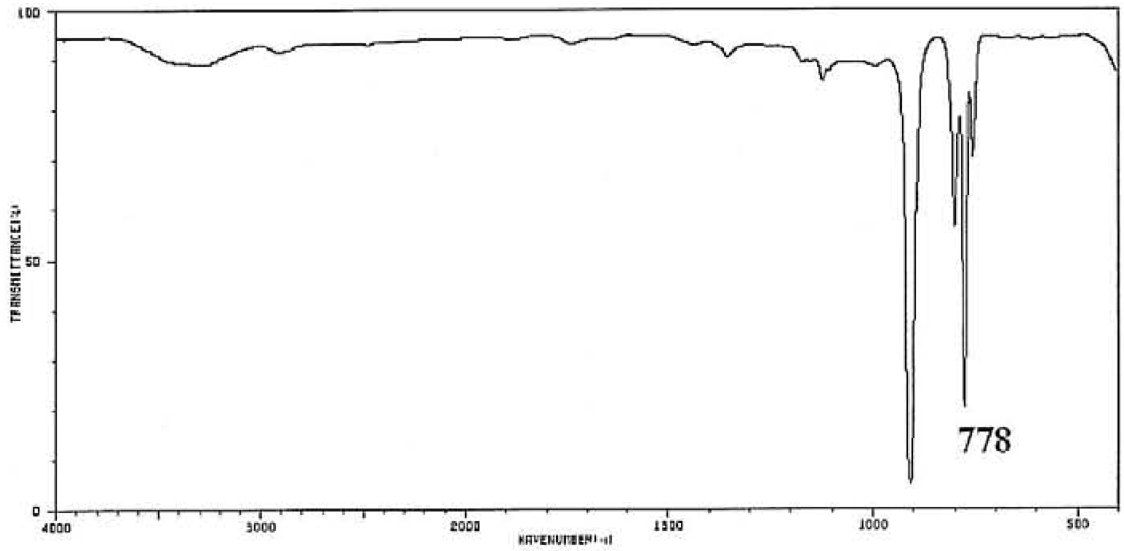

100
50
0
TRANSMITTANCE(%)
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)


Relative Intensity
m/z
29
43
57
71
86
0
20
40
60
80
100
10
30
50
70

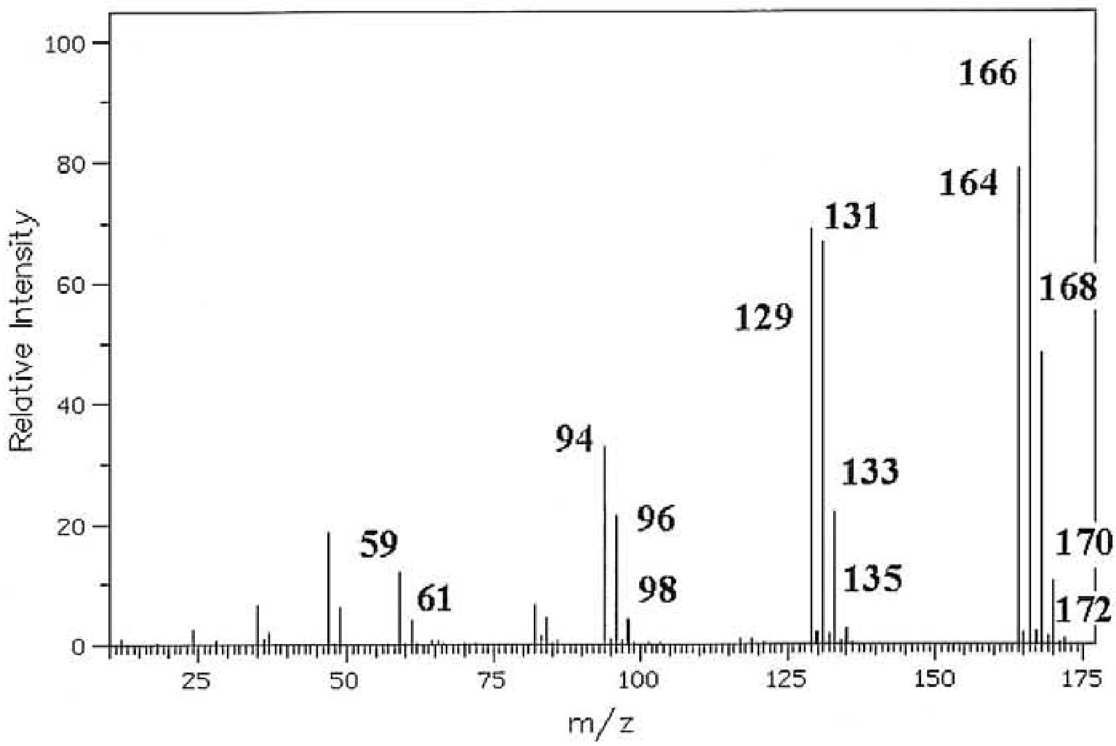

CH2
CH2
CH3
35
30
25
20
15
10
5
0
PPM


4
3
2
1
0
PPM

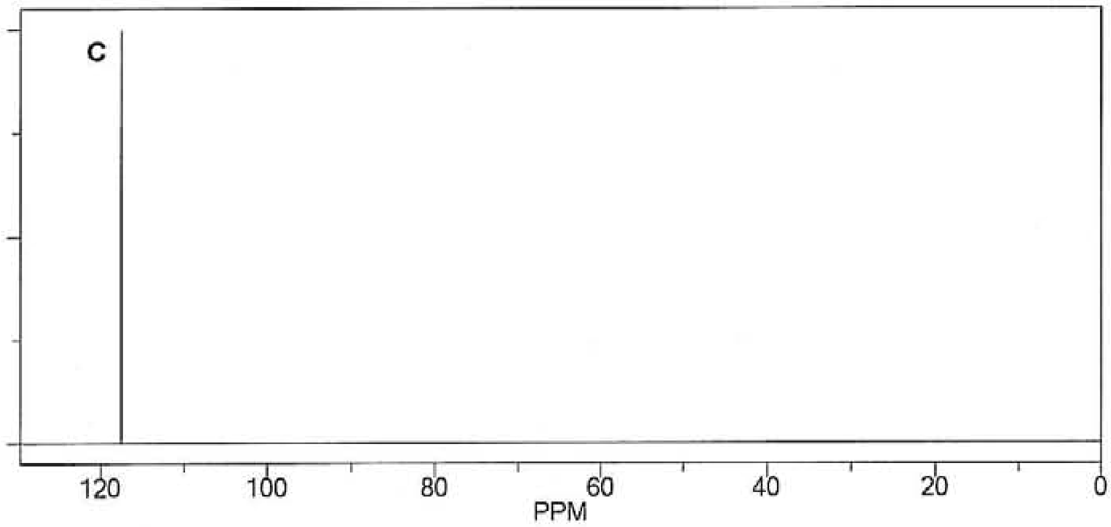
Compound N

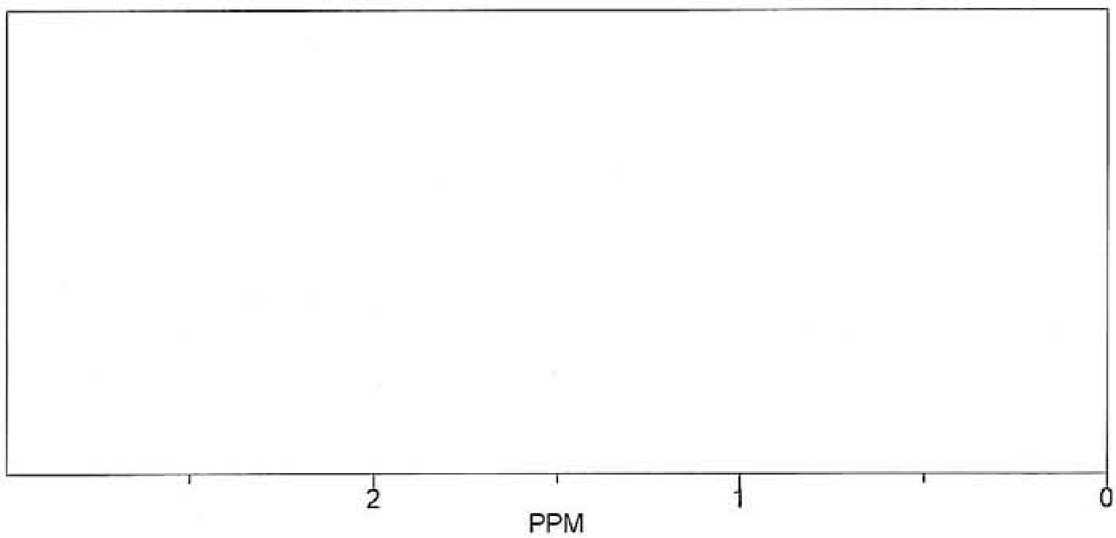


100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]
778

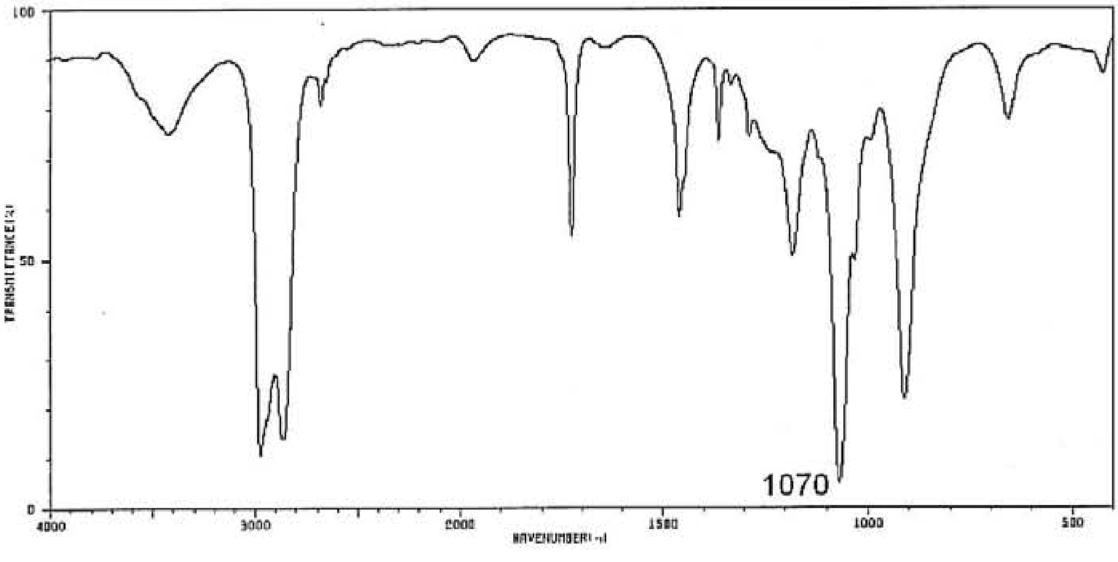


Relative Intensity
m/z
100
80
60
40
20
0
25
50
75
100
125
150
175
166
164
131
168
129
94
133
96
59
170
135
61
98
172

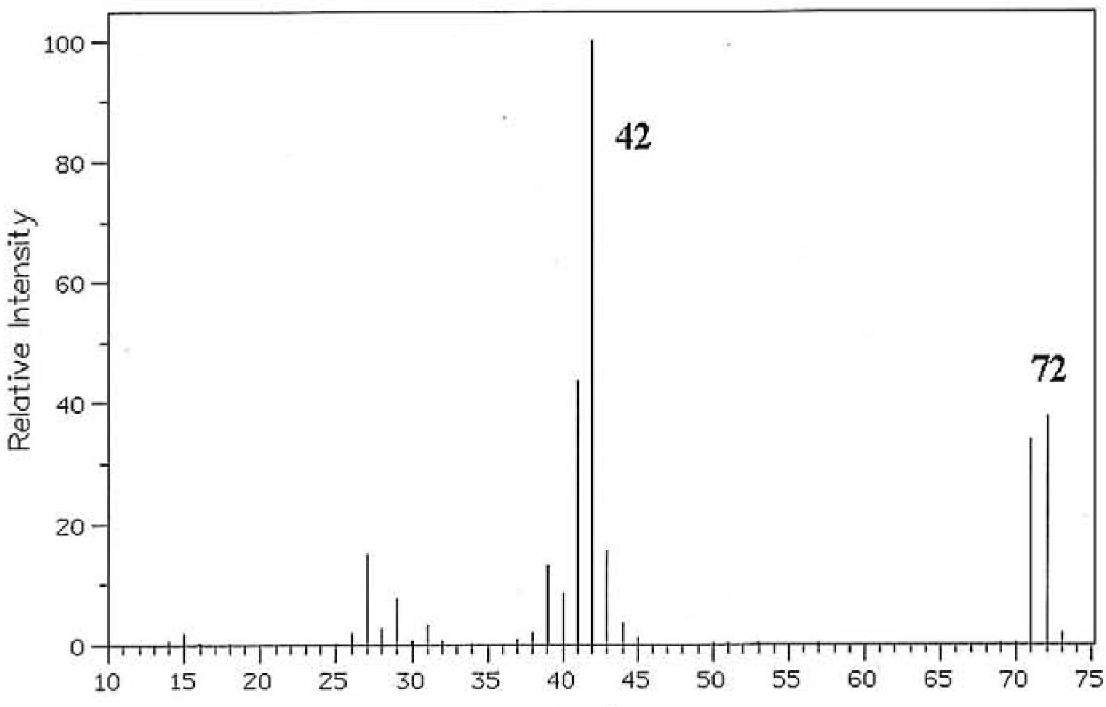

C
120
100
80
60
40
20
0
PPM


2
1
0
PPM

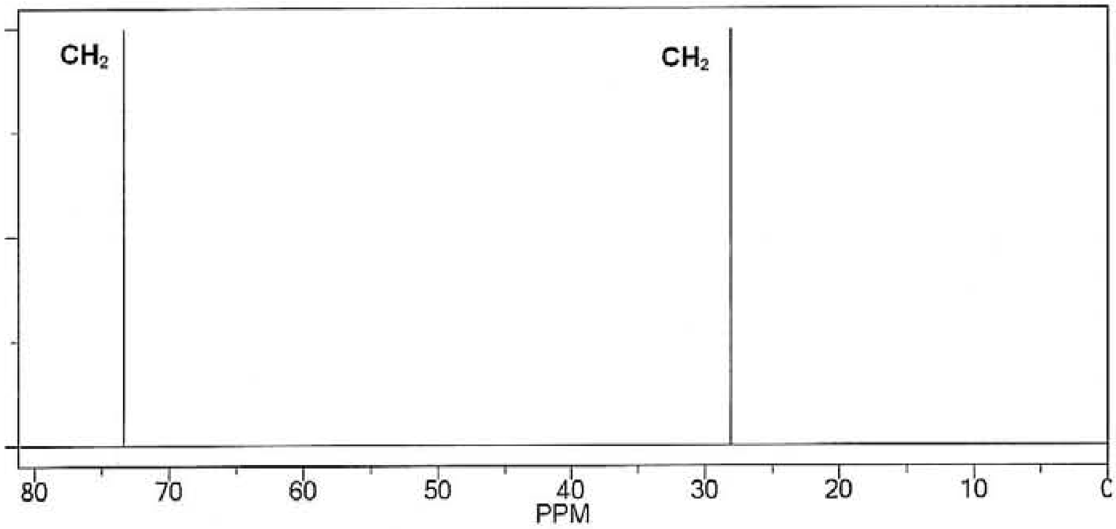
Compound O

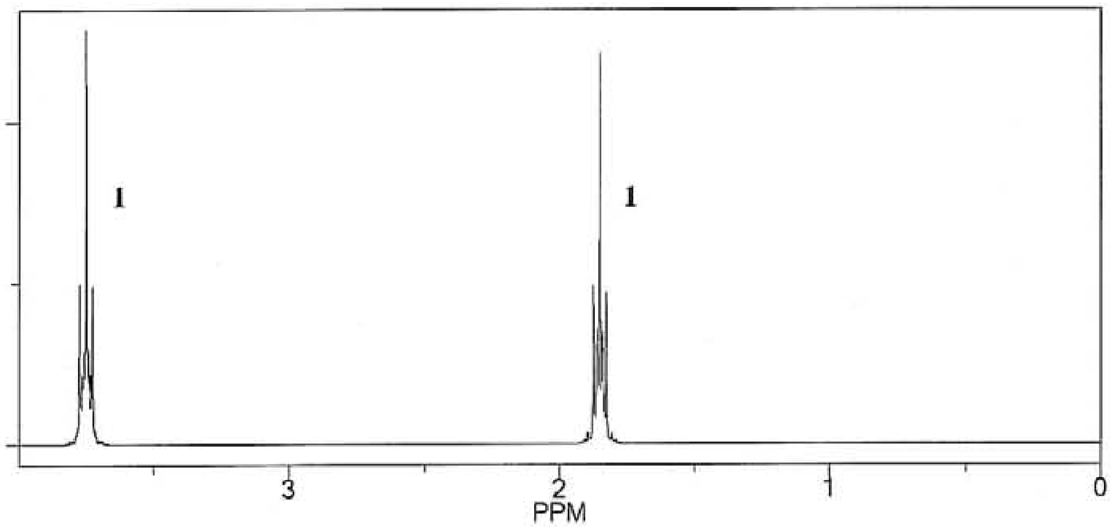


100
50
0
TRANSMITTANCE(%)
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)
1070

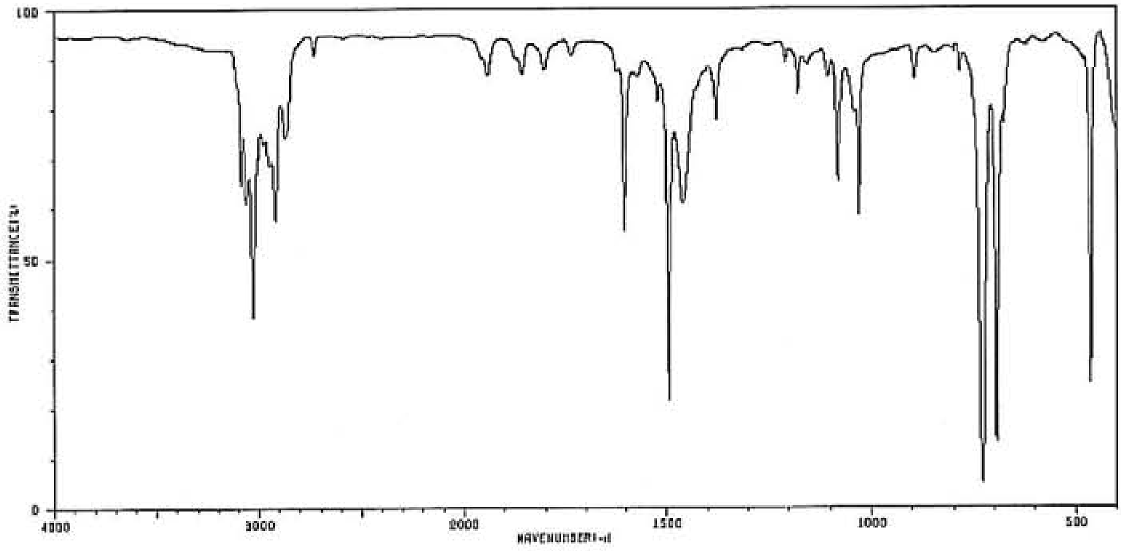


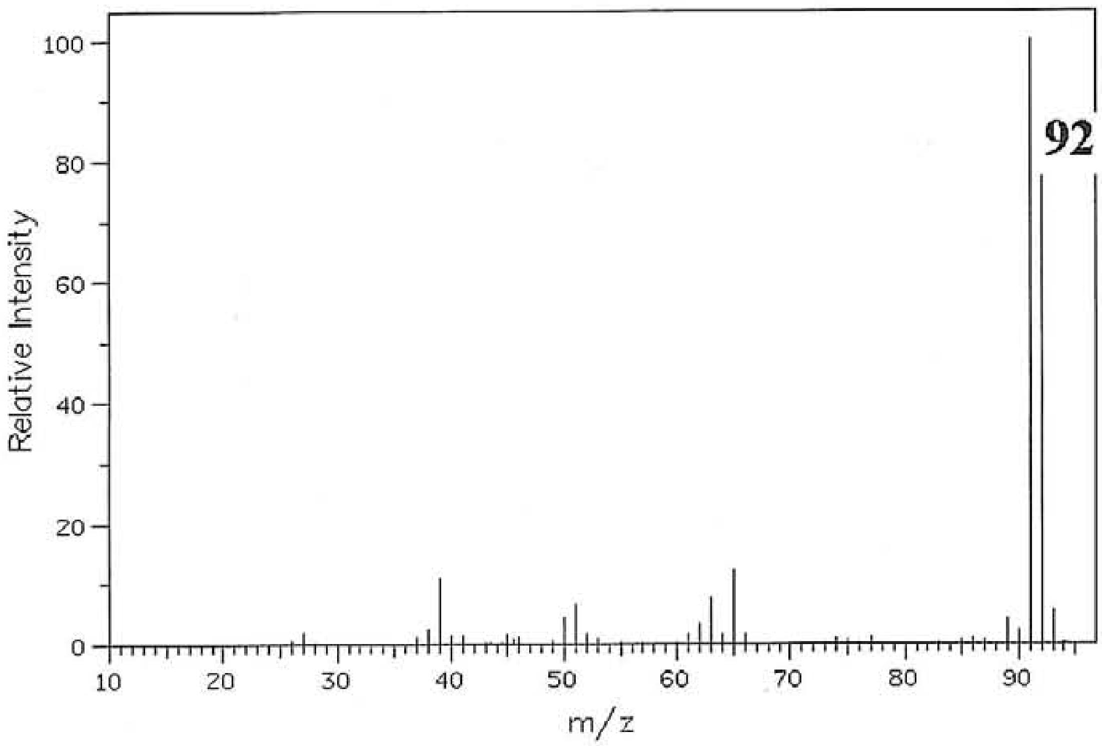
100
80
60
40
20
0
Relative Intensity
10
15
20
25
30
35
40
45
50
55
60
65
70
75
m/z
42
72

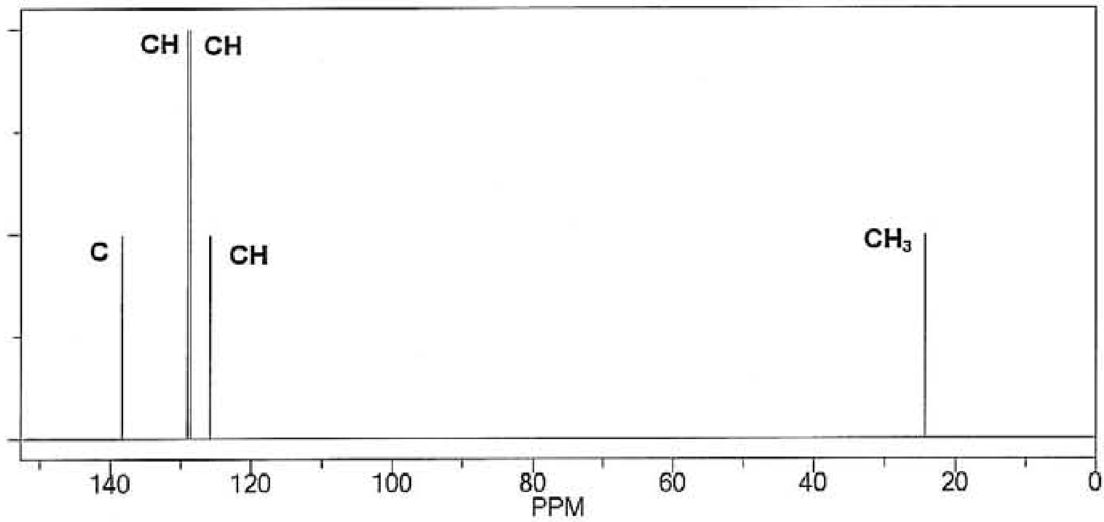

CH2
CH2
80
70
60
50
40
PPM
30
20
10
0

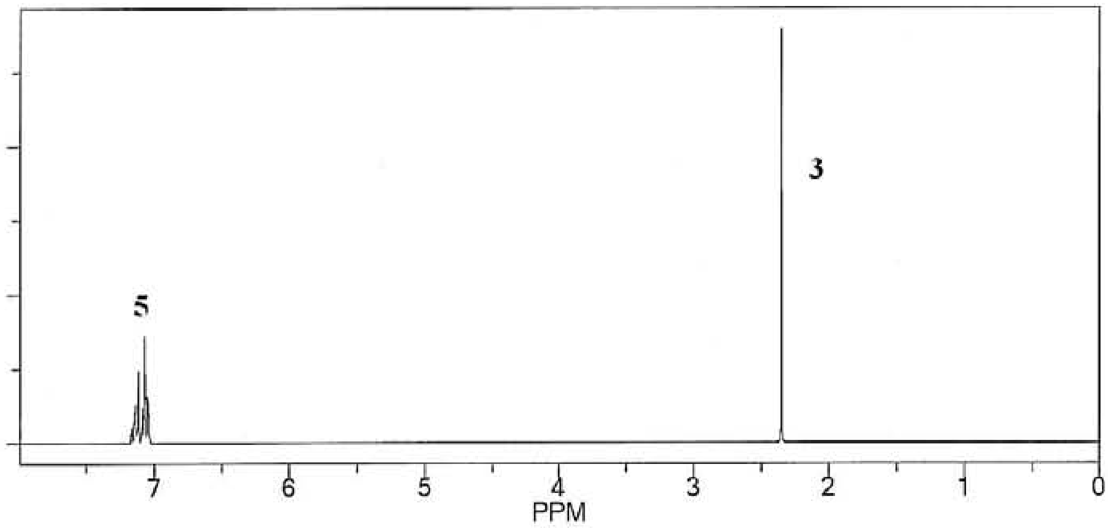

1
1
3
2
PPM
1
0

Compound P


100
TRANSMITTANCE[%]
50
0
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]


Relative Intensity
100
80
60
40
20
0
10
20
30
40
50
60
70
80
90
m/z
92


CH
CH
C
CH
CH3
140
120
100
80
60
40
20
0
PPM


3
5
7
6
5
4
3
2
1
0
PPM

Group Report

What might the molecules be used for?

Why are they suitable for that use?

Compound:

Reasoning:

IR spectrum:

Mass Spectrum:

^{13}C NMR Spectrum:

^{1}H NMR Spectrum:

Spectroscopic Data

Mass Spectrometry:

Mass lost	Possible group lost	Possible interpretation
15	CH_3	
17	NH_3 OH	 Alcohol
18	H_2O	Alcohol, Ketone, Aldehyde
29	C_2H_5 CHO	Ethyl ketone Aldehyde
31	OCH_3	Methyl ester
41	C_3H_5	Propyl ester
43	C_3H_7 or CH_3CO	
44	CO_2	Carboxylic acid, ester, anhydride
45	$COOH$ OC_2H_5	Carboxylic acid Ethyl ester
55	C_4H_7	Butyl ester
57	C_4H_9 or C_2H_5CO	
71	C_5H_{11} or C_3H_7CO	

Infrared Spectroscopy:

Functional group	Approx. Absorption range / cm^{-1}
N-H	3500 - 3250
CON-H	3500 - 3000
O-H	3700 - 3200
COO-H	3200 - 2200
C-H	3100 - 2700
C≡N	2300 - 2200
C≡C	2250 - 2100
C=O	1850 - 1640
C=C (unconjugated)	1680 - 1620
C=C (conjugated)	Can be as low as 1590
C-C Aromatic	1600-1500
C-Cl	800 - 400

Substituted carbonyl group	Approx. Absorption range / cm^{-1}	Approx. Absorption range / cm^{-1}
	R = Aliphatic	R = Conjugated alkene or aromatic
Anhydride, RCOOCOR	1850 - 1800 & 1790 - 1740	1830 - 1775 & 1770 - 1710
Acid chloride, RCOCl	1815 - 1790	1790 - 1750
Ester, RCOOR*	1800 - 1745	
Ester, RCOOAlkyl	1755 - 1730	1735 - 1710
Aldehyde, RCHO	1740 - 1715	1715 - 1680
Ketone, RCOAlkyl	1725 - 1700	1700 - 1665
Carboxylic acid, RCOOH	1725 - 1700	1715 - 1680
Amide, RCON	1680 - 1640	1695 - 1665

R* = aryl or vinyl

Some ^1H NMR chemical shifts

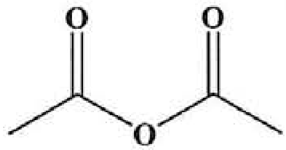
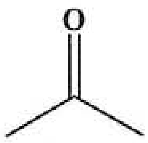
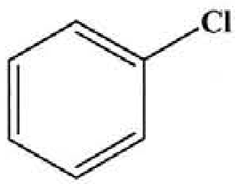
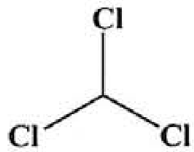
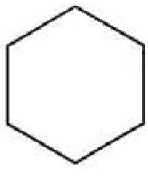
Group	Approx. ^1H chemical shift range / ppm
CH_3	0.9 - 3.8
CH_2	1.4 - 4.3
CH	1.5 - 4.5
C≡C-H	1.8 - 3.1
C=C-H	4.5 - 6.0
Ph	6.0 - 9.0
H-C=O	9.5 - 10

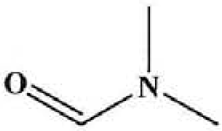
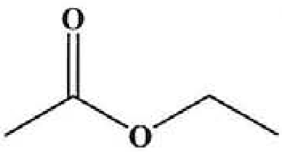
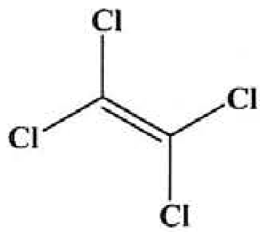
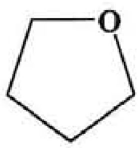
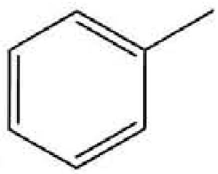
Some ^{13}C NMR chemical shifts

Group	Approx. ^{13}C chemical shift range / ppm
CH_3	5 - 70
CH_2	10 - 80
CH	20 - 90
$C\equiv C$	65 - 80
$C\equiv N$	115 - 130
C=C	100 - 170
Ph	110 - 170
C=O ester	160 - 180
C=O acid	170 - 190
C=O ketone or aldehyde	190 -210

APPENDIX 19

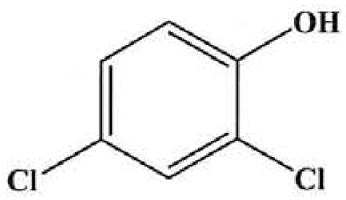
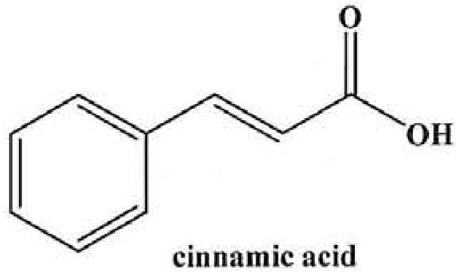
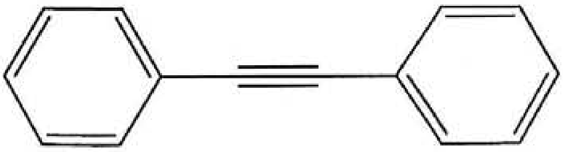
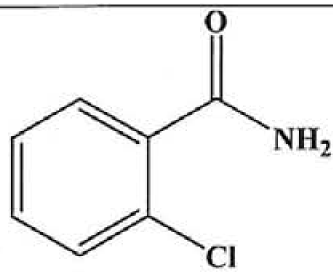
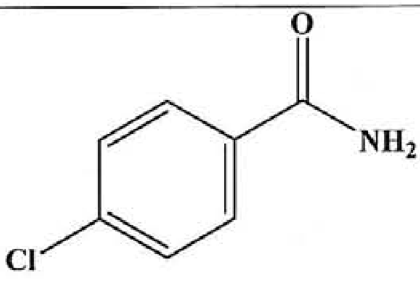
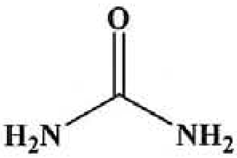
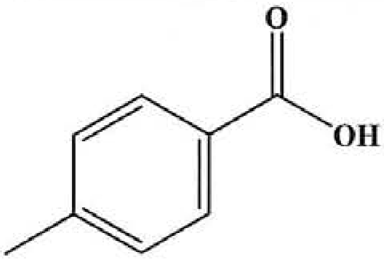
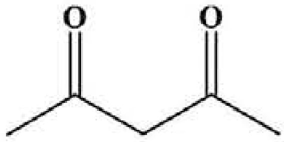
The Sixteen Solvents Used in the "Waste Disposal" Scenario

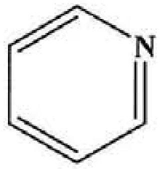
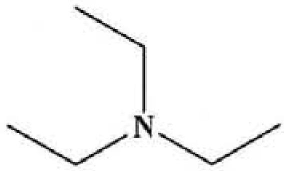
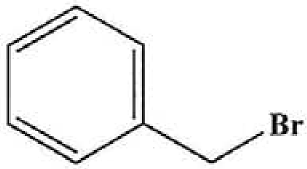
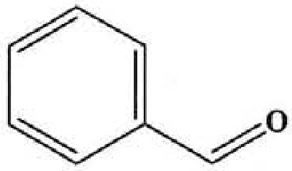
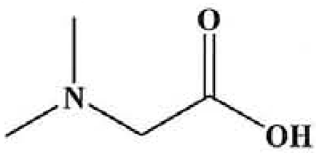
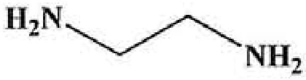
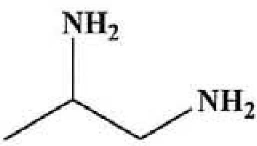
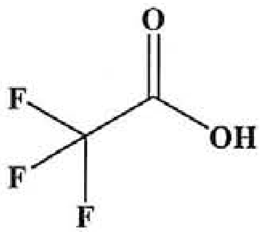
 1-propanol	 acetic anhydride
 acetone	 acetonitrile
 chlorobenzene	 chloroform
 cyclohexane	 dichloromethane

 **N,N-dimethylformamide**	 **ethanol**
 **ethyl acetate**	 **hexane**
 **methanol**	 **tetrachloroethylene**
 **tetrahydrofuran**	 **toluene**

APPENDIX 20

The Sixteen Molecules Used in the "Down the Drain" Scenario

 2,4-dichlorophenol	 cinnamic acid
 diphenylacetylene	 o-chlorobenzamide
 p-chlorobenzamide	 urea
 p-toluic acid	 2,4-pentanedione

 pyridine	 triethylamine
 benzyl bromide	 benzaldehyde
 N,N-dimethylglycine	 ethylene diamine
 propylene diamine	 trifluoroacetic acid

APPENDIX 21

Memorandum

TO: Staff, Analytical Department
FROM: Dave Carew, CEO
DATE: 19/10/07
SUBJECT: Environmental Science Department Sample Analysis

Dear Staff

The Environmental Science Department has recently sampled waste water from the Chemistry Department at the County University, after some dead fish were discovered in the river that the waste water runs into. Relatively large concentrations of several compounds have been discovered in the waste water. The spectra of these have already been produced, from ^{1}H NMR, ^{13}C NMR, IR Spectroscopy and Mass Spectrometry, by a colleague in the Analytical Department (spectra attached).

The Environmental Science Department has requested a report on the compounds that have been isolated from the water sample they provided. The report must include an identification of each compound and the full reasoning behind this identification.

Please can you use your chemical expertise to interpret the spectra. This must include identification of the compounds present, and assignment of the key peaks in the spectra provided.

I look forward to seeing your analysis report.

Many Thanks,

Dave Carew
Chief Executive Officer

Down the Drain Scenario

Peer Assessment of Group Activity

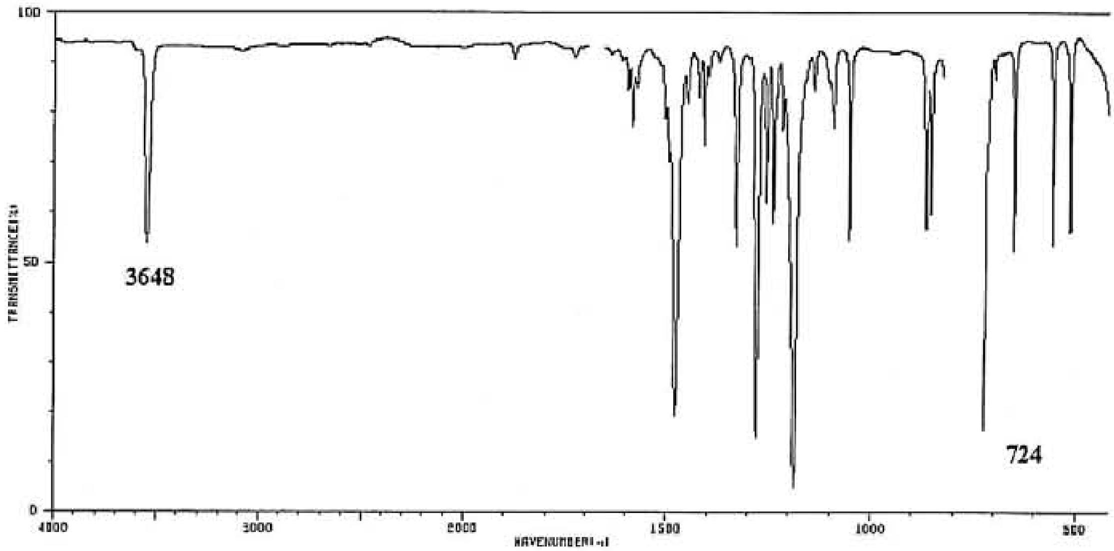
You will each receive group marks for each week's EBL activities as well as marks for your group report. Most of the groups are working together very well, though some are less successful. This is your opportunity to consider whether all of your fellow chemists pulled their weight. Did you feel that everyone contributed equally? Did you feel as if you were carrying anyone?

Consider how your group operated. Then give each team member a score from 0-100 %. If you feel that you all worked well together and made an effective team, then you may give everyone the same score. If the workload was unbalanced, then you may reflect this in your scoring. This assessment is confidential. You will all receive an average score from the rest of the team.

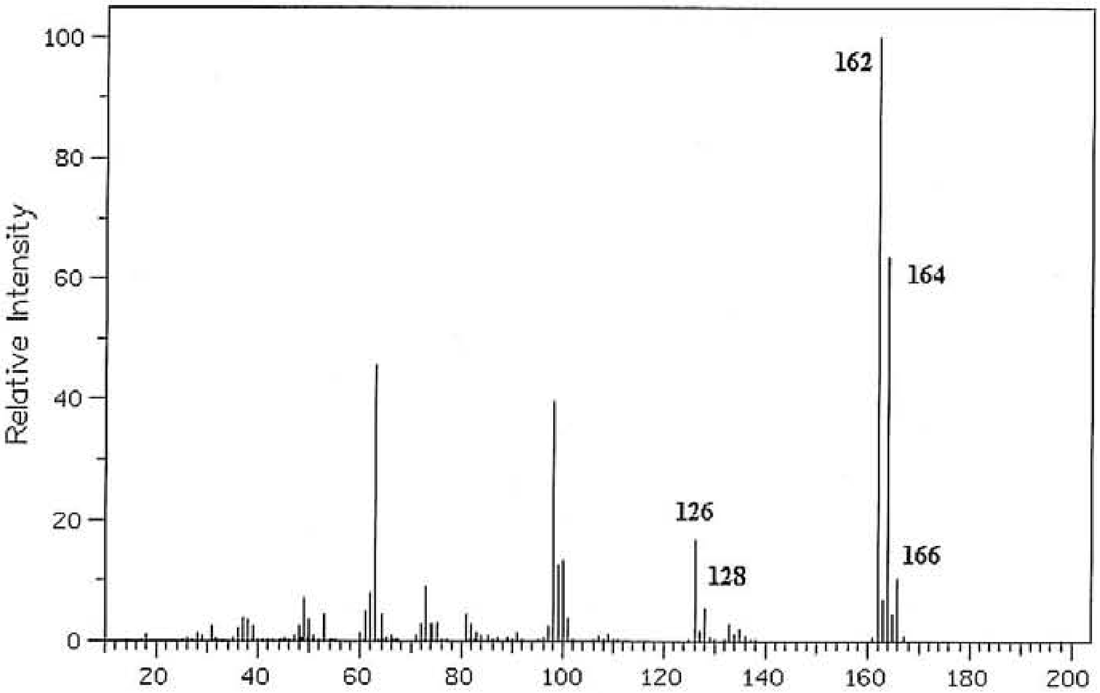
Your name:

Group 1	Score as %	Group 2	Score as %
Group 3	**Score as %**	**Group 4**	**Score as %**
Group 5	**Score as %**	**Group 6**	**Score as %**
Group 7	**Score as %**	**Group 8**	**Score as %**

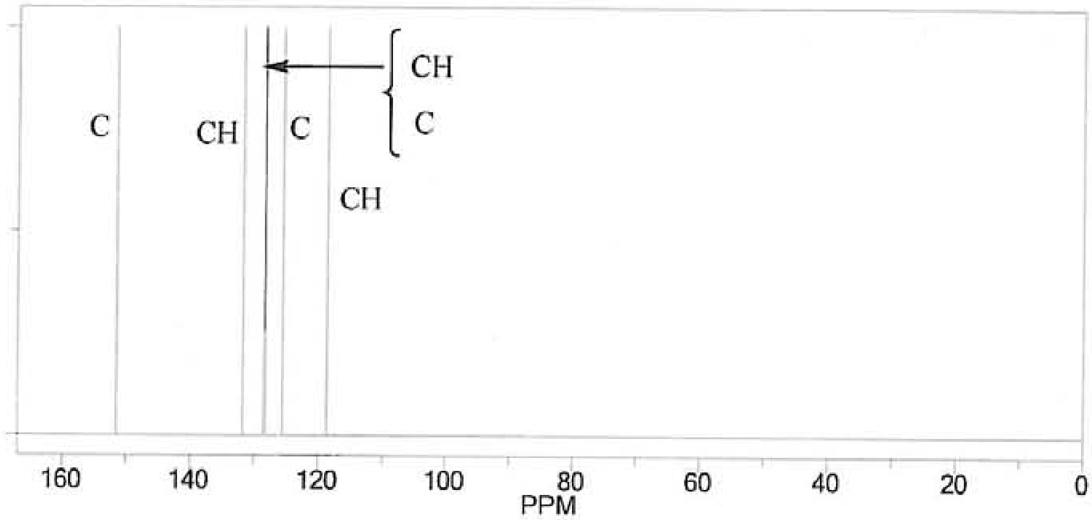
Compound 1

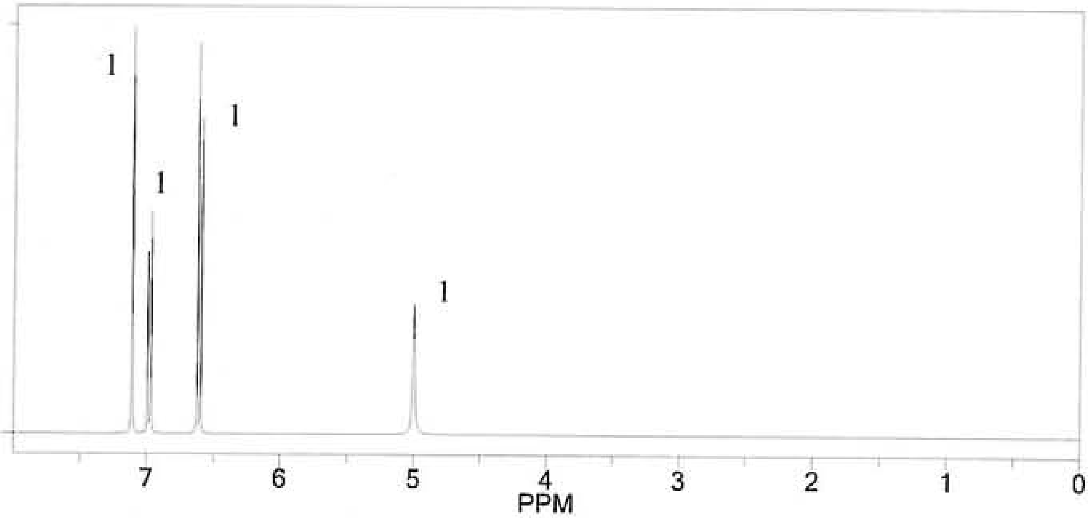


100
50
0
3648
724
4000
3000
2000
1500
1000
500
TRANSMITTANCE[%]
WAVENUMBER[-1]

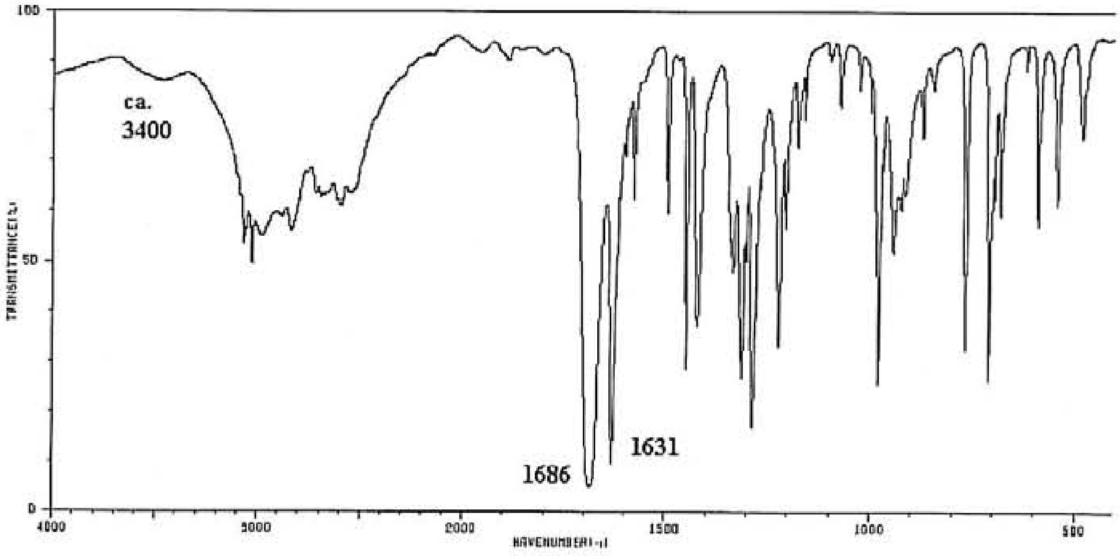


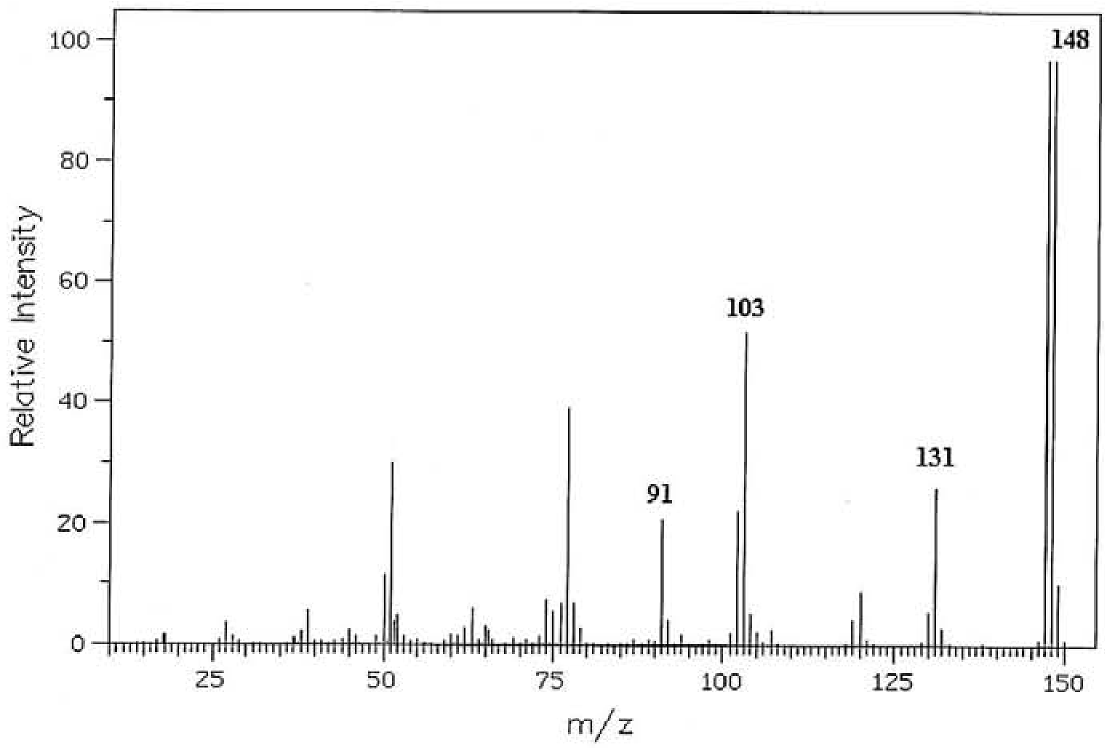
100
80
60
40
20
0
Relative Intensity
162
164
166
126
128
20
40
60
80
100
120
140
160
180
200
m/z

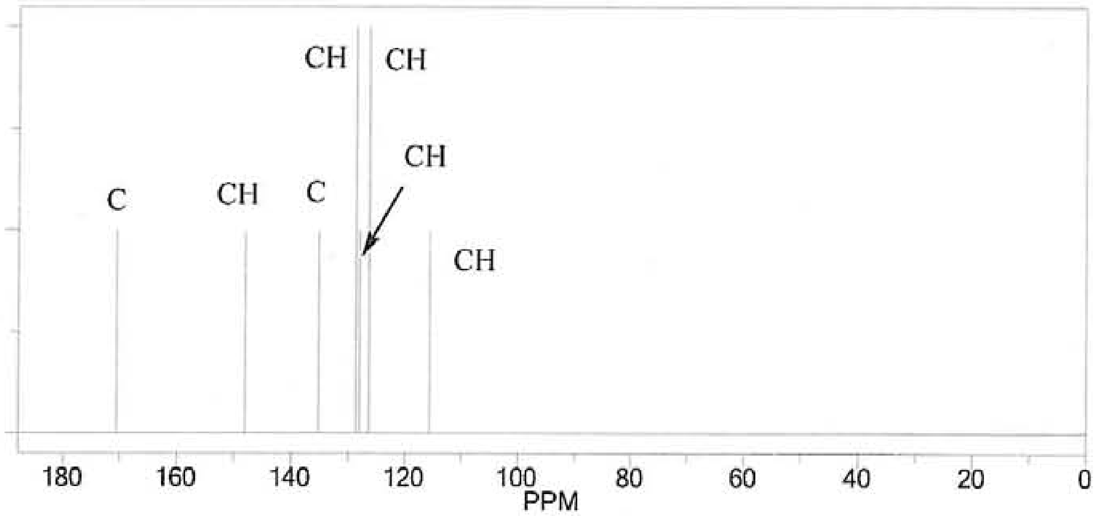

C
CH
C
CH
C
CH
160
140
120
100
80
PPM
60
40
20
0

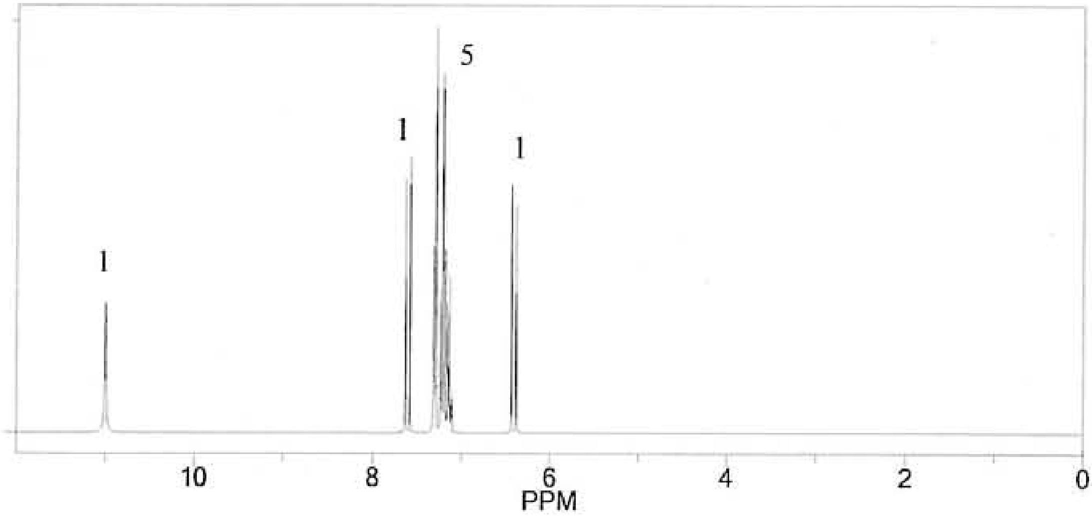

1
1
1
1
7
6
5
4
PPM
3
2
1
0

Compound 2

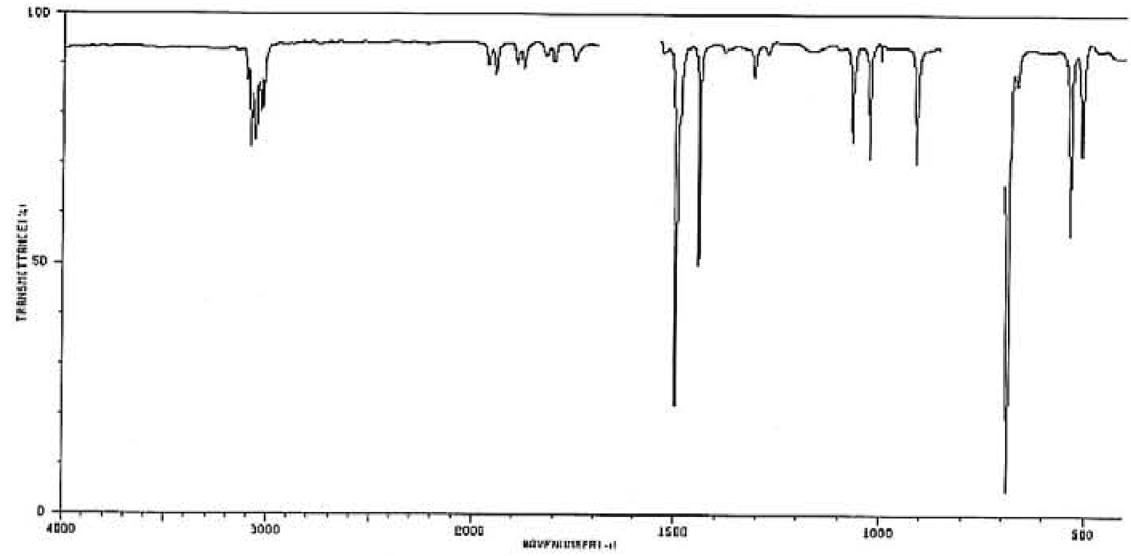

100
ca.
3400
TRANSMITTANCE(%)
50
0
1686
1631
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)


100
80
60
40
20
0
Relative Intensity
148
103
131
91
25
50
75
100
125
150
m/z

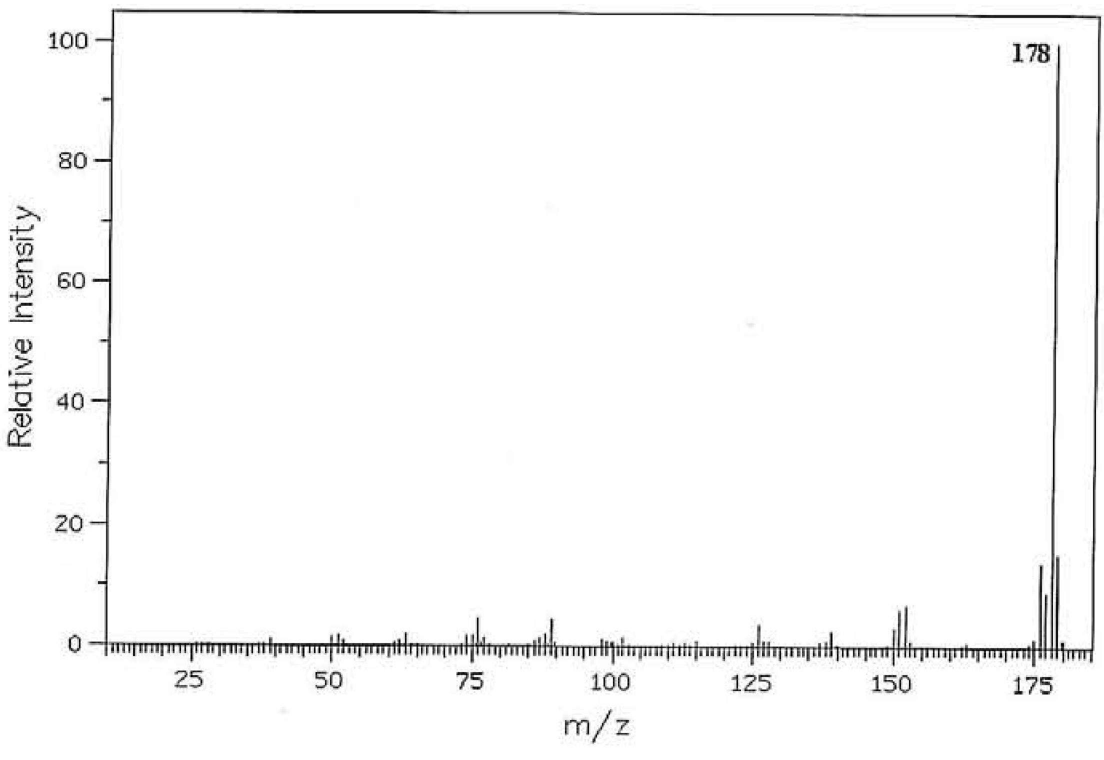

C
CH
C
CH
CH
CH
CH
180 160 140 120 100 80 60 40 20 0
PPM


1
1
5
1
10 8 6 4 2 0
PPM

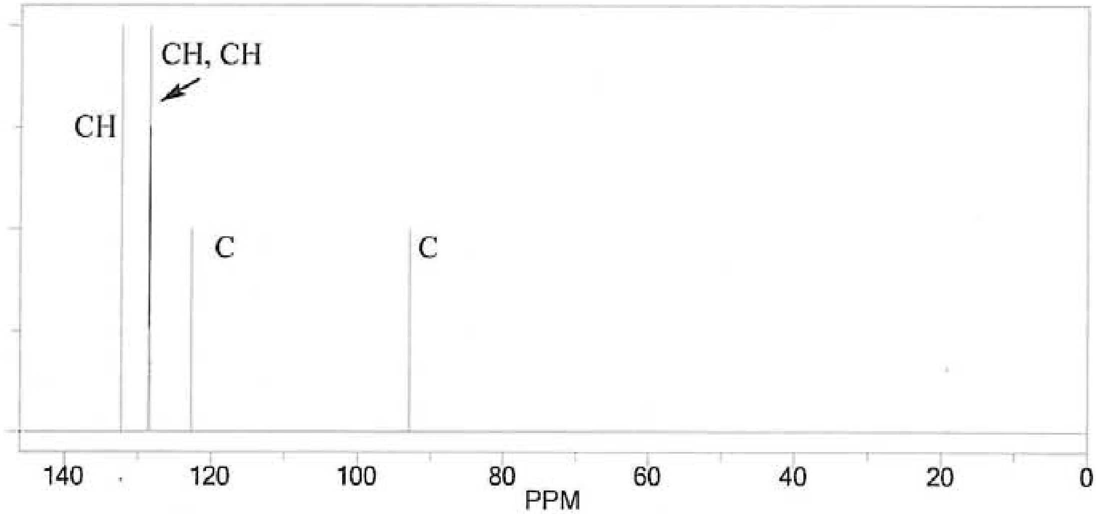
Compound 3

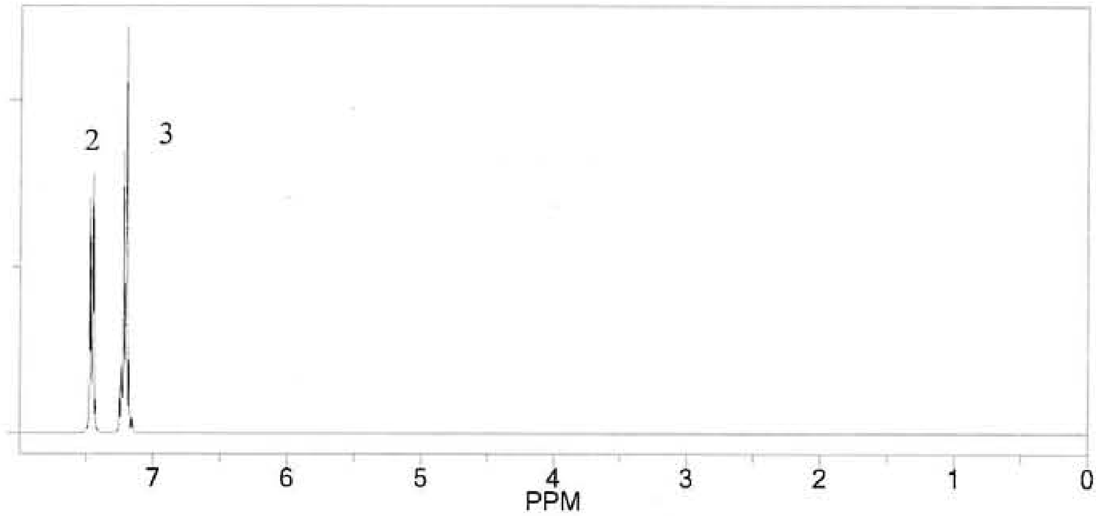


TRANSMITTANCE(%)
100
50
0
4000
3000
2000
1500
1000
500

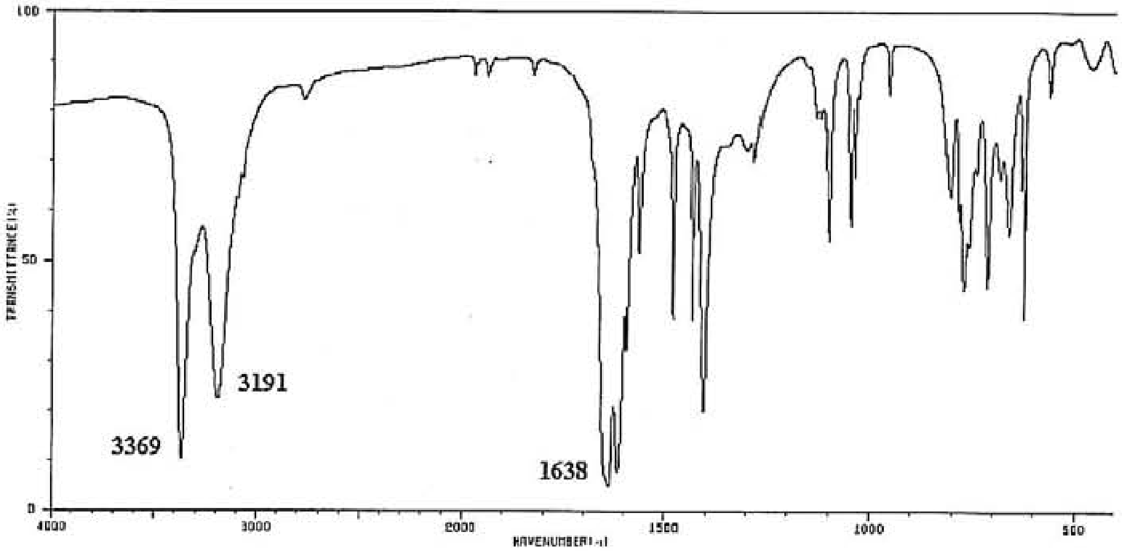


178
Relative Intensity
100
80
60
40
20
0
25
50
75
100
125
150
175
m/z

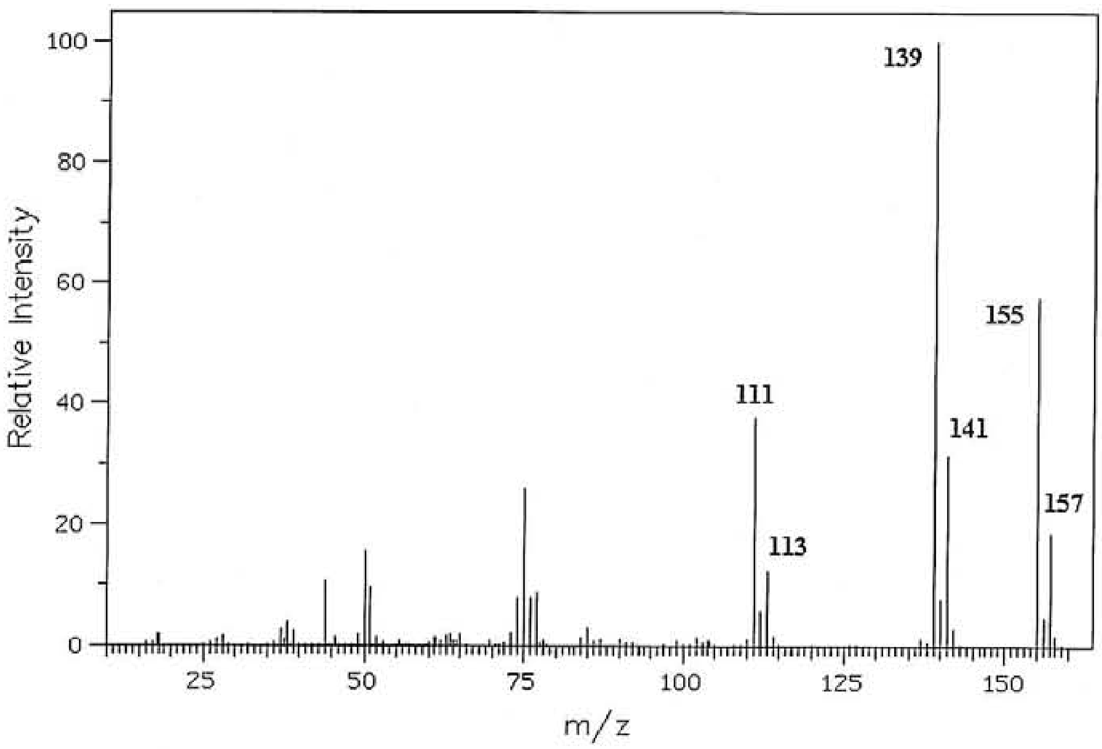

CH, CH
CH
C
C
140
120
100
80
60
40
20
0
PPM


2
3
7
6
5
4
3
2
1
0
PPM

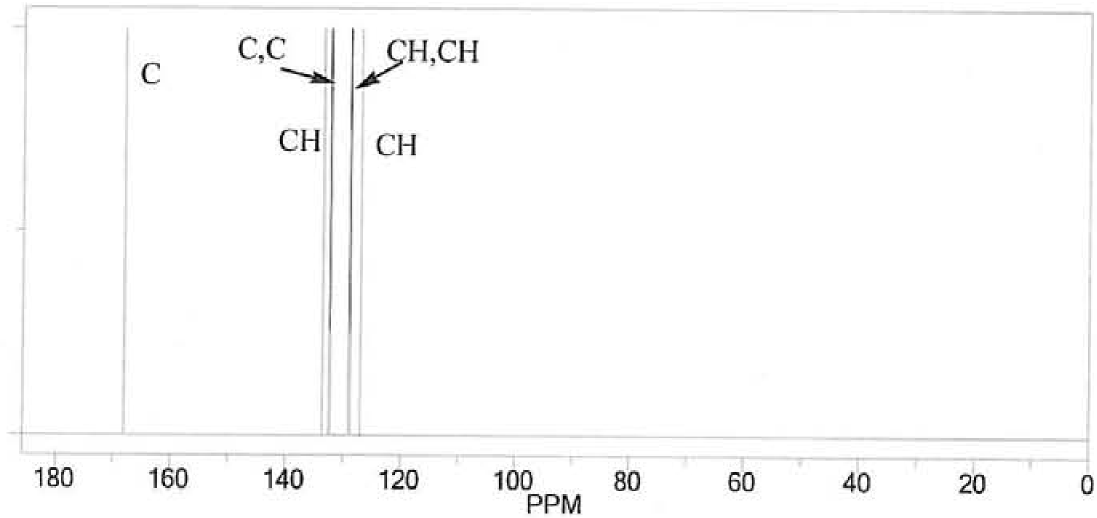
Compound 4

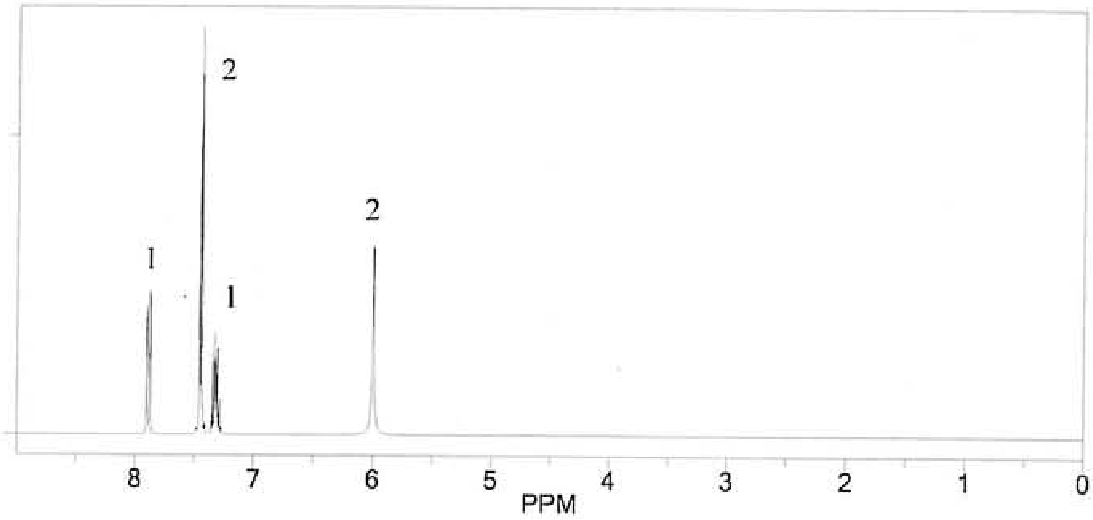


100
50
0
TRANSMITTANCE(%)
3369
3191
1638
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)

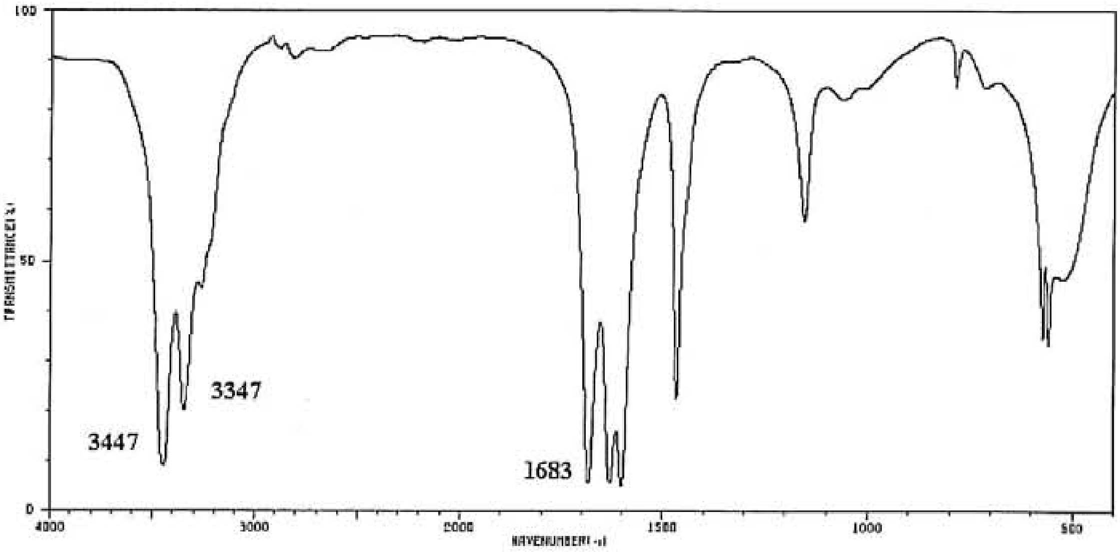


Relative Intensity
m/z
139
155
111
141
157
113
100
80
60
40
20
0
25
50
75
100
125
150

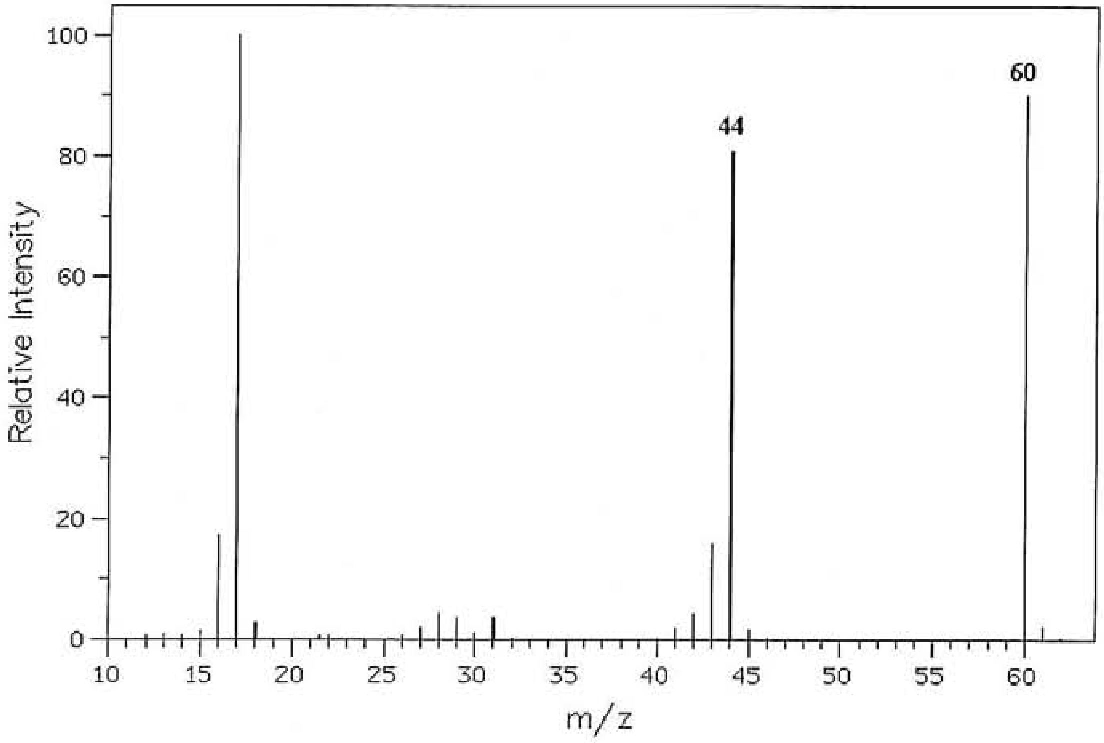

C
C,C
CH,CH
CH
CH
180
160
140
120
100
80
60
40
20
0
PPM


2
2
1
1
8
7
6
5
4
3
2
1
0
PPM

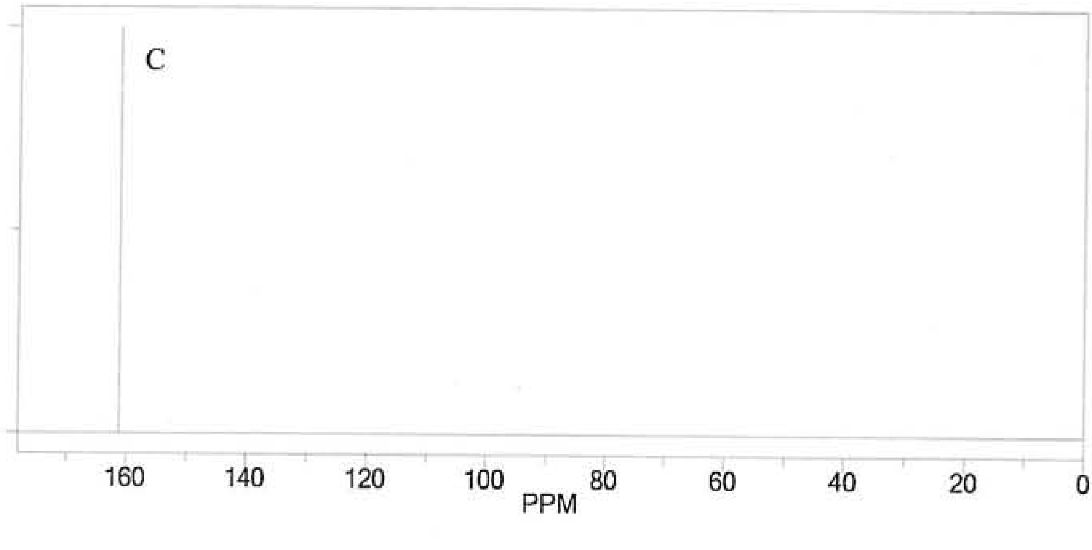
Compound 6



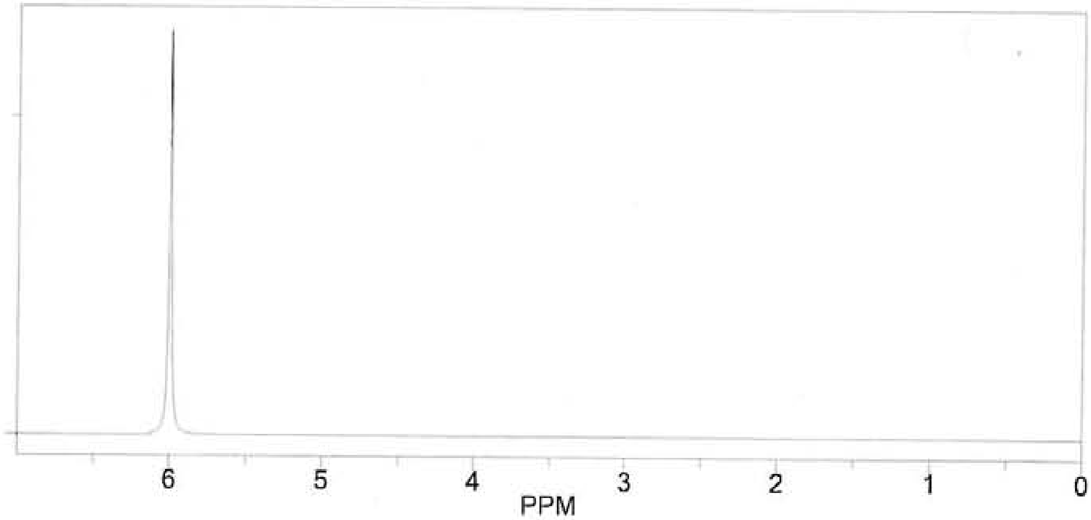
100
50
0
3447
3347
1683
4000
3000
2000
1500
1000
500



Relative Intensity
100
80
60
40
20
0
44
60
10
15
20
25
30
35
40
45
50
55
60
m/z

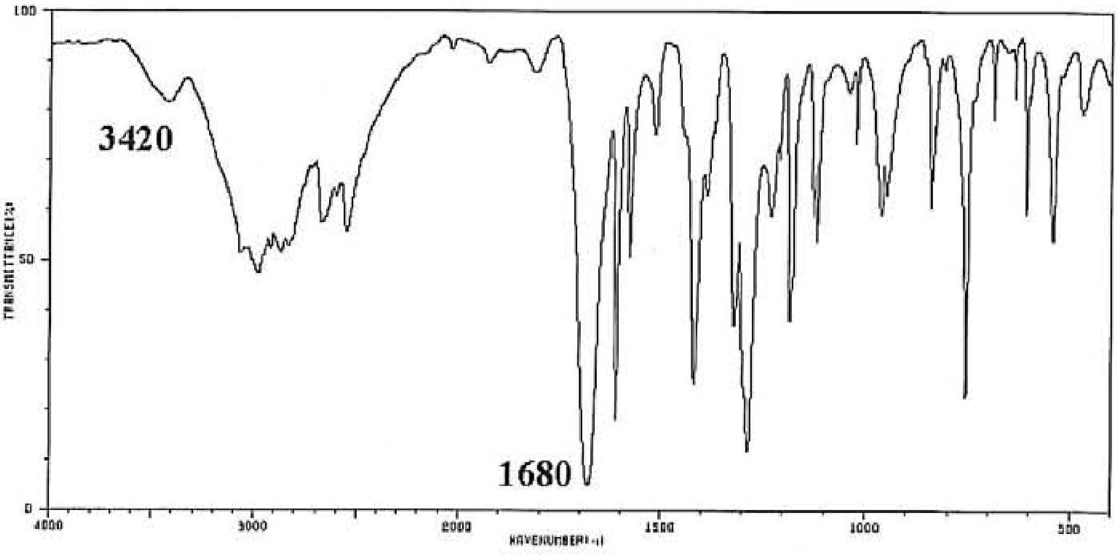


C
160
140
120
100
80
60
40
20
0
PPM

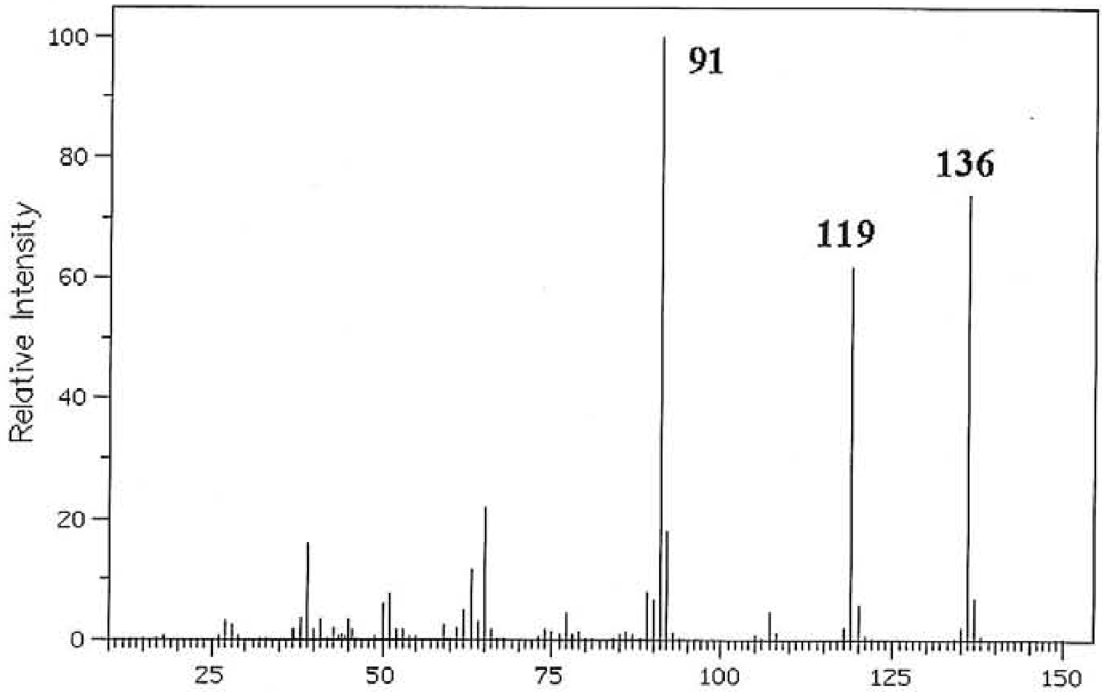


6
5
4
3
2
1
0
PPM

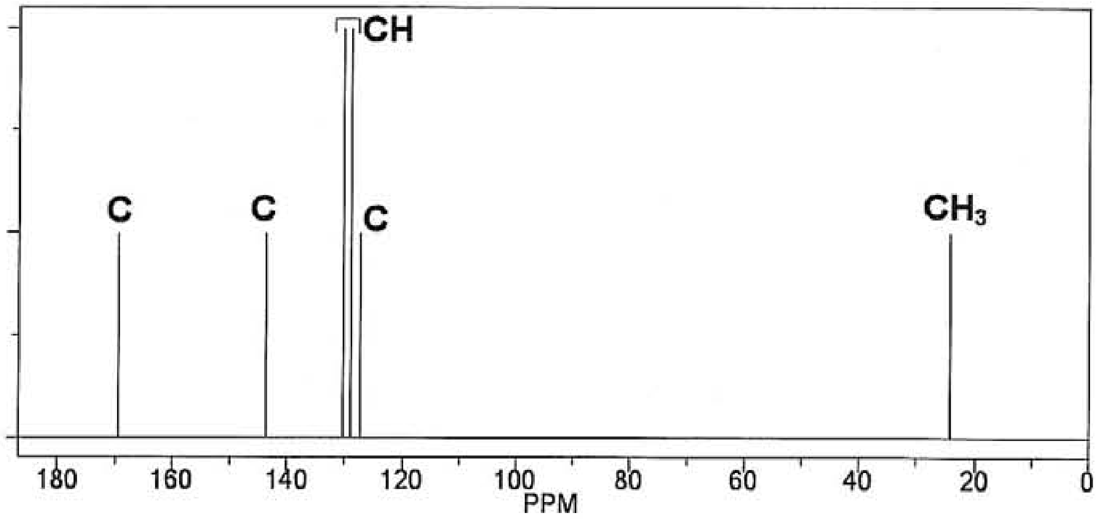
Compound 7

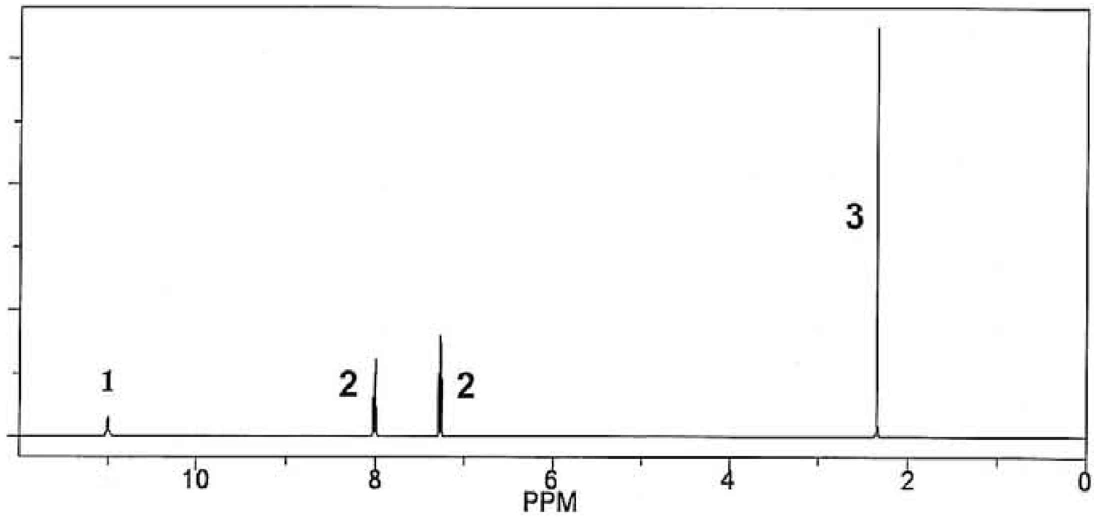


3420
1680
TRANSMITTANCE[%]
WAVENUMBER[-1]
100
50
0
4000
3000
2000
1500
1000
500

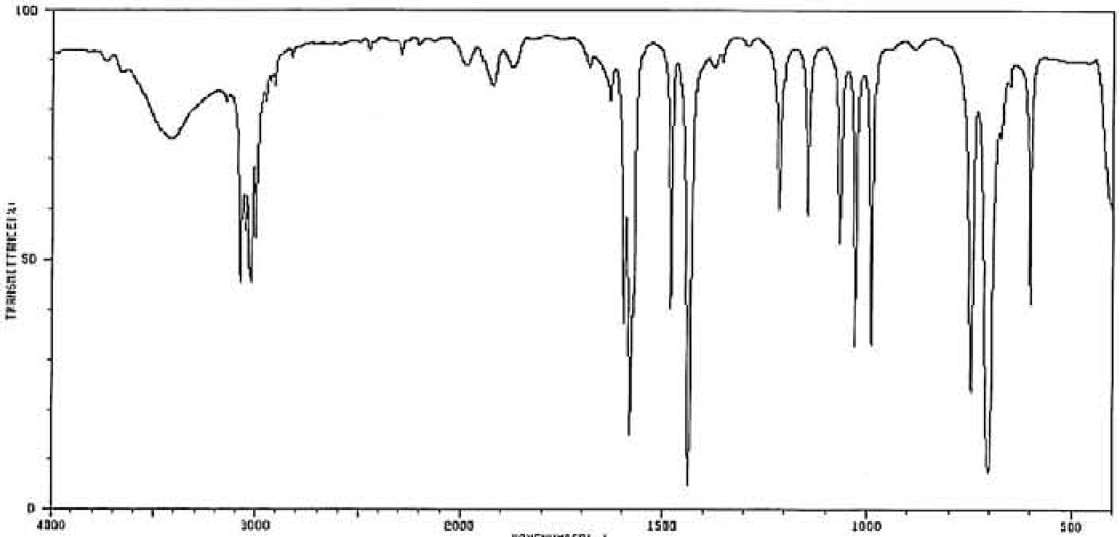


91
136
119
Relative Intensity
m/z
100
80
60
40
20
0
25
50
75
100
125
150

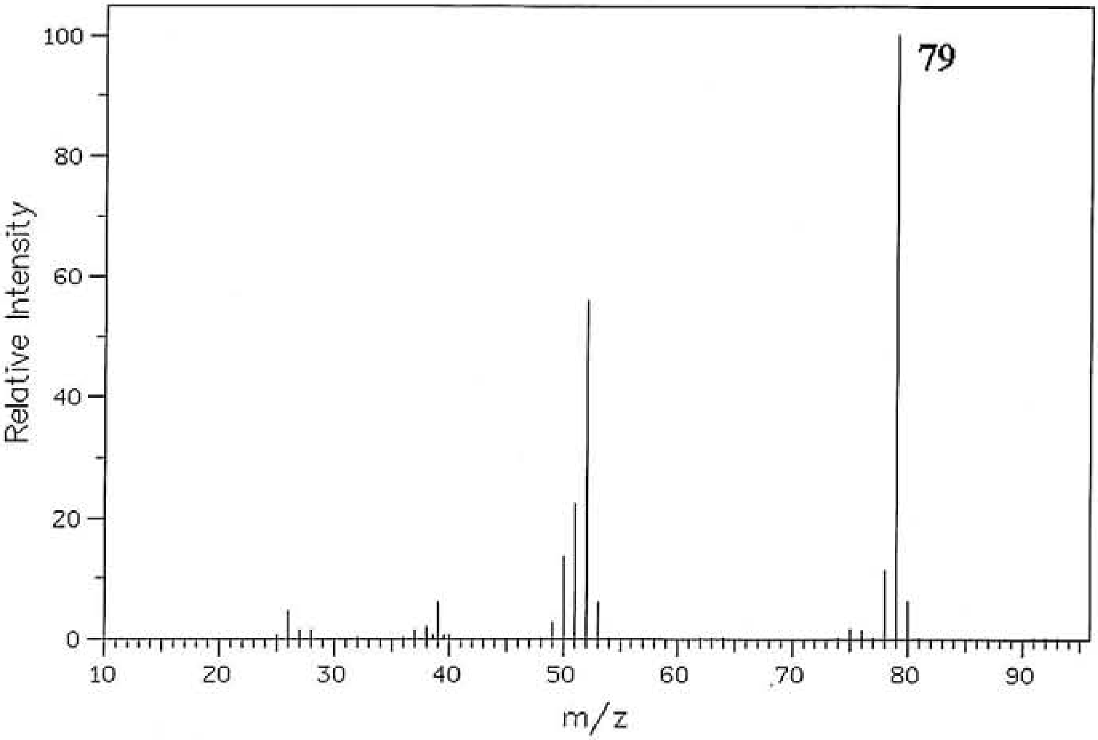

CH
C
C
C
CH_3
180
160
140
120
100
80
60
40
20
0
PPM


1
2
2
3
10
8
6
4
2
0
PPM

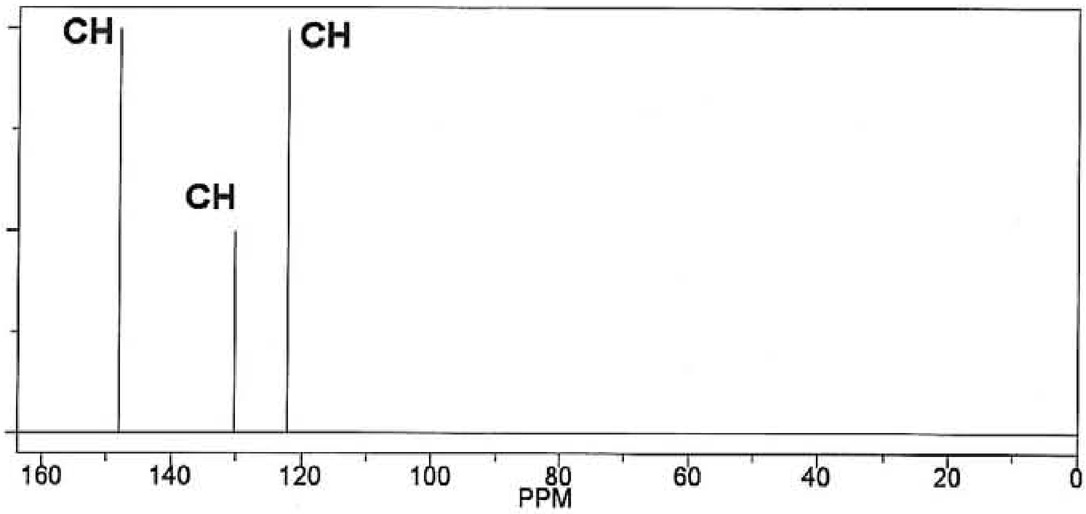
Compound 9

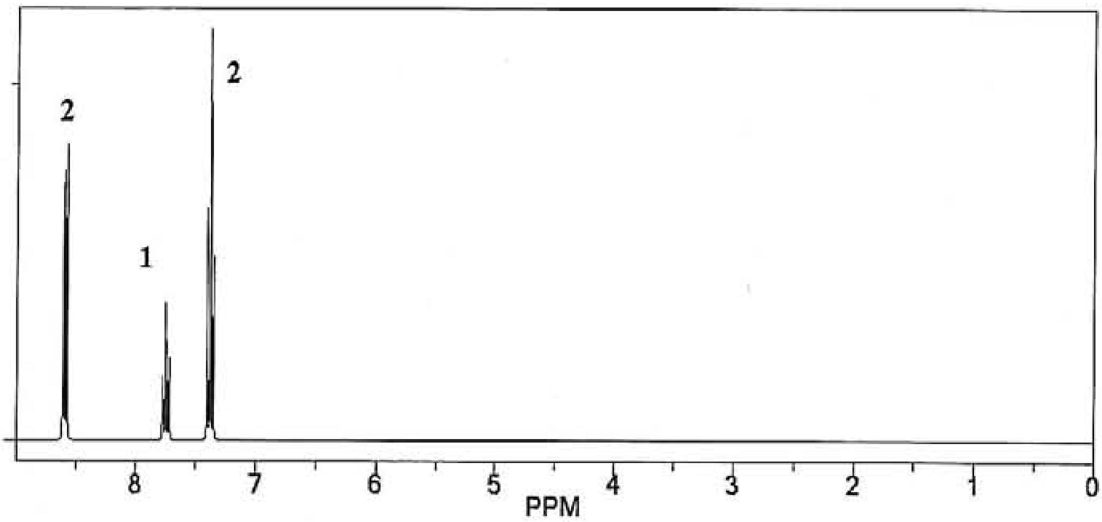


100
50
0
TRANSMITTANCE(%)
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)

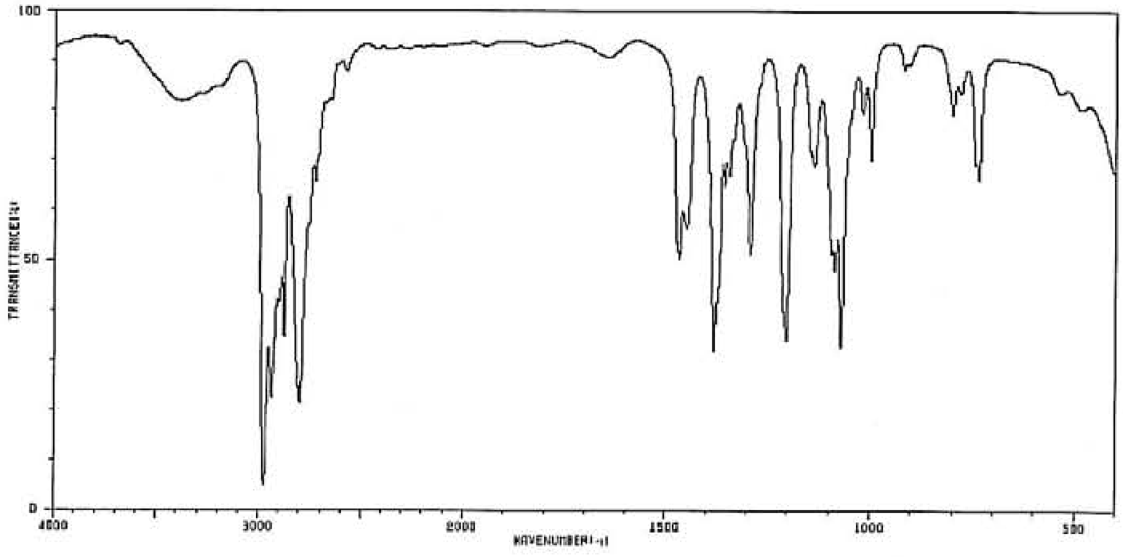


79
Relative Intensity
0
20
40
60
80
100
10
20
30
40
50
60
70
80
90
m/z

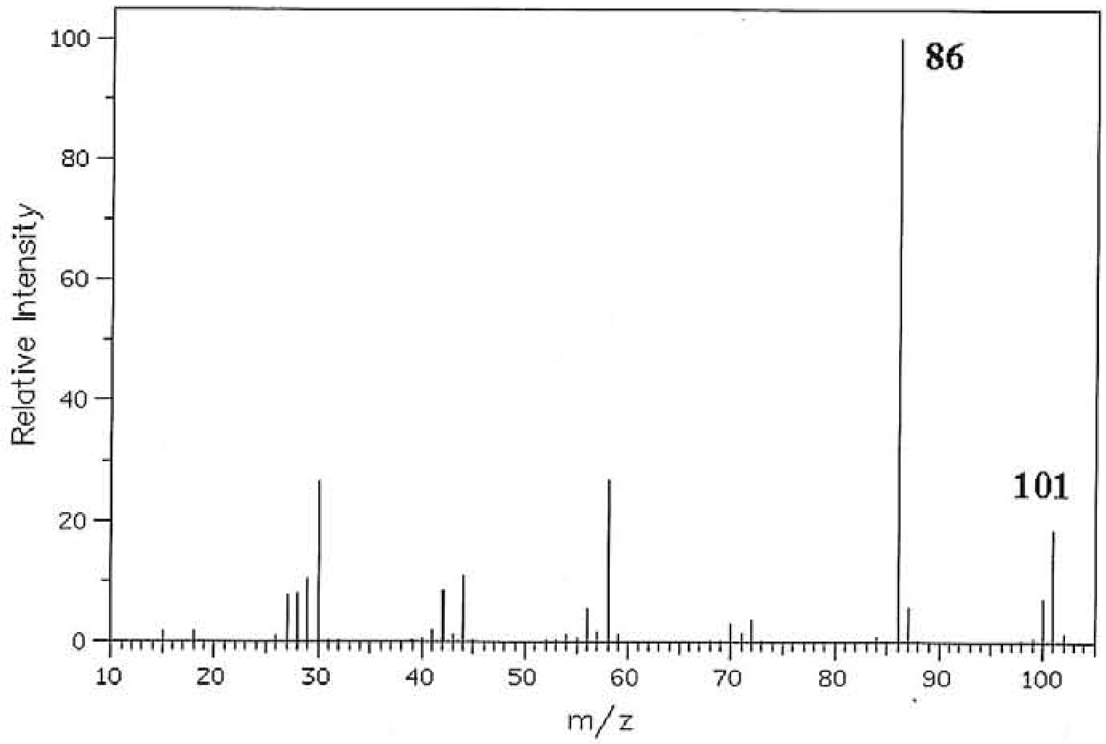

CH
CH
CH
160
140
120
100
80
PPM
60
40
20
0


2
1
2
8
7
6
5
4
3
2
1
0
PPM

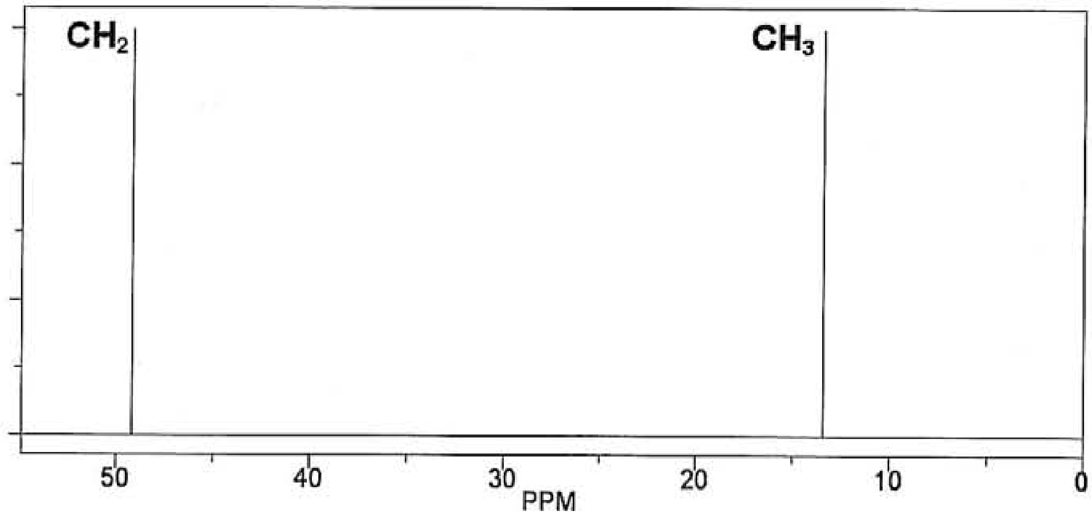
Compound 10

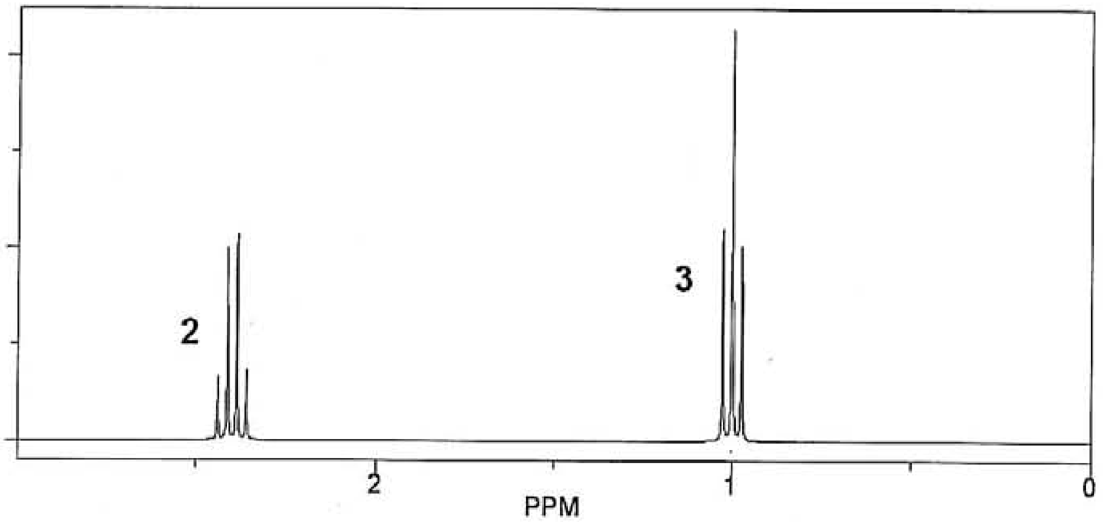


100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]



86
101
Relative Intensity
0
20
40
60
80
100
10
20
30
40
50
60
70
80
90
100
m/z


CH2
CH3
50
40
30
20
10
0
PPM


2
3
2
1
0
PPM

Compound:

Reasoning:

IR spectrum:

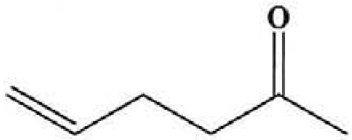
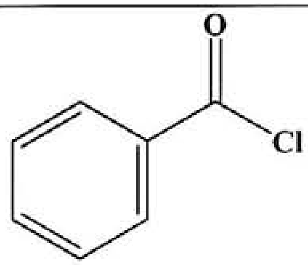
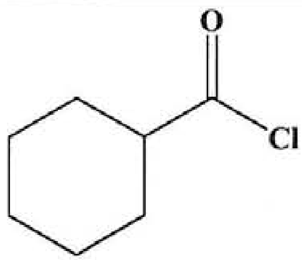
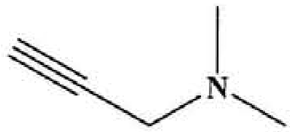
Mass Spectrum:

^{13}C NMR Spectrum:

^{1}H NMR Spectrum:

APPENDIX 22

Molecules Used in the "Carbonyl Conundrum" Scenario

 *trans*-2-pentenal	 5-hexen-2-one
 benzoyl chloride	 cyclohexanecarbonyl chloride
 valeronitrile	 N,N-dimethyl-2-propynylamine

APPENDIX 23

Memorandum

TO: Analytical Department
FROM: Dave Carew, CEO
DATE: 2/11/07
SUBJECT: Environmental Science Department Sample Analysis

Dear Team

Thank you for your recent report for the Environmental Science Department. They are reviewing your results.

Unfortunately, a report submitted to them a few weeks ago, on an unrelated case, has been misplaced. The only information that was recovered from this report was the spectra, initially provided by your department. The identity of the molecules is known, but the spectra have accidentally been mixed up. Using your knowledge of spectroscopy and carbonyl compounds, please can you indicate which spectra belong to each of the molecules?

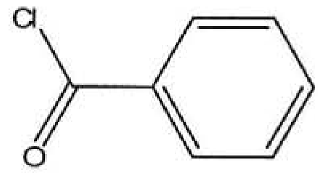
Many thanks,

Dave Carew
Chief Executive Officer

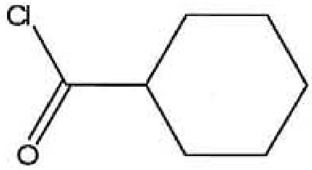
trans-2-Pentenal

5-Hexen-2-one

Benzoyl chloride

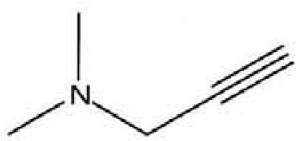


Cyclohexanecarbonyl chloride

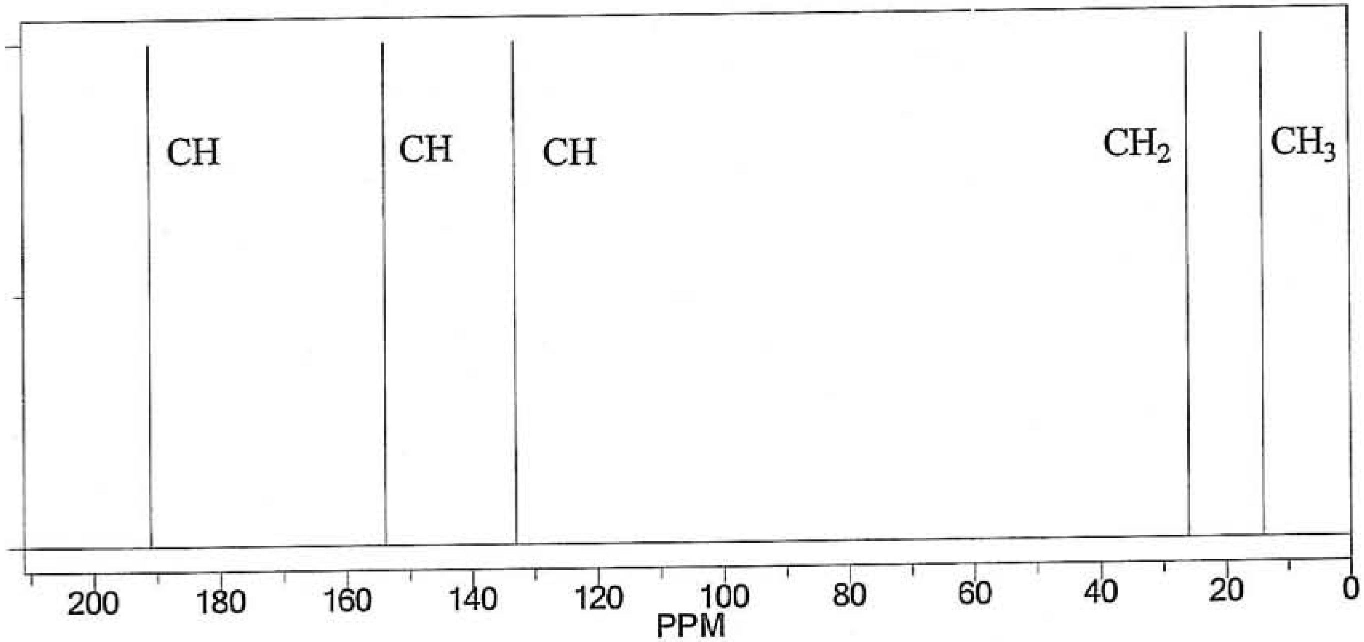


Valeronitrile

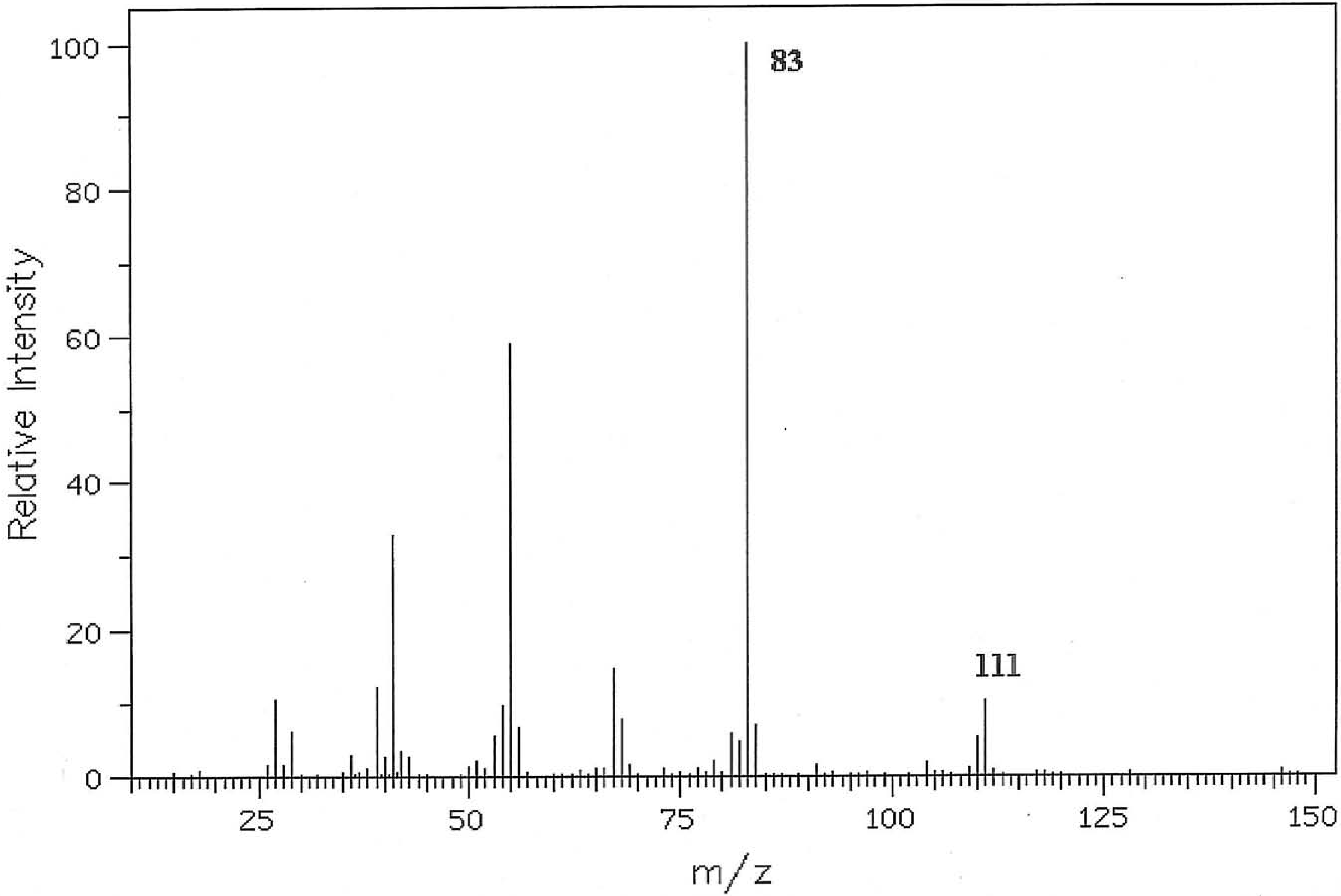
N,N-Dimethyl-2-propynylamine



17

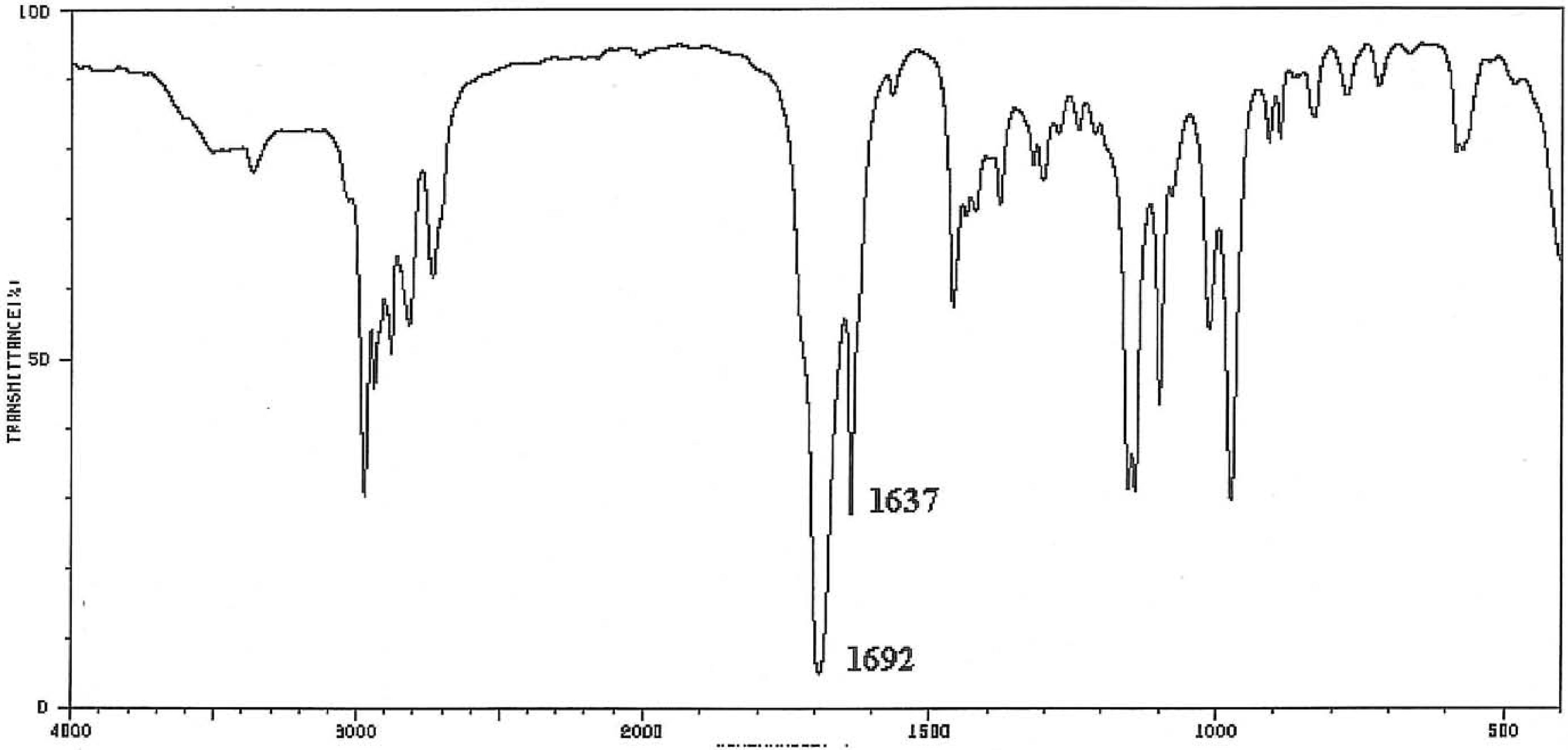


22

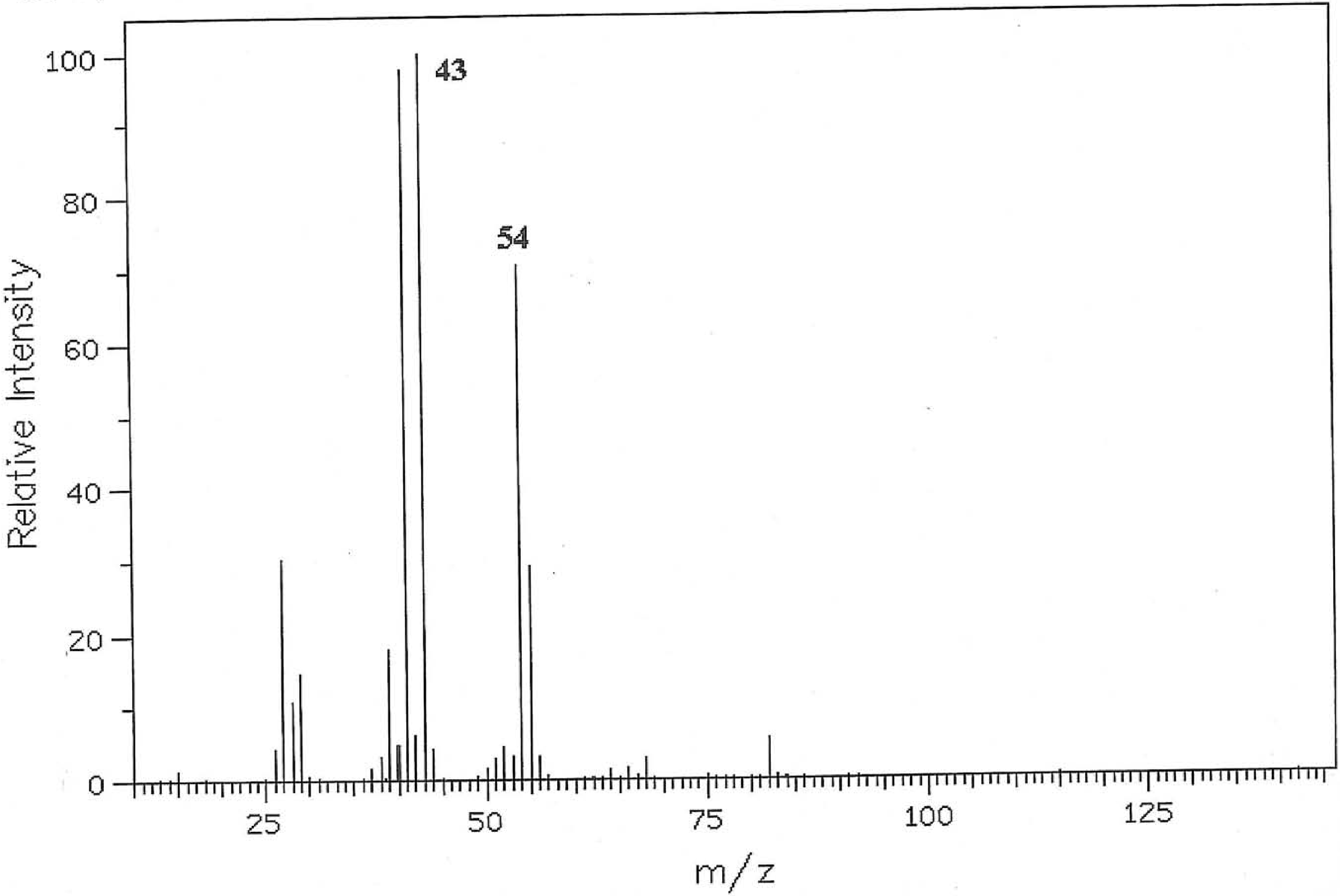


100
80
60
40
20
0
Relative Intensity
83
111
25
50
75
100
125
150
m/z

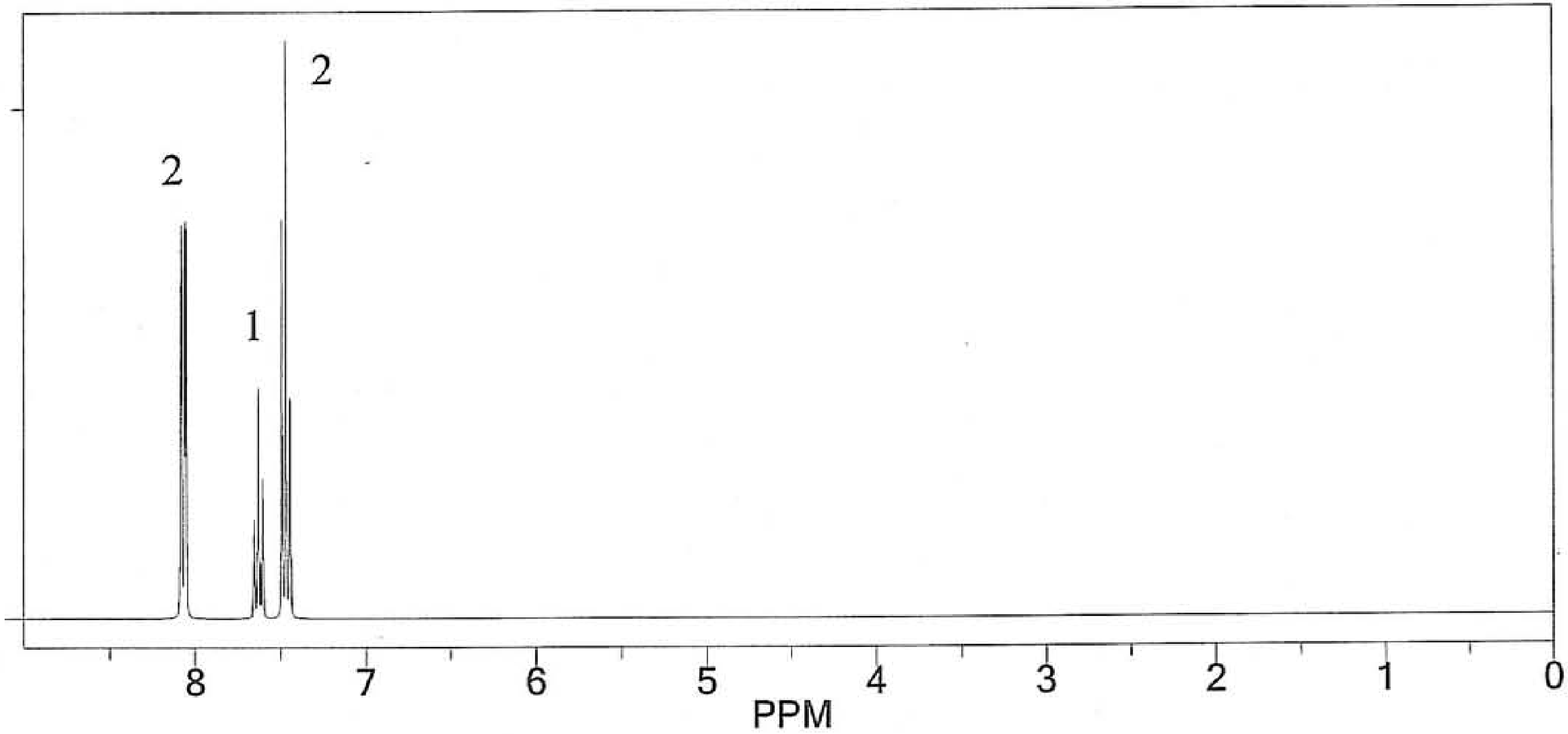
6


100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
1637
1692

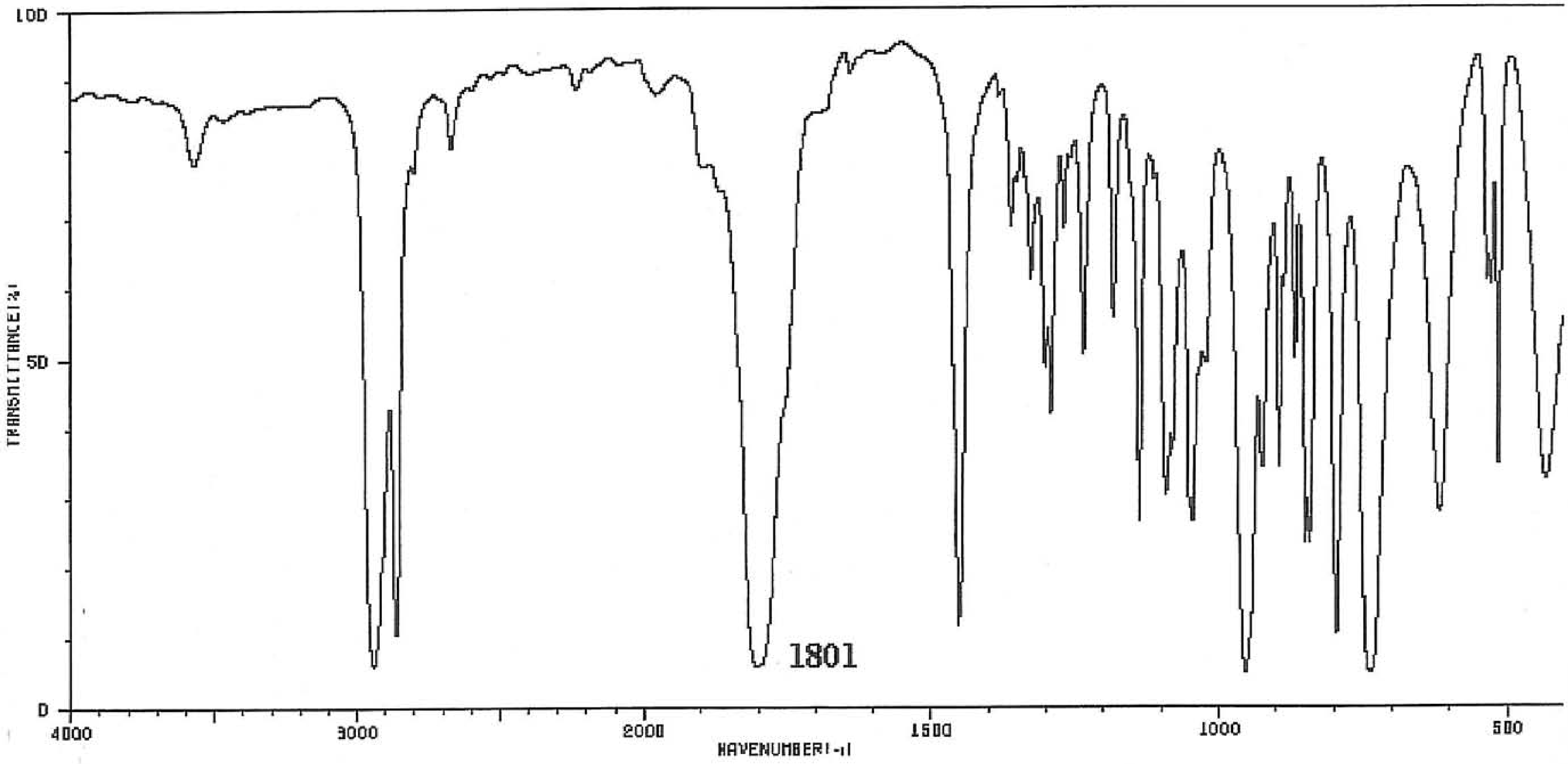
19



7

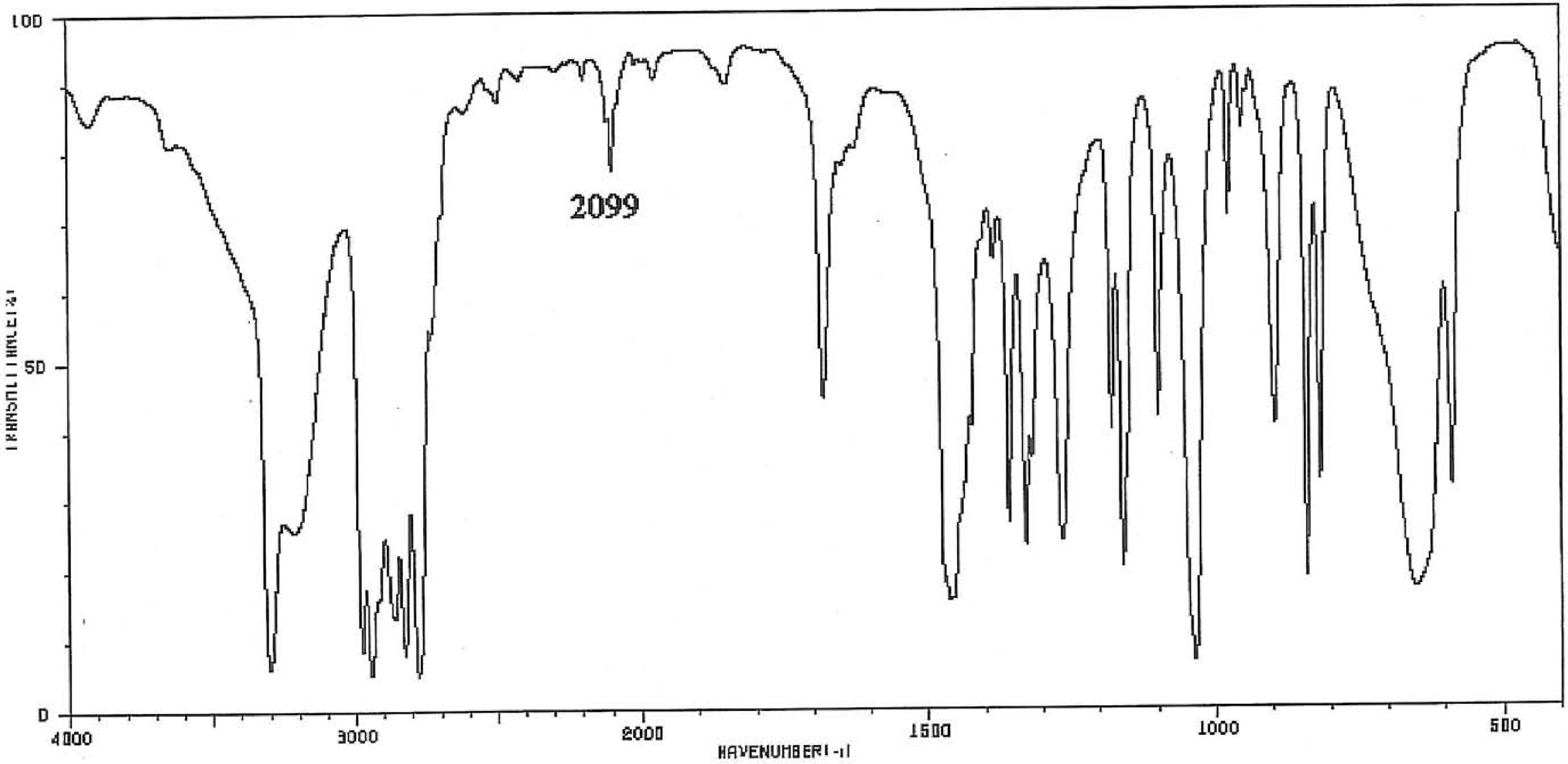


2



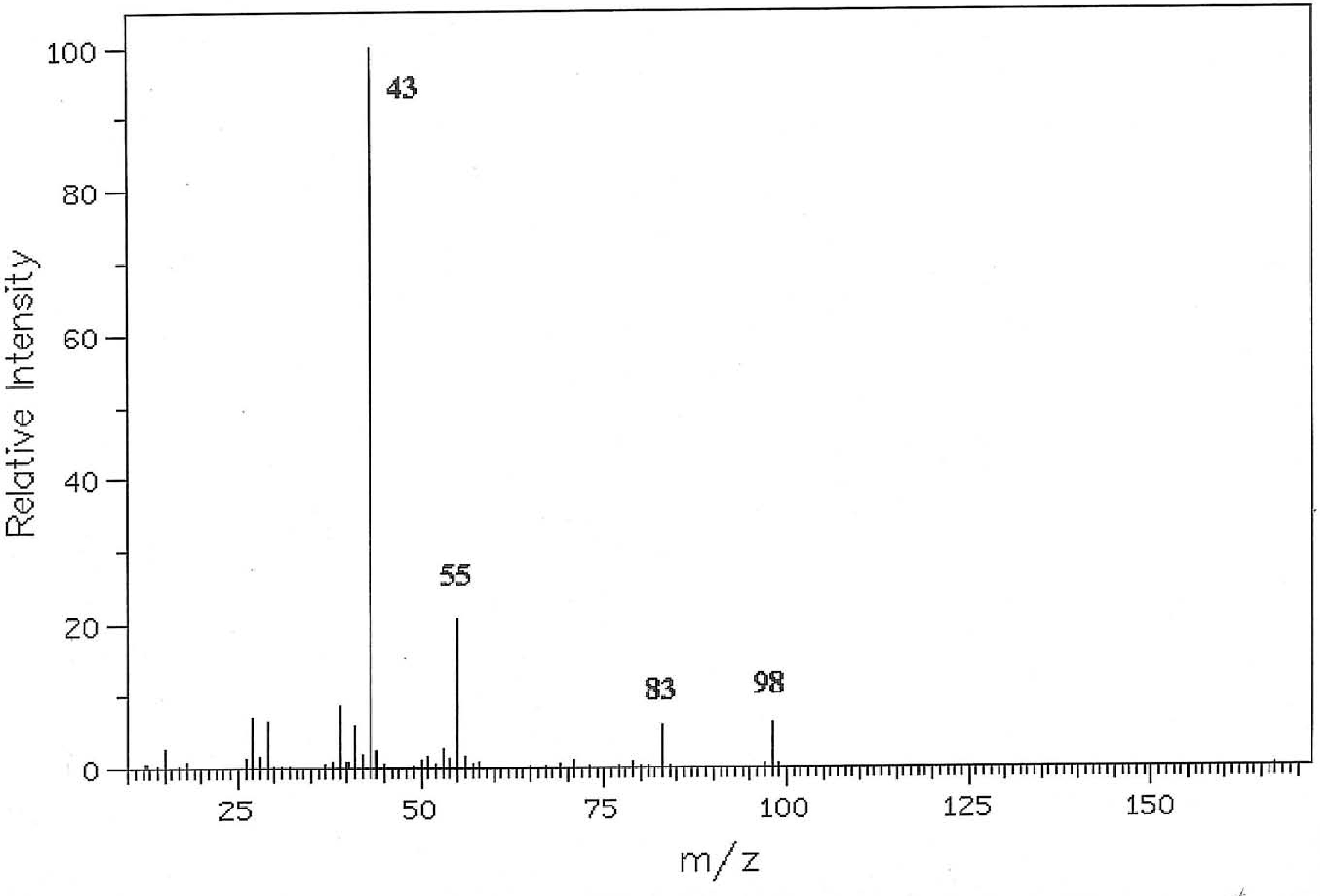
100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]
1801

4

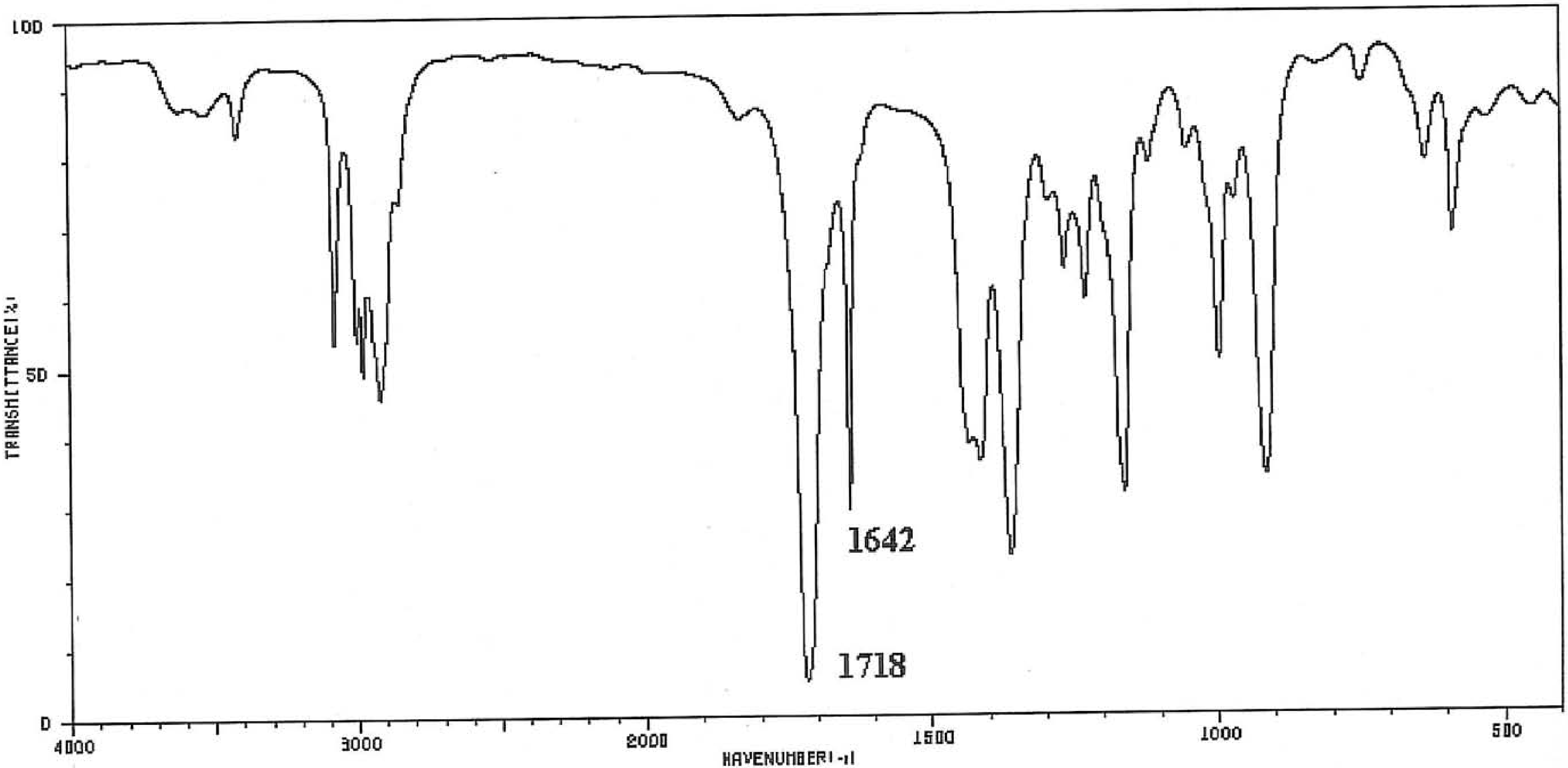


100
50
0
TRANSMITTANCE[%]
2099
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]

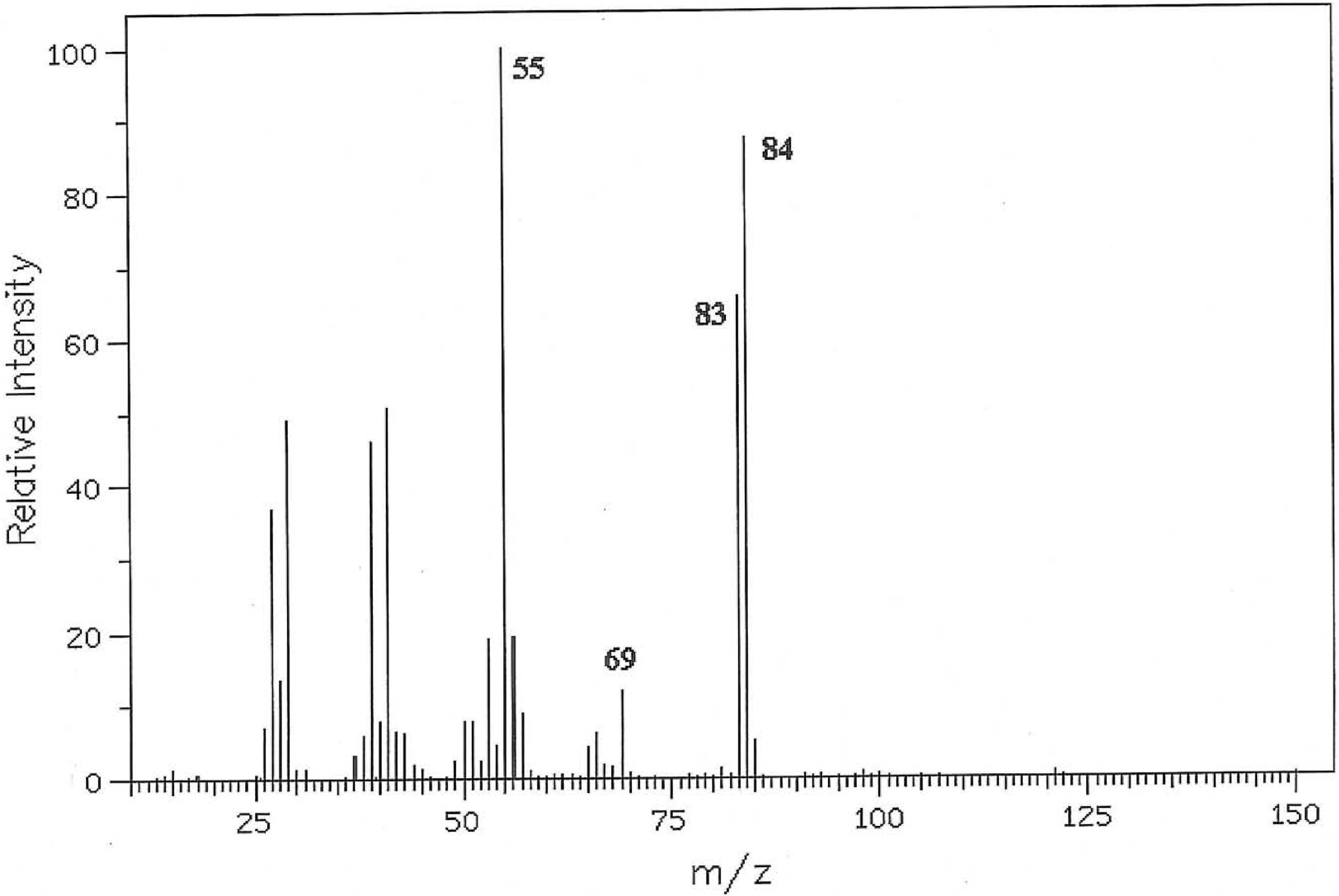
21



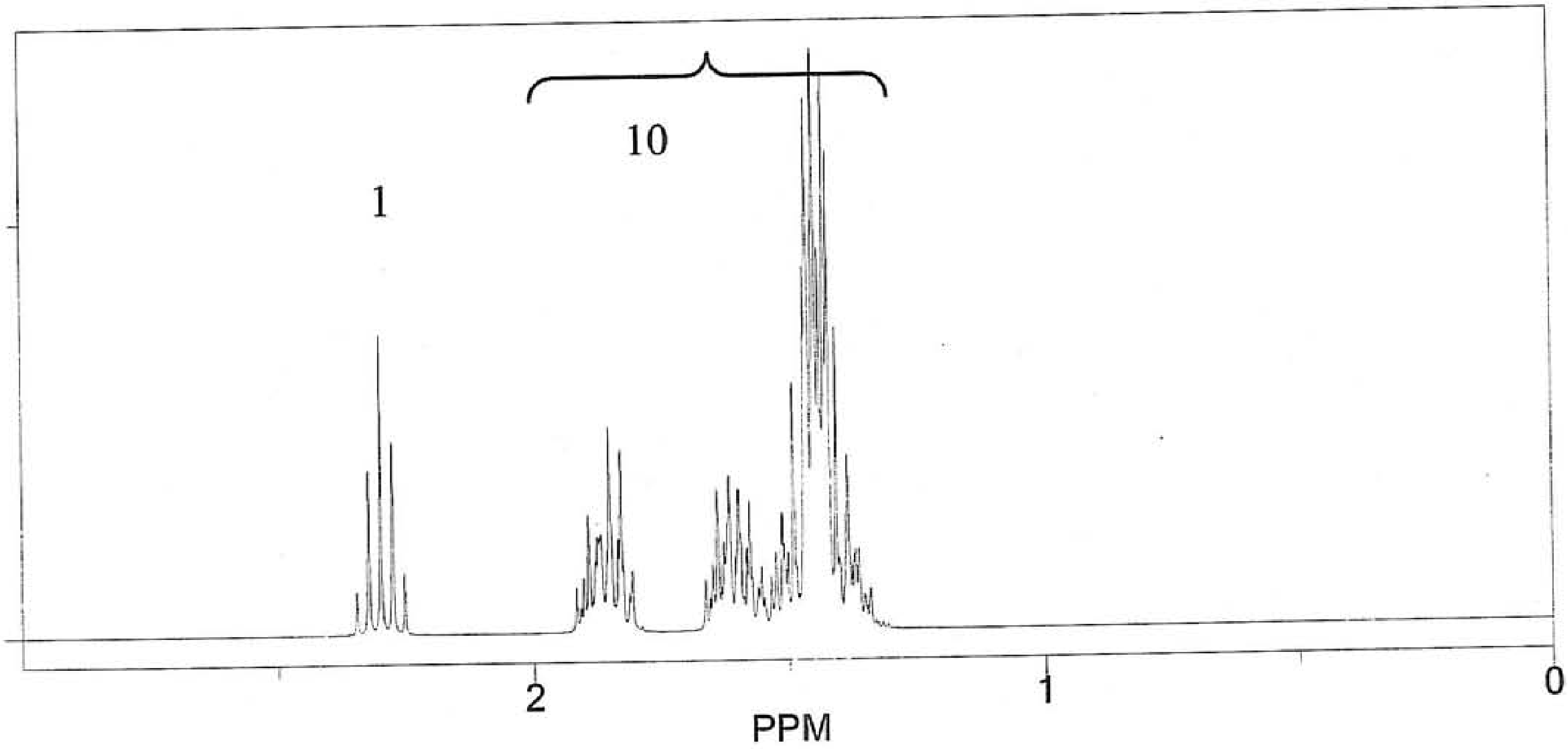
Relative Intensity
100
80
60
40
20
0
43
55
83
98
25
50
75
100
125
150
m/z


100
50
0
TRANSMITTANCE(%)
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)
1642
1718

23

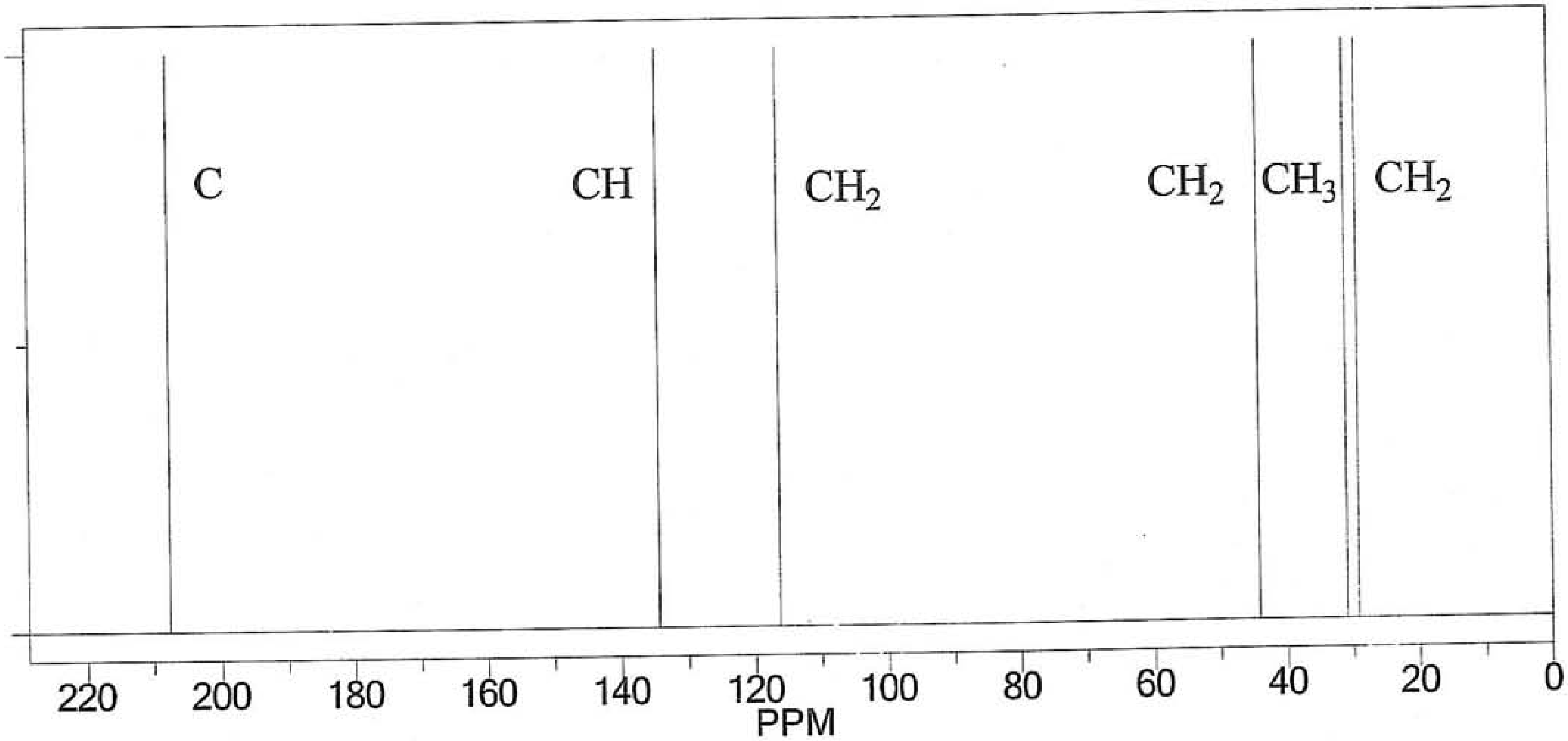


Relative Intensity
100
80
60
40
20
0
55
84
83
69
25
50
75
100
125
150
m/z

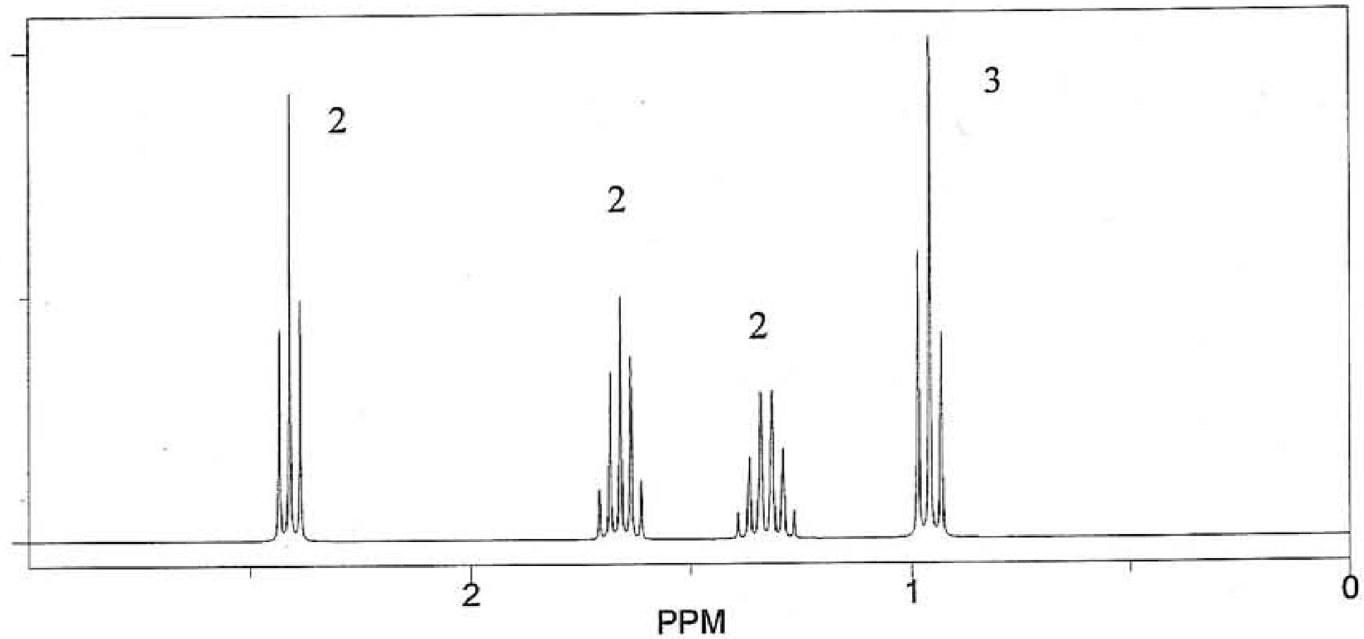


1
10
2
1
0
PPM

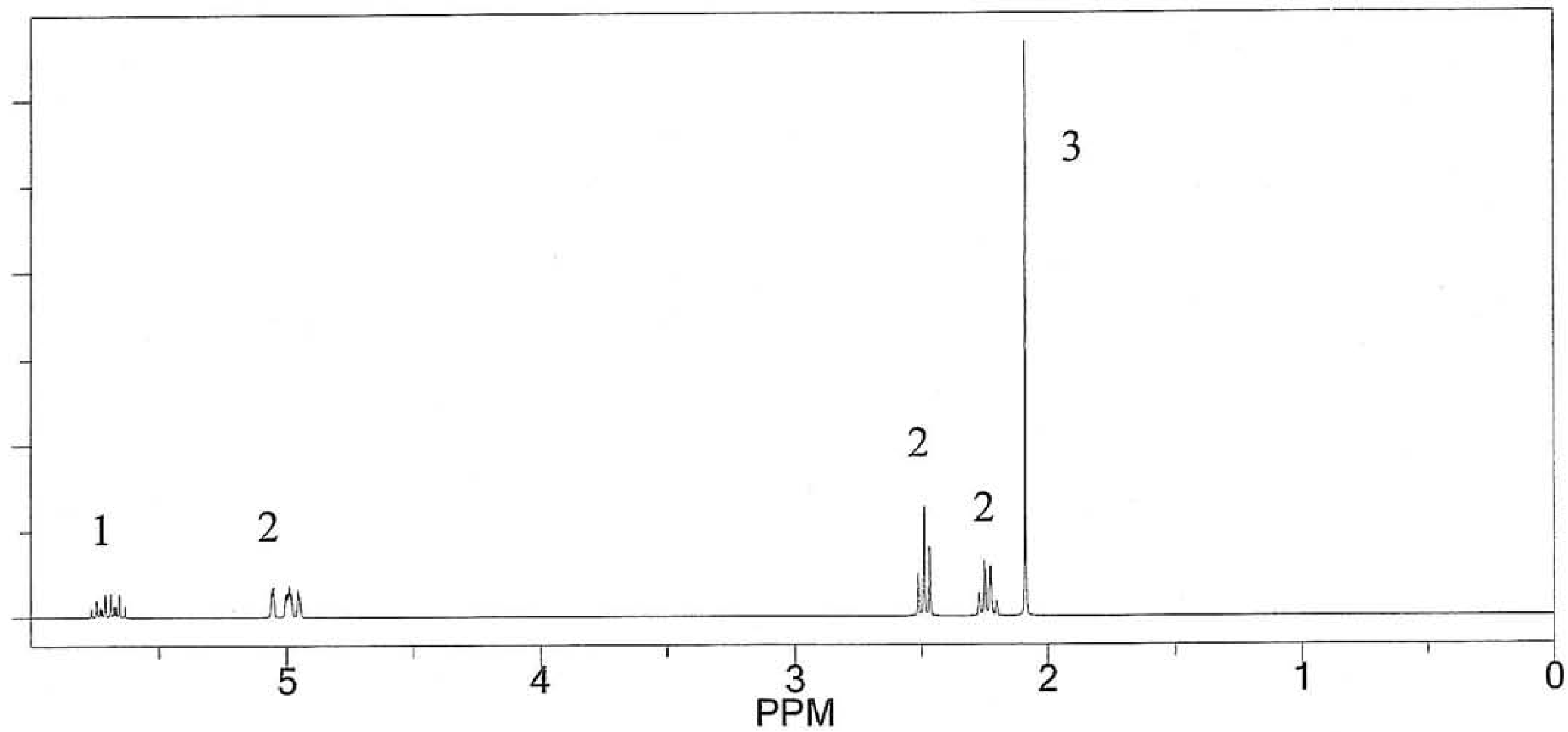
16



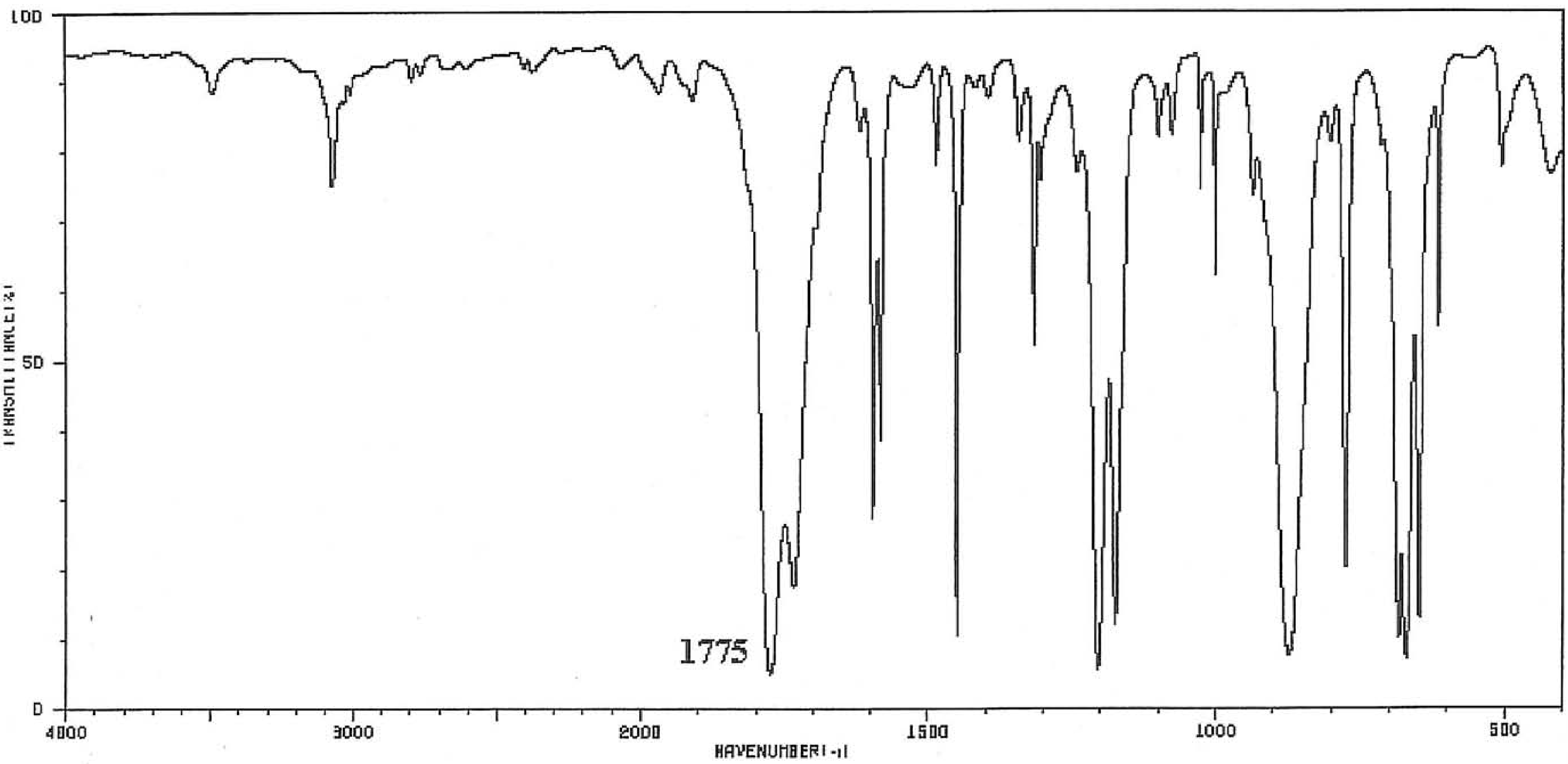
10



12

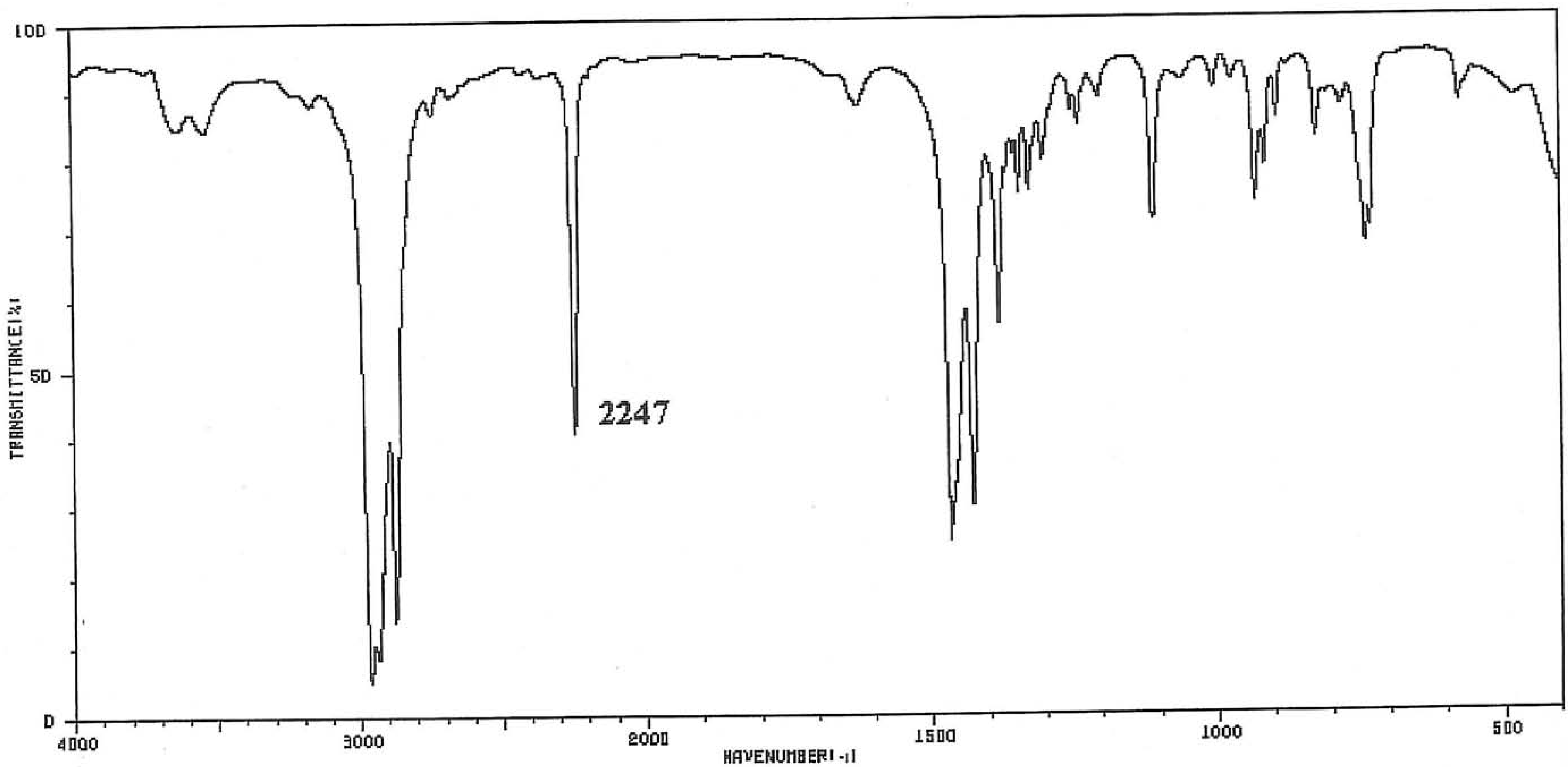


3



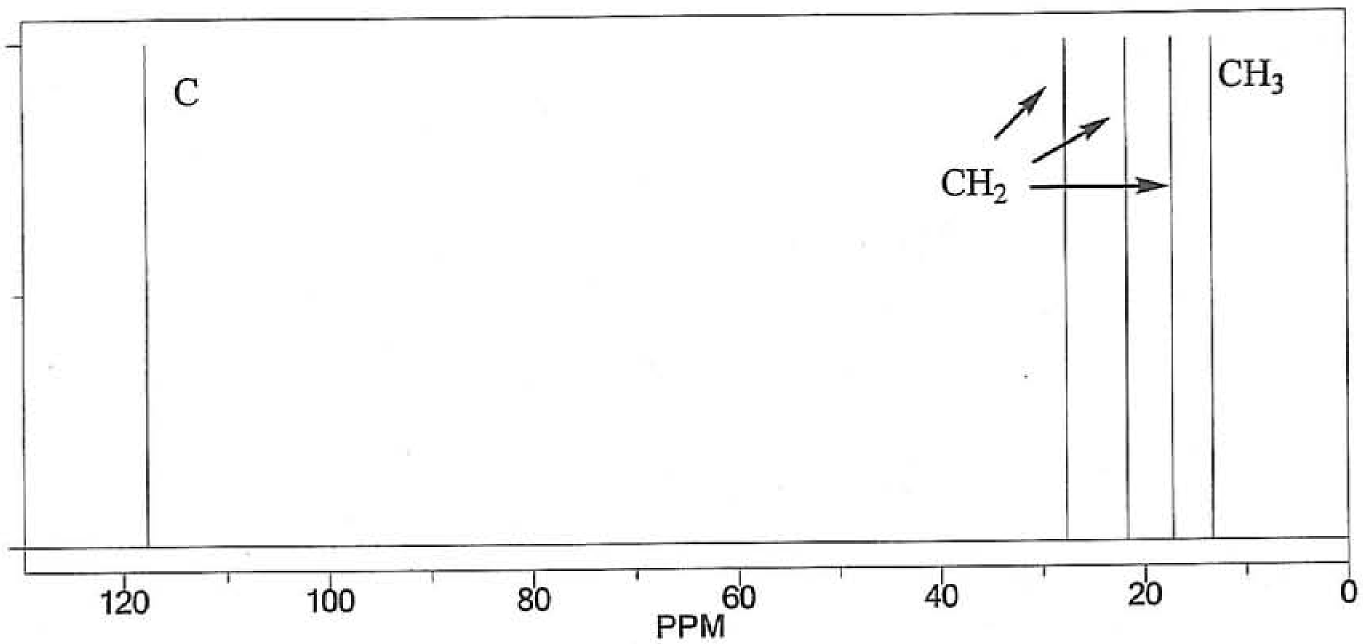
100
50
0
TRANSMITTANCE[%]
4000
3000
2000
1500
1000
500
WAVENUMBER[-1]
1775

5

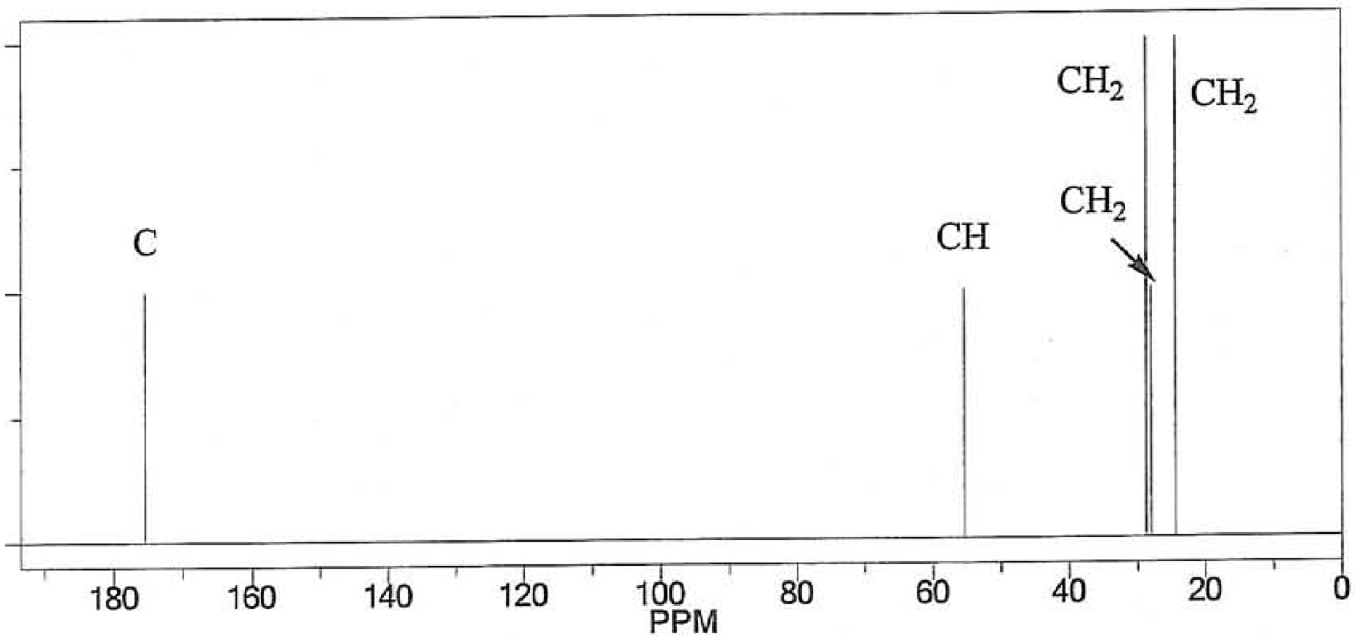


100
50
0
TRANSMITTANCE(%)
2247
4000
3000
2000
1500
1000
500
WAVENUMBER(-1)

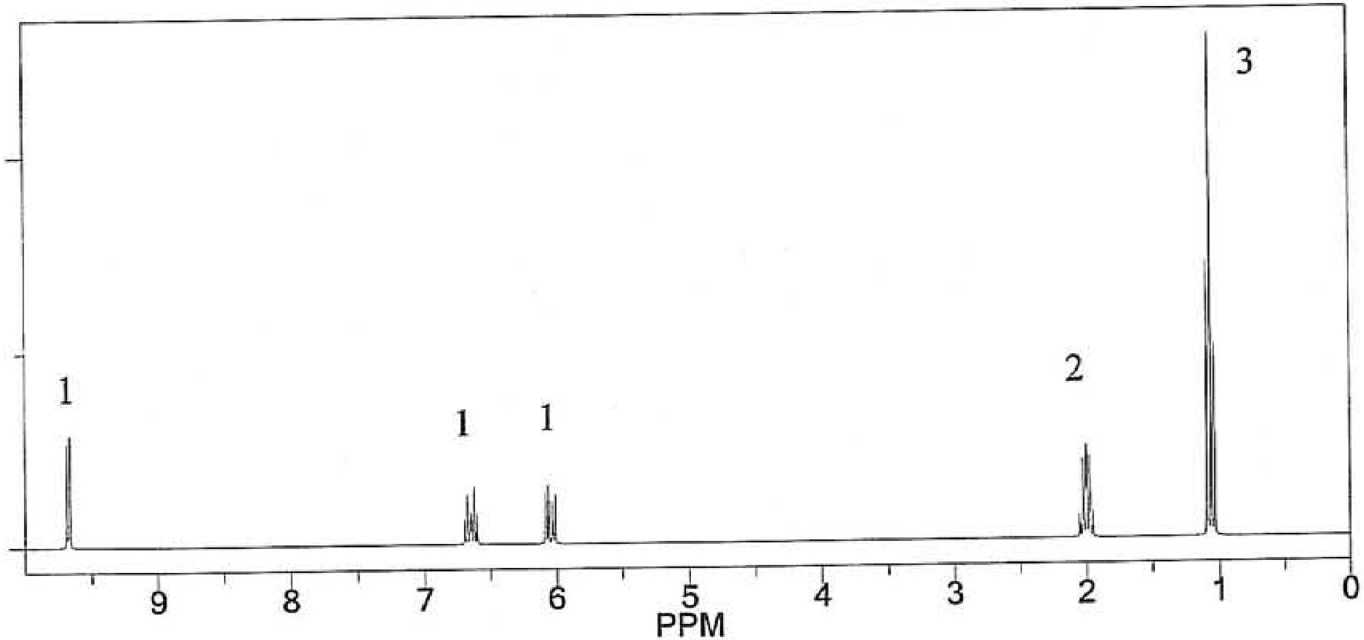
15



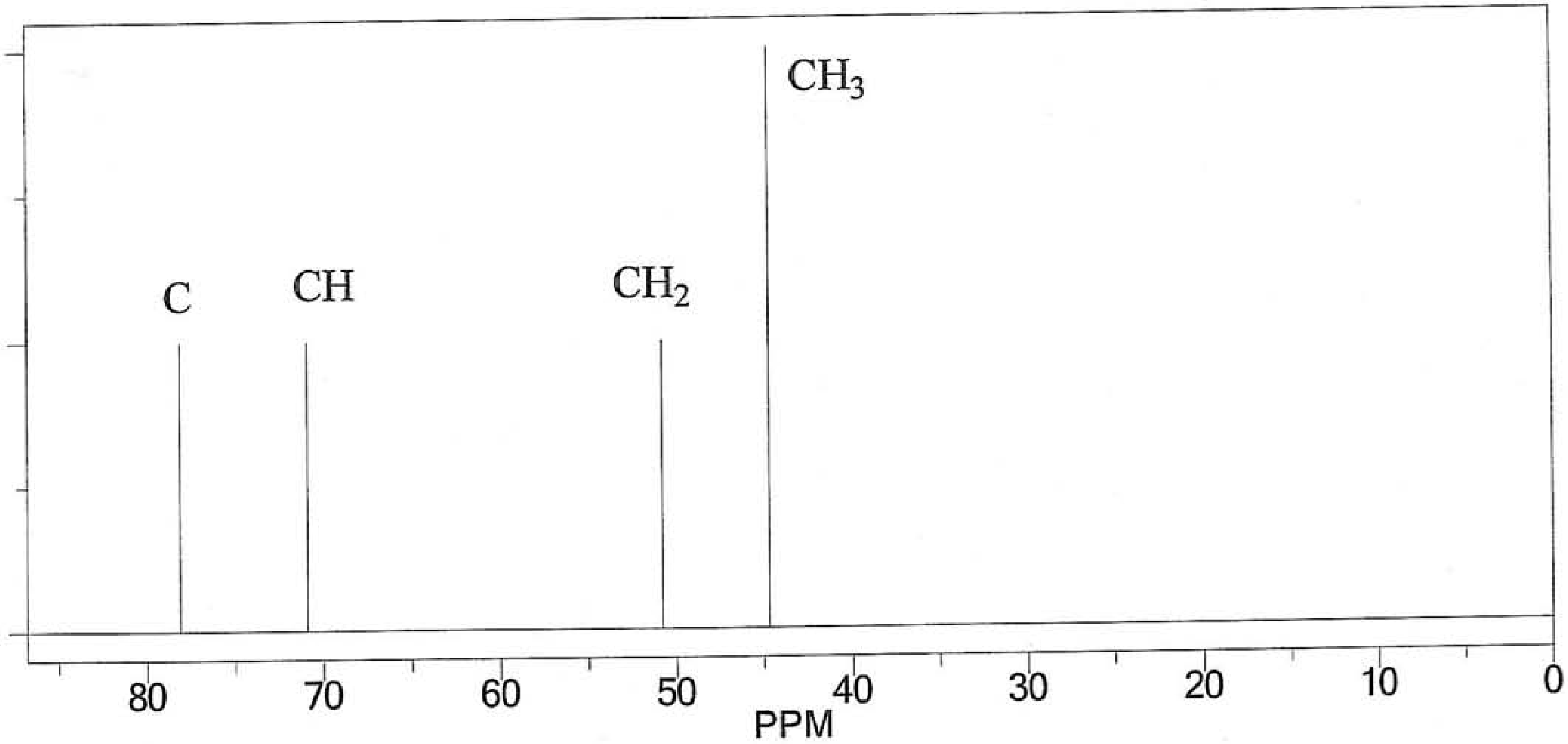
13



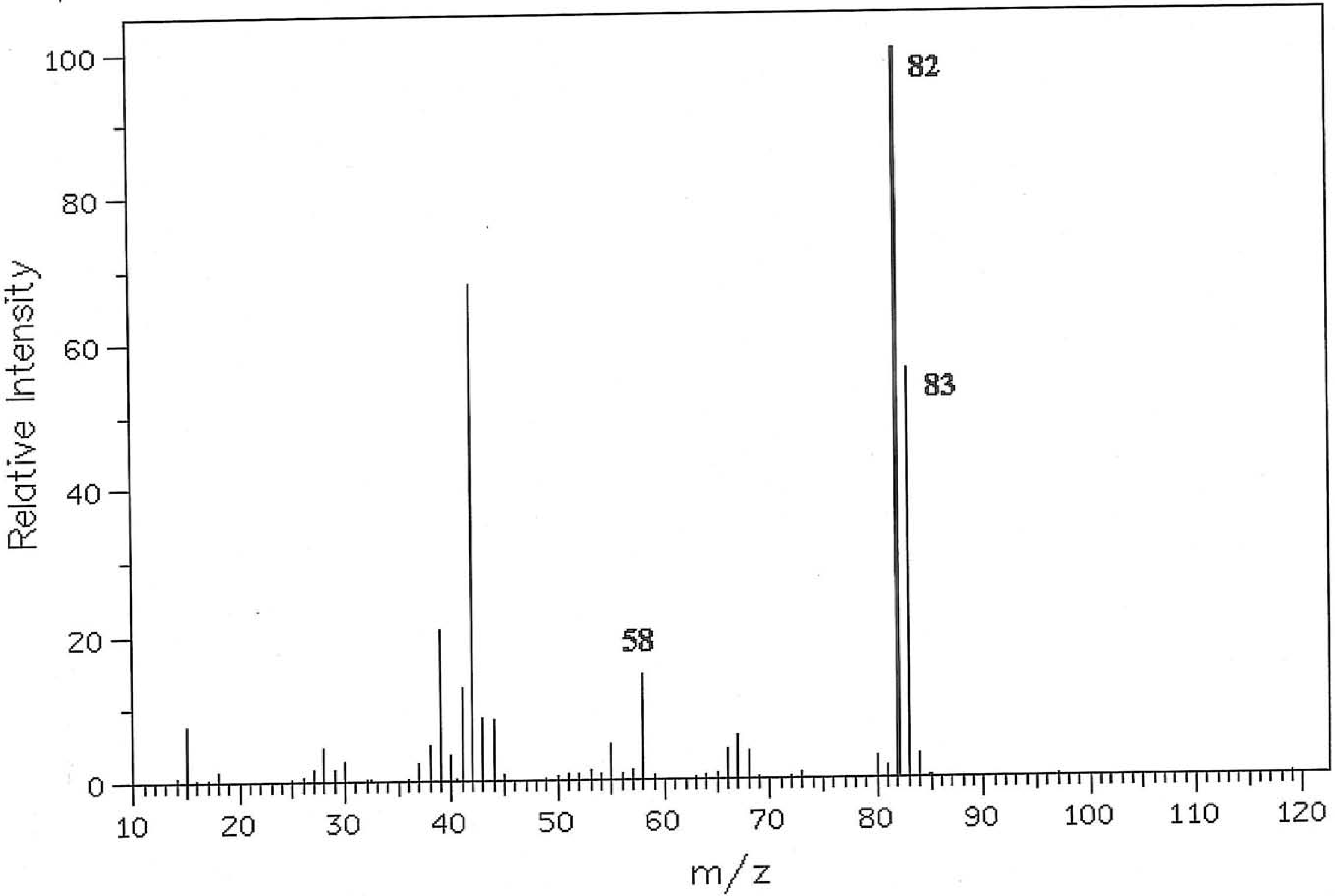
9



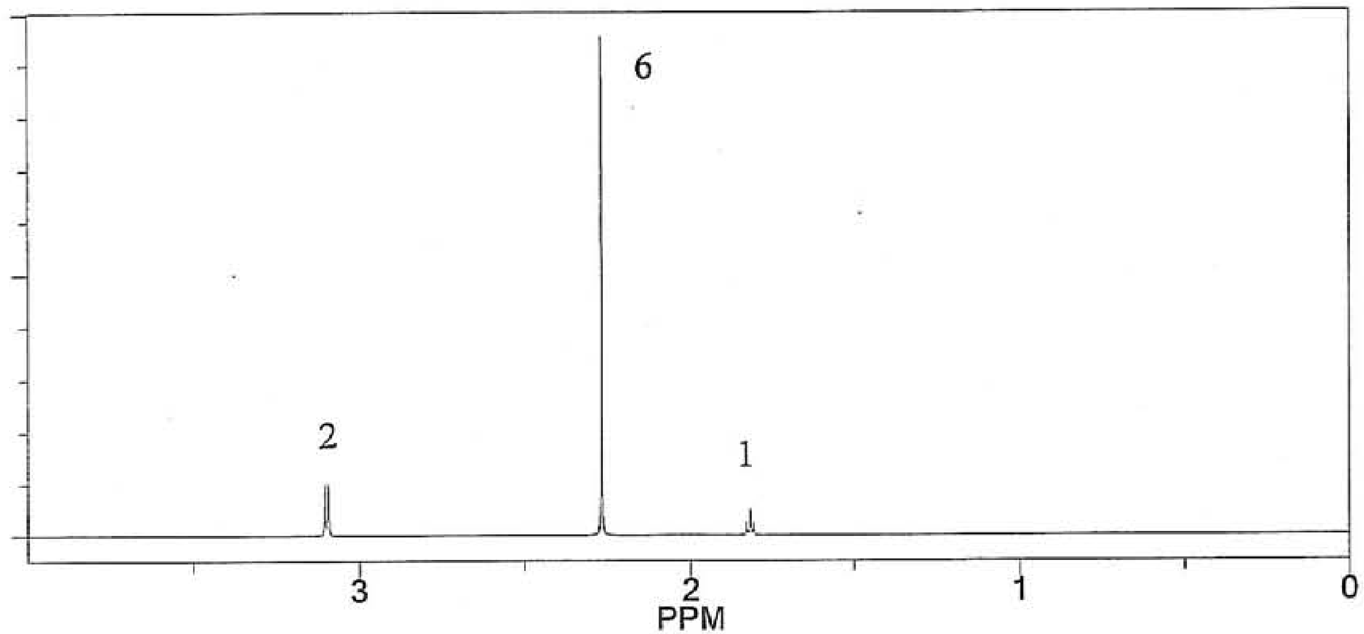
14



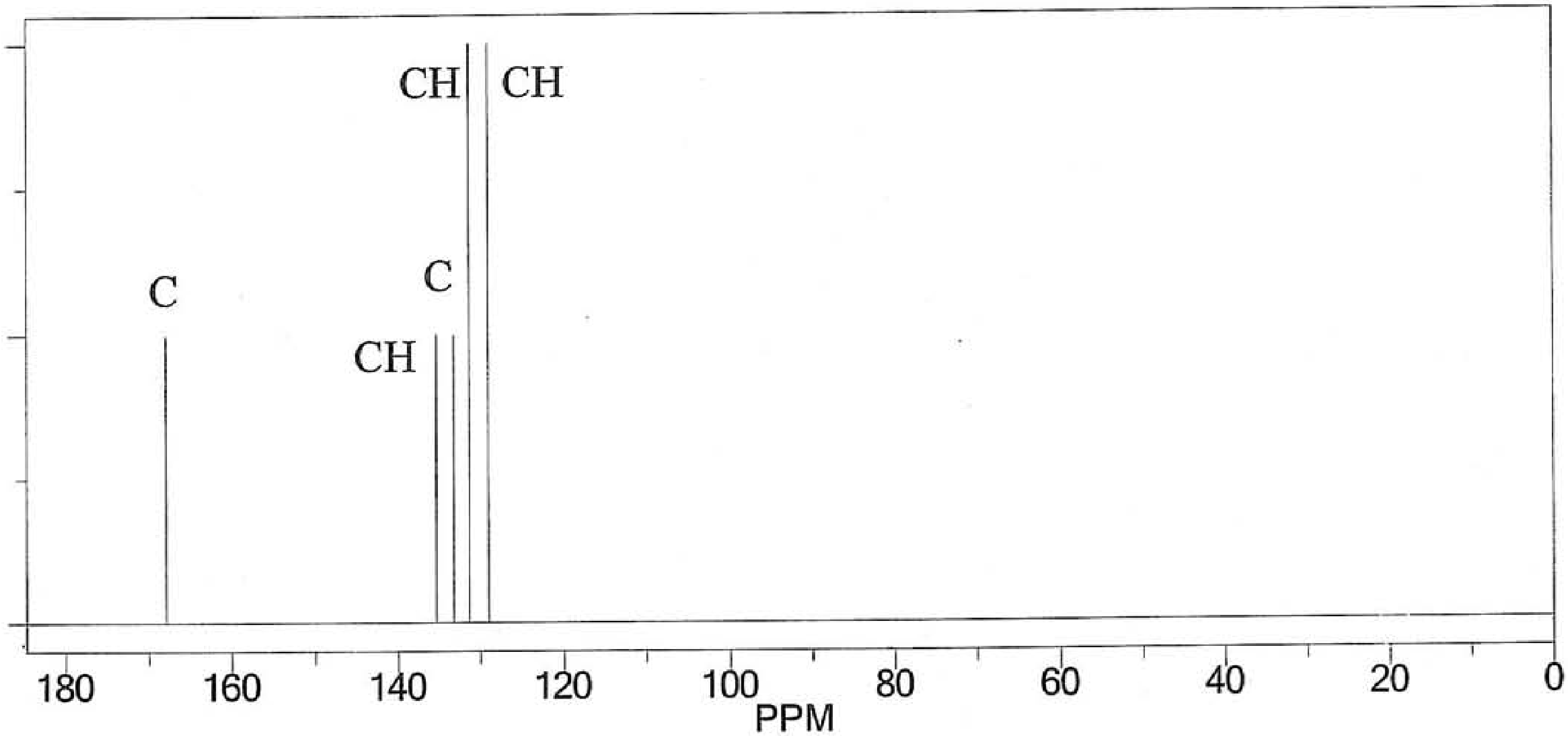
24


82
83
58
100
80
60
40
20
0
Relative Intensity
10
20
30
40
50
60
70
80
90
100
110
120
m/z

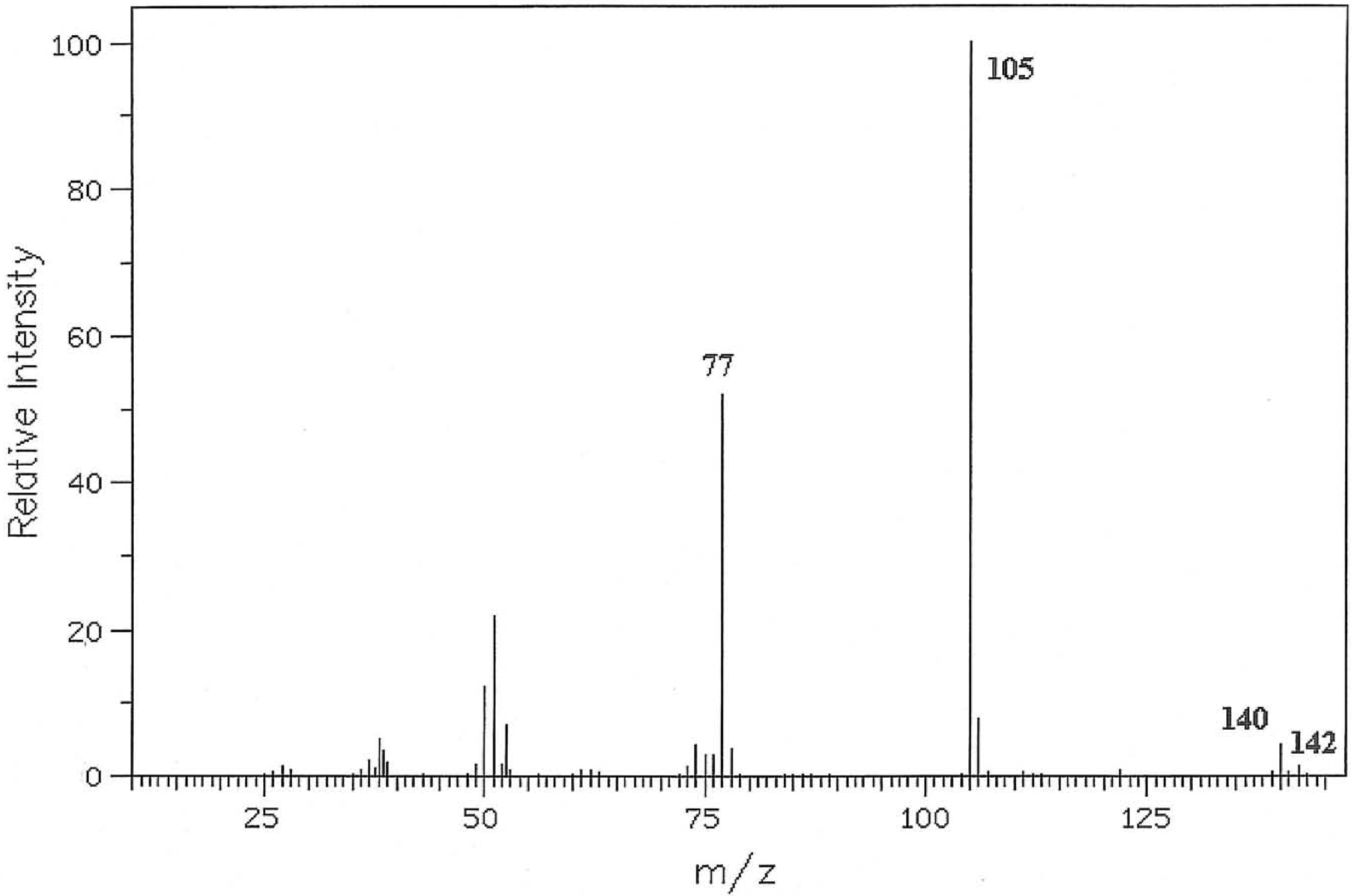
8



18



20


100
80
60
40
20
0
Relative Intensity
105
77
140
142
25
50
75
100
125
m/z

APPENDIX 24

Natalie Rowley

From: Shelley O'Halloran [shell_nmr@yahoo.co.uk]
Sent: 04 November 2008 16:13
To: N.M.Rowley@bham.ac.uk
Subject: Help with spectral interpretation please

Dear Dr Rowley

I am currently a postgraduate student at Birmingham Uni. Yesterday I ran a reaction to produce benzylamine from a recently ordered sample of benzamide, using the strong reducing agent lithium aluminium hydride (which is known to reduce amides to amines).

As this is the first time I have carried out this reaction, I was wondering if you can please confirm that I have produced the desired product, before I carry on with my experiment? Please can you assign the spectra (in your pigeon hole) and email me a brief report listing the key spectral features to confirm that I have produced benzylamine and don't have any starting material present.

Many thanks

Shelley

--
Shelley O'Halloran

School of Chemistry,
University of Birmingham,
Edgbaston

Reaction Dilemma Scenario

Peer Assessment of Group Activity

You will each receive group marks for each week's EBL activities as well as marks for your group report. Most of the groups are working together very well, though some are less successful. This is your opportunity to consider whether all of your fellow chemists pulled their weight. Did you feel that everyone contributed equally? Did you feel as if you were carrying anyone?

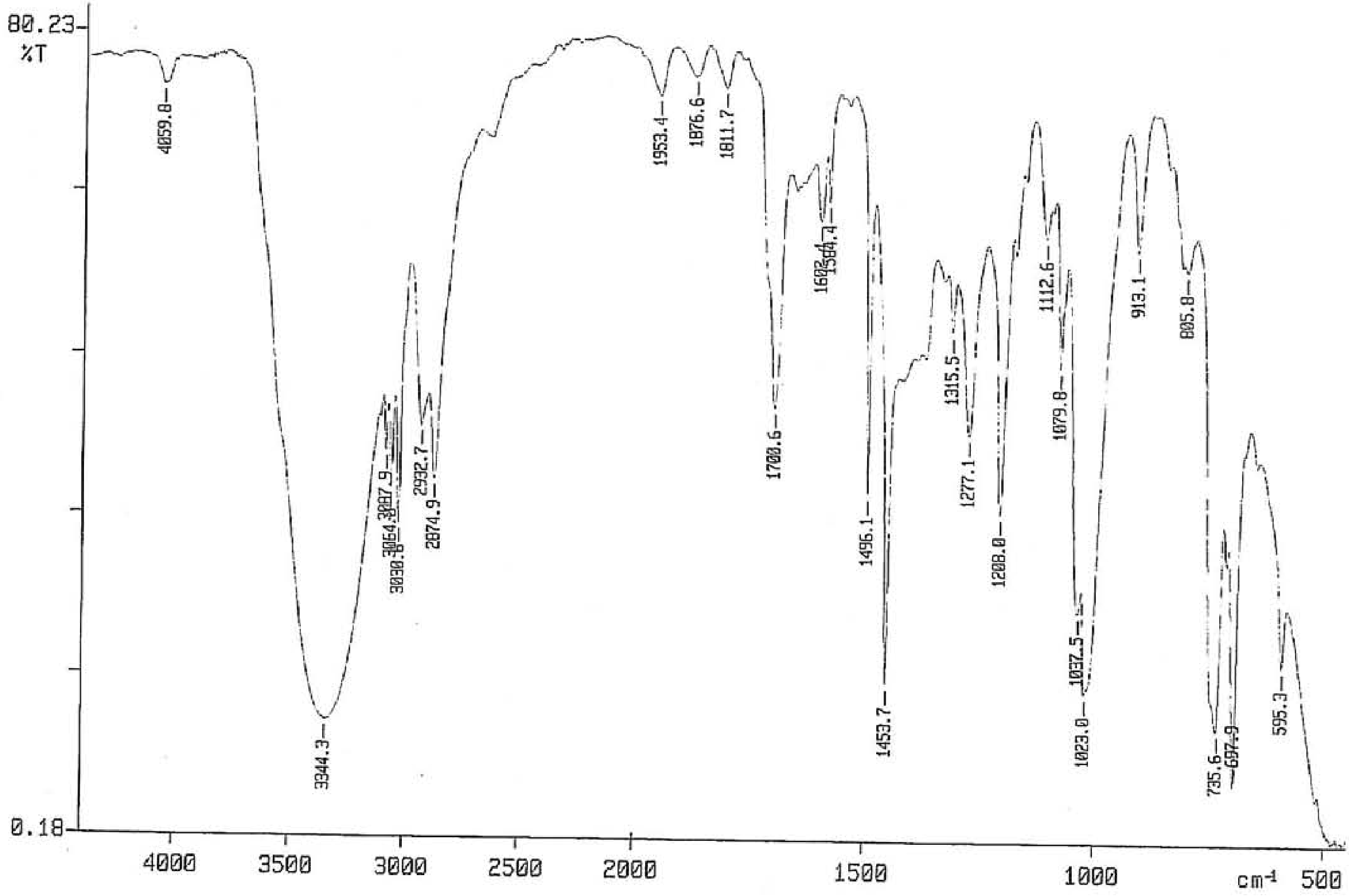
Consider how your group operated. Then give each team member a score from 0-100 %. If you feel that you all worked well together and made an effective team, then you may give everyone the same score. If the workload was unbalanced, then you may reflect this in your scoring. This assessment is confidential. You will all receive an average score from the rest of the team.

Your name:

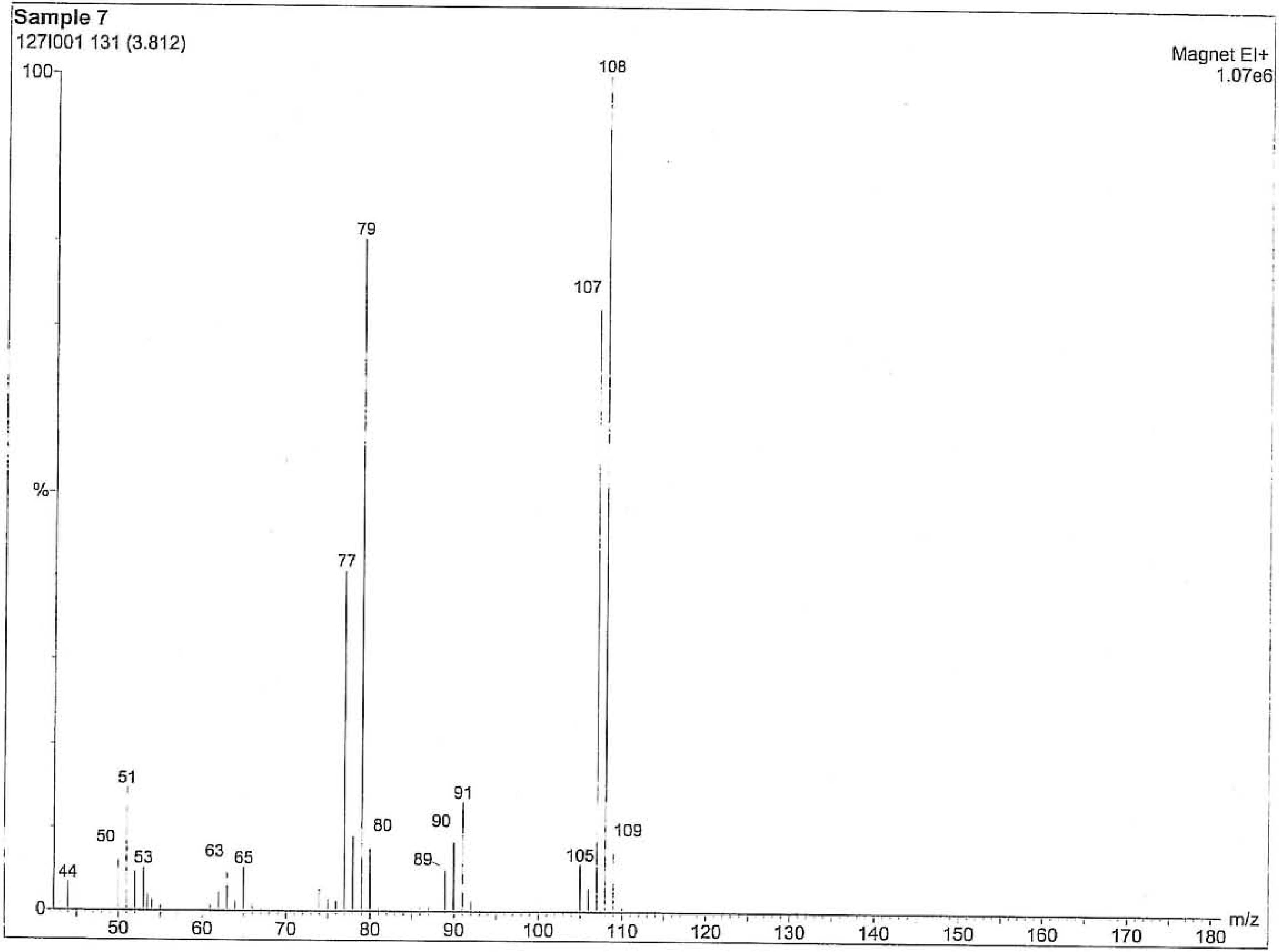
Group 1	Score as %	Group 2	Score as %
Group 3	**Score as %**	**Group 4**	**Score as %**
Group 5	**Score as %**	**Group 6**	**Score as %**
Group 7	**Score as %**	**Group 8**	**Score as %**

Sample 7

PERKIN ELMER



07/10/25 14:14
X: 1 scan, 4.0cm-1



Sample 7
127I001 131 (3.812)
Magnet EI+
1.07e6
100
%
0
44
50
51
53
63
65
77
79
80
89
90
91
105
107
108
109
50
60
70
80
90
100
110
120
130
140
150
160
170
180
m/z

Sample 7
13C-PENDANT, 1H-decoupled

Current Data Parameters
NAME 11-05.22.FAC
EXPNO 11
PROCNO 1

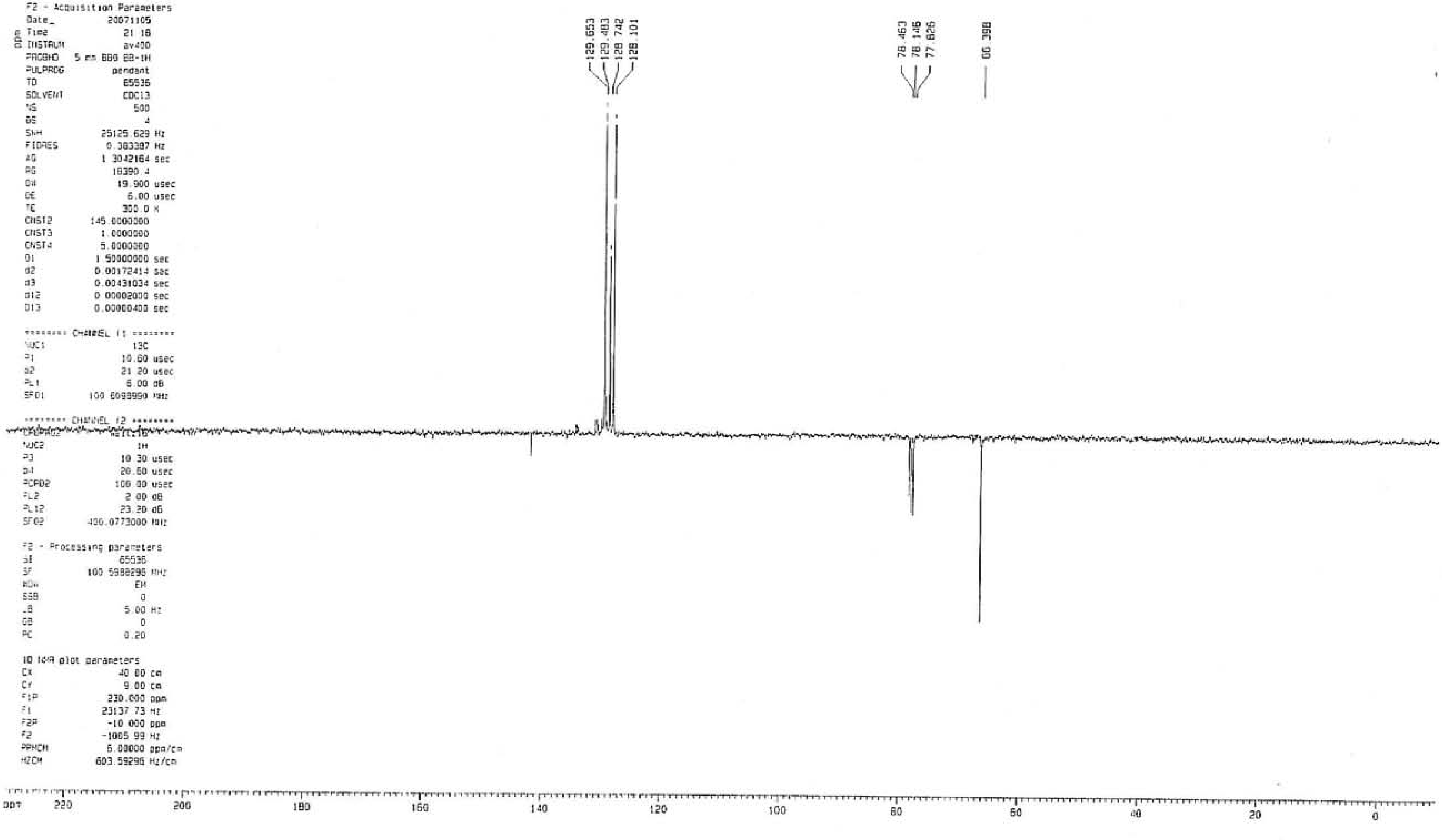
F2 - Acquisition Parameters
Date_ 20071105
Time 21.18
INSTRUM av400
PROBHD 5 mm BBO BB-1H
PULPROG pendant
TD 65536
SOLVENT CDCl3
NS 500
DS 4
SWH 25125.629 Hz
FIDRES 0.383387 Hz
AQ 1.3042164 sec
RG 18390.4
DW 19.900 usec
DE 6.00 usec
TE 300.0 K
CNST2 145.0000000
CNST3 1.0000000
CNST4 5.0000000
D1 1.50000000 sec
d2 0.00172414 sec
d3 0.00431034 sec
d12 0.00002000 sec
D13 0.00000400 sec

======== CHANNEL f1 ========
NUC1 13C
P1 10.60 usec
p2 21.20 usec
PL1 6.00 dB
SFO1 100.6098990 MHz

======== CHANNEL f2 ========
CPDPRG2 waltz16
NUC2 1H
P3 10.30 usec
p4 20.60 usec
PCPD2 100.00 usec
PL2 2.00 dB
PL12 23.20 dB
SFO2 400.0773000 MHz

F2 - Processing parameters
SI 65536
SF 100.5988295 MHz
WDW EM
SSB 0
LB 5.00 Hz
GB 0
PC 0.20

1D NMR plot parameters
CX 40.00 cm
CY 9.00 cm
F1P 230.000 ppm
F1 23137.73 Hz
F2P -10.000 ppm
F2 -1005.99 Hz
PPMCM 6.00000 ppm/cm
HZCM 603.59296 Hz/cm



Sample: 7
1H

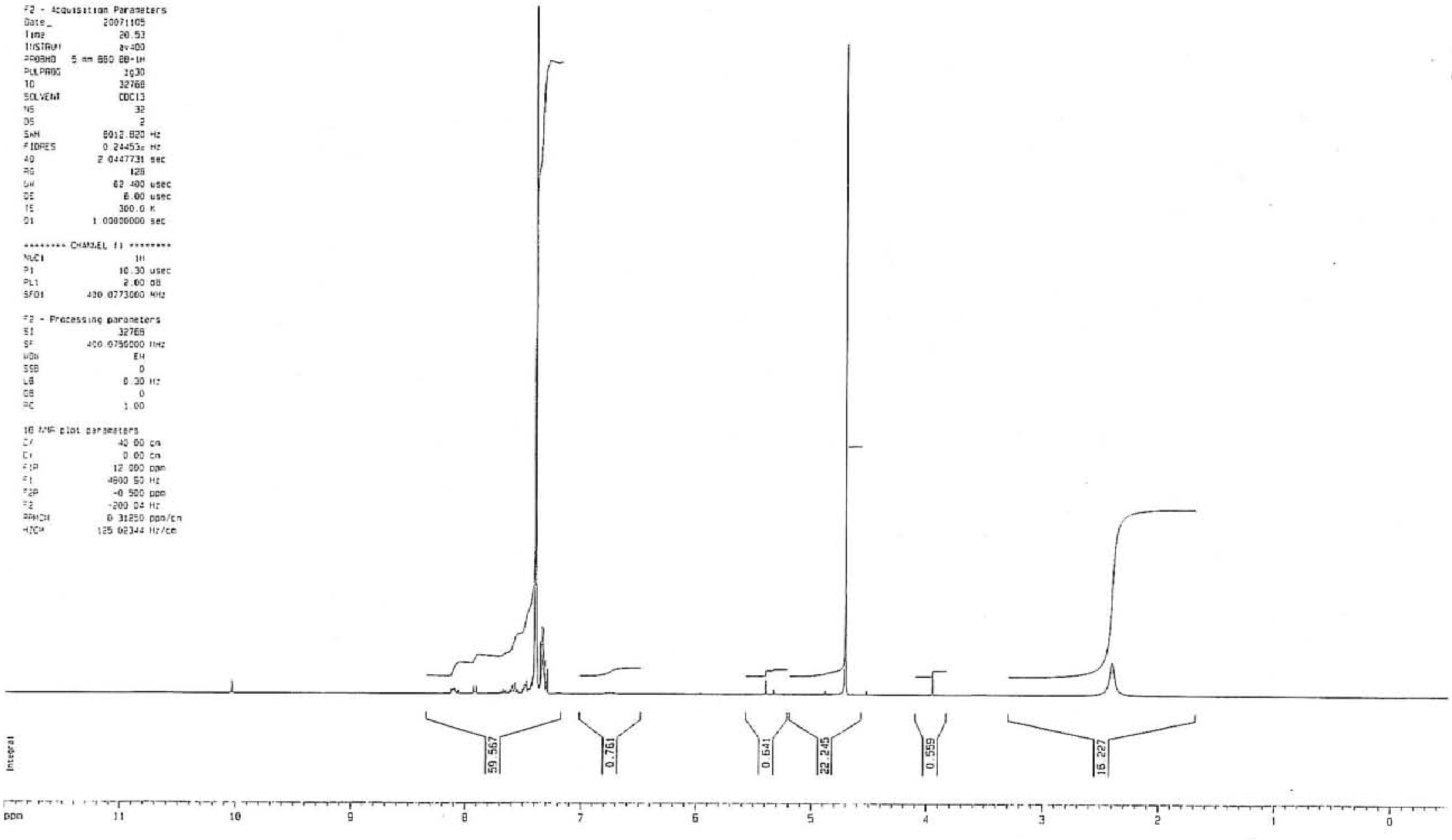
Current Data Parameters
NAME 11-05 22 FAC
EXPNO 10
PROCNO 1

F2 - Acquisition Parameters
Date_ 20071105
Time 20.53
INSTRUM av400
PROBHD 5 mm BBO BB-1H
PULPROG zg30
TD 32768
SOLVENT CDCl3
NS 32
DS 2
SWH 8012.820 Hz
FIDRES 0.244532 Hz
AQ 2.0447731 sec
RG 128
DW 62.400 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec

======== CHANNEL f1 ========
NUC1 1H
P1 10.30 usec
PL1 2.00 dB
SFO1 400.0773000 MHz

F2 - Processing parameters
SI 32768
SF 400.0750000 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00

1D NMR plot parameters
CX 40.00 cm
CY 0.00 cm
F1P 12.000 ppm
F1 4800.50 Hz
F2P -0.500 ppm
F2 -200.04 Hz
PPMCM 0.31250 ppm/cm
HZCM 125.02344 Hz/cm



APPENDIX 25

Email responses from Shelley:

If students correctly identified that Sample 7 is benzyl alcohol and not benzylamine but did not explain their reasoning:

Dear x

Thanks for your report. I am glad that I did not continue with my experiment using the wrong compound.

Please can you explain how you deduced the structure? I could do with some help interpreting the spectra! What are the key points for each spectrum please?

Many thanks

Best wishes

Shelley

If students did not identify that Sample 7 was benzyl alcohol:

Thanks for your report. I carried on with my experiment and found that I could not get my sample to react in the next step!

I've checked everything with the next step and I can't find any problems. I've looked at your report and I noticed that the molecular weight of the compound seems a little high. Also, I' m not sure that the absorption in the IR spectrum is correct for an amine.

Please can you re-check the spectra and get back to me?

Many thanks

Best wishes

Shelley

If students correctly identified that Sample 7 is benzyl alcohol and not benzylamine, sent following email and given spectra for actual starting material (example here is Sample 6 – propyl benzoate):

Dear x

Thanks for your report. I am glad that I did not continue with my experiment using the wrong compound.

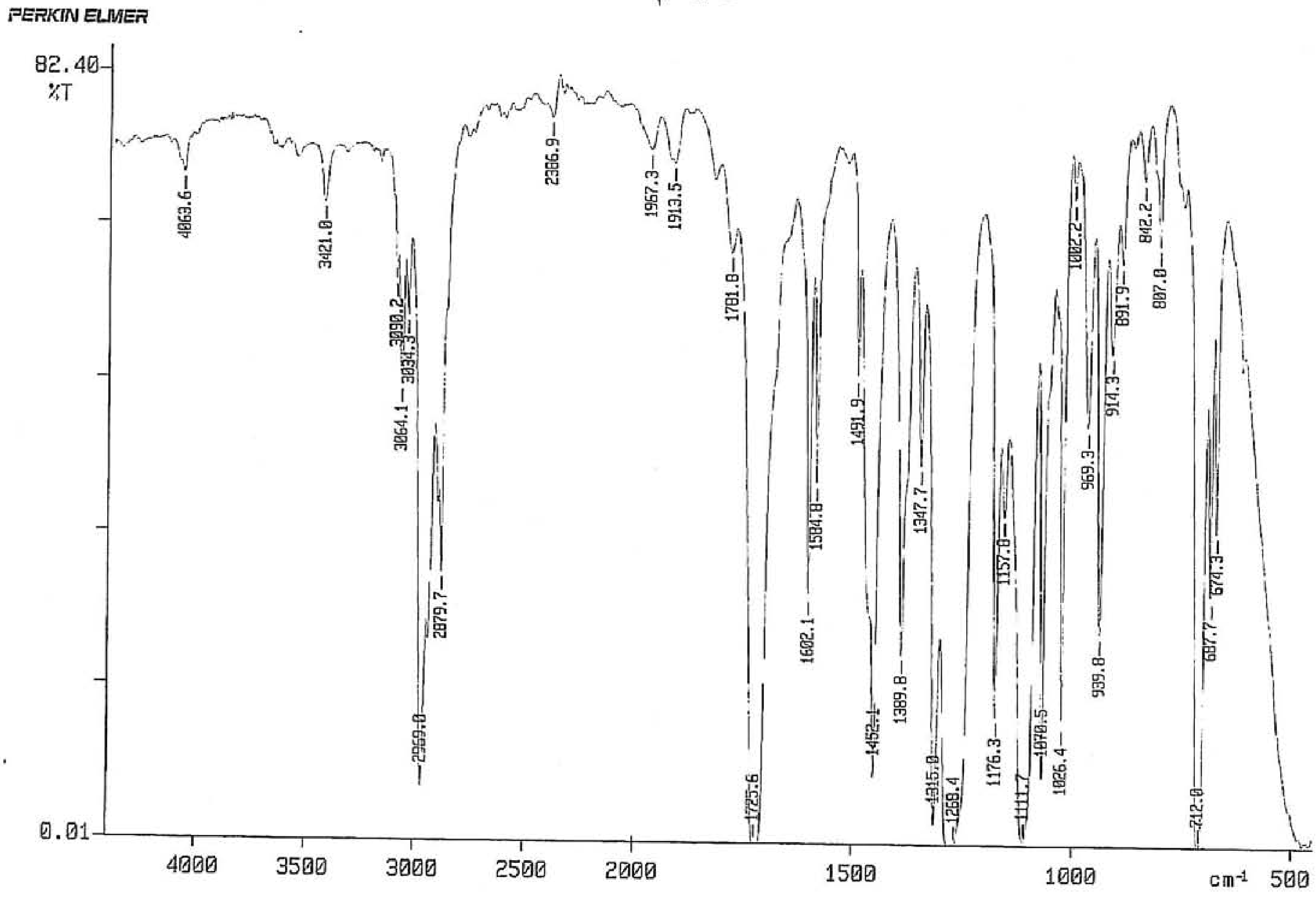
I've run the spectra for my starting material. Please can you help me to interpret them to work out what the compound is? I need to report back to the supplier as it does say benzamide on the label!

Many thanks

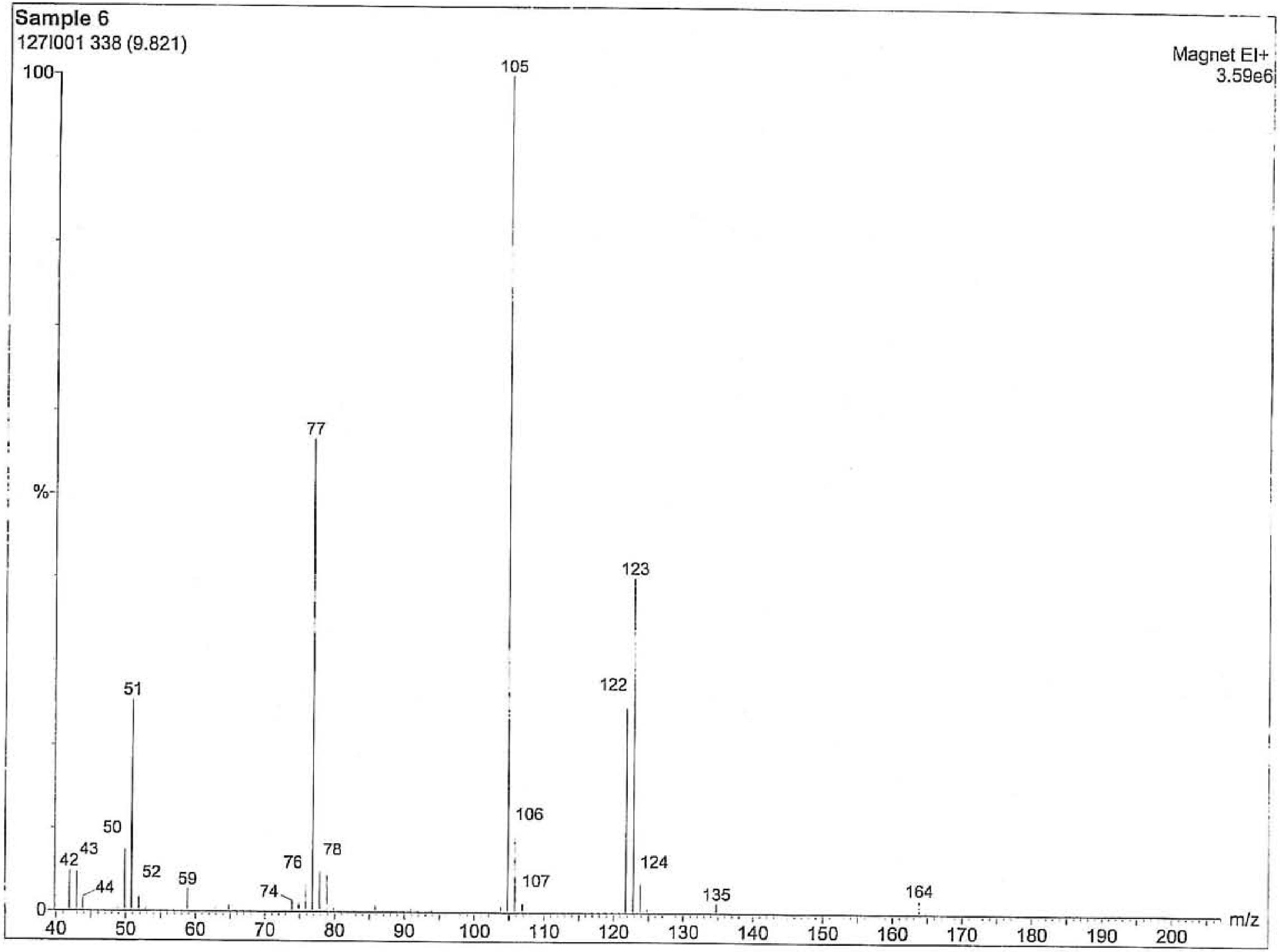
Best wishes

Shelley

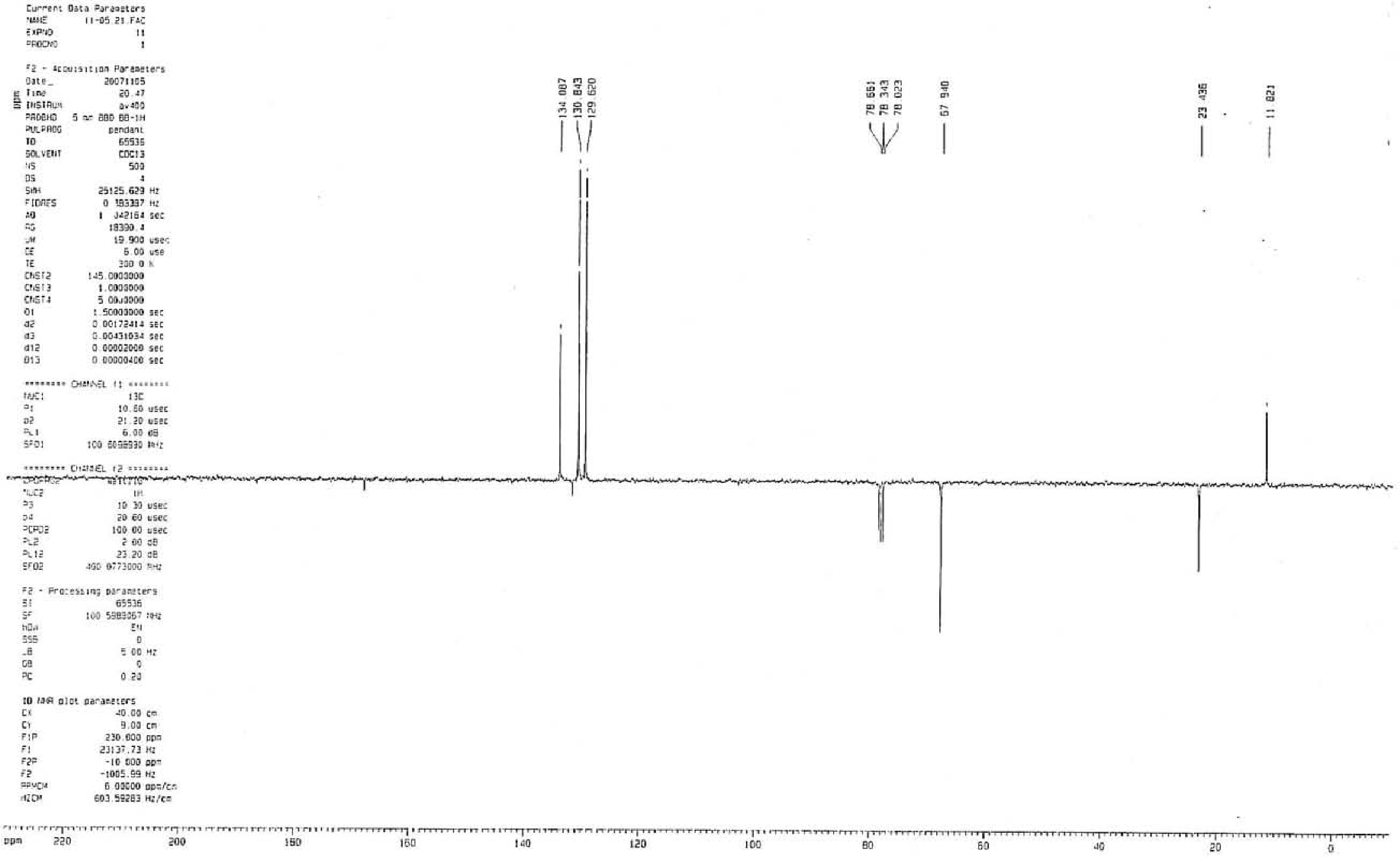
Sample 6

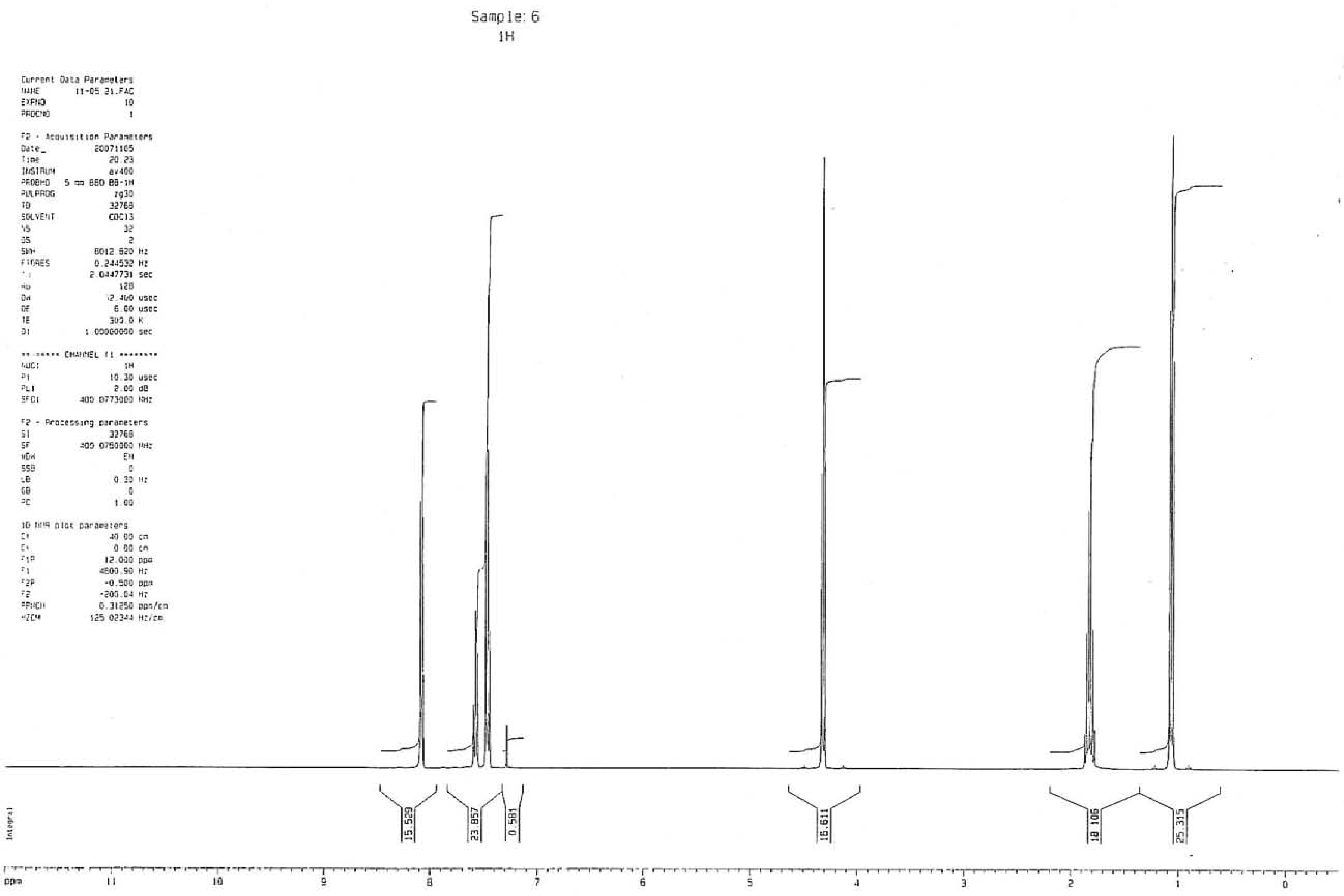


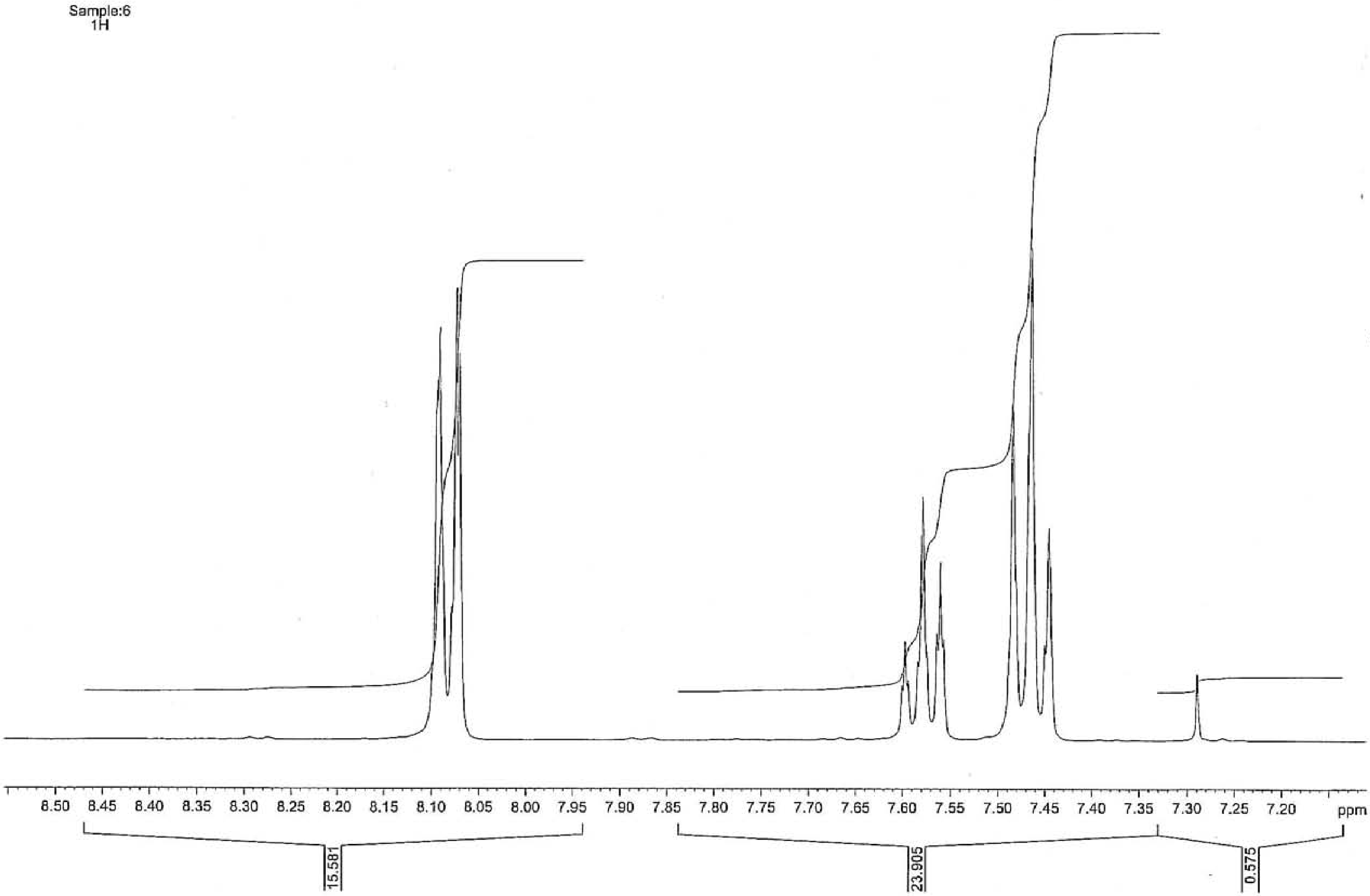
07/11/05 14:47
X: 1 scan, 4.0cm-1

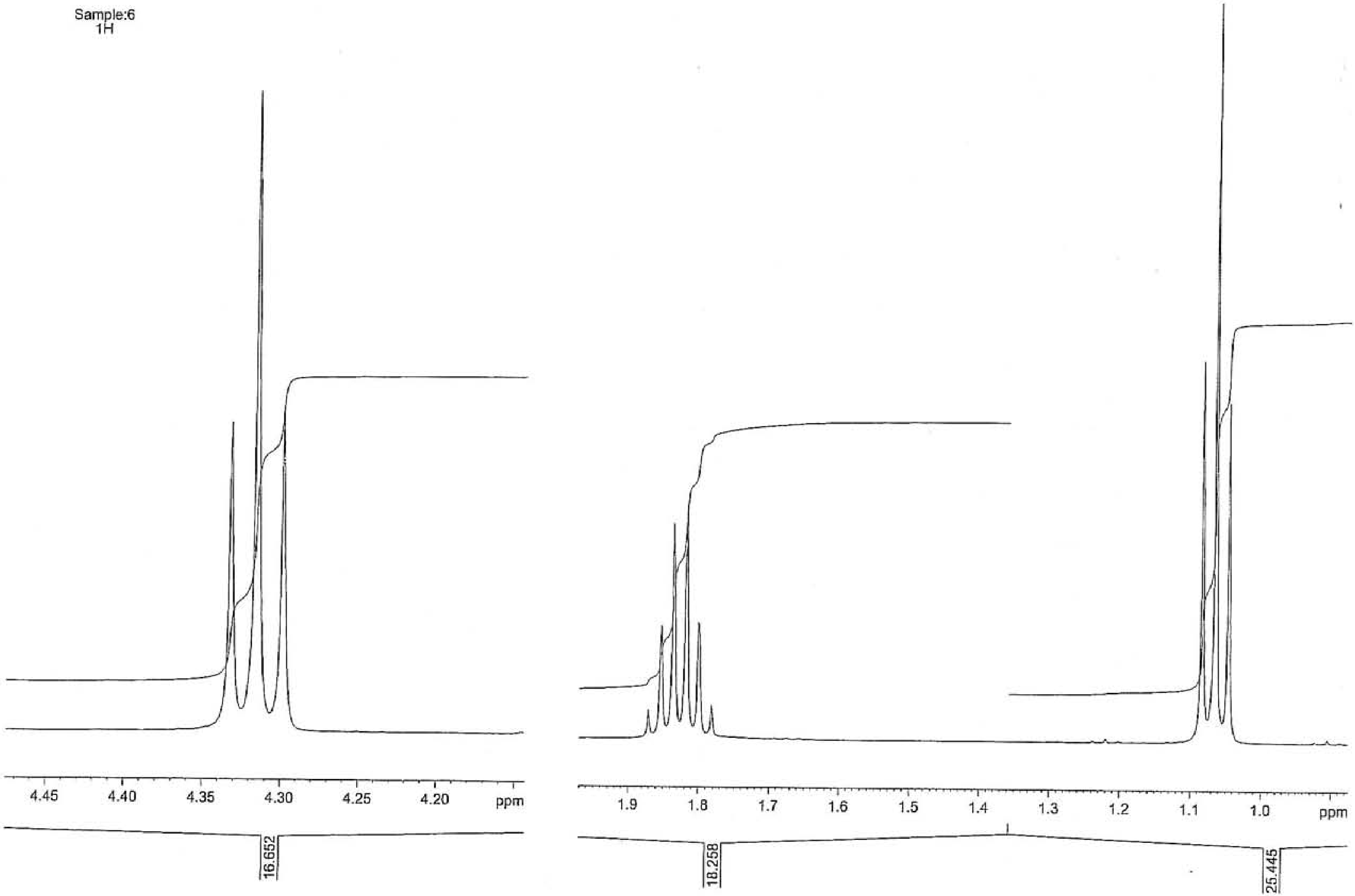

Sample 6
127I001 338 (9.821)
Magnet EI+
3.59e6
100
%
0
105
77
123
122
51
50
42
43
44
52
59
74
76
78
106
107
124
135
164
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
m/z

Sample: 6
13C-PENDANT, 1H-decoupled




Sample: 6
1H
Current Data Parameters
NAME 11-05 21.FAC
EXPNO 10
PROCNO 1
F2 - Acquisition Parameters
Date_ 20071105
Time 20.23
INSTRUM av400
PROBHD 5 mm BBO BB-1H
PULPROG zg30
TD 32768
SOLVENT CDCl3
NS 32
DS 2
SWH 8012.820 Hz
FIDRES 0.244532 Hz
2.0447731 sec
RG 128
DW 62.400 usec
DE 6.00 usec
TE 303.0 K
D1 1.00000000 sec
======== CHANNEL f1 ========
NUC1 1H
P1 10.30 usec
PL1 2.00 dB
SFO1 400.0773000 MHz
F2 - Processing parameters
SI 32768
SF 400.0750000 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00
1D NMR plot parameters
CX 40.00 cm
CY 0.00 cm
F1P 12.000 ppm
F1 4800.90 Hz
F2P -0.500 ppm
F2 -200.04 Hz
PPMCM 0.31250 ppm/cm
HZCM 125.02344 Hz/cm
Integral
15.529
23.857
0.581
16.611
18.106
25.315
ppm
11
10
9
8
7
6
5
4
3
2
1
0


Sample:6
1H
8.50 8.45 8.40 8.35 8.30 8.25 8.20 8.15 8.10 8.05 8.00 7.95 7.90 7.85 7.80 7.75 7.70 7.65 7.60 7.55 7.50 7.45 7.40 7.35 7.30 7.25 7.20 ppm
15.581
23.905
0.575



Sample:6
1H
4.45
4.40
4.35
4.30
4.25
4.20
ppm
16.652
1.9
1.8
1.7
1.6
1.5
1.4
1.3
1.2
1.1
1.0
ppm
18.258
25.445

APPENDIX 26

Natalie Rowley

From: Shelley [redacted]
Sent: 19 November 2007 08:26
To: N.M.Rowley@bham.ac.uk
Subject: Help with report for supplier please

Dear First Year Students

I have received an email from Shelley - she needs your help with one final task please.

Please can you INDIVIDUALLY submit a one page report for the supplier, detailing the problems encountered with the reaction. The report is to be handed in to the Teaching Centre between 12 and 2 pm on Friday 23rd November. If you have not already done so, you also need to hand in a peer assesment form at the same time.

Many thanks for your help with this

Best wishes

Natalie Rowley

Dear Dr Rowley

Thanks for the report. We have now contacted the supplier and they have sent us a new batch of chemicals.

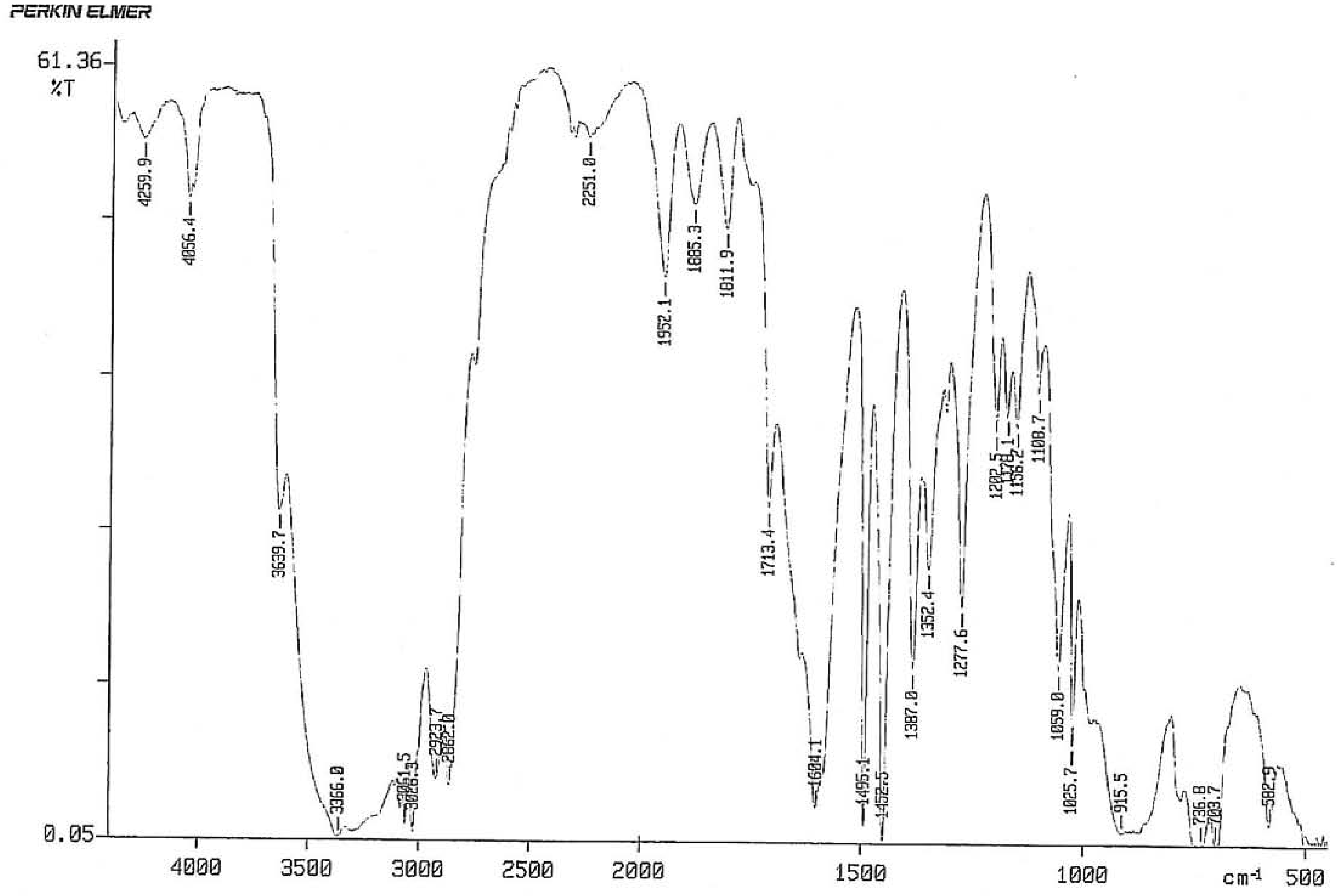
I've just re-run my reaction (hopefully for the last time) and I've run spectra to double check that I've got the right product this time. Could you please do a final analysis on the spectra for me (sample 2 is my new starting material, and sample 8 is the product). My supervisor has requested that I submit a one page report, detailing the problems I've had.

Could you please compile this one page report for me and attach any relevant, annotated spectra in the appendices.

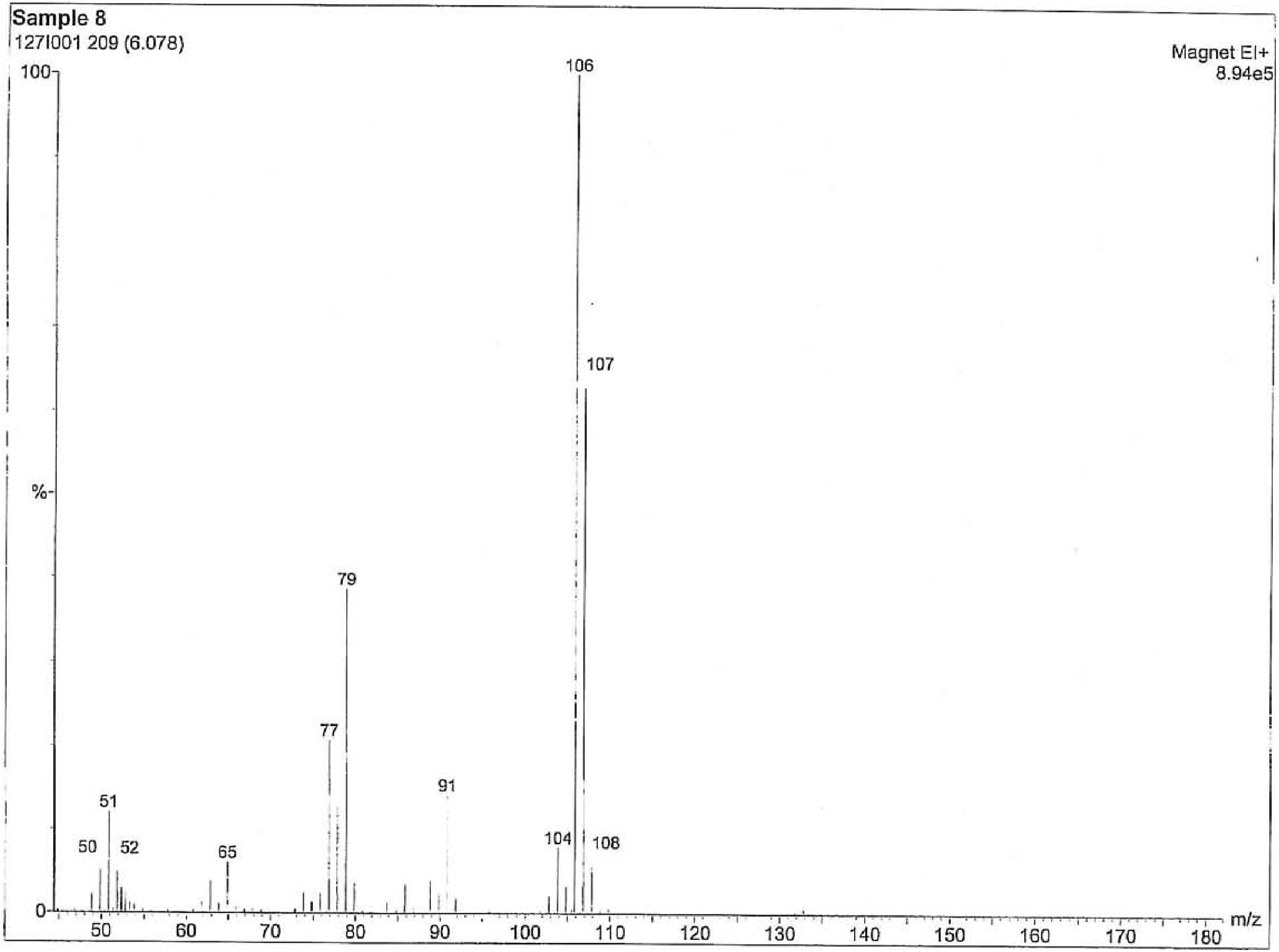
Many thanks

Shelley

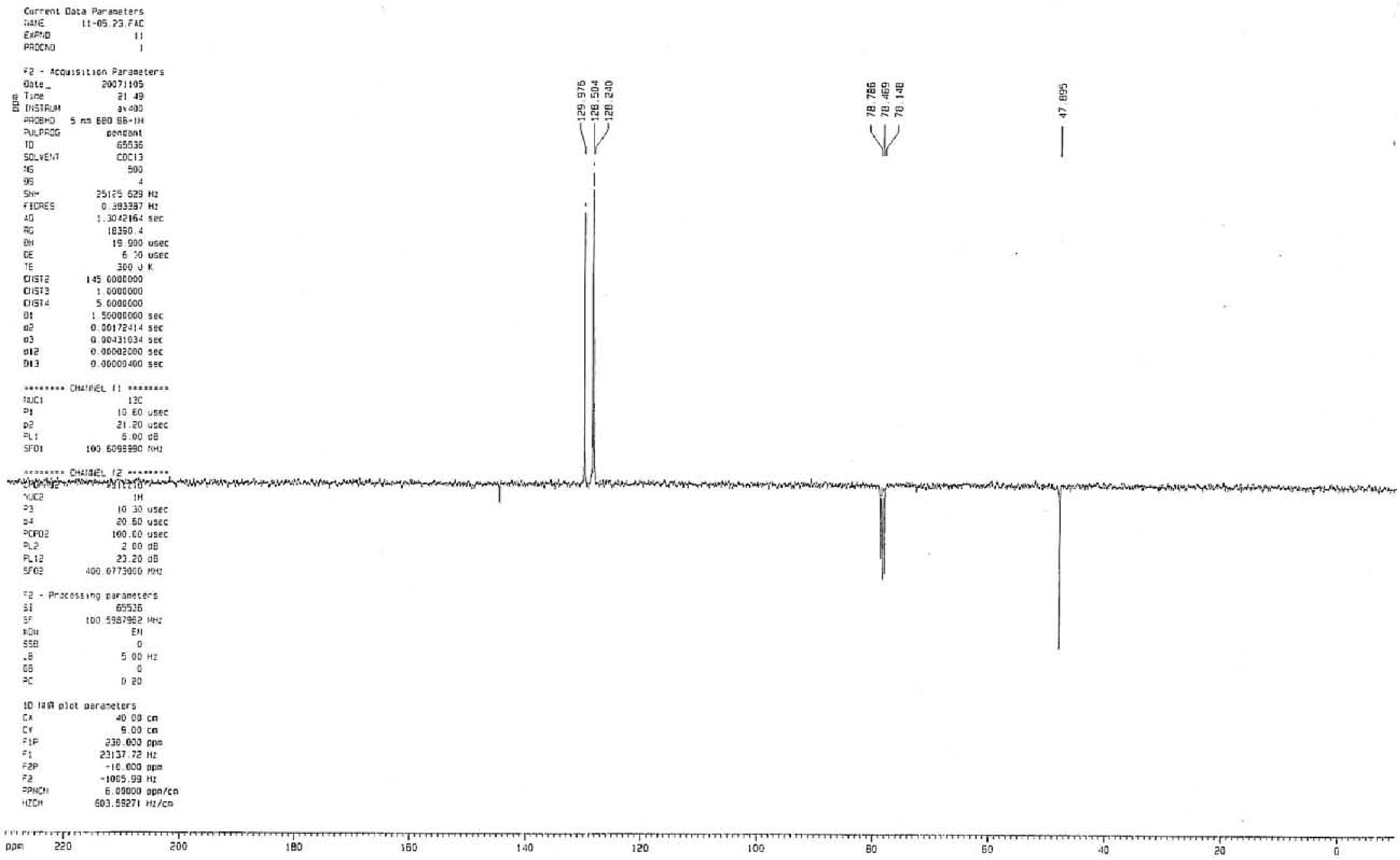
sample 8



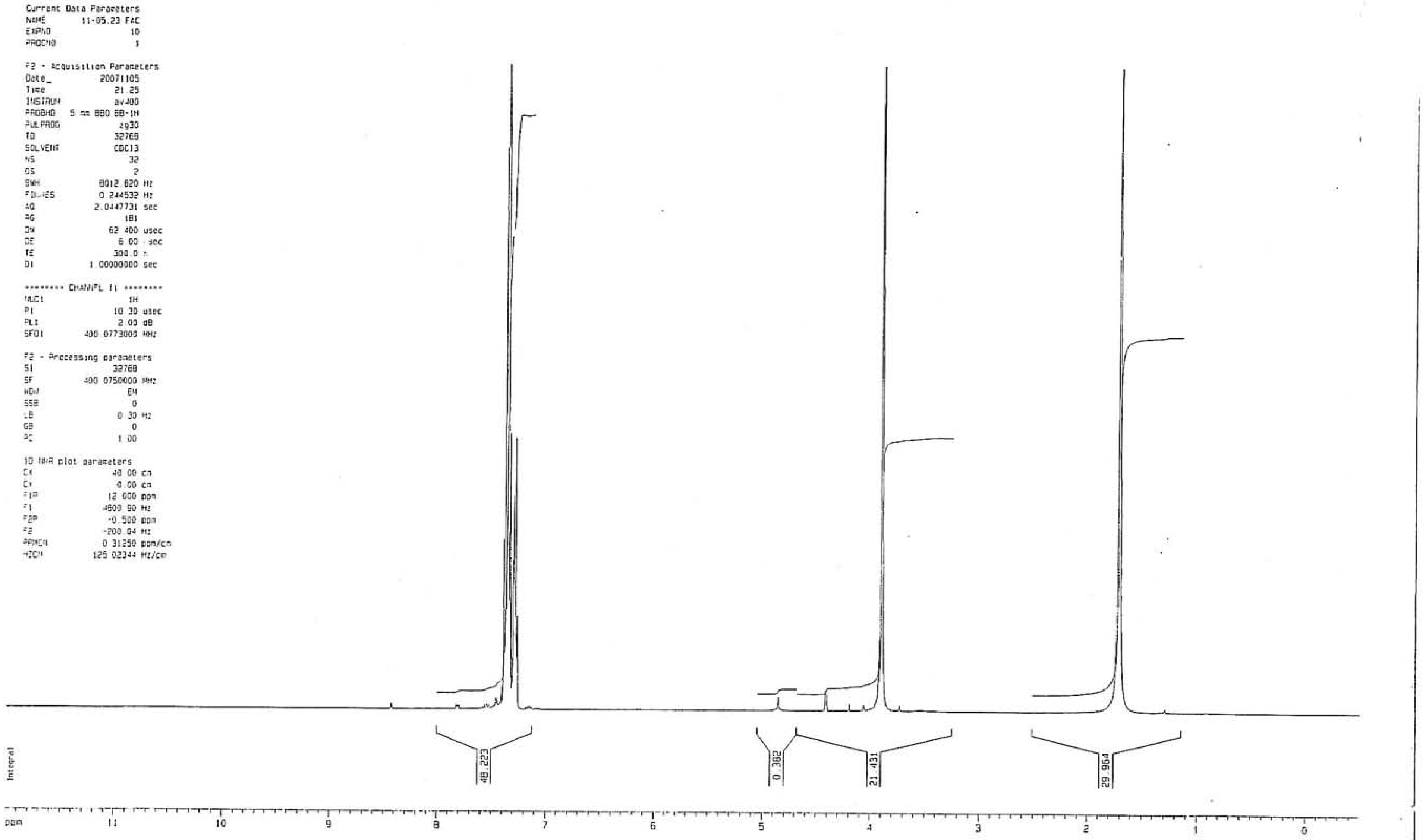
07/10/25 13:53
X: 1 scan, 4.0cm-1


Sample 8
127I001 209 (6.078)
Magnet EI+
8.94e5
100
%
0
106
107
79
77
91
51
50
52
65
104
108
50
60
70
80
90
100
110
120
130
140
150
160
170
180
m/z

Sample: B
13C-PENDANT, 1H-decoupled

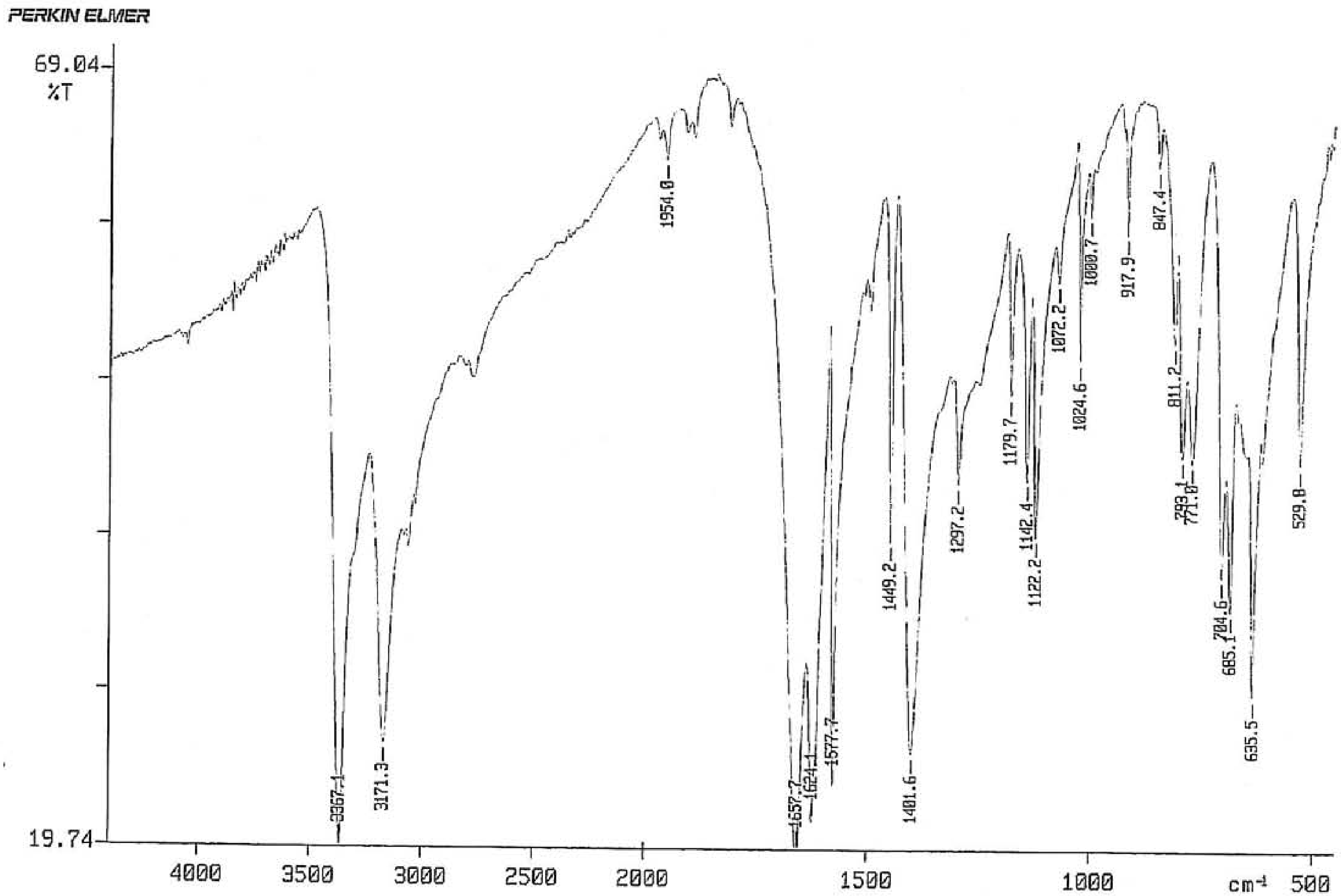


Sample: 8
1H

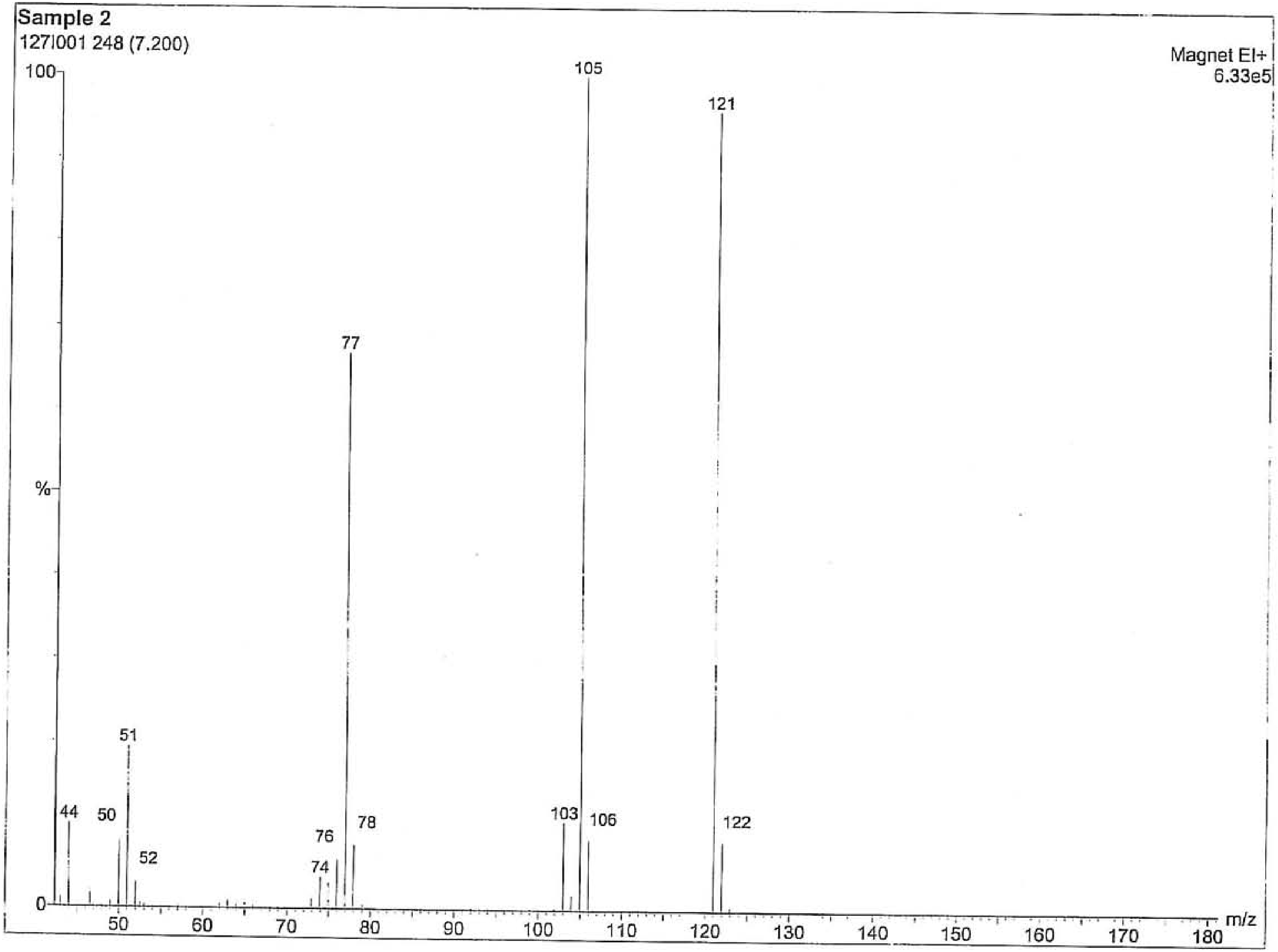


Current Data Parameters
NAME 11-05.23 FAC
EXPNO 10
PROCNO 1
F2 - Acquisition Parameters
Date_ 20071105
Time 21.25
INSTRUM av400
PROBHD 5 mm BBO BB-1H
PULPROG zg30
TD 32768
SOLVENT CDCl3
NS 32
DS 2
SWH 8012.820 Hz
FIDRES 0.244532 Hz
AQ 2.0447731 sec
RG 181
DW 62.400 usec
DE 6.00 usec
TE 300.0 K
D1 1.00000000 sec
======== CHANNEL f1 ========
NUC1 1H
P1 10.30 usec
PL1 2.00 dB
SFO1 400.0773000 MHz
F2 - Processing parameters
SI 32768
SF 400.0750000 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00
1D NMR plot parameters
CX 40.00 cm
CY 0.00 cm
F1P 12.600 ppm
F1 4800.50 Hz
F2P -0.500 ppm
F2 -200.04 Hz
PPMCM 0.31250 ppm/cm
HZCM 125.02344 Hz/cm
Integral
48.223
0.382
21.431
29.964
ppm
11
10
9
8
7
6
5
4
3
2
1
0

Sample

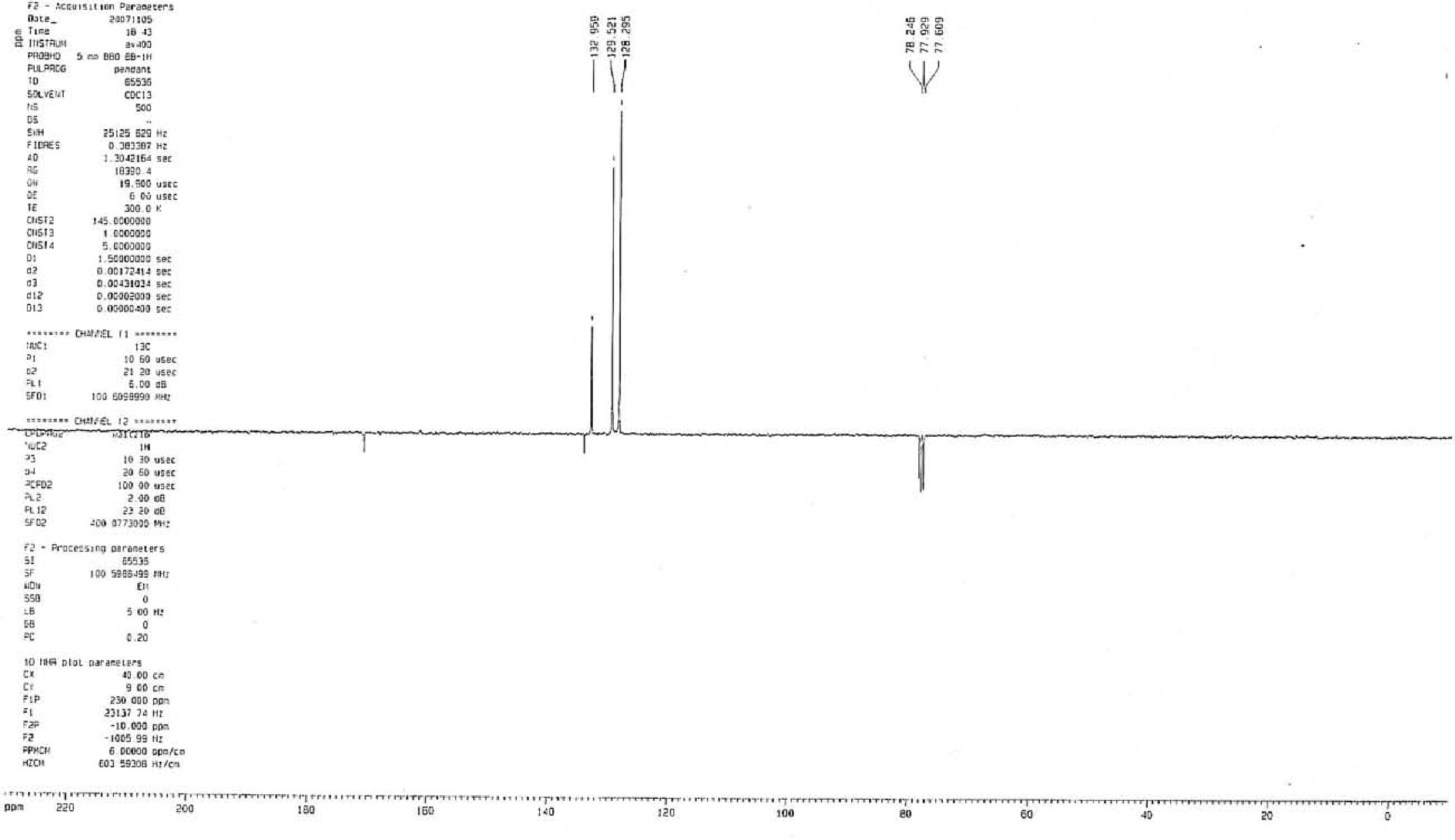


07/10/25 15:06
X: 1 scan, 4.0cm-1

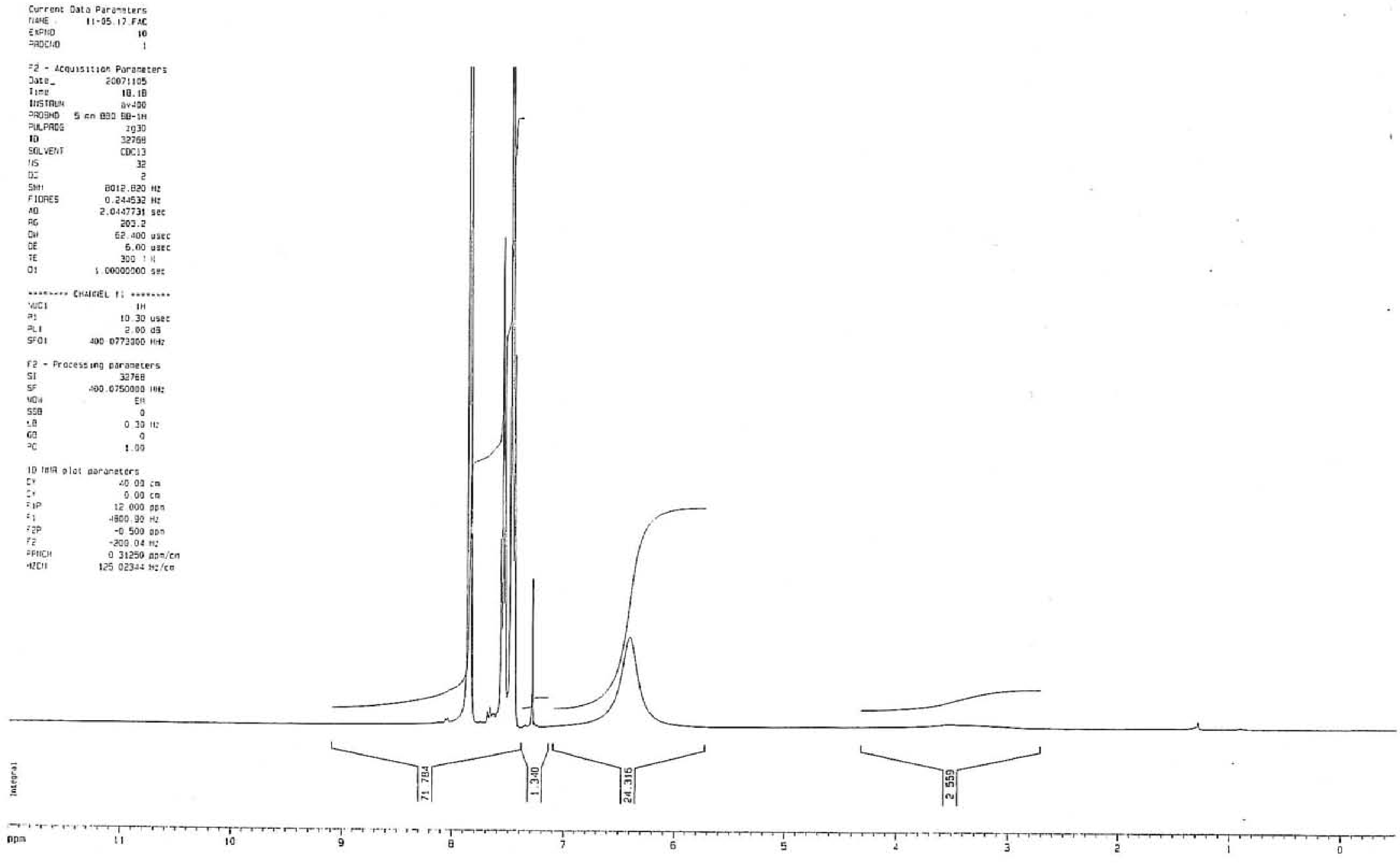

Sample 2
127I001 248 (7.200)
Magnet EI+
6.33e5
100
%
0
105
121
77
51
44
50
52
74
76
78
103
106
122
50
60
70
80
90
100
110
120
130
140
150
160
170
180
m/z

Sample: 2
13C-PENDANT, 1H-decoupled

```
Current Data Parameters
NAME          11-05.17.FAC
EXPNO                   11
PROCNO                   1

F2 - Acquisition Parameters
Date_             20071105
Time                 18.43
INSTRUM              av400
PROBHD    5 mm BBO BB-1H
PULPROG            pendant
TD                   65536
SOLVENT              CDCl3
NS                     500
DS
SWH             25125.629 Hz
FIDRES           0.383387 Hz
AQ              1.3042164 sec
RG                 18390.4
DW                  19.900 usec
DE                    6.00 usec
TE                   300.0 K
CNST2          145.0000000
CNST3            1.0000000
CNST4            5.0000000
D1              1.50000000 sec
d2              0.00172414 sec
d3              0.00431034 sec
d12             0.00002000 sec
D13             0.00000400 sec

======== CHANNEL f1 ========
NUC1                   13C
P1                   10.60 usec
p2                   21.20 usec
PL1                   6.00 dB
SFO1           100.6098990 MHz

======== CHANNEL f2 ========
CPDPRG2            waltz16
NUC2                    1H
P3                   10.30 usec
p4                   20.60 usec
PCPD2               100.00 usec
PL2                   2.00 dB
PL12                 23.20 dB
SFO2           400.0773000 MHz

F2 - Processing parameters
SI                   65536
SF             100.5986499 MHz
WDW                     EM
SSB                      0
LB                    5.00 Hz
GB                       0
PC                    0.20

1D NMR plot parameters
CX                   40.00 cm
CY                    9.00 cm
F1P                230.000 ppm
F1                23137.74 Hz
F2P                -10.000 ppm
F2                -1005.99 Hz
PPMCM              6.00000 ppm/cm
HZCM             603.59308 Hz/cm
```



Sample: 2
1H


Current Data Parameters
NAME 11-05.17.FAC
EXPNO 10
PROCNO 1
F2 - Acquisition Parameters
Date_ 20071105
Time 18.18
INSTRUM av400
PROBHD 5 mm BBO BB-1H
PULPROG zg30
TD 32768
SOLVENT CDCl3
NS 32
DS 2
SWH 8012.820 Hz
FIDRES 0.244532 Hz
AQ 2.0447731 sec
RG 203.2
DW 62.400 usec
DE 6.00 usec
TE 300.1 K
D1 1.00000000 sec
======== CHANNEL f1 ========
NUC1 1H
P1 10.30 usec
PL1 2.00 dB
SFO1 400.0773000 MHz
F2 - Processing parameters
SI 32768
SF 400.0750000 MHz
WDW EM
SSB 0
LB 0.30 Hz
GB 0
PC 1.00
1D NMR plot parameters
CX 40.00 cm
CY 0.00 cm
F1P 12.000 ppm
F1 4800.90 Hz
F2P -0.500 ppm
F2 -200.04 Hz
PPMCM 0.31250 ppm/cm
HZCM 125.02344 Hz/cm
71.784
1.340
24.316
2.559
Integral
ppm
11
10
9
8
7
6
5
4
3
2
1
0

APPENDIX 27

The Facilitators Role

The tutor must provide the problem to students and assist in the carrying out of the task but **not carry it out themselves**. A tutor in Enquiry-Based Learning is not required to be a context expert, and it is essential that the students are allowed to learn for themselves. A Facilitator is not expected to provide answers; instead they should pose questions that encourage the group to locate resources. It is important to get a balance between being too directive towards students (creating student dependency) and saying nothing at all.

To achieve an adequate balance the following are suggested:-

- Asking open-ended questions that provoke further discussion and stimulate deeper exploration;
- Supporting students, motivating them to engage with the task and valuing their ideas and contributions;
- Encouraging students to reflect on their experiences;
- Monitoring progress and ensuring that students understand where they are in the process;
- Challenging students thinking, encouraging them to extend their boundaries and to seek new ways to work with problems and situations;
- Developing an atmosphere of trust in which students are willing to share and exchange ideas or work co-operatively;

As with tutorials, group dynamics are an essential consideration when dealing with any co-operative group work such as enquiry-based learning.

PBL tutorial process

Step 1—Identify and clarify unfamiliar terms presented in the scenario; scribe lists those that remain unexplained after discussion

Step 2—Define the problem or problems to be discussed; students may have different views on the issues, but all should be considered; scribe records a list of agreed problems

Step 3—"Brainstorming" session to discuss the problem(s), suggesting possible explanations on basis of prior knowledge; students draw on each other's knowledge and identify areas of incomplete knowledge; scribe records all discussion

Step 4—Review steps 2 and 3 and arrange explanations into tentative solutions; scribe organises the explanations and restructures if necessary

Step 5—Formulate learning objectives; group reaches consensus on the learning objectives; tutor ensures learning objectives are focused, achievable, comprehensive, and appropriate

Step 6—Private study (all students gather information related to each learning objective)

Step 7—Group shares results of private study (students identify their learning resources and share their results); tutor checks learning and may assess the group

http://www.bmj.com/cgi/reprint/326/7384/328.pdf

APPENDIX 28

Group No:

Ice-breaker Quiz

1. What does DVD stand for?

2. Which element takes its name from the Greek for 'pale green'?

3. Strange, charm, up, down, top, and bottom are types of what?

4. Graphite is composed of which element?

5. What is the name of the study of the motion of the earth's crust?

6. Do astronauts have mass in outer space?

7. Which is the hardest tissue in the body?

8. What in Asia is a Tuk-tuk?

9. Under what name is the Chinese gooseberry normally sold?

10. What is the symbol of the element named after Einstein?

11. What kind of animal is a blue-fronted parrot?

12. Which is the only muscle in your body that is only attached at one end?

13. What extinct creature got its name from the Portuguese word for stupid?

14. Name the English football clubs that have won the European cup (Champions League).

15. Evaporation is changing from a liquid to gas. What is changing from a solid to a gas called?

16. Name anything that happened in Britain on September 3rd, 1752.

17. What colour is caffeine?

18. What is panophobia or pantophobia?

19. What was the first man-made object to move faster than the speed of sound?

20. Which is the first chemical element in alphabetical order?

APPENDIX 29

Enquiry-Based Learning Steps

1. What do we know as a group already?

2. What information does the problem give us?

3. What is the problem asking us to do?

4. What information do we need to find out?

5. What is our Action Plan (what we need to find out/do and for when do we need to do it)?

6. Who is "Group Leader" (responsible for keeping the discussion on topic and meeting deadline) and who is "Scribe" (person who writes the combined findings for the group)?

7. When and how are we going to meet to discuss the solution to the problem?

8. Produce solution to problem.

9. Evaluation - how well have you worked together as a group? What have you learnt as a result of this exercise?

APPENDIX 30

Screen Shot of a Discussion Board

Spectroscopy EBL Group 10

- Helpdesk (2 Messages / 2 New)
- Group Rules (2 Messages / 2 New)
- How the spectroscopic techniques work... (4 Messages / 4 New)
- What the spectroscopic techniques tell us... (4 Messages / 4 New)
- Compound 1 (6 Messages)
- Compound 2 (4 Messages / 4 New)
- What we have learnt... (5 Messages / 5 New)
- Waste Disposal Scenario (17 Messages / 17 New)
- Feedback (4 Messages)
- Down The Drain Scenario (7 Messages / 7 New)
- Reaction Dilemma (2 Messages / 2 New)

APPENDIX 31

Mid-EBL Short Answer Responses

1. **What are the positive things about the course?**

[[redacted]968] I learn to take my own responsibility and to gather information from the different sources. This makes me feel very able and confident.
[[redacted]807] It allows freedom to learn in a manner suited to the group
[[redacted]389] Group learning
[[redacted]514] It's a very good opportunity to meet people who otherwise I probably would not have spoke to. Working in a group means that we can look at the task and explain what we think to others – with feedback. Solving problems makes the subject less daunting.
[[redacted]410] A new style of learning, I am finding new ways of learning within a group. Team working skills. Trying different methods, being out of my comfort zone (which is good).
[[redacted]569] Team work, learning by being thrown into the deep end.
[[redacted]514] Builds team skills.
[[redacted]460] Repetitive tasks which allow learning to be embedded. Taking responsibility for my learning. Group works well to make sure everyone understands.
[[redacted]301] Develops communication and team skills. Ability to appreciate and recognise a range of inputs. Working together towards a common goal. Varied compared to lectures.
[[redacted]150] Get to learn from what others have been taught. Get to discuss problems if can't work out spectra.
[[redacted]031] Helped build my confidence when working in groups. Other people help me on things I have not learnt before.
[[redacted]915] Working as a group. Learning by doing.
[[redacted]175] Builds confidence.
[[redacted]076] Makes me use my skills myself so it helps my confidence in myself to some extent.
[[redacted]955] Get lots of practice of interpreting spectra.
[[redacted]613] Learning to think independently. Learning to handle problems in a group situation.
[[redacted]723] Learning is your own responsibility.
[[redacted]235] Take control over your own learning. Learn to work in a team.
[[redacted]598] Get to meet new people and have help from peers who have similar experiences as me. Helpful being able to post input online anytime of the day or night.
[[redacted]075] We get to meet new people and improve our team working skills. I like the idea of doing our own research to solve the identity of the compound.
[[redacted]488] Develops team working skills and teaches you to be responsible for your own learning – not relying on lecturers notes. It is a change from lectures.
[[redacted]662] Working as a team and being able to improve team working skills and communication skills.
[[redacted]433] Working as part of team – developing communication skills. Problem solving individually as part of a team. Enjoying the course as well as learning. Good use of Web CT.
[[redacted]640]
[[redacted]316]
[[redacted]333] Having a good time. Interactive. Group rivals.
[[redacted]871] Sharing information and working as a group.
[[redacted]527]
[[redacted]222]
[[redacted]951]
[[redacted]671] Having more confidence in working with other people.
[[redacted]156] Learning how to tackle problems.

2. **What are the negative things about the course?**

[[redacted]968] Sometimes you might want to work on your own totally and not get involved with others. But that is only a mood thing. There is more or less nothing negative about it.
[[redacted]807] It does not give all the information needed leaving people to find out for themselves however with no official reading list finding relevant books for the entire course is challenging.
[[redacted]389] Some of the information is hard to learn.
[[redacted]514] Difficult to be focused on Friday afternoon.
[[redacted]410] That some people contribute more towards task than others.
[[redacted]569] None – it's enjoyable.
[[redacted]514] Not much content is actually taught.

[[redacted]460] Friday afternoons.
[[redacted]301] Have to rely on team to remain focussed – not necessarily a negative but can be challenging. Don't know who your team will be therefore may be personality frictions, could be a positive however as less chat.
[[redacted]150] Hasn't provided any notes to refer to when working out the problems or when come to revise.
[[redacted]031] Haven't had proper notes to look back on when revising.
[[redacted]915] Friday afternoons!
[[redacted]915] I would prefer to be taught how to interpret spectra well, before starting group work, as many people in my group know more than me and I sometimes get left behind.
[[redacted]076] I don't really see what the objective is of reading all the spectra before we have learnt 1) how they work and 2) why, when we haven't learnt how to read them properly.
[[redacted]955] Some people can end up doing all the work, and others very little.
[[redacted]613] No way to ensure that the inter group teaching is accurate. People that don't contribute get grades for other peoples work.

[[redacted]723] Tend to use the same information sources for each task.
[[redacted]235] May end up with students who bring your own mark down due to group work.

[[redacted]598] Get marked by own team – have to rely on their interpretation for grades.
[[redacted]075] We are marked by our own team members, sometimes this is unfair as team members may have worked less but still be marked the same as others.
[[redacted]488] Difficult if you prefer to work on your own.
[[redacted]662]
[[redacted]433]

[[redacted]640]
[[redacted]316]
[[redacted]333]

[[redacted]871] Nothing negative

[[redacted]527]
[[redacted]222]
[[redacted]951]
[[redacted]671] Difficult tasks are sometimes assigned to us
[[redacted]156] Being responsible for your own learning.

3. What suggestions would you make to improve the course?

[[redacted]968] Nothing
[[redacted]807]
[[redacted]389]
[[redacted]514] Have slightly more structured sessions.

[[redacted]410] More info on resources, would be helpful.
[[redacted]569]
[[redacted]514] Introductory talk giving information about what we are doing.
[[redacted]460]
[[redacted]301] A better spectroscopy data sheet *e.g.* the one the foundation year received.
[[redacted]150] Perhaps have a couple of lectures about analysing the techniques in between the workshops, so that everyone develops a basic understanding of each technique before tackling the problems.
[[redacted]031] Get given notes for revision purposes.
[[redacted]915] Maybe give us some basic information to start with.
[[redacted]915]
[[redacted]076]
[[redacted]955]
[[redacted]613] Not have it on having Friday afternoon/evening. Having more than one copy of the spectra so that more work can be done individually.

[[redacted]235] Try and include an individual assessment (not the peer assessment) that judges everyone's work in the group

[[redacted]598] Mark students using staff not team members. Give personal feedback as well as group.
[[redacted]075] I would rather do the lectures for the course first, to reinforce my knowledge of the course.
[[redacted]488] Ensure everyone has equal ability in spectroscopic techniques.
[[redacted]662] More feedback on how we work as a team and not just on work done by the team.
[[redacted]433] On WebCT – if mistakes are made – can edit them after posting information.

[[redacted]640]
[[redacted]316]

[[redacted]333] Using a bigger room.
[[redacted]871]

[[redacted]527]
[[redacted]222]
[[redacted]951]
[[redacted]671]
[[redacted]156] Bigger class room.

4. **Any other comments**

[[redacted]968] None
[[redacted]807]
[[redacted]389]
[[redacted]410] Maybe have an extra aim to work towards as the group each week it changes

[[redacted]569]
[[redacted]514]
[[redacted]460]
[[redacted]150]
[[redacted]031]
[[redacted]915]
[[redacted]915]
[[redacted]076]
[[redacted]955]
[[redacted]613]
[[redacted]235]
[[redacted]598] I enjoy working like this and feel I am more able to tackle the task when in a team situation because if I get stuck there is always someone to help.
[[redacted]075]
[[redacted]488]
[[redacted]662]
[[redacted]433]
[[redacted]640]
[[redacted]316]
[[redacted]333]
[[redacted]871]
[[redacted]527]
[[redacted]222]
[[redacted]951]
[[redacted]671]
[[redacted]156]

APPENDIX 32

Post-Lecture Short Answer Responses

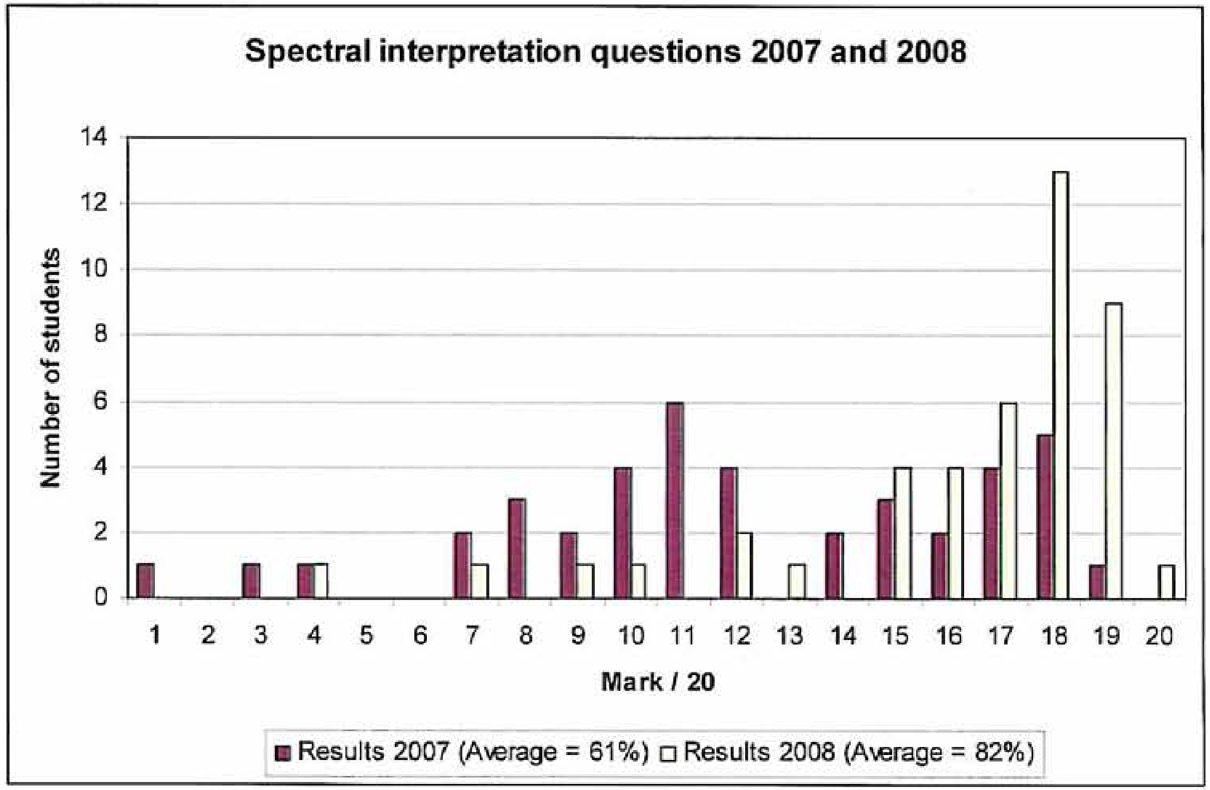
1. What are the positive things about the course?

[[redacted]968]
[[redacted]807]
[[redacted]389] It gives you freedom to think for yourself and gives you the opportunity to find the answers yourself.
[[redacted]514] Getting to know others on the course. Learning in an alternative way. If you worked effectively as a team, the work was not too much. Though the course was challenging, it was not impossible.
[[redacted]410] Different learning style, having to take control of my own learning was a different experience. Like having to organise time. Working together as a team although difficult at times seemed to be helpful in the end, as of the skills I learned.
[[redacted]569]
[[redacted]514]
[[redacted]460] I am now confident in using all the spectra. A very easy course to understand which contained difficult topics.
[[redacted]301]
[[redacted]150] Opportunity to work with others which probably wouldn't have chosen to.
[[redacted]031] It has helped me to feel more confident at working in a team.
[[redacted]915]
[[redacted]175] I now feel confident interpreting spectra more than I first started.
[[redacted]955]
[[redacted]613] I am more confident about my ability to interpret spectra.
[[redacted]723]
[[redacted]235] Group work, communication, range of ideas brought forward to solve problems.
[[redacted]598] Felt a sense of achievement at working out answers and finding information on our own.
[[redacted]075] The EBL sessions and worksheets allowed me to use knowledge learnt, where as other courses don't have enough workshops.
[[redacted]488] Forces you to work as part of a team even if you don't really want to. Allows you to meet and talk to new people.
[[redacted]662] The EBL sessions and working in groups.
[[redacted]433] EBL workshops.
[[redacted]640]
[[redacted]316]
[[redacted]333] Better than sitting in lectures for 4 hours solid.
[[redacted]871]
[[redacted]527] Group Work, rather than individual work.
[[redacted]222]
[[redacted]951] Group work.
[[redacted]671]
[[redacted]159] Interactive Learning and teamwork.
[[redacted]076]

2. What are the negative things about the course?

[[redacted]968]
[[redacted]807] EBL
[[redacted]389] It was difficult not knowing exactly what I was doing.
[[redacted]514] Did not have enough overview of the spectroscopic methods at the start.
[[redacted]410] When titles such as team captain, were given the group seemed to think that they were solemnly in-charge. Sometimes stressful when group is hard to co-operate with but generally not too bad.
[[redacted]569]
[[redacted]514]
[[redacted]460] EBL didn't work as well as I would have liked as there wasn't as much co-operation within the group, which meant that there was little helping one another.
[[redacted]301]
[[redacted]150] EBL done before any lectures taught on spectroscopy.

APPENDIX 33


Spectral interpretation questions 2007 and 2008
Number of students
0
2
4
6
8
10
12
14
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
Mark / 20
Results 2007 (Average = 61%)
Results 2008 (Average = 82%)