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PhD thesis

A STUDY OF THE EFFECTS OF PRE-LEARNING ON FIRST YEAR UNIVERSITY CHEMISTRY STUDENTS

by

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Dedication

To my parents, my wife,

and my sons and daughters.

Abstract

This study was conducted to look at the General Chemistry course at the University of Glasgow. The General Chemistry course is a first year chemistry course of a four year degree. It was launched in the academic year 1993/94 and was designed on the basis of certain educational principles to meet the needs of students who had a wide variety of chemistry entry qualifications (including SCOTVEC modules, Access, Scottish Standard Grade) or even no previous experience of chemistry at all with limited grasp of basic mathematics. General Chemistry students take chemistry as part of a degree in another subject discipline.

The General Chemistry course was studied over a six-year period (1993/94 to 1998/99). The following areas were examined:

(1) In the first year of this study (1997/98), the first step was to look at the history of the General Chemistry course from it's birth in the academic years 1993/94 till 1997/98 to monitor and explore many features of the course: structure, organisation, and the changes made to the course which might affect the original pattern and objectives. The study was aimed to compare students' exam results during the time of this course (1993/94 to 1997/98) and to explore the observations made previously that exam performance was not linked to entry qualifications.

(2) The research sought to identify areas of student difficulty, to find out the reasons behind these learning difficulties, and to design materials to reduce obstacles to learning. Using questionnaires and interviews along with a detailed analysis of examination scripts and overall performance of students, a detailed picture was built up of the areas of student difficulties, with some insights into the reasons for these difficulties.

(3) Students' opinions about the chemistry courses (both at school and university levels) were gathered in an attempt to develop an overall picture of student attitudes, especially those attitudes which might influence performance.

(4) The parallel course (Chemistry-1) was also studied for comparative purposes, recognising that its aims and structures were somewhat different.

For the first two years (1993/94 and 1994/95), examination performance in the General Chemistry course was found not to be related to chemistry entry qualifications, confirming previous observations. For the next three years (1995/96, 1996/97, and 1997/98), examination performance was related to entry qualifications. The only factor that was found which might account for this was the use of pre-lectures which were employed over the first two years but were no longer in operation over the subsequent three years. By

contrast, in the Chemistry-1 course (with no pre-lectures), the examination performance was always related to students' entry qualifications. On this basis, it is suggested that pre-lectures may be a useful tool in enabling students to make more sense of lectures, the effect being particularly important for students whose background in chemistry is less than adequate.

Based on an Information Processing Model and the analyses of areas of students' difficulty, support materials (the Chemorganisers) were introduced to the General Chemistry course in the academic year 1998/99.

These paper-based teaching materials (Chemorganisers) were designed and written to cover four areas: the mathematical techniques needed for chemistry students, inorganic chemistry, physical chemistry, and organic chemistry. The Chemorganisers' role is to prepare the minds of the students, by filling knowledge gaps, clarifying concepts already held, and encouraging meaningful links between previous knowledge and new teaching. As far as possible, Chemorganisers were designed to mimic the pre-lecture sessions.

Overall it was observed that examination performance was not correlated with entry qualifications when pre-lectures (in the years 1993/94 and 1994/95) or Chemorganisers (in the year 1998/99) were in use. However, when neither were used, examination performance was correlated with entry qualifications.

Students' opinions of the usefulness of introducing the Chemorganisers and their attitudes towards them was evaluated by means of questionnaires and interviews. The responses to the Chemorganisers were very positive and the material was highly appreciated. From all the evidence gathered, it seems that the Chemorganisers were reaching most of their aims.

The project has established the great importance if pre-learning in a conceptually-based subject where pre-lectures and Chemorganisers are able to benefit the less-well qualified students, leading to improved performance.

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Chapter One

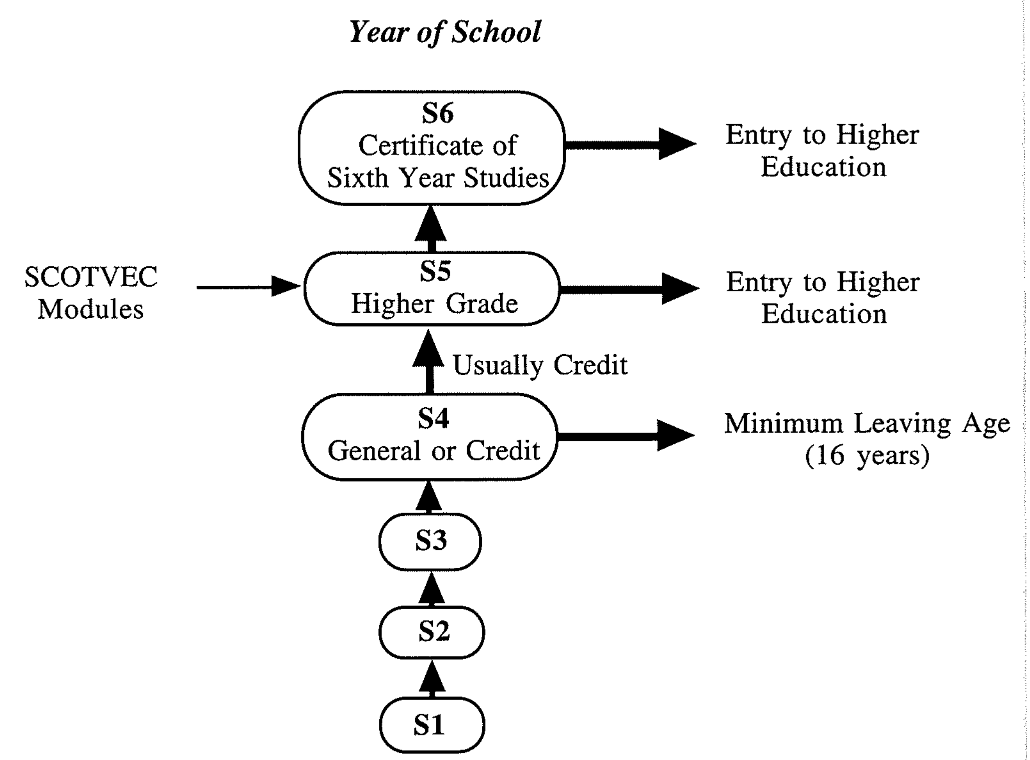
INTRODUCING THE GENERAL CHEMISTRY COURSE

General Chemistry (Gen Chem) is a first year chemistry course of a four year degree and was designed on the basis of certain educational principles to meet the needs of students who had a wide variety of chemistry qualifications and who were taking chemistry as part of a degree usually in another subject discipline. The course was monitored for two years and some surprising outcomes were observed. This chapter introduces the development and the early monitoring of the course. In light of this earlier work, the work to be carried out in this project will be outlined.

1.1 The School System

Everyone enters primary school at about age five and progresses to secondary at about age twelve. Pupils leave secondary schools between the ages of sixteen and eighteen (see figure 1.1). Most pupils then move to a college or a university for post-school education.

Figure 1.1: The Scottish Education System



At primary school, environmental studies occupy about 25% of the school curriculum. Science is about one quarter of this contribution. In the first two years of secondary schooling, (S1/S2), science is usually integrated including aspects of chemistry, biology, and physics. This is usually taught by one teacher. Some schools (10%) teach separate science subjects involving three teachers (Jackson, 1999).

In the middle secondary schooling stage (S3/S4), all pupils must do a minimum of one science subject from chemistry, biology, physics, and science. At the end of the two years, pupils sit national examinations at Standard Grade. About 30% of pupils also do a second science usually biology and chemistry or chemistry and physics, and about 5-10% do all three sciences (Jackson, 1999).

In the upper secondary schooling, (S5/S6), Higher Grade and Sixth Year Studies courses are available. Passes in these courses are normal routes of entry to higher education.

Pupils meet chemistry for the first time at the start of secondary schooling, the curriculum formerly being laid down by Curriculum Papers Number 7 (SED, 1969) and currently by the National Guidelines of Environmental Studies 5-14 (SOED, 1993). Pupils can take chemistry as a discrete subject for Standard Grade (S3/S4) and about 40% of the year group choose to study the course.

Progression is to a one-year Higher-Grade course for students in fifth year and then the Certificate of Sixth Year Studies (CSYS). The Higher-Grade course is, usually, also available for students in sixth year who wish to improve on their fifth-year performance or who elect to study at that level for the first time.

Courses at Standard Grade, Higher Grade, and Certificate of Sixth Year Studies are described in publications from the Scottish Qualifications Authority (SQA), formerly the Scottish Examination Board (SEB). As with the other science courses, chemistry is highly popular with close to 25,000 students taking chemistry at Standard Grade—approximately 38% of the cohort compared with 23% in 1973 (see figure 1.2), over 11,500 studying at Higher Grade (see figure 1.3), and just under 1900 taking CSYS, making chemistry at this level second in popularity to mathematics (Buchanan, 1999).

Figure 1.2: Trends at Scottish Standard Grade

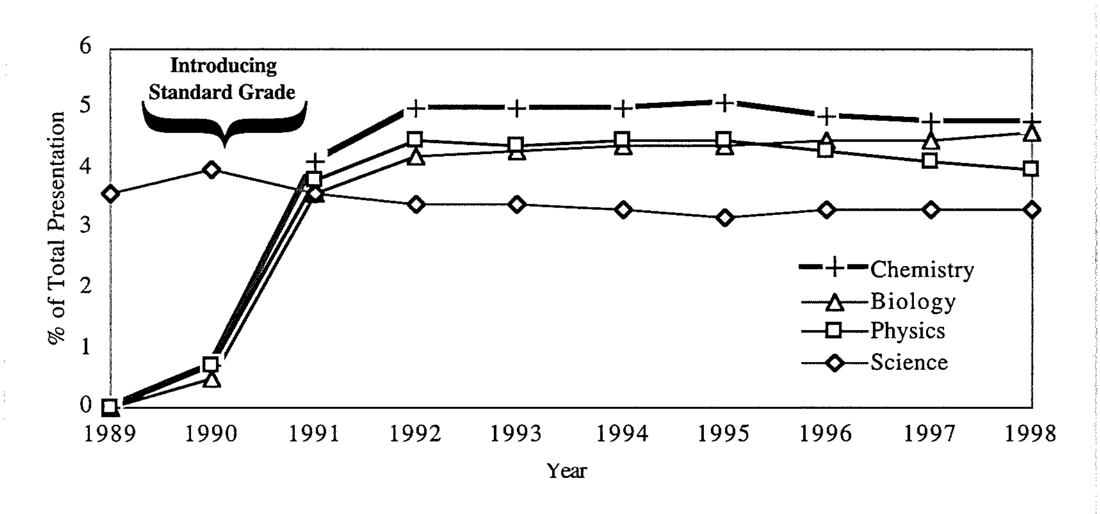
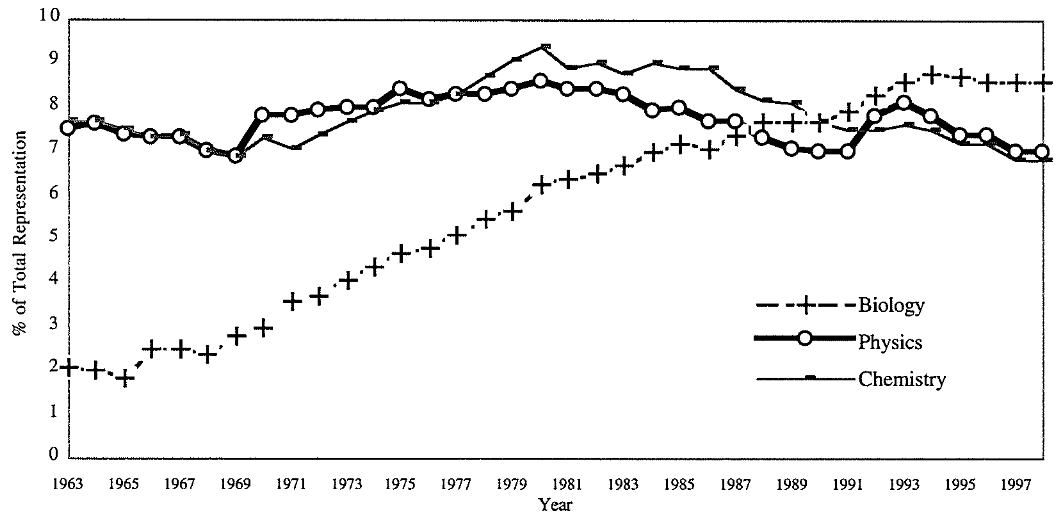


Figure 1.3: Trends at Scottish Higher Grade



Internally assessed Scottish Vocational Educational Council (SCOTVEC) modules provide an alternative provision and such modules are usually offered at Further Education colleges. Chemistry, like many other subjects, is offered at a variety of levels. These modular courses are mainly used by day-release and night class students sponsored by industry (at the moment, the system of Scottish Higher Grade and Certificate of Sixth Year Studies is being changed to Higher Grade and Advanced Higher).

Over the past few decades, there have been major changes in the way chemistry has been taught in secondary schools. Apart from relatively major changes to the syllabuses, class sizes have fallen (to a maximum of twenty) and pupils tend to be more active with less teacher centred work. Chemistry has largely retained its high popularity and, with the growing school population, the numbers achieving chemistry passes have risen markedly over the past twenty five years (Jackson, 1999).

1.2 From School to Higher Education

Upper Secondary Schooling, Further Education, and Higher Education in Scotland have all faced many changes in the last twenty years. Some of these changes include the use of modular courses, the introduction of qualifications based on them (such as SCOTVEC), and the introduction of Standard Grade and subsequent revision of Higher Grade courses. This has led to a growing population in the upper secondary school in Scotland that has affected the expansion of universities. The number of science students has grown during the past years, leading to larger classes and a wider spectrum of student ability and motivation. Higher Education has also faced many pressures in the last two decades, with new universities, many new courses, and new types of organisations. The University of

Glasgow (like other British Universities) has seen an increase in the total number of undergraduates. For example, in the past fifteen years, the Faculty of Science has seen numbers grow by just over 50% (Gray, 1997).

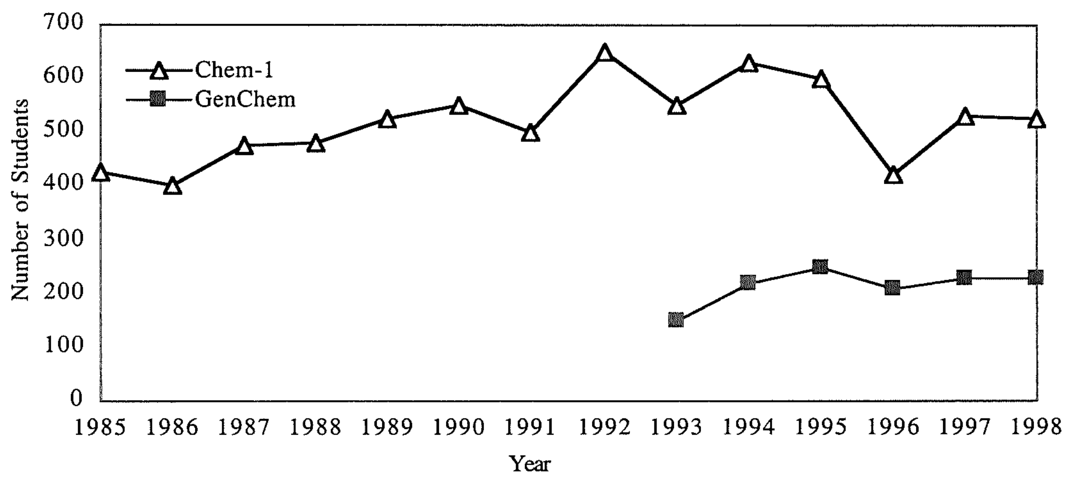
In Scottish Universities, undergraduate students enrol to study in a particular Faculty. At this stage, they are not committed to a particular subject to be pursued to Honours level. Students who find themselves making the wrong choice may be able to transfer to another course or Faculty. Once accepted into a Faculty, most students have a very wide choice of subjects to study. Usually three subjects are taken in the first year and this can include other subjects offered in other Faculties. Many students take chemistry at level-1 and 2 as part of a degree in other departments. The degrees offered to undergraduate students by the University of Glasgow are:

B.Sc.	(Ordinary) duration of study 3 years.
B.Sc.	(Honours) duration of study 4 years.
M.Sci.	(Honours) duration of study 4 years.

1.3 The General Chemistry Course at the University of Glasgow

In the mid 1980s, the first year intake to Chemistry remained around 400 of whom 100 graduated as chemists and the remaining 300 used chemistry as a service subject on the way to specialise in other sciences. In the late 1980s and early 1990s the intake numbers grew steadily to between 600 to 800 students (see figure 1.4).

Figure 1.4: Number of Students Undertaking Level-1 Chemistry Classes at the University of Glasgow



Before the academic year 1993/94, all students studying chemistry at level-1 followed the same course. The class included students who planned to study chemistry as their main subject, those who were taking a first year chemistry course to support some other discipline, and those who were taking the course merely to complete their first year curriculum. Since students typically take three subjects during their first year, the Level-1 Chemistry course was designed to occupy one third of the workload and include about 100 hours of lectures. The level of the course was appropriate for students who had obtained a pass (A, B or C) in Chemistry at Higher Grade.

1.3.1 The Problem

Before the academic year 1993/94, the Department of Chemistry delivered a traditional course of lectures, labs, workshops, and occasional tutorials. It was designed to cater for honours chemists, but at the same time, tried to provide a broad relevant chemical foundation for other science subjects.

In the early 1990s, students with a wide spectrum of chemistry entry backgrounds enrolled in the existing first year chemistry course in increasing numbers. This included mature students and others with a wide range of entrance qualifications including SCOTVEC modules, Access, Standard Grade, or even no previous experience of chemistry at all, with little grasp of basic mathematics.

Such students were studying Chemistry for only one year to support a related science (often a biological science) which was their intended degree subject. They required more support because they were attending a class where the demand level was high, especially designed for students with different interests, motivational patterns, needs, abilities, and learning styles. They stood little chance of success in chemistry although many of them were keen to learn.

1.3.2 Designer Team Aims

To solve the problem of the changing profile of entrance qualifications, the Department of Chemistry divided the existing first year chemistry course into two classes for session 1993/94. The mainstream class known as Chemistry-1 (Chem-1) for students entering with a pass (A, B or C) in chemistry at Higher Grade or above and the smaller class known as General Chemistry (Gen Chem) which contained students with widely diverse entry qualifications. A few had passed Chemistry at the Scottish Certificate of Sixth Year Studies (CSYS) but there were also those who had indicated no formal chemistry qualification at all, their entry to the university being based on qualifications in other subjects. Success in either course allowed students to continue to Chemistry-2.

The General Chemistry course was designed to be a slightly less demanding and a more general course in chemistry than Chemistry-1. General Chemistry was planned as a basis for the future and to provide a service for other departments in the university, particularly in biological sciences.

A team of lecturers designed the new self-contained, one-year course, based on their experience and conclusions from previous educational research. Particular attention was paid to the need to provide a suitable course for less well prepared entrants. The General Chemistry course, which began in session 1993/94, has been specifically designed with the following major aims (Gray, 1997):

(1) *To illustrate the interactions of chemistry with other sciences and everyday life.*

(2) *To develop students' understanding through group work, discussion, and developing written and oral communication skills.*

(3) *To encourage the development of analytical and lateral thinking and experimental strategy.*

(4) *To support students with a service course which would provide:*

   (a) The necessary background concepts in chemistry and mathematics for their future studies.

   (b) A demanding course with content similar to that of Chemistry-1 with topics related to the biological and geological interests of students.

   (c) A route into second year chemistry for students who did well and wished to pursue the subject further.

1.3.3 Philosophical and Educational Principles

To design a course that fulfilled the above aims, the lecturer team began by accepting the educational principles listed in figure 1.5. They planned a course structure for students with a widely diverse chemistry background before deciding the chemical content.

Figure 1.5: The Educational Principles

(1) *What you learn is controlled by what you already know and understand.*

(2) *How you learn is controlled by how you have learned successfully in the past.*

(3) *If learning is to be meaningful it has to link on to existing knowledge and skills enriching and extending both.*

(4) *The amount of material to be processed in unit time is limited.*

(5) *Feedback and reassurance are necessary for comfortable learning and assessment should be humane.*

(6) *Cognisance should be taken of learning styles and motivation.*

(7) *Students should consolidate their learning by asking themselves about what goes on in their own heads.*

(8) *There should be room for problem solving in its fullest sense.*

(9) *There should be room to create, defend, try-out, hypothesise.*

(10) *There should be opportunity given to teach (You don't really learn until you teach).*

(From Johnstone, 1997a)

1.3.4 The Shape of the Course

The General Chemistry course (Gen Chem), was seen as a self-contained, one year course aimed at those with no previous experience or poor qualifications, and those primarily interested only in the subject as a service course. However, Gen Chem was not to be an easy option with the integrity of the course being high enough to allow those who took the course to move on into Chemistry-2.

The course started by assuming very little previous knowledge of chemistry and by providing background material for those who needed it. It aimed to take advantage of what students already knew of the behaviour of materials, to build on that, to look for generalisations and rationalisations, and to construct theories, terminology and symbolism where necessary.

The course had five teaching times (of 50 minutes) a week. A teaching time could be a traditional lecture, a pre-lecture session, a revision workshop, or a diagnostic test. At the beginning of each block of lectures, pre-lecture sessions were introduced to ensure that students were ready for the new lectures. Detailed explanations of the pre-lectures will be given in section 1.6.

Accordingly, depending on the pre-lecture findings, the lecturer planned his block of lectures to facilitate students' previous knowledge and to establish a solid foundation for the new ideas and key points.

After completing a block of lectures, a problem-solving workshop was held to practice student's ability in using the knowledge gained in solving problems. No credit was given but attendance was compulsory—students signed for attendance. Workshops were offered to help students to improve their performance. Studies conducted by Turner (1990) and Hollister (1993) show the influence of workshop's attendance on students' performance.

In a typical workshop session, in the Chemistry Department in Glasgow University, each student had a problem sheet. Students sat in such a way to leave vacant rows to allow staff to circulate and reach everyone. After a short introduction, students were asked to work through the problems, collaborating with friends if they wished. Several tutors were available to help with the problems or related lecture material, and the staff discussed the solutions after the students had attempted the problems themselves (students could ask for help while they were trying to solve questions). Sometimes supplementary problems were provided to try at home.

1.4 Past Research on Level-1 Chemistry Courses

Percival (Johnstone and Percival, 1976) studied teaching methods in tertiary education. He proposed the presence of what were termed "micro-sleeps", when students' attention appeared to be lost. Such breaks forced students to shut down before refreshing themselves for new information and appeared to cause relatively poor performances in related diagnostic tests.

Su (1991) showed that students could have problems in lectures when lecturers assumed the presence of prior knowledge that was either absent or had been forgotten. This would lead to inefficient processing of the lecture material when the student was note taking.

Vianna (Johnstone *et al.*, 1994) used a learning model (see figure 3.1) to modify a level-1 inorganic chemistry teaching laboratory. Vianna developed pre-laboratory exercises to alert students to relevant material they would meet and prepare their minds to handle the new task. He found that the pre-lab exercises were the single biggest factor in improving the laboratory experience of all the modifications he explored.

1.5 Early Observations on the New General Chemistry Course

The success of Vianna's work (the pre-laboratory exercise) had suggested the idea of introducing **pre-lecture** sessions in the new General Chemistry course (full descriptions for pre-lecture sessions will be included in section 1.6). In the academic year 1993/94, Gray (1997) conducted research to monitor the new Level-1 Chemistry course (General Chemistry).

Gray's research focussed on the following areas:

(1) *Building up a "student-eye-view" of the General Chemistry course and its innovations from the inside.*

(2) *Considering the examination results to determine if the General Chemistry course did indeed offer a realisable goal for students of varied chemistry and mathematics backgrounds.*

(3) *Measuring the effect of students entrance qualification on their examination performance by monitoring both Level-1 Chemistry courses—General Chemistry and Chemistry-1.*

(4) *Measuring the effect of other factors that might influence students achievements—such as age, gender, living place, personality factors (Introversion/Extroversion and Neuroticism), cognitive style (Field-Dependence/Independence), and educational maturity.*

Surprisingly, he found that, when looking at both exams (January and June) in the General Chemistry course, no significant link was found between entrance qualifications held by students and their examination results. This meant that success in the General Chemistry course was unrelated to the previous chemistry experience of the students. This was not the case for Chemistry-1, where the success was related to the previous chemistry experience (Sirhan *et al.*, 1999).

Gray examined numerous factors that might have been thought to influence examination performance. He found that none of them correlated with examination performance. As a result, he looked for any key feature of the General Chemistry course which might have provided an explanation. He deduced that it was likely that the presence of pre-lectures was the factor which might be allowing students examination success not to relate to previous chemistry qualifications.

1.6 Pre-lecture Sessions

The decision to develop a new introductory course provided an opportunity to introduce pre-lectures. They can be described as an activity carried out before a block of lectures that was designed to ensure that essential background knowledge is established and accessible so that new learning can be built upon a sound foundation.

A pre-lecture can take many forms. Kristine (1985) reported a system of pre-lecture assignments; involving preview reading and review, the aim being to encourage study skill development.

However, in the General Chemistry course, the following procedure was adopted. Working in an ordinary lecture theatre, the pre-lecture involved a short test (multiple choice and/or very short answers) which sought to check on necessary background knowledge. The students marked this for themselves. Both the test and marking took less than 15 minutes. The test performance provided the students with some evidence about the level of their background knowledge and understanding (Gray, 1997).

They were invited to see themselves as "needing help" or "willing to offer help" and the class was re-organised to form pairs or trios to allow the "helping" students to interact with those "needing helps". In this way, support was available for those students in need of help to understand the background knowledge that would enable them to make sense of the lecture course. Those able to offer help assisted in this process of teaching, and, by the very act of teaching others, they themselves were assisted in ensuring that their own ideas were grasped clearly and correctly. Pre-lecture sessions encouraged discussion within the pairs and trios. The lecturer, supported by a demonstrator, was on hand to offer assistance as required (Johnstone, 1997a).

1.7 Conclusions

Over the period from 1993 to 1995, the General Chemistry course had been monitored by analysing the January class and June degree exams results, determining the changes made to the course and their effectiveness on students' performances, analysing the class handbooks, and meeting and discussing the features of the General Chemistry course with the class head and other members of staff.

The following conclusions can be made:

(i) *The General Chemistry course achieved many of its aims during the first two academic years, 1993/94 and 1994/95, as was expected by its designers (Sirhan et al., 1999).*

(ii) *At the end of the academic year 1994/95, a major change was the discontinuation of the pre-lecture sessions as described above. The time was allocated to extra lectures.*

In considering the above conclusions, there was an opportunity to revisit the course to see what was happening. The General Chemistry course was monitored during two successive academic years (1997/98 and 1998/99) in the following way:

(1) *Continue monitoring Level-1 Chemistry courses by analysing the January class and June degree exams results and looking at the effect of students' chemistry entry qualifications on their performances.*

(2) *Measuring students' attitudes towards their school and university chemistry courses.*

(3) *Determining the most difficult areas in Level-1 Chemistry courses by examining in detail the formal tests and exam scripts during the academic year 1997/98. A questionnaire to determine students' views to the most difficult areas was also applied.*

(4) *Accordingly, teaching materials (Chemorganisers) were designed and written for the General Chemistry students.*

(5) *The Chemorganisers were given to the General Chemistry students in the academic year 1998/99 at the beginning of each block of lectures (where possible). The effect of the Chemorganisers on students' performance was monitored by means of questionnaires and interviews.*

(6) *The above steps 1, 2 and 3 above were repeated.*

Chapter Two

LEARNING MODELS

There are a number of models which provide a useful framework for research in chemical education. Science educators have attempted to take account of educational psychology models and have tried to link science, as a subject to be taught, to the students' cognitive structure. Although there have been several educational psychology approaches intended to help educators to apply these models in educational processes, some major approaches in particular have had considerable influence in the field of science education, namely, Piaget's intellectual development, Bruner's discovery learning, Gagne's conditions of learning, Ausubel's meaningful verbal learning, and Constructivism.

These contributions may be helpful in interpreting empirical observations and guiding classroom practice. Each of these models illuminates a different aspect of the teaching/learning process, and each may be useful in understanding a particular situation.

Although the Information Processing Model will be the main theoretical basis for this project (see chapter 3), it is important to see how other (older) models throw light on the processes of learning.

2.1 Piaget's Intellectual Development Model

Piaget (1961) was primarily interested in how knowledge developed in human organisms. He had a background in both Biology and Philosophy and concepts from both subjects influence his research of child development which led to the study of the psychology of thinking and intelligence.

From Piaget's point of view, the child is growing in an environment that affects his development. He is adapting to his surroundings and absorbing (assimilation) what is required for growth and necessarily changing his behaviour (accommodation) at the same time. Piaget describes the thought processes that bring about this adaptation as schemata. During child growth, schemata are constantly created to deal with the different conditions and situations that appear. Through time, schemata become internalised and organised into complex thought structures. The abilities to comprehend, manipulate abstract verbal symbols, make relationships, and employ abstract schemata also develop with age (Hyde, 1970).

Child growth consists of a constant effort to adapt to the environment in terms of assimilation and accommodation. In this sense, Piaget's model is similar in nature to other constructivist perspectives of learning (such as Bruner).

Piaget believed (Flavell, 1963) that cognitive development is a group of logical successive equilibrations (a constant adjustment of balance between assimilation and accommodation) of cognitive structure, each structure deriving from the previous one. They consist of internally stored information from the events and experiences that have occurred.

Piaget's approach postulates the following:

(1) *Types of knowledge (physical, logical-mathematical, and social-arbitrary).*

(2) *Stages of intellectual development (sensori-motor, pre-operational, concrete operational, and formal operational).*

(3) *Processes that enable the transition from one stage to another (assimilation, accommodation, and equilibration).*

The function of cognitive growth is to produce increasingly powerful cognitive structures that permit the individual to act on the environment with greater flexibility (Piaget and Inhelder, 1969).

2.1.1 Piaget's Stages of Intellectual Development

Piaget (1961) described intellectual development in terms of four stages; sensori-motor, pre-operational, concrete operational, and formal operational. While these stages are associated with characteristic age spans, they vary for every individual. Furthermore, each stage has many detailed structural forms. The last two of these stages are important in secondary and tertiary levels.

Johnstone (1987) described the last two stages in the context of science. The concrete operational stage is characterised by:

(i) *Thinking about or doing things with physical objects.*

(ii) *Ordering, classifying and arranging.*

(iii) *Manipulating things in the mind.*

(iv) *Limited exploration of possibilities.*

In this stage the learner is able to solve problems but his solutions are characteristically in terms of direct experiences. By contrast, the formal operational stage is characterised by:

(i) *Logical reasoning, drawing conclusions from premises.*

(ii) *Testing hypotheses.*

(iii) *Planning experiments.*

(iv) *Formulating general rules.*

(v) *Manipulating propositions in the mind.*

(vi) *Exploring many possibilities.*

These characteristics are highly desirable in a scientist and teachers would hope to find these in their students when progressing from secondary to higher education.

An important thing to understand about these different stages as envisaged by Piaget is that they are qualitatively different. In other words, at each successive stage, it is not just a matter of doing something better, but of doing a different thing altogether. This is seen as a fixed step process rather than a gradual one. For example, a student who is considered a concrete thinker today may be changed to a formal thinker next month. Novak (1978) argued that much work has shown that this is just not so. Others have raised serious questions about the dangers in applying Piagetian ideas too rigidly (Jenkins, 1978; Dawson, 1978).

McKinnon and Renner (1971) came to the conclusion that students at university level are often assumed to have completed their mental development and are able to use an abstract level of reasoning. However, their findings indicated that 50% of entering college students tested were operating completely at Piaget's concrete level of thought, and only 25% of the sample could be considered fully formal in their thought.

Herron (1975) has studied the relationship between first year university students' achievement in a chemistry course and students' level of intellectual development, as described by Piaget as formal operational. He reported that there is a high correlation between students' performance on a group of Piagetian tasks and the total marks earned in the chemistry course he supervised. He extended his study by applying the same test to another sample of first year students from other courses. He found that the correlation, in this case, was about the same as the first one. He concluded that there is a substantial number of entering college students who do not function at the formal level. This has happened because they have not been asked to function at this level. Normally the content of chemistry and the approach we take in teaching chemistry requires that the student operates at the formal level if he/she is to comprehend the concepts that are presented.

Piaget's description of cognitive growth in terms of four stages has made a contribution to research in learning difficulties, especially at school level. A series of studies has looked at how this information might be used to facilitate student achievement by closing the gap between students' limitations in learning and curriculum development.

The complexity of the thought necessary for understanding each section of the Nuffield chemistry course (a school course developed in England in the 1960's) has been analysed by Shayer and Adey (1981) using Piagetian ideas. They claimed that the complexity is often incompatible with the age of the student. Their "remedy" would seem to be to leave out the complex parts until the students are ready. Johnstone (1993) suggested that the above argument breaks down when it is shown that a given group of students in one discipline may be thinking at a higher level than the same students in another discipline. They are capable of the high level thought but do not use this capability in chemistry.

2.1.2 Criticisms

Many theorists consider Piaget to be among some of most outstanding cognitive and development psychologists of all time. Driver and Easly (1978) have provided a critical analysis of Piaget's work and suggest that a series of replication studies which focussed more on the actual content of the pupils' ideas and less on the supposed underlying logical structures would be useful.

Reflecting on Piaget's contribution to science education, Johnstone (1987) suggested that Piaget's model has a detailed description of a set of stages in the mental development of young people. It helps us to think more clearly about students and their learning difficulties, but it was never meant to be a predictive model in teaching.

Lovell (1974) gave two examples to illustrate the limitations of Piaget's model. The first is that the model does not explain why concepts with the same apparent intellectual structure are not all elaborated at the same time. It does not explain why thinking strategies, of which the pupils are capable, are not used in certain circumstances. Secondly, it is very hard to specify precisely the tasks that can always be solved by adolescent or adults and never by younger children.

Piaget's qualitatively distinct stages of intellectual development have been much criticised and not easily accepted by many for various reasons:

(1) *using too rigid boundaries to define the stages of cognitive development. Development would be gradual while the individual transfers from one level to another (Ausubel et al., 1978).*

(2) *using unsystematic methods when carrying out his research. He did not pay enough attention to the sample number, the statistical significance, and reliability (Ausubel et al., 1978).*

(3) *ignoring the great influence of experience and environment on intellectual development (Bruner, 1996).*

(4) *using cross-sectional studies to measure cognitive changes which perhaps required following the same group over a number of years to produce real results (Ausubel, 1964).*

Overall, Piaget believed that the learning and teaching process is an active process, and that the learner explores the environment to construct the knowledge through interaction with the surrounding materials. This means that children can learn by discovery learning (Bruner has the same idea) unlike other models (such as Ausubel) which consider the learning and teaching process as reception learning, organised and introduced by the teacher.

2.2 Bruner's Discovery Learning Model

Bruner took a different approach to cognitive psychology than that of Piaget. Based on studies of child development, he believed that cognitive science had taken too narrow a view of the logical systematic aspects of internal life.

Bruner's model (1966) is a general framework for instruction based upon the study of cognition. He assumed that learning is an active, social process in which learners construct new ideas or concepts based upon their current/past knowledge. The learner selects and transforms information, constructs hypotheses, and makes decisions, relying on a cognitive structure to do so. Cognitive structure provides meaning and organisation to experiences and allows the individual to "go beyond the information given". Bruner's research and arguments were strongly related to learning science and mathematics.

Bruner (1966) has observed that any model of instruction must be concerned with the nature of:

(i) *the knowledge to be learned.*

(ii) *the learning process.*

(iii) *the individual learner.*

The structure of knowledge may be described in three inter-related ways (Bruner, 1966):

(1) *its mode of representation (i.e. enactive, iconic or symbolic).*

(2) *its economy (i.e. the amount of information we must have and work with to achieve understanding).*

(3) *its power (i.e. its capacity for enabling new connections to be made).*

For example, the symbolic formula (PV = nRT) is both more economical and more powerful than the original data involving volumes, temperatures, pressures, number of moles, and the gas constant. To understand such a formula, however, the learner must start with the original data and gradually work towards the abstract relationship.

In his model (Bruner, 1986), development of thinking was seen as a function of experience and was apparently independent of maturational factor. The key concept was 'representation', which was the way that humans represent their knowledge. He proposed three distinct modes of representation:

(i) *Enactive:* *where the response takes the form of physical action.*

(ii) *Iconic:* *where internal visual imagery depicts events and relations.*

(iii) *Symbolic:* *using a symbol system as in mathematics, language, and chemistry formulae.*

Bruner was influenced by the work of Piaget. This can be noted in the stages of cognitive formation proposed by Bruner. These stages are classified in similar manner to that proposed by Piaget:

Bruner	**Piaget**
Enactive	*Sensori-motor stage*
Iconic	*Pre-operational stage*
Symbolic	*Concrete operational stage*

Although there is this superficial relationship between Piaget and Bruner, it has to be remembered that Piaget emphasised cognitive growth while Bruner spoke of the availability of symbolic processes.

Bruner (1966) considered the mode of representation not to be age-dependent. Mature adults need to use all three modes. He suggested that the structure and form of the knowledge to be learned and the sequence in which the materials to be learned or presented should be matched to the ability of the learner.

Motivation of the learner and reinforcement in terms of knowledge of results are also emphasised by Bruner. It is important, in learning a subject, that the learner builds, in his mind, a coherent conceptual structure and is actively involved in erecting and adapting this structure (Bruner, 1966).

The importance of active involvement has led Bruner to advocate discovery learning as a general teaching method. This learning is the way that the learner collects, links, and constructs his cognitive structure by himself. For example, when the learner is faced with a problem, he starts to think, and explores his surroundings looking for the required information to solve the problem. This is against Gagne's idea (which will be discussed in the next section) which suggests that the prerequisite knowledge and skills should be introduced to the learner first.

In this situation, Bruner believed that the role of the teacher is to pose questions or problems that stimulate students to seek answers in an active way. Despite his obvious reservations about cognitive development stages, Bruner recommended that Piaget's model be considered during any curriculum design (Flavell, 1963). The availability of a variety of teaching methods, many choices, and multi-age peer groups may all facilitate learning. The curriculum should be organised in a spiral manner so that the student continually builds upon what he or she has already learned.

Nevertheless, there are many differences in these two theorist's beliefs, especially regarding the ways that internal and external factors affect cognitive growth. Bruner was primarily interested in social issues such as language and culture, whereas Piaget was more concerned with maturational factors. It appeared that Bruner (1972) was convinced that psychologists alone could not construct a model that assisted the development of the mind. Bruner's ideas can be summed as follows:

(1) *Bruner used spiral learning in science curriculum design. The subjects are introduced from general to specific and from easy to difficult.*

(2) *He focussed on the mental processes used in discovery learning not on the results (what is discovered).*

(3) *He used the concepts which are suitable to the learners' capability and readiness.*

(4) *He focussed on motivation and reinforcement in the evaluation.*

(5) *He focussed on the quantity of prerequisite knowledge, how it is organised, and not on the quality (how the learner thinks).*

(6) *He linked intellectual development with linguistic development whereas Piaget linked them to age (maturation).*

(7) *He believed that intellectual development could be recognised from the ability of the learner to interpret by words and symbols.*

2.3 Gagne's Conditions of Learning Model

Gagne's views were influenced by Ausubel's meaningful learning ideas (which will be discussed in the next section) and Bruner's work about mental processes. He focussed on the objectives and analysis of the teaching process.

Gagne (1985) suggested conditions of learning and he developed a model of instruction based upon them. He defined learning as a change in human capability that persists over a time that is not simply assigned to processes of growth. Gagne believed that growth is determined genetically, whereas learning is controlled by environmental influences that interact with the individual. Any learning situation consists of the student, the stimulus, the contents of the students' memory, and the response or performance. Learning takes place when both the stimulus situation and the previous knowledge together affect the student in such a way that his or her performance changes.

2.3.1 Gagne's Taxonomy of Learning Outcomes

Gagne's model stipulates that there are several different types or levels of learning. The significance of these classifications is that each different type requires different types of instruction. Gagne identifies five major categories of learning: Verbal information, intellectual skills, cognitive strategies, motor skills, and attitudes. Different internal and external conditions are necessary for each type of learning.

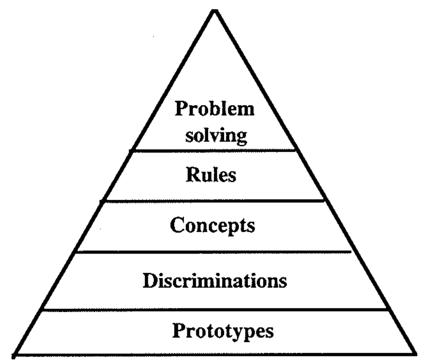
The notion of different levels of learning or knowing something is very useful in education. Gagne thought it was important for teachers and instructional designers to think carefully about the nature of the skill or task they wanted to teach, then to make sure that the learner had the necessary prerequisites to acquire that skill. Gagne (1970) proposed a model that was concerned with the prior knowledge that determined what further learning can occur. He also suggested that learning tasks for intellectual skills can be organised in a hierarchy according to complexity:

Signal learning	*the individual learns to make a general, diffuse response to a signal.*
Stimulus-response learning	*the learner acquires a precise response to a discriminated stimulus.*
Chaining	*a chain of two or more stimulus-response connections is acquired.*
Verbal association	*the learning of chains that are verbal.*
Discrimination learning	*the individual learns to make different identifying responses to many different stimuli which may resemble each other in physical appearance.*
Concept formation	*the learner acquires a capability of making a common response to a class of stimuli.*
Rule application	*a rule is a chain of two or more concepts.*
Problem solving	*a kind of learning that requires the internal events usually called thinking.*

Each of them is representing a different kind of learning capability. The primary significance of the hierarchy is to identify prerequisites that should be completed to facilitate learning at each level. Prerequisites are identified by doing a task analysis of a learning/training task. Learning hierarchies provide a basis for the sequencing of instruction.

Later, Gagne (1985) classified the first four skills (signal learning, stimulus-response learning, chaining, and verbal association) into one category named as basic prototypes. Figure 2.1 shows the new hierarchy of intellectual skills. The highest ability (problem solving) requires that the learner has progressed through all the previous stages. Any particular skill requires the prior learning of those skills below it in the hierarchy.

Figure 2.1: The Hierarchy of Intellectual Skills



In addition, the model outlines nine instructional events and corresponding cognitive processes:

<u>*Preparation for learning:*</u>

(1) *Reception, gain learner's attention.*

(2) *Expectancy, inform learner of objectives.*

(3) *Retrieval, recall relevant information and/or skills to working memory or stimulate recall of prior learning.*

<u>*Acquisition and performance:*</u>

(4) *Selective perception, remembering stimulus features, distinctive features.*

(5) *Semantic encoding, provide learning guidance.*

(6) *Retrieval and responding, elicit a performance.*

(7) *Reinforcement, provide informative feedback.*

<u>*Retrieval and transfer:*</u>

(8) *Cueing retrieval, assess performance.*

(9) *Generalising, applying learning to a new situation.*

These events should satisfy or provide the necessary conditions for learning and serve as the basis for designing instruction and selecting appropriate media (Gagne *et al.*, 1992).

Gagne (1968) has focussed on the importance of the fact that sequentially structured content (like chemistry) can only be meaningfully learnt if each proceeding concept or intellectual skill is properly acquired by the learner. He concluded that it is important to consider not only the changes in performance following instruction, but the capabilities that students already possess prior to instruction.

According to Gagne, the learning process should be sequenced according to the prepared learning hierarchy, for this represents the logical sequence of steps. This view is shared by White (1979) who has drawn attention to a substantial body of research which shows that intellectual skills (i.e. concepts and principles) are learned hierarchically. He argued that learning hierarchies are powerful tools which teachers can employ for development of intellectual skills.

White (1974a) has developed procedures for establishing a hierarchy and checking its validity in the learning situation. The learner's ability to apply or solve problems will depend on the acquisition of such a hierarchy. The idea of hierarchy enables teachers to plan the particularities of a topic to which they must give attention. It also assists them to check their starting assumptions and to identify learning failures more effectively.

When considering the writing of teaching materials, a number of studies have used Gagne's learning hierarchies:

(1) *Gagne's ideas of learning seem to have direct application to classroom learning (White, 1974b; Gower et al., 1977).*

(2) *Gagne's model is most successful within a single lesson (Deming, 1975).*

(3) *The procedure of validating learning hierarchies is long and time consuming (Copie and Jones, 1971; White, 1974b and 1974c).*

Gagne's model of learning hierarchies is widely criticised. Soulsby (1975) claimed that Gagne's model does not cover the learners' affective domain, although he described learning as a whole. Meanwhile, it does not tell about the conditions external to learning. Mahmoud (1979) pointed out that the recall and use of hierarchy by individuals could cause memory overload.

Gagne's model is based on the behaviourist view and his model supports the following ideas:

(a) *Learning causes an observable change in the learner.*

(b) *Skills should be learned one at a time.*

(c) *Each new skill learned should build on previously acquired skills.*

(d) *Learning and knowledge are both hierarchical in nature.*

2.4 Ausubel's Meaningful Verbal Learning Model

Ausubel's meaningful verbal learning model (or meaningful reception model) is concerned with how individuals learn large amounts of meaningful material from verbal/textual representations in classroom or self-study. The model is also concerned about the influence of prior knowledge on how learning occurs. This prior knowledge provides a framework stored in the learner's mind that grows and develops towards formal reasoning.

Ausubel (1968) focussed on both the presentational methods of teaching and the acquisition of subject matter in the curriculum. He drew a distinction between psychology (being concerned with problems of learning) and educational psychology (an applied science which studies those aspects of learning that can be related to ways of effectively bringing about assimilation of organised bodies of knowledge). New information will be more easily learned if it is explained and also related to relevant ideas in the student's cognitive structure. Meaningful learning occurs when new information is linked to prior information in the learner's own cognitive structure.

2.4.1 Dimensions of the Learning Process

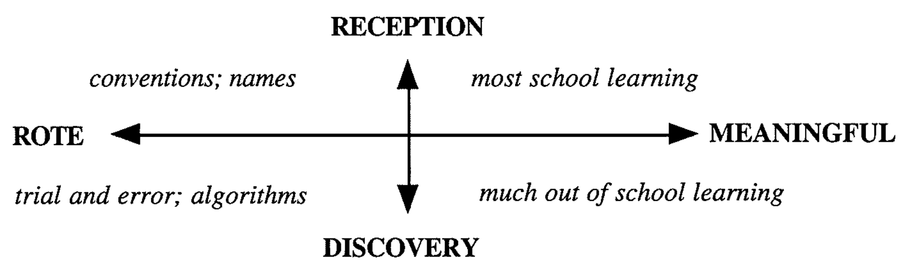
Ausubel's model is based on real classroom learning situations, and two fundamental dimensions of learning processes are involved in his model. One dimension relates to the ways information is made available to the learner (reception or discovery). The other dimension relates to the degree of meaningfulness (rote or meaningful) by which the learner assimilates the formation into his existing cognitive structure. These two dimensions are assumed to be unrelated (Johnstone, 1997b). Life is too short to rediscover everything. Education is a condensed way of presenting existing knowledge in an assimilable way, thus saving time.

According to Ausubel, people acquire knowledge primarily through reception rather than through discovery (as Bruner believed). Concepts, principles, and ideas are presented and understood, not discovered. The more organised and focussed the presentation, the more thoroughly the individual will learn. He stressed meaningful verbal learning. Rote learning, for example, is not considered meaningful since memorisation does not require the connection of new knowledge with existing knowledge. Ausubel also proposed his expository teaching model to encourage meaningful rather than rote reception learning. In this approach to learning, teachers present material in a carefully organised, sequenced, and finished form. Students receive the most usable material in the most efficient way in this manner. Ausubel believed that learning should progress deductively (from the general to the specific) and not inductively as Bruner recommended.

On the other hand, in discovery learning, the material to be learned is not presented to the student in its finished form. The material requires the student to undertake some kind of prior mental activity (rearrangement, recognisation, interpretation or transformation) to convert the final result into cognitive structures. Accordingly, Ausubel indicated that both reception and discovery learning can be either meaningful or rote learning.

Ausubel *et al.* (1978) have presented a pattern showing the "rote-meaningful" learning continuum and its relation to the "reception-discovery" mode of information acquisition. The pattern is shown in figure 2.2.

Figure 2.2: The Dimensions of Learning



2.4.2 Rote and Meaningful Learning

Johnstone (1997a), described meaningful learning as "good, well-integrated, branched, retrievable and usable learning" while rote learning is "at best, isolated and boxed learning that relates to nothing else in the mind of learner". Ausubel (1968) emphasised that to learn meaningfully, individuals must choose to relate new knowledge to relevant concepts and propositions they already know. In rote learning, on the other hand, new knowledge may be acquired by verbatim memorisation, and arbitrarily added to a person's knowledge structure without interacting with what is already there.

West and Fensham (1974) indicated that meaningful learning occurs when the learner's appropriate existing knowledge interacts with the new learning. Bodner (1986) stated:

> *"The idea that knowledge is constructed in the mind of the learner on the basis of preexisting cognitive structures or schemes provides a theoretical basis for Ausubel's distinction between meaningful and rote learning".*

However, in order for the material to be learned meaningfully, it is necessary to meet the following conditions (McClelland, 1982):

(i) *The material itself must be meaningful, that is, it must make sense or conform to experience.*

(ii) *The learner must have enough relevant knowledge for the meaning in the material to be within grasp.*

(iii) *The learner must intend to learn meaningfully, that is, must intend to fit the new material into what is already known rather than to memorise it word by word.*

Rote learning, on the other hand, can be considered as any learning in which these conditions are not present.

Johnstone (1987) also emphasised that students are not "empty pots to be filled". What they already know controls what and how they learn. He concluded that information is not transmitted but is reconstructed idiosyncratically by each student. This emphasises connections between the existing mental framework and the incoming material. Therefore each student revises the material in his own way according to his previous experience, interests and knowledge.

Ausubel used the term "subsumer" to identify any concept or principle that can provide an anchorage for new knowledge. In the process of subsumption, both the anchoring concept and the new knowledge are modified but continue to hold separate identities. The new knowledge is assimilated into the cognitive structure which, as a result, becomes more elaborated with new interconnections between concepts. Novak *et al.* (1971) has pictorial representations of the roles of subsumers and organisers (see figure 2.3).

Figure 2.3: Pictorial Representations to Support Ausubel's Model

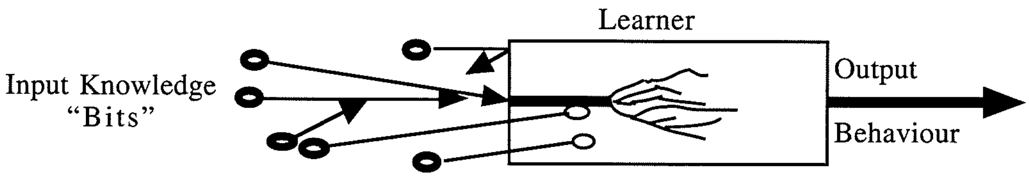


Figure 2.3 (a): Schemata showing that knowledge bits which can be associated with existing concepts are accepted and 'subsumed' to enlarge and strengthen this concept (meaningful learning). Non-subsumable bits are not accepted by the learner, or are learned independently (rote learning).

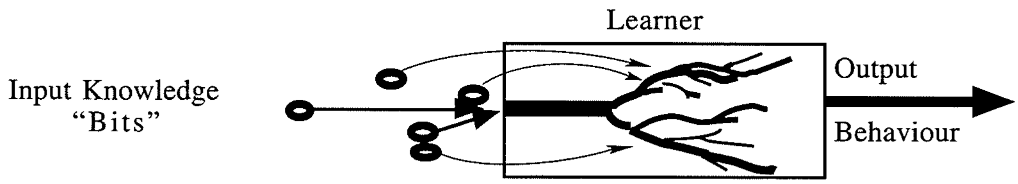


Figure 2.3 (b): Schema showing that additional meaningful learning can result in subsumption of prior concepts into larger, more inclusive concepts.

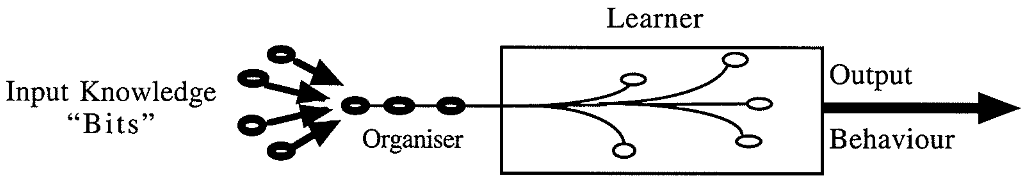


Figure 2.3 (c): Schema showing that appropriate knowledge sequence can serve as 'organisers' to facilitate subsequent meaningful learning.

(Extracted from Novak et al., 1971)

Meaningful learning results in the continuous modification and elaboration of the learner's cognitive structure, and individual variation in attainment is a function of the specific learning experiences rather than maturation (Novak, 1978).

Ausubel's model seems to be a sensible model and much empirical work has been reported in the literature related to science education, e.g., Kempa and Nicholls (1983); Johnstone and Moynihan (1985); Ring and Novak (1971).

Kempa and Nicholls (1983) indirectly supported Ausubel's model in the contribution of prior knowledge subsumers to the learning process. They tried to find the relationship between students' problem solving ability and their cognitive structures represented as cognitive maps by using a "Word Association Technique" for some chemical concepts.

Their findings indicated that the students' ability to solve examination-type problems can be explained in terms of their cognitive structures, since they found that good problem solvers have a more complex cognitive structure than poor problem solvers.

Ring and Novak (1971) were of the same opinion after having investigated the relative effect of students' existing cognitive structures on the learning of new material in the light of their achievement in college chemistry.

Johnstone and Moynihan (1985) conducted a study covering sections of a Scottish Chemistry Syllabus. All the pupils were in the age range 14-15 years and were drawn from five different secondary schools in Scotland. They used a word association test to find the relationship between the cognitive structure as reflected by associations in a word association test with performance in an achievement test. They found that there was a positive correlation between performance in the word association test and in the objective test. They concluded that this study would seem to support Ausubel's view of the effect of existing cognitive structure on meaningful learning and retention.

Ausubel's model lays great stress upon the internal mental networks that a student develops for him or herself rather than upon external teaching networks as with the Gagne model. Every student constructs his own knowledge in his own way. Knowledge cannot be passed intact from the head of the teacher to the head of the student. The student has to store what he or she is taught and then re-stores it in a way that suits his or her previous knowledge and learning style (Johnstone, 1993).

Ausubel (1968) has summed up his own work in this way:

> "*If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly*".

Ausubel's notions help us to understand conditions that affect the acquisition of new information and include it in the long-term memory store where the previous knowledge is stored. Thus, the interconnections between concepts are clear and the information can be recalled (Herron, 1978).

Ausubel's model has similarities with Bruner's "spiral learning" model , although Ausubel emphasises that subsumption involves reorganisation of existing cognitive structures, not the development of new structures as constructivist models suggest (which will be discussed in the next section).

The principal idea in Ausubel's model is that what you know controls what and how you learn. It is, therefore, based on the students' prior knowledge. He did not relate learning and the age of the learner with Piaget's idea. He believed that the difference between the child and adults is only in the amount of knowledge they hold, and not on the intellectual processes. This explains why Ausubel and his interpreters concentrated on introducing general information firstly then moving to more detailed and concrete ideas.

As West and Fensham (1974) have pointed out, the obvious relation of Ausubel's model to the teacher's task makes it worthy of consideration and deserves wider acceptance than any other model. The teacher should assess students' prior knowledge before introducing the new material.

Ausubel's model is based on the cognitive view and his model supports the following ideas:

- *(i) Inputs to learning are important.*
- *(ii) Learning materials should be well organised.*
- *(iii) New ideas and concepts must be potentially meaningful to the learner.*
- *(iv) Anchoring new concepts into the learner's already existing cognitive structure will make the new concepts more easily recalled.*
- *(v) The most general ideas of a subject should be presented first and then progressively differentiated in terms of detail and specificity.*
- *(vi) Instructional materials should attempt to integrate new material with previously presented information through comparisons and cross-referencing of new and old ideas.*

2.5 Constructivism

Although not associated with any one person, constructivism appears frequently in the science education literature. The origins of constructivism lie in the work of Piaget and Ausubel in the 1960's.

Bodner (1986) gave a useful account of the mechanisms that Piaget proposed, and sets them in the context of a wider set of ideas about teaching and learning that are currently referred to as constructivist views of learning and of teaching. He summarised the constructivism model as: "Knowledge is constructed in the mind of the learner". He also argued that this model is good if and when it works and when it allows us to achieve our goals.

Bodner also gave another account of constructivism and its recognition that learners have not only to construct knowledge for themselves, but also to continually test it against the realities they experience. One of those realities for chemistry students, is being able to make use of the knowledge in everyday situations. Another is being able to share in the discourse and activities of the community of chemists, who have developed their own set of terms and meanings as powerful aids to communication amongst themselves.

Many forms of constructivism appear in literature such as:

Personal constructivism believed that construction of knowledge is something that is done by individuals to meet their own needs. It is an outgrowth of Piaget's model of cognitive structures as a collection of mental structures (Bodner, 1986).

Radical constructivism associated with the work of Glasersfeld (1995) who has built his view of constructivism on two principles:

(i) *Knowledge is not passively received, it is actively built by the individual.*

(ii) *The goal of cognition is to organise our experiences of the world by making these experiences meaningful.*

Social constructivism focussed on the way in which social interactions influence the process by which knowledge is constructed. The importance of social interaction in the construction of meaning was strongly promoted by Solomon (1987). She accepted the notion that knowledge is held by individuals but tried to incorporate, into constructivist forms, the role that social effects might have in modifying the ideas these individuals construct.

From the above, it can be concluded that constructivists focussed only on the prior knowledge which is held in the long-term memory (which will be discussed in chapter 3) and did not focus on the whole process.

2.6 Conclusions

All these learning models have stressed, to a greater or lesser extent, the following important features of the learning process:

(1) The content structure of the material:

Gagne has emphasised the hierarchical ordering of concepts and principles, Bruner has emphasised the basic structure of knowledge, and Piaget has related the difficulty level of the material to the developmental stages of learning.

(2) The cognitive ability of the learner:

Gagne and Ausubel have both emphasised the importance of prior knowledge in providing the basis for further learning. Bruner and Ausubel have interpreted learning as the continual modification and restructuring of the learner's cognitive structure. Bruner and Piaget have stressed the developmental levels of cognitive ability.

(3) The learning experience:

All the models have emphasised the importance of correct sequencing. Ausubel and Gagne have favoured an expository teaching style, while Bruner opted for discovery learning. All of them have stressed the need for the learner to be actively involved in the learning process, to be motivated, and to receive reinforcement in the form of knowledge of results.

(4) The conditions to facilitate learning:

Ausubel's model has at least one thing in common with Gagne's model. It concerns itself primarily with intentional learning in school or university classes. In that way, both models differ from behaviourism and cognitive information processing, which attempt to explain aspects of all human learning or memory. Thus, Ausubel's model, like Gagne's, suggests how teachers or instructional designers can best arrange the conditions that facilitate learning for students.

Chapter Three

INFORMATION PROCESSING MODELS

Many versions of information-processing models are to be found in literature (such as Atkinson-Shiffrin, 1971; Sanford, 1985; Child, 1993). The model proposed by Johnstone (1993) is an attempt to suggest mechanisms for learning. It takes into account various models of learning (especially that of Ausubel) and seems to encompass the observations from many perspectives on learning. Such a model (figure 3.1) makes predictions about how input information is dealt with in the human mind so that meaningful learning can take place. It includes the key characteristics emphasised by Ashcraft (1994), where any standard model should contain three components of memory—sensory memory, short-term memory, and long-term memory.

3.1 Human Memory System

The information processing approach, based on an analogy with computer processing, is one model for describing cognition—how you select, encode, store, retrieve and use information (Ashcraft, 1994). This approach is found at the heart of much of the work carried out in the field of Cognitive Psychology of which the core areas of interest are memory, attention, thinking and reasoning (French and Colman, 1995), concept formation and problem solving (Eysenck, 1994).

In the mind, there are three kinds of memory stores—sensory memory, short-term memory, and long-term memory (Ashcraft, 1994). There are also processes for transferring information from one to another (see figure 3.1).

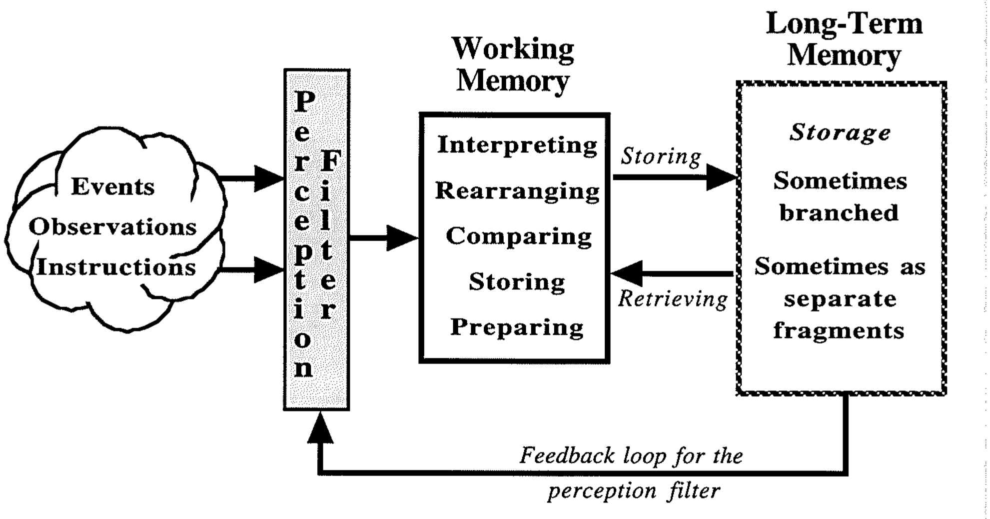
3.1.1 The Memory Components

Sensory Memory

Ashcraft (1994) describes two types of sensory memory: visual sensory memory which receives visual stimuli (lasts for about one second), and auditory sensory memory which receives auditory stimuli (for about four seconds).

Sensory memory is where the learner selects information that is important to him. It stores the incoming stimuli for a very brief period. It is defined as a continuation or persistence of the process involved in perceiving a stimulus when that stimulus is no longer physically present. It is a high-capacity system that registers all sensory inputs in their original form.

Figure 3.1: A Model of Information Processing



(From Johnstone, 1993)

Johnstone (1993) called the sensory memory a "perception filter" through which all events, observations, and instructions come. The perception filter (see Figure 3.1) is influenced by the long-term memory to select information. Many factors play a part in perception: the learner's previous knowledge, biases, prejudices, preferences, likes and dislikes, and beliefs (cultural, political, or religious).

The selection of events is very important in learning. According to White (1988), what the learner selects:

(i) *is affected by his previous knowledge, abilities, and attitudes.*

(ii) *depends upon the attributes of events, attributes of the observer, and interaction between the events and the observer.*

Short-Term Memory

Short-term memory (Atkinson and Shiffrin, 1971; White, 1988) and working memory (Schneider and Shiffrin, 1977; Baddeley, 1986; Johnstone, 1988) are used in the literature. Johnstone (1984) gave a precise explanation for the distinction between short-term memory and working memory. Memorising a set of numbers, then recalling them in the same order within seconds means that no processing takes place and the space is used completely as a short-term memory. By contrast, if the same person is asked to sum the numbers, then multiply them by the first, in this case a working process begins to operate and the space is called a working memory. This is defined by Johnstone (1984) as "that part of the brain where we hold information, work upon it, organise it, and shape it, before storing it in the long-term memory for further use".

This memory is characterised by a limitation in both the capacity for storage and the duration. Miller has demonstrated (1956) that short-term memory capacity is around 7±2 chunks of information. He indicated that it is possible to encode information in a recognisable grouping by making what he called "chunks". Each chunk is controlled by previous knowledge, experience, and acquired skills. The term chunk (e.g. PV = nRT) could be any unit (a single word or more) that is familiar to the learner.

Johnstone and Kellett (1980) argued that the ability of expert (e.g. knowledgeable person, teacher) and novice (e.g. beginner, student) chemists to recognise structural chemical formulae depends on their ability to chunk the information. They also emphasised that if a task exceeds the human's working memory capacity or space, it requires a good degree of understanding to chunk the many pieces into a workable load, or the subject must have a "trick" which enables him to lighten the load. Eysenck (1984) suggested that the chunk refers to any familiar unit of information based on previous learning while Johnstone and El-Banna (1986) believed that chunks are controlled by students' previous knowledge, experience, and acquired skills.

Ashcraft (1994) described the working memory as "the mental workplace for retrieval and use of already known information". He pointed out that short-term memory implies a static, short-lived store. Working memory implies action—a busy place limited by how much work can be done. The more information to be held, the less processing can occur and vice versa. Workers like Baddeley (Baddeley and Hitch, 1974: Baddeley, 1992) have confirmed this dual role and indeed Baddeley has presented quite detailed models of working memory (Baddeley, 1995).

Thus, working memory fulfils the same function as short-term memory in the Atkinson and Shiffrin model (1971). Both views agree that the system has limited capacity, whether this limit is set by number of items, amount of information, or time (Bruning *et al.*, 1995).

In order to retain any information in long-term memory, we need to process it in some way either by repeating it over again and again (rehearsal), or by linking it to something we already know (coding). Contents may be retained in working memory for up to a minute (Craik and Lockhart, 1972). Also, when we are wrestling with an idea it may remain in the working memory for a long time while interacting with new or recalled information.

Long-Term Memory

Long-term memory is where processed information is stored and made available for recall for much longer periods of time, perhaps up to a lifetime. In this store, facts are kept, concepts are developed, and attitudes are formed (Johnstone *et al.*, 1994). There appears to be no limit to the capacity of long-term memory (Solso, 1995).

The stored information has been subjected to considerable processing. Deeper-level processing results in better recalling of information, because it allows more elaboration of the stimulus, and more links are made with relevant information already existing in long-term memory (Craik and Lockhart, 1972).

Tulving (1986) considered that in long-term memory, there are two kinds of information stored: episodic knowledge (tends to be specific to an individual, such as, 'feelings of achievement') and semantic knowledge (tends to be general information held by many people, such as, 'Paris is the capital of France').

3.1.2 Flow of Information

The information model can be considered by looking at the flow of information during learning.

(i) ***Perception Process (filtering, admitting, and enhancing)***: The information is initially received from the external phenomena (words, images, and experiences) by the perception filter (the sensory memory) through one of the learner senses. The filter detects stimulus inputs from the environment. The learner filters out some of these stimulus inputs, paying attention to some, ignoring others. In other words, he selects the "signals" (the familiar stimuli such as what he believes to be important, interesting or helpful) and ignores "noise" (unhelpful stimuli). He also adds from his experience, beliefs, previous knowledge or misknowledge to the sensory information and manipulates it to be more meaningful. The whole process is driven by what the learner already knows and understands—what already exists in his long-term memory (Johnstone, 2000).

However, perception has other functions, including that of enhancement and interpretation. Perception and attention are guided by prior knowledge. What is already known profoundly affects the stimuli we perceive, how easily we recognise these stimuli, and even what meaning we give them. Students should be encouraged to use what they know to help them process new information.

(ii) ***Holding and Thinking Process***: The filtered material now passes into the conscious part of the mind (working space), where further processing takes place. Relationships are sought, fits between old and new are found, patterns are established or enriched and ideas are prepared for storage or rejection. Working memory has two functions, holding and thinking, which operate simultaneously in a limited, shared space (Baddeley, 1986).

This space is used for the temporary holding of material while it undergoes various operations. These operations are matching, reshaping, organising, transforming, and allowing the interaction with already held knowledge brought into consciousness from long-term memory (information required for outputs must first be retrieved from long-term memory into working memory, then it can be used to generate outputs).

The new ideas are organised, attached to existing knowledge, modified it, and then returned to long-term memory for storage and later retrieval. This newly modified knowledge can then feed into the perceptual process to alter the filtration. This part of the processing has been thoroughly researched by workers such as Baddeley (1986).

Our working memory allows us to keep information on 'temporary hold' until we decide what to do with it, but once the information disappears from our working memory, it will be lost for ever. Before this happens, we can decide to transfer it to long-term memory, or to make a permanent record of it, for example, on paper.

***(iii) Storage and Retrieval Process*:** Information can be transferred to long-term memory in order to store learned material in a meaningful form that is easy to retrieve and use. The processed material from working space is stored in long-term memory in three ways:

(1) *as disconnected items from any other learned material—rote learning (Ausubel et al., 1978);*

(2) *as new ideas linked to existing knowledge in a rational way, making it richer, more interconnected, and accessible easily—meaningful learning (Ausubel et al., 1978); or*

(3) *as new ideas linked to old, but rationalised wrongly—the birth of alternative frameworks or misconceptions (Nakhleh, 1992).*

Therefore, our knowledge is enriched to be a more organised and interconnected network of information. This information becomes the basic foundation for processing a new situation.

(iv) *Pattern Recognition Process (Feedback)*: There is another pathway in the flow of information that connects the perception filter with long-term memory. This is not a direct pathway for storage of stimuli but it is hypothesised that whenever a stimulus enters the filter, a contact is made with long-term memory to see if the stimulus has been encountered and stored before.

These processes face some problems such as the limitation of working space and sometimes the absence of existing knowledge or using misleading linking methods. According to Ausubel (Ausubel *et al.*, 1978), "the most important single factor influencing learning is what the learner already knows". This includes his previous knowledge, biases, prejudices, preferences, likes and dislikes, and beliefs. In any country or culture much of this will be held in common, although, each individual will have a unique set of held knowledge and beliefs that identifies them as separate people and personalities. Alternative frameworks (misconceptions) can be developed (Garforth *et al.*, 1976; Nakhleh, 1992). Poor storage and retrieval will affect all other steps in learning by introducing errors of perception and processing. This will in turn lead to further poor storage and the birth of misconceptions or alternative frameworks (Taber, 1996).

If much information has to be held, there is little space for operations, and vice versa. If the filtration process has been faulty or not selective enough, the working space is filled with "noise" (irrelevant information which is not important), and so the learning operations cannot take place or they happen incorrectly (Johnstone, 1997a).

3.2 "Working Space" Overload

Many researchers have become aware of the ability of students to hold only a limited number of facts, ideas, or concepts, while answering a question. Johnstone (1984) and Johnstone and El-Banna (1986) showed that the working space, the conscious part of the brain which is accepting new information, recalling old information and skills from long-term memory store, modifying, interconnecting, judging, organising, shaping, and then re-storing for further use, has a very limited capacity.

Johnstone (1984) has paid attention to the function of working memory. He emphasised that working memory is responsible for holding the information and manipulating it. This means that working memory capacity is smaller than short-term memory capacity, in that some part of the working memory model is probably nearer to 6 ± 2 (or even less), and that allows some space for operations.

Johnstone also showed that a sudden drop in the learner's performance was apparent when any task load exceeded the upper limit of the learner's working memory capacity. It is possible to distinguish between Miller's and Johnstone's work in short-term memory. Miller (1956) emphasised that the function of short-term memory is to hold the information (7 ± 2) without manipulating it. The amount of the information in short-term memory could be increased by increasing the amount of the information per chunk or unit.

Studies (Johnstone and Wham, 1982; Johnstone and Letton, 1991) show that working memory overload appears when the learner is incapable of discriminating between the "noise" (irrelevant information or that which the teacher considers unimportant information) and "signals" (relevant information or that which the teacher considers important information). They suggested that, to overcome this problem, careful organisation of material into a logical arrangement for students and making clear statements of the objectives is important. Also, the work of Kempa and Nicholls (1983) suggested that a student's performance was linked to the complexity of his/her long-term memory network.

Moreover, the information which enters working memory space may be displaced unless an efficient system is instigated which would manipulate and organise such information in a way which would incur no loss, by chunking, selecting or ignoring "noise".

3.3 Applying the Model

The model has helped us to understand that filtration takes place in the mind of each student, by which the things we are teaching are considered to be important or unimportant, understandable or baffling, interesting or boring. All of this is controlled by what is already held in long-term memory. It has also emphasised the limitations of working space in the information processing train. In both of these areas, learning can go wrong or not take place at all.

In lectures, Su (1991) found that students on average recorded around 10% of what was said. He also found that the more information there was to be processed, the less efficient the recording.

In the laboratory, Johnstone and Wham (1982) and Johnstone (1984) found that students blindly processed only the instructions and seldom recorded or interpreted the observations.

To solve the problem of overload in the laboratory, Vianna (Johnstone *et al.*, 1994) conducted an experiment in chemistry laboratories involving pre- and post-laboratories. The overall statistical measurements showed that students mainly favoured the pre-laboratory sessions. Vianna also pointed out that first-time, unprepared learners are not in a position to process laboratory experiences with understanding, no matter what way the experiment was done. If what we already know and understand controls what we learn, the pre-laboratory is necessary to prepare the mind to recognise the expected changes, to be surprised when something different occurs, and to have requisite theory to guide what is going to be experienced.

Similar research conducted by Zaman (Johnstone *et al.*, 1998) in physics labs found that in every case, the students who began with a pre-laboratory significantly outperformed those who began without a pre-laboratory. The researcher went further. He found that the post-laboratories served two functions: to anchor the learning in the laboratory to previous knowledge and to allow the students to use laboratory learning to do something original. The idea of pre-laboratories was found to be effective and was later extended to develop pre-lectures (Johnstone, 1997a).

3.4 Conclusions

It can be concluded that messages from information-processing models include:

(i) *Preparing the mind of the learner before learning is essential to enhance learning and to minimise mislearning. This is clear from introducing both pre-laboratories and pre-lectures.*

(ii) *The way of storing information is an important process for later retrieval. Linking new information correctly to existing knowledge is the main issue to facilitate learning. Post-laboratories and post-lectures can play the main part in this case.*

(iii) *First time learners must encounter new material in such a form as to keep a task's demand within the working space capacity of the learner. As a learner's understanding of a subject increases, the teacher can increase the amount of "noise" to allow the student the opportunity to extract the useful "signal".*

(v) *Perception of and attending to incoming information is controlled by what is already in long-term memory.*

(vi) *Processing new information is controlled by existing material retrieved from long-term memory. To operate efficiently, previous knowledge should be used to chunk information.*

(vii) *The retrieval process is controlled by the storage process: access to meaningful learning is easier than rote learning.*

(viii) *Both perception and processing are affected by poor storage which can sometimes cause the birth of misconceptions.*

Chapter Four

UNIVERSITY STUDENTS AND LEARNING DIFFICULTIES

This chapter seeks to look at the general perspectives arising from various models of learning. Evidence about what is happening in university learning is surveyed and discussed specifically in the context of learning chemistry.

4.1 The Goals of Higher Education

Students who now attend university are no longer drawn from a special selected group but are more heterogeneous and representative of the general population. Both universities and students are adjusting to these changes with varying degrees of success. Throughout the world, in the science field, the goals of the higher education sector and of those who teach courses within them, show common patterns. Drawing together contributions from several authors (such as Ramsden, 1992; Garratt, 1998; Garratt et al., 1999) gives a list of some potential goals:

(1) *To help students learn how to think and not just what to think.*

(2) *To recognise that learning to be a scientist involves more than learning scientific facts.*

(3) *To help students learn to question, to think critically and creatively, to make judgments, and to manage their own learning.*

(4) *To increase the individual's capacity to learn, to provide them with a framework with which to analyse problems and increase their capacity to deal with new information.*

(5) *To develop a capacity to look at problems from a number of different perspectives (to analyse, to gather evidence, to synthesise, and to be flexible, creative thinkers).*

(6) *To develop students' intellectual and thinking skills and to teach students to comprehend principles or generalisations.*

Dahlgren (1984) reviewed a number of studies on the outcomes of student learning at university and found that final-year students were generally able to reproduce large amounts of factual information, complete complex routine skills and computations, apply algorithms, demonstrate detailed subject knowledge using the appropriate terminology, and pass the set examinations. However, he also found that many students continued to hold misconceptions of important concepts, and were unable to demonstrate that they understood what they had learned, apply their knowledge to a new problem, or work cooperatively to solve problems. As a result of his review, he concluded that university students' conceptual changes were relatively rare and context-dependent occurrences.

Many studies reviewed by Ramsden (1992) also confirmed Dahlgren's general findings. Ramsden concluded that many students graduated without achieving the intended goals of university education. They achieved only a basic understanding of the subject they were studying. They were able to repeat facts, manipulate the jargon, and survive the assessments, but lacked awareness of their own limited understanding of the principles of the subject.

The way in which students view and approach their learning, and the ways in which teachers view and approach their teaching may provide some explanation of why students do not achieve the learning that universities claim they provide.

4.2 Students' Views and their Approaches to Learning

At the beginning of any course, students start their study with a set of beliefs about the nature of learning and what they intend to achieve (Biggs and Moore, 1993). These beliefs are derived from earlier school and learning experiences as well as their current goals and motives.

In a study conducted by Marton *et al.* (1993), students were asked to describe their thoughts about learning. From these views, the conceptions of learning held by university students were categorised by Marton *et al.* as:

(1) ***Quantitative conceptions:*** *they relate to knowing more and are concerned with acquiring isolated facts, skills or procedures. This learning involves lower level cognitive processes such as rote learning or perception.*

(2) ***Qualitative conceptions:*** *they relate to understanding and are concerned with understanding the meaning of information and relating new information to what is already known. This learning involves higher level cognitive processes, such as critical analysis and evaluation.*

Entwistle (1988) identified three possible approaches:

(a) ***Surface approach,*** *where the students' aim is simply to reproduce the material necessary to complete their course;*

(b) ***Deep approach,*** *where the students' aim is to reach a personal understanding of the material; and*

(c) ***Strategic approach,*** *where the students' aim is to be successful by whatever means are necessary.*

These approaches tend to lead to different learning strategies and hence different outcomes. A surface approach leads to rote learning; a deep approach can lead to the student examining evidence and relating it to his or her ideas in a constructive way; and a student with a strategic approach will use whichever strategy he or she perceives will result in the best marks. What they learn is affected by the strategies they use: rote learning at best results in a substantial knowledge of factual information, but a deep approach can result in a deeper level of understanding.

High-quality learning requires a deep approach (Van Rossum and Schenk, 1984) but most students employ a strategic approach and they will switch between a deep and a surface approach according to what they think will be most effective.

However, students approach learning in different ways and their approach to a particular course or activity is affected by its context and by their motivation. To help students learn in the fullest sense, teachers of chemistry need to encourage them to try to understand the material at a deep level.

Ausubel (1963) identified a difference between 'meaningful' and 'rote' learning and he maintained that students' motivation was an important factor for inducing meaningful learning. This is similar to (but not the same as) the difference between 'deep' and 'surface' learning, which is discussed by Entwistle (1988).

The key factors affecting students' approach to learning are their previous experience, the style of learning they have previously employed, and their perceptions of the activity and its context (Ramsden, 1988). According to Ramsden, the key features which facilitate a deep approach are:

- *(i)* *The activity should be perceived by the students as interesting and relevant.*
- *(ii)* *Students should have more autonomy over their study methods.*
- *(iii)* *The workload should not be excessive.*
- *(iv)* *Students should not be anxious about the exercise or feel threatened by the exercise in any way.*

Biggs and Moore (1993) have suggested other features. Among these, students should:

- *(a)* *Be actively involved in the exercise.*
- *(b)* *Interact with each other.*
- *(c)* *Have time to reflect on the exercise afterwards, to consider what they have learned, how they learned it, and how it fits with what else they know.*

Craik and Lockhart (1972) developed a framework for thinking about how different kinds of encoding activities influence memory. They argued that memory depends on what learners do as they encode new information. In this view, memory for new information is seen as a by-product of the learner's perceptual and cognitive analyses performed on incoming information. This information will be:

(1) *Well remembered if the meaning of the new information is the focus of processing.*

(2) *Less well remembered, if only superficial or surface aspects of the new information are analysed.*

Some students (for example in chemistry) see no connection between the numerous facts. They are also unable to visualise the abstract concepts. Therefore, surface-level processing strategies, such as rote memorisation to pass an examination, are used and the result is that students see chemistry as a subject made up of many different and unconnected topics.

Bodner (1986) found that a better way of teaching the inter-relationship between chemical concepts is through the use of deep-level processing strategies, where new information is linked to previously learned materials. The result of using these strategies enhances comprehension and skills, and leads to better retention of knowledge.

Learning is idiosyncratic and individual, but students can be helped to learn by discussion (Johnstone, 1997a). Without such help, students can imagine that learning chemistry is a rote process and this may be made worse by the kind of assessment teachers tend to use. This shallow learning can become a way of life for students who imagine that this is what chemistry is about. Inter-linked, multidimensional learning is a necessary and satisfying condition for learning.

4.3 Teachers' Views and their Approaches to Teaching

University teachers also hold beliefs about the nature of teaching which affect their way of teaching. Teachers' conceptions of teaching are reflected in their approaches to teaching. Two main approaches can be observed among university teachers:

(a) The **teacher-directed** (transmission) approach to teaching, which is based on the principle of transmitting knowledge, skills, and procedures from the teacher to the students without reasoning. Johnstone (1997b) argued that this should not be the case and knowledge is not transmitted from the head of the teacher to the heads of the students. Using this approach leads to a "spoon feeding" type of course, with little opportunity for student activity. In this case, teachers aim to present the material clearly and accurately, and all responsibilities for learning are undertaken by the student in his own time.

(b) On the other hand, the second approach is the **student-directed** (cooperative) approach to teaching, which is based on the principle of facilitating student learning through helping students develop problem solving skills and critical thinking abilities (Garratt *et al.*, 1999). The teacher uses the students' existing understanding and knowledge as the starting point of the teaching process. He presents the material as a way to introduce concepts and processes. Classes are usually interactive and group oriented. Teaching activities are selected from a range of alternative methods for the purpose of leading the students to construct their own knowledge, make their own sense of reality, and adopt a conceptual framework in line with that shared by the experts in the class. There is wider access to new technology and a broader range of information sources. Teachers adopting this approach hold that an important part of their role is to enhance motivation and to stimulate the students' interest.

Samuelowicz and Bain (1992) and Gow and Kember (1993) argued that, by the end of the course using the first method, teachers usually assessed student learning by determining how much and how accurately information is known rather than by what is understood. By contrast, using the second method, learning is assessed by determining what is understood rather than what is known. However, the remedy is not simply to provide more methods for teaching and assessment, but to integrate how we teach with how students learn.

4.4 Learning Strategies

An understanding of how students learn can help teachers to devise effective strategies for teaching. This requires that research into the learning process is made accessible (Clow, 1998). To facilitate the development of students' views of knowledge, students need to be supported at the appropriate level. A student who strongly believes that there is only one correct answer, will find an exercise which shows a multiplicity of possible interpretations confusing and unhelpful.

Derry and Murphy (1986) described learning strategies as a collection of cognitive or mental tactics that are used by an individual in a particular learning situation to facilitate learning. Chalmers and Fuller (1996) identified a number of learning strategies. Two of them are mentioned here (as shown in figure 4.1):

(a) ***Cognitive strategies*** *which enable the learner to encode, store, and retrieve information and relate it to the basic cognitive processes of learning.*

(b) ***Metacognition strategies*** *which are concerned with knowledge about cognition, and the control and regulation of cognition.*

Figure 4.1: Learning Strategies

(a) Cognitive Strategies

Strategies	Used to	Example
Rehearsal	Encode information in order to learn and reproduce information exactly as it is presented.	Rote learning, repeating task again and again.
Elaborational	Increase the connections between new information and what is already known in order to increase the meaningfulness of the information.	Mnemonics such as the rhyme "Thirty days hath September ..." to help us remember the number of days in each month.
Organisational	Structure information so that it is encoded and stored with related information.	Outlining the main ideas and generating charts or tables.

(b) Metacognitive Strategies

Strategies	Include	Example
Planning	Identifying and setting goals and then formulating a plan of action to achieve the goals by selecting strategies that are likely to be effective in reaching these goals.	Learners may choose to skim read in order to gain an overview of a topic and then to generate their own questions to guide learning of that topic.
Monitoring	Testing, revising, rescheduling, and reorganising while actually involved in the learning task.	May include self-testing, checking the focus of attention, and test-taking strategies.
Regulating	Some changes should be made to the learning process (when monitoring).	Learners who realise that they are not understanding what they are reading might decide to adjust their reading rate or re-read and review the materials.

4.5 Learning Difficulties in Chemistry

Chemistry is often regarded as a difficult subject. With the establishment of new syllabuses in chemistry in secondary schools in Scotland in the 1960s, one study (Johnstone, 1974) reported that the problem areas in the subject, from the pupils' point of view, persisted well into university education, the most difficult topics being the mole, chemical formulae and equations, and, in organic chemistry, condensations and hydrolysis.

Over a number of years, each of the above difficult areas was subjected to a detailed study to try to identify the point of difficulty and to seek common factors among the nature of these difficulties (Johnstone *et al.*, 1977; Duncan and Johnstone, 1973; Kellett and Johnstone, 1974; Garforth *et al.*, 1976). Johnstone and El-Banna (1986) suggested a predictive model that enabled them to raise and test an important hypothesis which was then applied to chemistry learning as well as to learning in other science disciplines.

Chemistry, by its very nature, is highly conceptual. While much can be acquired by rote learning (this often being reflected by efficient recall in examination questions), real understanding demands the bringing together of conceptual understandings in a meaningful way. Thus, while students show some evidence of learning and understanding in examination papers, researchers find evidence of misconceptions, rote learning, and of certain areas of basic chemistry which are still not understood even at degree-level (Johnstone,1984; Bodner, 1991). What is taught is not always what is learned.

Garratt (1998) pointed that there are many reasons for students finding chemistry difficult to learn. He noted that teachers may not know what students are supposed to have learned from previous courses and that student knowledge is often undermined by misconceptions.

4.6 Areas of Concern

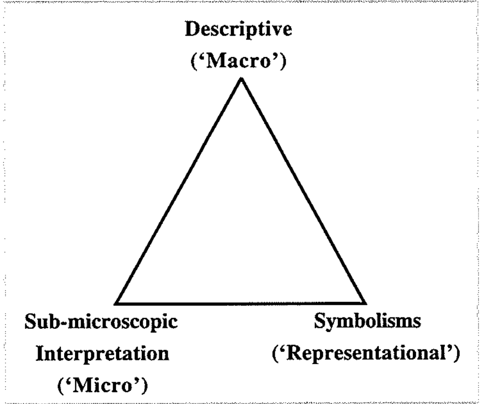
The numerous studies on learning difficulties in chemistry suggest five main areas of concern.

4.6.1 Curriculum Content

The advent of revised school syllabuses in the 1960s and 1970s in many countries saw a move towards the presentation of school chemistry in a logical order, the logic usually being that of the experienced academic chemist. Thus, early chapters in almost all textbooks for first level higher education courses start with atomic theory, line spectra, Schrodinger equations, orbitals, hybridisation, bonding, formulae, equations, balancing ionic equations, calculations and stoichiometry. This is the 'grammar and syntax' (Jenkins, 1992) of chemistry but is daunting for the student. Arguments against this 'logical' presentation have been made cogently by Johnstone (2000).

Much school chemistry taught before 1960 laid great emphasis on descriptive chemistry, memorisation being an important skill to achieve examination success. The sub-microscopic interpretation and symbolic representation were left until later (see Figure 4.2). Today, the descriptive is taught along side both the 'micro' and 'representational'. Johnstone (1982) has argued that the learner cannot cope with all three levels being taught at once and this is supported by Gabel (1999). Indeed, today, there is a danger that chemistry depends too much on the representational, with inadequate emphasis on the descriptive.

Figure 4.2: The Chemistry Triangle



Johnstone (1984 and 1991) indicated that the nature of chemistry concepts and the way the concepts are represented (macroscopic, microscopic, or representational) make chemistry difficult to learn. The methods by which students learn are potentially in conflict with the nature of science which, in turn, influences the methods by which teachers have traditionally taught (Johnstone,1980).

In order to determine whether student's understanding of chemistry would increase if the particulate nature of matter (sub-microscopic level) was emphasised, Gabel (1993) conducted a study involving students in an introductory chemistry course. Introducing extra instruction to the experimental group that required students to link the particulate nature of matter to other levels (macroscopic and symbolic levels), Gabel found that the experimental group performed higher in all levels than the control group. It seems that additional instruction is effective in helping students make connections between the three levels on which chemistry can be both taught and understood.

Sawrey (1990) found that, in an introductory chemistry course, significantly more students were able to solve the problems that used symbols and numbers than could solve those depicting particles. Bunce *et al.* (1991) interviewed students who had solved problems out loud. This study indicated that students rarely thought about the phenomenon itself but they searched in their minds until they came upon something that fitted the conditions of the problem.

Osborne and Cosgrove (1983) showed how students (at several school age levels) understood little about the particulate nature of matter or about chemical phenomena in their everyday lives. Surprisingly, some of the incorrect explanations that students gave to common phenomena are concepts they have been formulated after formal school instruction. Bodner (1991) then used the same questions developed by Osborne and Cosgrove to determine how prevalent these ideas were among the graduate students. His findings indicated that nonscientific explanations persist for some students even after they had graduated with a major in chemistry. He concluded that students have difficulty in applying their knowledge and they do not extend their knowledge into the real world.

4.6.2 Overload of Students' "Working Space"

The working space is of limited capacity (Baddeley, 1999). This limited shared space is a link between what has to be held in conscious memory and the processing activities required to handle it, transform it, manipulate it, and get it ready for storage in long-term memory.

When students are faced with learning situations where there is too much to handle in the limited working space, they have difficulty selecting the important information from the other less important information. The latter has been described as "noise", the student having difficulty in separating the signal from the noise (Johnstone and Letton, 1991)

Faced with new and often conceptually complex material, the chemistry student needs to develop skills to organise the ideas so that the working space is not overloaded. Without the organising structures available to the experienced teacher, the student frequently has to resort to rote learning which does not guarantee understanding. To solve this type of problem, Johnstone (1999) has argued that teachers have to look more closely at what is known about human learning and also look at the nature of our discipline and its intellectual structure in an effort to harmonise them.

4.6.3 Language and Communication

Language has been shown to be another contributor to information overload (Johnstone, 1984). Language problems include unfamiliar or misleading vocabulary, familiar vocabulary which changes its meaning as it moves into chemistry, use of high-sounding language, and the use of double or triple negatives (Cassels and Johnstone, 1985).

In the USA, Gabel (1999) has noted that difficulties students have with chemistry may not necessarily be related to the subject matter itself but to the way of talking about it. In Australia, Gardner (1972) made a study of the vocabulary skills of pupils in secondary schools. He drew up word lists to show which non-technical words were inaccessible to pupils at various stages. He also examined the words and phrases which connect parts of a sentence and which give logical coherence to it (development of logical arguments are impossible without these logical connectives). He found that many words used frequently by science teachers were just not accessible to their pupils.

In Scotland, similar investigations were conducted and extended into higher education. The study by Cassels and Johnstone (1980) has shown that the non-technical words associated with science were a cause of misunderstanding for pupils and students. Words which were understandable in normal English usage changed their meaning (sometimes quite subtly) when transferred into, or out of, a science situation. For example, the word "volatile" was assumed by students to mean "unstable", "explosive" or "flammable". It's scientific meaning of "easily vaporised" was unknown. The reason for the confusion was that "volatile", applied to a person, does imply instability or excitability and this meaning was naturally carried over into the science context with consequent confusion.

White (1977) argued that learning involves the interaction of the information that the learner receives through his sensory system and the information that he or she already has available in his or her long-term memory. This enables the learner to recognise and organise the incoming information and make sense of it. Unfamiliar or confusing words and constructions come into conflict with the organisational process. White also emphasised that the cognitive processes may be considered to involve the interaction of the components of memory—working memory and long-term memory.

Language is influencing the thinking processes necessary to tackle any task, this being supported by the following observations (Cassels and Johnstone, 1984):

(1) *The memory span is not determined by the number of words but by the grammatical structures (e.g., embedded clauses) that may themselves load the memory.*

(2) *The important factor in the sentence is its meaning.*

(3) *Sentences with a negative require more of working memory capacity than do otherwise identical sentences lacking the negative.*

4.6.4 Concept Formation

Real understanding requires not only the grasp of key concepts but the establishment of meaningful links to bring the concepts into a coherent whole. Ausubel's seminal work (1968) has laid the basis for understanding how meaningful learning can occur.

There has been an enormous number of studies on misconceptions in chemistry and there are several reviews of this area (Anderson, 1990; Stavy, 1991 and 1995; Nakhleh, 1992; Gabel and Bunce, 1994; Wandersee *et al.*, 1994). In addition, various studies indicate that students' difficulties in learning science concepts may be due to the teachers' lack of knowledge regarding students' prior understanding of concepts (Driver and Easley, 1978; McDermott, 1984). Bodner (1986) makes a salutary point when he notes that, 'We can teach···and teach well···without having the students learn".

Various other studies have focussed on students' concepts and their inter-connections. Fensham and George (1973) investigated problems arising from the learning of organic chemistry while Kellett (Kellett and Johnstone, 1974) indicated that students had little conceptual understanding of functional groups and their role. This caused difficulties with, for example, esterification, condensation, and hydrolysis. Kempa and Nicholls (1983) found that problem-solving ability, above the algorithm level, depends on the strength of concept-interlinking in a student's mind. They also found that a student's ability was dependent on context, such that individual students can do well in some areas and badly in others.

Bodner (1991) listed some factors that may lead to misconceptions:

(1) *students own knowledge without understanding (rote learning).*

(2) *building on misleading information collected from the media.*

(3) *the way teachers introduce the first ideas; students' prior experiences to the world.*

(4) *the scientific language remains constant while the meaning of the terms change until they become misleading.*

Many research tools appear in literature to identify students' misconceptions. Examples include the diagnostic tests developed by Treagust (1988) and by Krishnan and Howe (1994).

4.6.5 Motivation

There is no doubt that motivation to learn is an important factor controlling the success of learning and teachers face problems when their students do not all have the motivation to seek to understand. However, the difficulty of a topic as perceived by students will be a major factor in their ability and willingness to learn it (Johnstone and Kellett, 1980).

Students' motivation to learn is important but does not necessarily determine whether they employ a deep or a surface approach. Aspects of students' motivation to learn can be classified as either intrinsic (e.g. wanting to know for its own sake) or extrinsic (e.g. wanting to learn what is on an exam syllabus) (Entwistle *et al.*, 1974). There is also a third class, called 'amotivational' learning, which covers the situation where students do things (like attending lectures) without any conscious belief that this will help them learn anything (Vallerand and Bissonnette, 1992).

Resnick (1987) found that students will engage more easily with problems that are embedded in challenging real-world contexts that have apparent relevance to their lives. If the problems are interesting, meaningful, challenging, and engaging they tend to be intrinsically motivating for students. However, Song and Black, (1991) indicated that students may need help in recognising that school-based scientific knowledge is useful in real-world contexts.

White (1988) argued that the issue of long-term and short-term goals is relevant to the learning of science. The student who goes to lectures with a short-term goal of passing examinations often has a specific approach to learning. Scientific laws and potentially meaningful facts are learned as propositions unrelated to experience. Too often examinations reward the recall of such facts. On the contrary, the students who have a stronger sense of achievement, or who want to learn about science, may attend the lectures with a long-term goals of a deeper understanding and appreciation of science. They may approach it involving advanced learning strategies of reflection and inter-linking of knowledge. With the pace of normal lectures, there is unfortunately little opportunity for this to occur during the lectures. Ames and Ames (1984) have pointed out that students' motivations for learning from lectures have important consequences for what they are attending to, how they are processing information, and how they are reacting to the lectures.

Adar (1969) proposed the existence of four motivational traits that are attributable to students' needs. She introduced the notion of motivational pattern and implied that learners differ with respect to their preference for and responsiveness to different instructional features. She was also able to identify empirically the four major motivational patterns in her student sample, and accordingly she divided students into four types: the achievers, the curious, the conscientious, and the sociable. Hofstein and Kempa (1985) followed this line of research and found that students of different motivational patterns have their preferred modes of learning as well.

Kempa and Diaz (1990a) found that a high proportion of the total student population could be fairly clearly assigned to one of the four motivational patterns. Kempa and Diaz (1990b) went on to suggest that students with the conscientious or achievers type of motivational pattern would exhibit a strong preference for formal modes of teaching. Numerous other studies have sought to probe motivational features of learning (such as Ward and Bodner, 1993; Nakhleh and Mitchell, 1993). Together, they give an insight into the vital importance of taking motivational features into account in a learning situation.

4.7 Reducing Obstacles to Learning

It is, of course, the aim of chemistry teachers at all levels to make the subject accessible in such a way that maximum meaningful learning can take place. Selvaratnam (1993) has listed a number of important aspects to aid such learning. These are consistent with the need to avoid working space overload and to take into account concepts already held.

One of the greatest difficulties in avoiding working space overload lies in the fact that the learner does not yet have the experience (such as the development of "schema, tricks, techniques and previous knowledge" which may be called "strategies") to be able to reduce the working space overload (Johnstone and El-Banna, 1986). Unfortunately, the acquisition of such strategies (e.g. chunking) is a highly personal process.

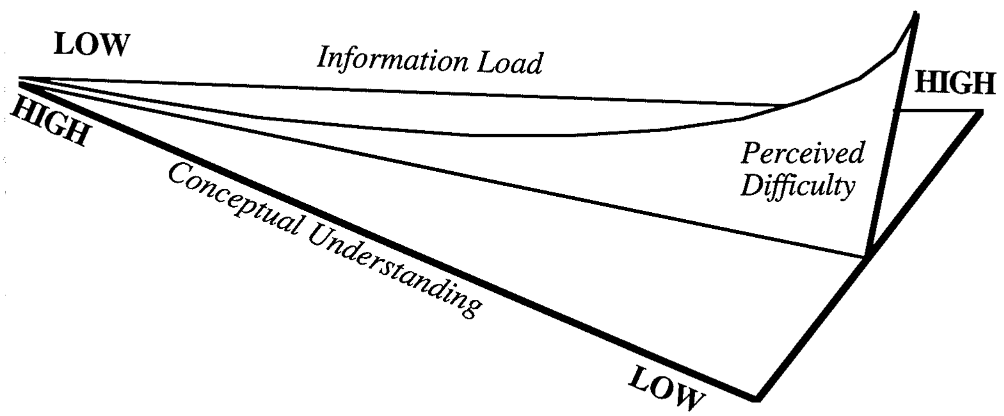
According to White (1988), we chunk the world, that is we combine our sensations into a small number of patterns. Therefore, chunking is a function of knowledge. The size and number of chunks perceived in a situation is one of the big differences between the knowledgeable person (e.g. expert, teacher, adult) and the novice (e.g. beginner, student, child). The knowledgeable person can collect the phenomena or events into a smaller number of meaningful units. The lecturer already has such strategies but these cannot necessarily be applied by all students. It is important, therefore, to minimise working space demands and to provide several routes to meaningful learning. It may be necessary to teach students the strategies which enable them to reduce the overload. Some of these strategies were mentioned earlier in section 4.5.

Kellett (1978) proposed a relationship between Information Content, Conceptual Understanding, and Difficulty. It stated that where the learners had a lack of conceptual understanding then those learners may perform reasonably in low information load situations, but their performance would decrease in high information load situations, causing complaints of difficulty.

Those with high conceptual understanding could use this to chunk information, and thus reduce the information load to one which their working spaces could handle. High conceptual understanding would also allow the learners to separate relevant from irrelevant and focus in on the relevant only, which would also reduce the information load burden.

The relationship between Information Content, Information Load, and Perceived Difficulty was summarised by Johnstone in the "Concorde" diagram which is shown in figure 4.3 (Johnstone, 1980). As the Information Load increases for a student with low Conceptual Ability, so the Perceived Difficulty barrier increases, the reverse being the case for a student of high Conceptual Understanding.

Figure 4.3: The "Concorde" Diagram



(From Johnstone, 1980)

A new learner is naturally at the Low end of the Concept Understanding axis. If the lecturer presents his new learner with material at the High end of the Information Load, then the Perceived Difficulty barrier will prevent the learner from "seeing" what is going on. If this continues then a student's complaint of "I don't understand" could easily become "I will never understand"—an attitude towards a topic which may prove difficult or impossible to alter later. If the lecturer adopts a lower Information Load, increasing it only as a students' Concept Understanding develops, then the difficulty should remain (essentially) constant.

4.7.1 Using "Working Space" Efficiently

The ability to develop strategies to cope with information overload depends heavily on the conceptual framework already established in the long term memory. Working space cannot be expanded but it can be used more efficiently. However, this depends upon some recognisable conceptual framework that enables student to draw on old, or systematise new, material. Miller (1956) suggested the idea of "chunking" (the ability to use some strategy to bring together several items into one meaningful unit, thus reducing working space demands).

Difficulties in conceptual understanding have been related to working memory space and the idea of chunking (Johnstone and Kellett, 1980; Johnstone, 1980). The use of summary frameworks is discussed by Salvaratnam and Frazer,1982) while Johnstone discusses ways by which extraneous excess information ("noise") can be reduced (Johnstone, 1980; Johnstone and Wham, 1982).

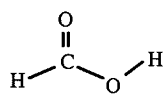
Items are stored in the working memory as 'chunks' of information. These can vary from single characters to abstract concepts and complex images (Johnstone and Kellett, 1980). We can compensate for the limited capacity of working memory by restructuring the information. For example, the Centre telephone number (01413306565) is difficult to remember as eleven digits, but if the same number is broken up into three smaller groups (0141-330-6565), it is much easier to remember. The effect is to reduce the storage required from eleven chunks to three or maybe two. This becomes useful when they form "concepts". In the previous number, "0141 = Glasgow", "330 = University", and "6565 = the Centre", this means there are three chunks, but if we considered that all Glasgow University numbers begin this way = 0141-330 this means that two "concepts" have chunked to one and the overall number becomes two chunks only ("0141330 = Glasgow University" and "6565 = the Centre").

Therefore, chunking is a process of organising information which allows a number of items to be viewed as a single unit, with probably a name or label. It is an important factor in both communication and learning (White, 1988). Ability to chunk information is a learned strategy, and the act of chunking will show how well the topic is known. The more you know about the topic the easier it is for you to chunk it. The number of chunks a person can hold may be a more fixed characteristic, and will vary from person to person.

Johnstone (1984) pointed out that "The teacher's working memory is already organised, but this is not the case for the learner. Each learner has to analyse the information coming in and organise it for himself, or be helped to organise it, if the learning is to become part of him. If he tries to take on the teacher's information and structure, he has to resort to rote memorisation which certainly does not guarantee understanding".

In trying to solve a problem, the student may find his working memory under stress. Solving problems is full of "noisy" things, "noisy" in the sense that they distract from the "signal" or "message" that is to be conveyed. The "noise" can occupy a substantial part of working memory leaving little space for the "signal" and even less space for thinking about what they are all trying to say. Information crowds in from lecture notes, textbooks, workshops, tutorials, peer discussions, things to recall, and then to interpret.

To overcome these limitations, expansion of the size of each chunk of information is necessary. For example, experienced instructors (unlike novices) can condense a complicated stoichiometry problem to one chunk by recognising it as a gram-to-gram problem. Similarly chemists do not see a carbon atom, two oxygen atoms, two hydrogen atoms, a double bond, and three single bonds (nine pieces of information), instead they see it as a carboxylic acid (one piece). Pattern formation is one way of chunking, that is, integrating a larger number of information bits into a smaller number.



Cassels and Johnstone (1984) found that students with a low working memory capacity can be helped by designing exam questions in such a way as to remove any irrelevant information. The problems for the students include language difficulties (such as words change meaning in a chemical context or exam questions which include double or triple negatives) and encountering unfamiliar topics (such as atomic theory).

4.7.2 Learning How to Think

Learners need to recognise that they need to develop their own metacognitive strategies. Metacognition has received much attention in the research to understand learning. It is being aware of one's own thinking processes and being able to plan and organise cognitive strategies. The more learners are able to think about the strategies that they use, the more control they have over their own learning (Nisbet, 1990).

A learner's metacognitive knowledge is also useful for ascertaining any learning difficulties. Learners usually focus on the immediate task in front of them and the more instructions the teacher gives, the more likely it is that the learners will become confused about what they are supposed to be doing, even if the task is easy (Johnstone and Letton, 1991).

The metacognitive strategies that students use are key factors for effective learning, and teaching them to students is one of the key strategies for effective teachers. There are two aims for teaching; teaching students specific knowledge, skills, and attitudes, and teaching students how to learn. Successful students are those who have learned how to select strategies. Unsuccessful students have no strategies for learning and therefore no way to break out the vicious circle of failure unless the teacher helps them.

One of the earliest attempts at using metacognitive strategies (see figure 4.1) was to teach how to plan and tackle a task through self-control (Meichenbaum and Asarnow, 1979). The learner is taught a series of self statements that can be used to guide his thinking. A typical sequence is:

□ *problem identification:*	which involves defining and self-interrogation skills ('*What is it I have to do?*');
□ *focusing attention:*	which involves response guidance to self-inquiry ('*Now, carefully stop and repeat the instructions*');
□ *self-reinforcement:*	which involves goal setting and self-evaluation ('*Good, I have finished the whole page*'); and
□ *coping skills:*	which involve error-correction strategies ('*That is OK···when I make an error I can go back and change it*').

This is a self-control process for planning. Students can use this metacognitive strategy in a variety of situations, across a range of tasks and people.

4.7.3 Paying Attention to Incoming Information

Learners have to focus on a specific task within a 'noisy' environment (irrelevant material), but also, within the task, they have to select specific information that is relevant (meaningful) for them. Teachers can only really find out whether learners are attending by ascertaining what they are learning (Ausubel, 1968). Learners need to know when and where to pay attention, and also to what to pay attention.

Fox (1993) claimed that attention is affected by the complexity of the task and the motivation of the individual. The focus of the learners' attention determines what information is processed. Learners can attend to only a very limited number of the demands that compete for their attention. Johnstone and Percival (1976) found that attention breaks do appear to exist, and occur generally throughout lectures. Such breaks can be relatively easily detected by the observer, and those attention breaks appear as genuine loss of learning in subsequent diagnostic tests. A learners' ability to select the important information to attend to is a key strategy for effective learning. Selective or discriminatory attention has been shown to underlie learners' rates of learning.

Preparing the mind of the learner (Sirhan *et al.*, 1999) is one way to help students to focus their attention on the new information by linking it to their previous knowledge (the knowledge they already know and understand). Students who know more about a topic find it easier to identify and focus on important information. For this reason, carefully choosing the delivered material may greatly facilitate learning.

4.7.4 Recalling Previous Knowledge Easily

To make the material easier for recall, learners actively need to construct, organise, and structure internal connections that hold the information together. The systematic organisation of knowledge, which may be considered to be the ordering of the component knowledge items in a logical, coherent, concise, and principle-based manner, is of fundamental importance for the effective learning, recall, manipulation, and use of knowledge.

Salvaratnam (1993) found that effectiveness of knowledge organisation is increased:

(i) *If the knowledge stored in memory is principle/concept based, coherent, systematic and concise, and*

(ii) *If the organisation is around the minimum amount of essential knowledge (number of principles and concepts).*

Unnecessary principles, concepts, definitions, and terms should be excluded. He listed five aspects which would aid the learning, understanding, recalling, and application of knowledge:

(1) *Use the underlying principles and concepts as the sole basis for knowledge organisation;*

(2) *Exclude unnecessary laws, concepts, definitions, and terms;*

(3) *Use systematic and meaningful terms and definitions;*

(4) *Link the component items of knowledge sharply and coherently; and*

(5) *Store knowledge concisely.*

These ways could help to reduce memory overload, aid learning and understanding, and avoid mistakes.

In this complexity and because knowledge construction is not easy, students often are tempted to engage in rote learning rather than meaningful learning. The teachers' task is to try to find ways to (Novak and Gowin, 1984):

(a) *increase meaningful learning.*

(b) *actively involve students in the process of knowledge construction.*

(c) *empower students to become responsible for their own learning.*

Learners need to decide on the level of complexity at which they will process new information. For example, a student can take notes and either write them as key words or makes connections between this information and the previous knowledge (Su, 1991). The more elaborative, or complex, the learner's processing of the information, the more he tries to make meaningful the new information, the more likely he is to remember it. This could be done by giving different examples on the same problem and making interconnections between it and the learners' knowledge to facilitate memorisation.

4.8 Conclusions

It is not being suggested here that chemistry can be made simple by avoiding teaching difficult topics! The key lies in seeing chemistry from the point of view of the student learner. Such learners approach each topic with all kinds of ideas stored in long term memory. New material will link onto previous ideas and this can cause confusions and misunderstandings. On the basis of the observations made with these students, it is possible to generate some suggestions which might prove useful in seeking to assist meaningful learning:

(1) *The teacher needs to be keenly aware of those topics which persistently cause difficulties.*

(2) *Many students come to the class with wrong ideas, confused ideas or even a complete lack of background knowledge. Learning experiences need to be offered to prepare students to grasp new material by clarifying or correcting previously held concepts or by providing fundamental instruction on such concepts.*

(3) *Many of the most difficult topics make working memory demands beyond the capacity of students. The material to be taught needs re-structuring in order to reduce overload.*

(4) *Regular diagnostic testing (mainly self-assessment), with appropriate backup teaching material, will provide early feedback on student difficulties, will boost confidence and encourage positive motivation towards learning.*

(5) *Being aware of which background concepts are secure and which are confused when students approach a new topic, will allow the teacher to present new material in such a way that it can be linked appropriately onto previous held ideas.*

(6) *Language and symbolisms must be chosen carefully in order to avoid unnecessary confusions and overload of working space.*

(7) *Each piece of new chemical content needs to be explicitly linked to what the student already knows. The more linkages the student can make for each piece of knowledge the deeper his or her understanding will be.*

(8) *Students need to construct these links for themselves by being challenged to engage their minds with the task. The effort of interlinking is ultimately a labour saving device.*

(9) *The teacher needs to have another look at so-called logical order and ask if it is the psychological order. It is necessary to begin where the learner is and lead him into the subject.*

If these general principles are applied in the design of new instructional materials it would be possible to overcome most of the identified difficulties.

Chapter Five

MONITORING LEVEL-1 CHEMISTRY COURSES

5.1 Introduction

In 1968, Ausubel made the comment: "If I had to reduce all of educational psychology to just one principle, I would say this: the most important single factor influencing learning is what the learner already knows. Ascertain this and teach him accordingly". This bold assertion has been supported by subsequent work. Thus, for example, Su (1991) showed that students could have problems in lectures when lecturers assumed the presence of prior knowledge when, in fact, it was absent or had been forgotten. Ebenezer (1992) applied Ausubel's idea in the development of concepts in chemistry. Johnstone (1997a) developed the ideas further in suggesting a set of educational principles (known as "Ten Commandments") for learning (see figure 1.5). Among these were the statements: "What you learn is controlled by what you already know" and "If learning is to be meaningful, it has to link on to existing knowledge and skills, enriching and extending both".

While appropriate knowledge and skills must be present in the learner's mind, it is important to recognise that they must be accessible (able to be retrieved in a meaningful form) at the time when new material is presented. The new material also must be presented in a manner consistent with the way the previous knowledge and skills have been laid down in the long term memory. It is, therefore, important that the minds of the students are prepared for lectures if the learning is to be meaningful for the students (Johnstone, 1997b).

It is not easy to put these general principles into practice since students will come to lectures with a wide variety of background knowledge. In some cases, previous learning in chemistry may have led to an incomplete or incorrect grasp of concepts (Nakhleh, 1992). For other students, ideas once known and understood may not have been used for many months, making it difficult to retrieve them from long-term memory. In order to allow effective learning, it is important to ensure that the background knowledge and understanding are not only present but stored in such a way that they are accessible and understood correctly. As mentioned earlier in section 1.4, the success of introducing pre-laboratories by Vianna (Johnstone *et al.*,1994) led to the idea of introducing pre-lectures in a new introductory chemistry course at the University of Glasgow (the General Chemistry course).

5.2 Re-visiting the General Chemistry Course

The birth of the General Chemistry course was monitored by Gray (1997) during the academic years 1993/94 and 1994/95 (for more detail about the General Chemistry course see chapter 1). Gray looked at various features of this course and identified many successful features. He examined a wide diversity of factors: preferred learning styles (following the Perry model and extent of field dependence), gender of students, whether they stayed at home or away from home, personality characteristics (e.g., extent of extroversion, extent of neuroticism), maturity, and qualifications in mathematics. Gray (1997) indicated that none of these factors correlated with examination performance. He also found that despite the wide diversity of entry qualification in chemistry, success in the course was not related to chemistry entry qualifications. He concluded that it was likely that the presence of pre-lectures might be the main factor that influenced students' performance in the course (for more detail see section 1.6).

In the current study, the General Chemistry course was re-visited in the academic year 1997/98, the first year of this project. There were three very general questions emerging from the previous research which needed to be answered, particularly in light of the welcome lack of correlation between entry qualifications and exam performances:

(1) *What has happened to the General Chemistry course during the period between 1993/94 and 1996/97?*

(2) *If there have been any changes made to the General Chemistry course, what are these changes? What are their effects on the course outcomes?*

(3) *Is there any factor(s), except the pre-lectures, that may have had an effect on the students' performance in the course?*

Methodology

The major consideration at this stage was to find an appropriate strategy to investigate the questions raised. The researcher was not involved in any of the teaching activities but he was acting as observer, making sure that the whole picture of the teaching environment was clear to him. To be able to do this effectively, the following strategy was planned:

(1) *Revisiting Level-1 Chemistry courses (Chemistry-1 and General Chemistry) over the academic years 1993/94 to 1997/98 in order to:*

- (a) *monitor both courses over two periods, the birth of the General Chemistry course (1993/94 to 1994/95) and the latter three years (1995/96 to 1997/98)*
- (b) *compare the two periods above to explore any interesting pattern of results that may be happening in the courses.*
- (c) *establish a clear idea to plan for the next step in this research.*

(2) Holding meetings and discussions with the class heads of Level-1 Chemistry courses and members of staff. The purpose of these meetings was to:

(a) explore any changes made to the courses during the above period.

(b) look at the previous exams results.

(c) analyse all formal assessment exams to continue monitoring students' performance throughout the session 1997/98.

5.3 Monitoring Level-1 Chemistry Courses

During the five-year period (1993/94 to 1997/98), numerous aspects of Level-1 Chemistry courses (Chemistry-1 and General Chemistry) were monitored. For the purpose of this current study, and examining the key issues raised by Gray's results, only one aspect is considered here: student performance related to entry qualification in chemistry.

The relationship between entrance qualifications and ultimate success achieved by students in the formal assessment procedures was explored in order to build up a picture about Level-1 Chemistry courses during the period from 1993/94 to 1997/98.

By examining the spread of examination results achieved by each qualification cohort, it would become clear if there was any significant difference in the pattern observed caused by the students' past experience. All percentages quoted in the tables, in this and subsequent chapters, are in terms of the students who completed the course and sat the June exams. This followed the pattern set by Gray (1997) to allow comparisons to be consistent.

5.3.1 The General Chemistry Course

In General Chemistry, there were four main groups of students in terms of entry qualifications, those with,

H *Scottish Higher Grade pass in Chemistry (almost all of whom had a "C" pass).*

S *Scottish Standard Grade pass in chemistry (approximately that of GCSE).*

A *Alternative qualifications in chemistry based on Access courses (often modular) or passes in Modules.*

None *No formal qualification in chemistry.*

Following the same categories used by Gray (1997) and because of the number of the General Chemistry students in each sub-groups was small, it was decided to divide the students into two (approximately) equal groups and compare the examination performance of these two groups:

Group 1: *those with an **upper level** of entry qualification in chemistry (a pass at Scottish Higher Grade at "C" or better).*

Group 2: *those with a **lower level** of entry qualification in chemistry (less than a Scottish Higher Grade pass at "C").*

Table 5.1 shows the breakdown of students according to the above groups.

Table 5.1: Breakdown of General Chemistry Entrance Qualifications by Class and Gender

Year		Class N (%)	Upper N (%)	Lower N (%)	H N (%)	S N (%)	A N (%)	None N (%)
93/94	All	**110** (100)	**56** (50.9)	**47** (42.7)	**52** (47.3)	**21** (19.1)	**16** (14.6)	**10** (9.1)
	M	**46** (41.8)	**18** (39.1)	**28** (60.9)	**15** (32.1)	**9** (19.6)	**10** (21.4)	**3** (6.5)
	F	**64** (58.2)	**38** (59.4)	**26** (40.6)	**37** (57.8)	**12** (18.8)	**6** (9.4)	**7** (10.9)
94/95	All	**180** (100)	**90** (50.0)	**72** (40.0)	**85** (47.2)	**23** (12.8)	**28** (15.6)	**21** (11.7)
	M	**69** (38.3)	**25** (36.2)	**44** (63.7)	**23** (33.3)	**14** (20.3)	**13** (18.8)	**29** (42.0)
	F	**111** (61.7)	**65** (58.6)	**46** (41.4)	**62** (55.9)	**9** (8.1)	**15** (13.5)	**12** (10.8)
95/96	All	**169** (100)	**86** (50.9)	**69** (40.8)	**77** (45.6)	**19** (11.2)	**22** (13.0)	**13** (7.7)
	M	**77** (45.6)	**26** (33.8)	**41** (53.2)	**20** (26.0)	**10** (13.0)	**12** (15.6)	**8** (10.4)
	F	**92** (54.4)	**60** (65.2)	**28** (30.4)	**57** (62.0)	**9** (9.8)	**10** (10.9)	**5** (5.4)
96/97	All	**163** (100)	**71** (43.2)	**79** (48.4)	**58** (35.6)	**25** (15.3)	**23** (14.1)	**17** (10.4)
	M	**59** (36.2)	**20** (33.9)	**35** (59.3)	**14** (23.7)	11 (18.6)	**11** (18.6)	**8** (13.6)
	F	**104** (63.8)	**51** (49.0)	**44** (42.3)	**44** (42.3)	**14** (13.5)	**12** (11.5)	**9** (18.7)
97/98	All	**229** (100)	**119** (52.0)	**95** (41.4)	**109** (47.6)	**26** (11.4)	**18** (7.9)	**26** (11.4)
	M	**89** (38.9)	**44** (49.4)	**38** (42.7)	**41** (46.1)	**7** (7.9)	**12** (13.4)	**7** (7.9)
	F	**140** (61.1)	**75** (53.6)	**57** (40.7)	**68** (48.6)	**19** (13.6)	**6** (4.3)	**19** (13.6)

Note:
M Male; F Female; N Number of students
H Scottish Higher Grade; S Scottish Standard Grade; A Alternative qualifications in chemistry; None No formal qualifications in chemistry

Table 5.1 above shows that the nature of the population of the class varies from year to year. It also shows that female students are often more experienced in chemistry than their male counterparts with more of them having the upper level of entry qualification in chemistry. It is most likely that better qualified females do General Chemistry as a preliminary study for Biology which is "female dominated".

(i) Examination Results

It is expected that those with the upper level of entry qualifications would obtain high results in the class on the basis of past experience. On the other hand, students with lower level of entry qualifications are expected to be lower achievers. The following analysis will explain this in detail.

(a) January Class Examinations

Students usually sit class exams in January of each year. This takes place at the beginning of term-2 and covers the material taught in term-1. The average marks for the January class exams over the academic years 1993/94 to 1997/98 are shown by table 5.2. It details the results for students with upper and lower level of chemistry entry qualifications in each year.

Table 5.2: General Chemistry January Class Examination Average Marks with Chemistry Entry Qualifications

Year	All	*Main groups*		*Sub-groups*			
		Upper level	Lower level	Higher Grade	Standard Grade	Alternative Qualifications	No formal chemistry
93/94	53.3	54.4	51.3	53.5	55.2	50.3	44.5
94/95	48.7	49.5	49.3	48.4	50.8	50.5	46.1
95/96	40.7	44.3	37.1	44.4	36.2	37.6	31.4
96/97	45.8	50.3	42.0	49.4	42.9	41.0	42.3
97/98	45.1	46.8	43.9	46.6	35.7	49.8	44.5

The above table (table 5.2) shows that in the first two years (1993/94 and 1994/95) students with a lower level of chemistry entry qualifications (such as students with Scottish Standard Grade) obtained similar average marks to their colleagues with the Scottish Higher Grade and sometimes obtained even better. On the other hand, in the latter three years (1995/96 to 1997/98), this trend could not be recognised. Almost all sub-groups obtained lower average marks than their colleagues with upper level. To confirm the above results, figures 5.1 and 5.2 show the distributions of the average marks of the main groups and sub-groups in the academic years 1994/95 and 1995/96 respectively. The figures for other years are shown in Appendix A.

Figure 5.1: Distribution of General Chemistry (1994/95) January Exam Marks

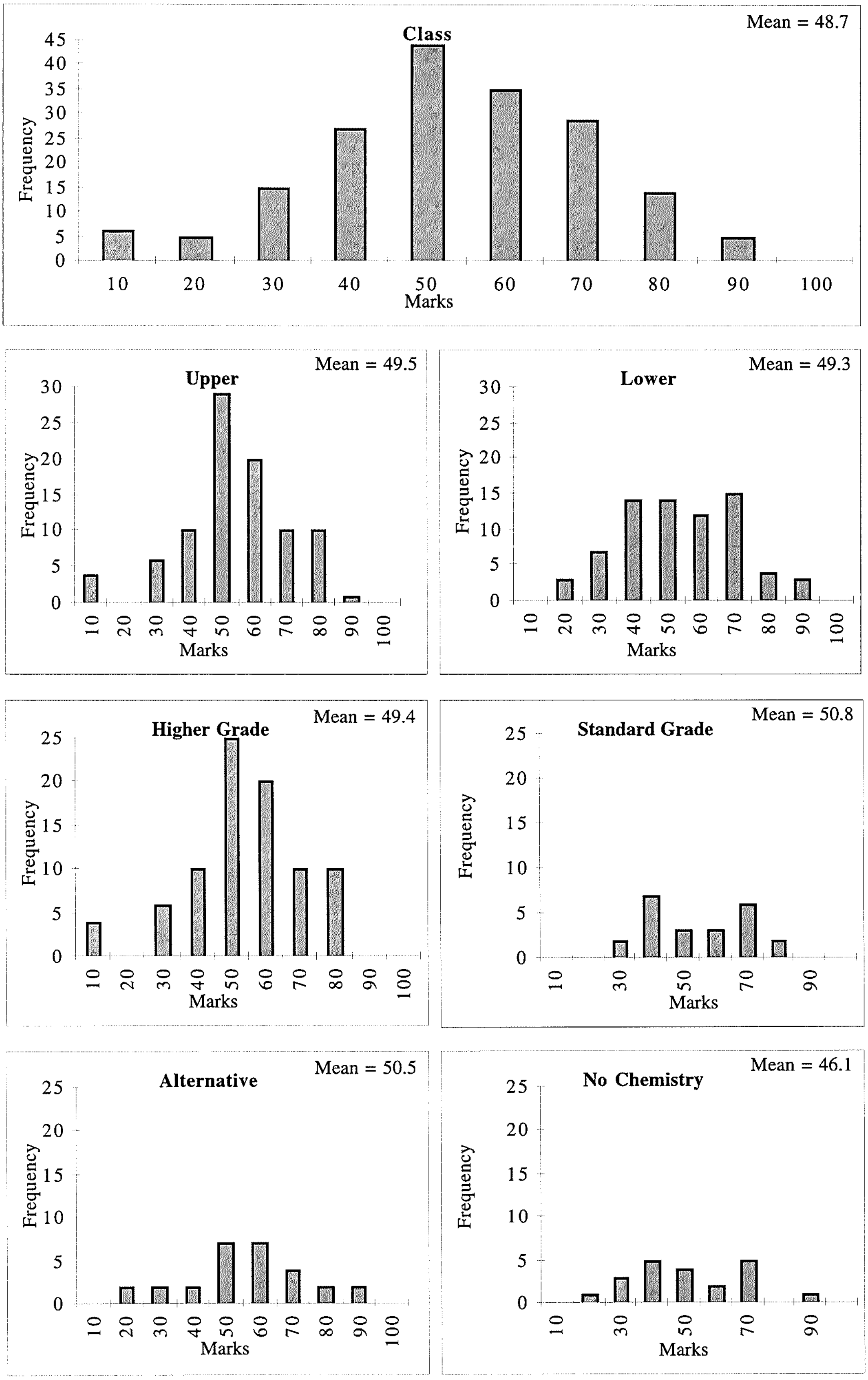
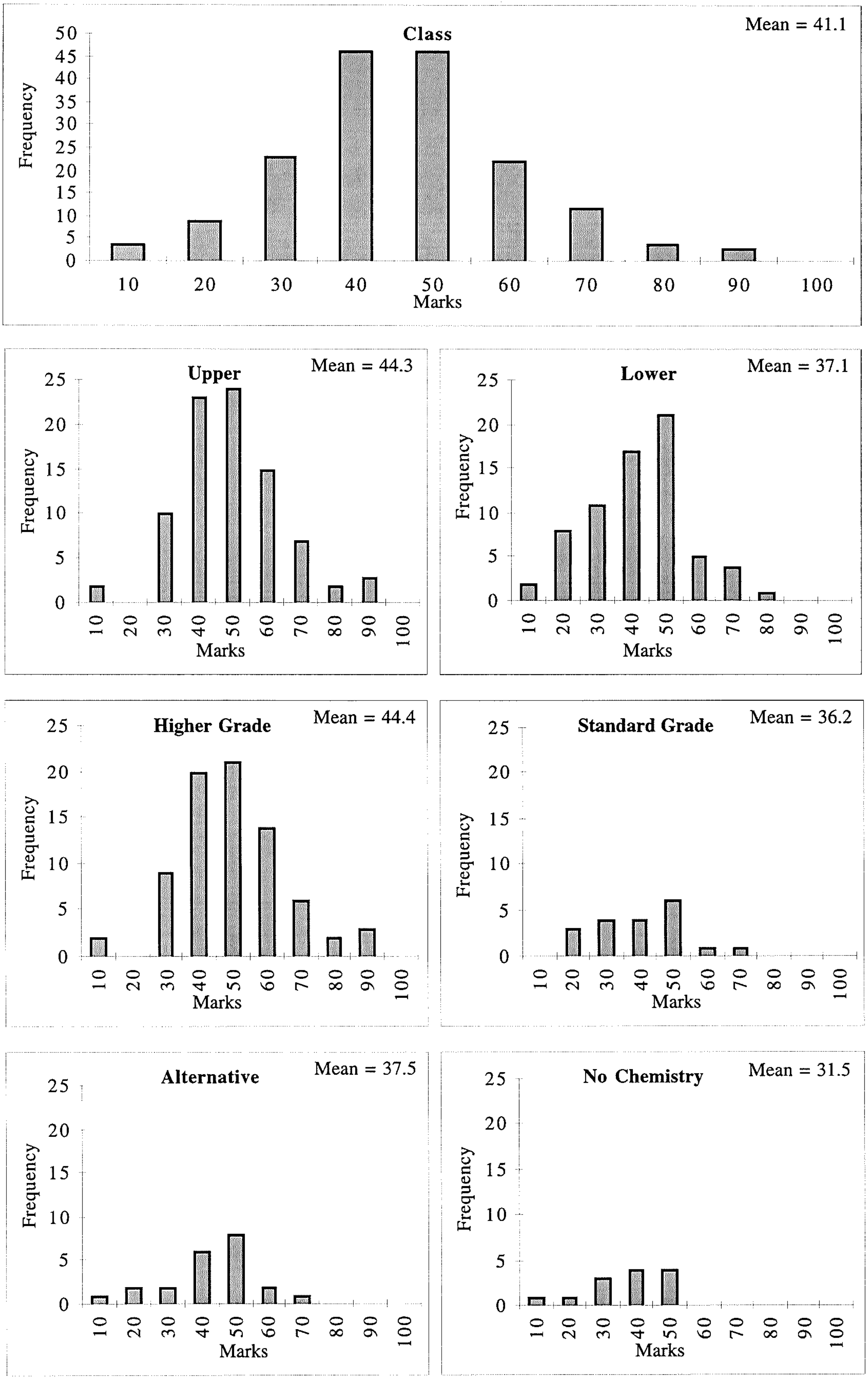


Figure 5.2: Distribution of General Chemistry (1995/96) January Exam Marks



(b) June Degree Examinations

Students usually sit degree exams in June of each year. This covers all the material taught in the year and counts 50% of the final mark. The results for the June exams from 1993/94 to 1997/98 were similarly analysed by the same tests as the January class exams. Similar observations to that in the January exams have been seen. Table 5.3 displays the average marks of the main groups and sub-groups.

Table 5.3: General Chemistry June Examination Average Marks with Chemistry Entry Qualifications

Year	**All**	**Main Groups**		**Sub-groups**			
		Upper level	Lower level	Higher Grade	Standard Grade	Alternative Qualifications	No formal chemistry
93/94	47.3	47.4	46.3	47.2	50.2	42.7	44.1
94/95	48.6	48.8	48.7	49.2	49.3	50.7	45.2
95/96	45.2	49.4	40.3	49.6	38.1	42.0	39.7
96/97	43.4	46.1	41.9	45.0	41.2	40.0	47.3
97/98	43.2	46.1	38.7	47.1	30.5	42.2	41.7

The above table (table 5.3) shows that in the first two years (1993/94 and 1994/95) students with a lower level of chemistry entry qualifications (such as students with Scottish Standard Grade) obtained similar average marks to their colleagues with the Scottish Higher Grade and sometimes obtained even better. On the other hand, in the latter three years (1995/96 to 1997/98), this trend could not be recognised. Almost all sub-groups obtained lower average marks than their colleagues with upper level. To confirm the above results, figures 5.3 and 5.4 show the distributions of the average marks of the main groups and sub-groups in the academic years 1994/95 and 1995/96 respectively. The figures for other years are shown in Appendix B.

Figure 5.3: Distribution of General Chemistry (1994/95) June Exam Marks

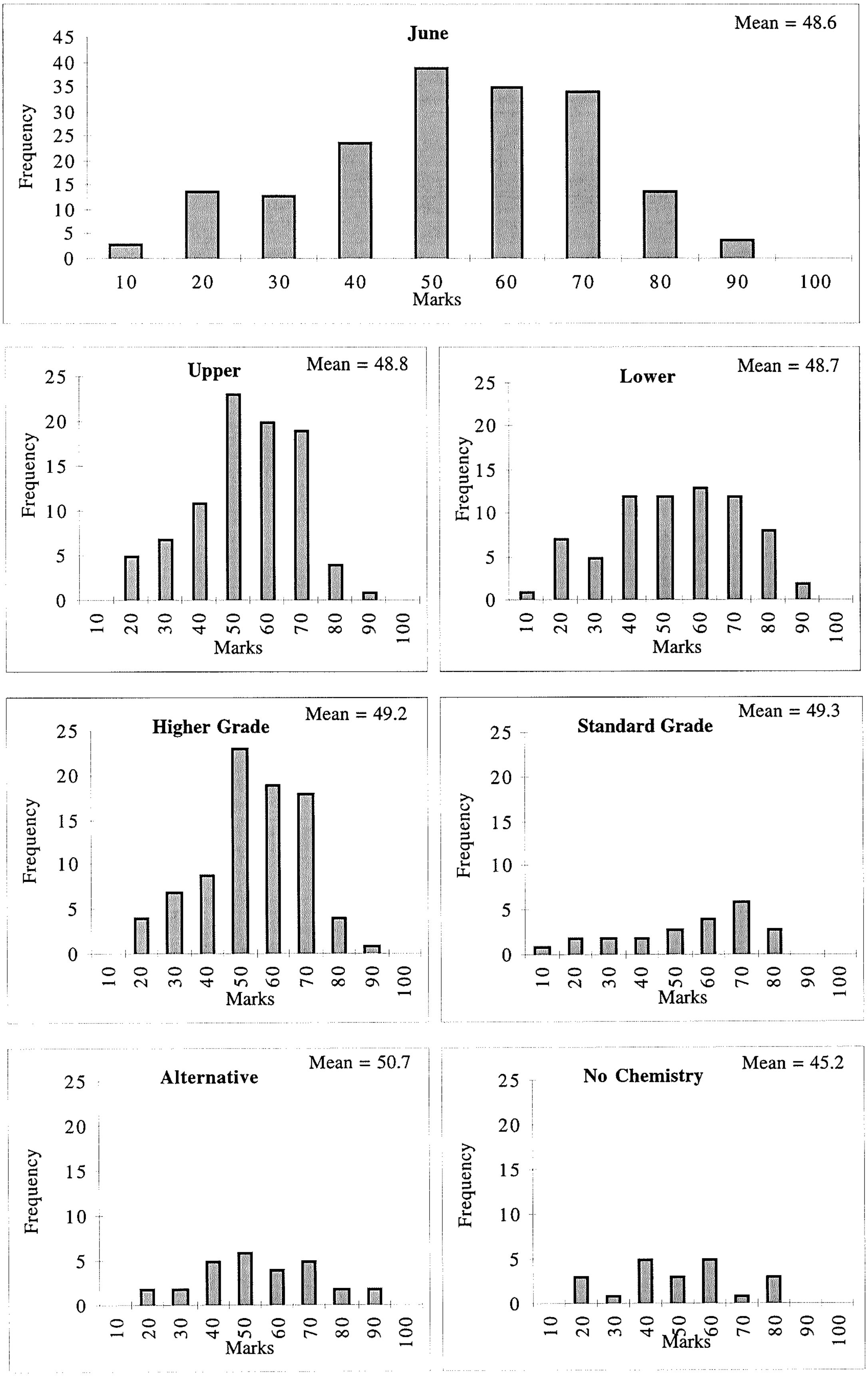
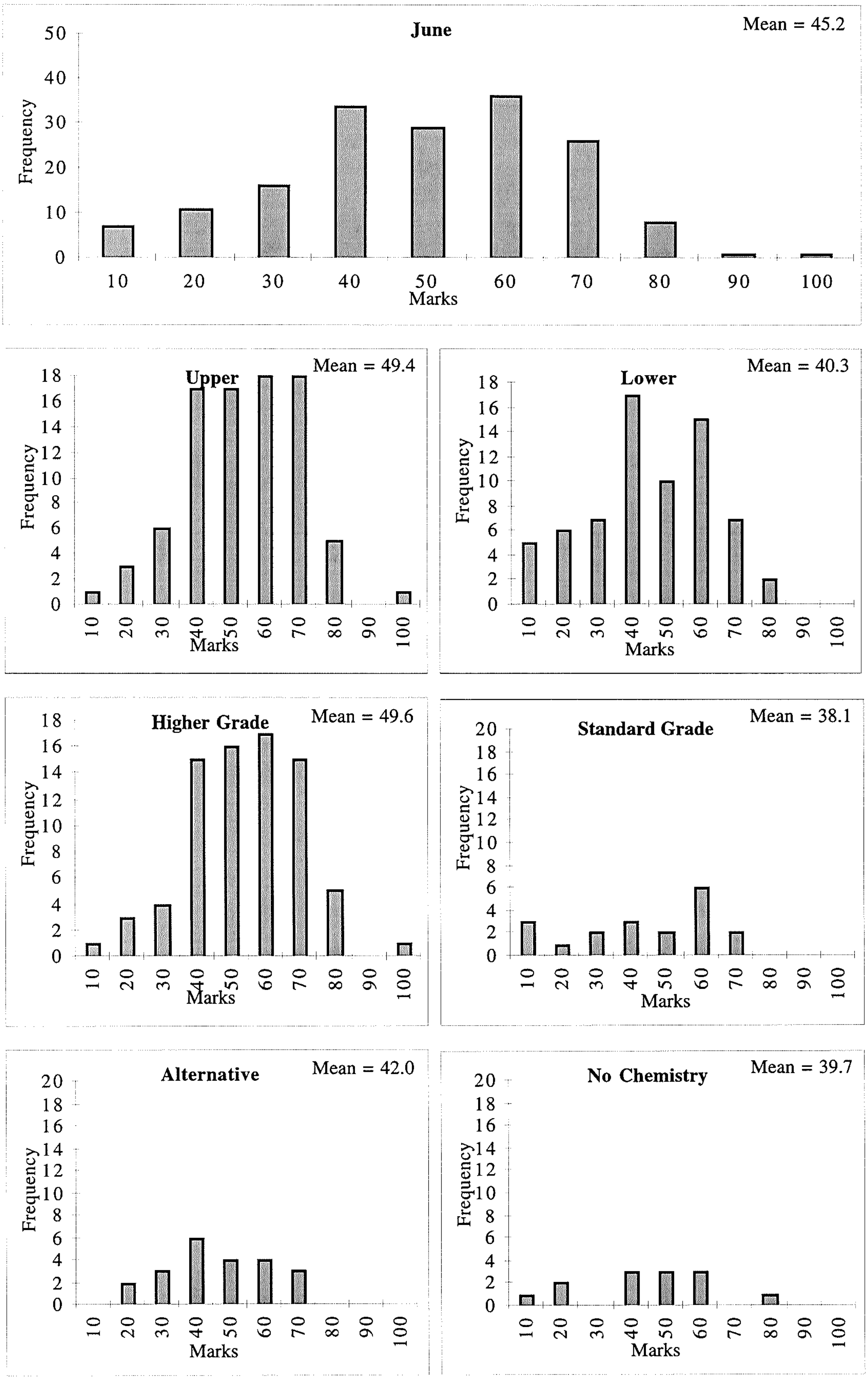


Figure 5.4: Distribution of General Chemistry (1995/96) June Exam Marks



A further step to clarify the results for both January and June exams was carried out by examining the results of the main groups and sub-groups using the Mann-Whitney test which makes no assumption about the shape of population distribution (for more detail see Appendix E2). Table 5.4 shows the statistical analysis for both exam performances (January and June) based on chemistry entry qualifications.

Table 5.4: Relationship Between Entry Qualifications and Examinations Success

	January	*June*
Pre-lectures (93/94 and 94/95)	*No significant differences between groups based on entry qualifications.*	*No significant differences between groups based on entry qualifications.*
No pre-lectures (95/96 to 97/98)	Significant differences between (i) *Upper and lower levels in 95/96 and 96/97.* *(ii) Scottish Standard Grade and Upper level in 95/96. all groups in 97/98.*	Significant differences between (i) *Upper and lower levels in 95/96 and 97/98.* *(ii) Scottish Standard Grade and Upper level in 95/96 and 97/98. Lower level groups in 97/98.*

The main findings from the statistical analysis in table 5.4 confirm the previous results which were drawn from tables 5.2 and 5.3 and figures 5.1 to 5.4.

As shown from table 5.4, the General Chemistry students' performances in both exams (January and June) in the first two years (1993/94 and 1994/95) are not related to their chemistry entry qualifications, while in the latter three years (1995/96 to 1997/98) they are frequently related. Appendices J1 and J2 display the results of the Mann-Whitney test analysis of these sub-groups for January and June exams.

(ii) Changes Made to the General Chemistry Course

At the beginning of the academic year 1997/98, meetings with the heads of Level-1 Chemistry classes (General Chemistry and Chemistry-1) were held to discuss many issues such as the structure, the features, and the organisation of the courses. The handbooks given to the students at the beginning of each year were also analysed.

As this study mainly aimed to look at the General Chemistry course, the course structure was analysed over the five-year period (1993/94 to 1997/98) and it was found that a loss of two pre-lectures was noticed in term-1 of the academic year 1994/95 due to the term timetable and re-ordering of the material covered in the first block of lectures (Gray, 1997). However, at the beginning of the academic year 1995/96, for a variety of organisational reasons, the pre-lectures in the form originally used were removed completely from the structure of the General Chemistry course and replaced by normal lectures. Other changes did occur over the five-year period but no specific change was found to have taken place at the end of the academic year 1994/95 other than the removal of the pre-lectures (as described in section 1.6).

(iii) Discussion

Looking at the results which were drawn from the statistical analysis of the January and June exam performances in General Chemistry course over the five-year period of this study (using the Mann-Whitney test), it can be concluded that in the first two years (1993/94 and 1994/95), in all four exams, there are no significant differences found between the results of students with upper level of entry qualifications and those with lower level. By contrast, in the latter years (1995/96 to 1997/98), in four out of six exams, it was observed that students' performances were related to their entrance qualifications. These observations are surprising and will be explored further by using another approach to look at the data to confirm the findings from the Mann-Whitney test.

The marks of the upper and lower groups of students in the two exams were examined by using t-test in order to be sure that the results were examined by more than one method and under different assumptions (the most important of which is that the Mann-Whitney test makes no assumptions of normal distribution while t-test assumes normal distribution, more detail in Appendix E2). Table 5.5 displays the findings of both tests (Mann-Whitney and t-test). It shows the average mark values for the whole class and the upper and lower groups in January and June exams. It seems that there is a consistency in the results obtained from both tests (Mann-Whitney and t-test).

Table 5.5: Results of Statistical Analysis of General Chemistry Students' Examination Performances Based on Chemistry Entry Qualifications

Year	N	Exam	Average Marks			t-test	Mann-Whitney test
			Class	Upper	Lower		
1993/94	110	January	53.3	54.4	51.3	not sig.	not sig.
		June	47.3	47.4	46.3	not sig.	not sig.
1994/95	180	January	48.7	49.5	49.3	not sig.	not sig.
		June	48.6	48.8	48.6	not sig.	not sig.
1995/96	169	January	41	44.3	37.1	sig. at 0.1%	sig. at 1.0%
		June	45.2	49.4	40.3	sig. at 0.1%	sig. at 1.0%
1996/97	163	January	45.8	50.3	42.0	sig. at 1.0%	sig. at 1.0%
		June	43.4	46.1	41.9	not sig.	not sig.
1997/98	229	January	45.1	46.8	43.9	not sig.	not sig.
		June	43.2	46.6	38.7	sig. at 0.1%	sig. at 0.1%

Another Way of Looking at the Data

Another way of looking at the main findings emerging from the previous analysis was to calculate the *differences* in the average marks of the two main groups (upper and lower levels of entry qualifications) in all exams (January and June) over the five-year period (1993/94 to 1997/98). This was followed by calculating the average differences in both exams in the same year. For example, in the academic year 1993/94, the differences in the average marks for the upper and lower level groups in the January exam is 3.1 and in the June exam is 1.1. Therefore, the average differences over the whole year in the two exams is 2.1. Other values were calculated in the same way. These calculations were run for the same students who sat both January and June exams. Table 5.6 displays these differences. Differences which are due to chance can be rejected as shown in the table (e.g. 0.1% means that we can be more than 99.9% certain that the differences are significant).

Table 5.6: General Chemistry Main Groups Performances (Upper and Lower)

Year	Number of pre-lectures	% of Students		January			June			Average differences between Upper and Lower in January and June
				Average Marks		Differences	Average Marks		Differences	
		Upper	Lower	Upper	Lower	Upper - Lower	Upper	Lower	Upper - Lower	
93/94	8	50.9	42.7	54.4	51.3	3.1	47.4	46.3	1.1	2.1
94/95	6	50.0	40.0	49.5	49.3	0.2	48.8	48.7	0.2	0.2
95/96	0	50.9	40.8	44.3	37.1	7.2	49.4	40.3	9.2	8.2 (sig at 0.1%)
96/97	0	43.2	48.4	50.3	47.0	8.3	46.1	41.9	4.2	6.3 (sig at 0.1%)
97/98	0	52	41.4	46.8	43.9	2.9	46.6	38.7	7.9	5.4 (sig at 0.1%)

In the academic years 1993/94 and 1994/95, the upper level performed marginally better in both examinations (January and June) but the difference in performances is small and no significant differences were observed (using both Mann-Whitney and t-tests). On the other hand, in the latter three years (1995/96, 1996/97, and 1997/98), the table shows that the upper group performed consistently better in both examinations and the overall performance is statistically better in all three years.

From the above approaches, it may be concluded that the structure of the General Chemistry course, when pre-lectures were operating, was providing all students with a reasonably equal opportunity to perform well irrespective of entry qualifications. When pre-lectures were removed, the upper level candidates consistently performed better than the lower level group. This followed the pattern observed in the Chemistry-1 course where pre-lectures were never used (see section 5.3.2).

A Look at Sub-groups

In the General Chemistry course, in any one year group, the size of the lower level sub-groups (such as Scottish Standard Grade, Alternative qualifications, and No formal qualification in chemistry) were too small to make meaningful comparisons possible. However, it is possible to add years together to make such comparisons. For this purpose, students in 1993/94 and 1994/95 (when pre-lectures operated) were taken together and compared to students in 1995/96, 1996/97, and 1997/98 (when pre-lectures did not operate). Table 5.7 shows the weighted average marks for the above four sub-groups, taking into consideration, for each sub-group, the number of students in each year and their average marks. These four main sub-groups involve the majority of the students.

Table 5.7: General Chemistry Main Sub-Groups

(a) The first two years

Groups	1993/94			1994/95			Two years			
	N	January	June	N	January	June	N	January	June	Average
Higher	52	53.5	47.2	85	48.4	49.2	137	50.3	48.4	49.4
Standard	21	55.2	50.2	23	50.8	49.3	44	52.9	49.7	51.3
Alternative	16	50.3	42.7	28	50.5	50.7	44	50.4	47.3	48.9
None	10	44.5	44.1	21	46.1	45.2	31	45.6	44.9	45.2

(b) The latter three years

Groups	1995/96			1996/97			1997/98			Three years			
	N	January	June	N	January	June	N	January	June	N	January	June	Average
Higher	77	44.4	49.6	58	49.4	45.0	109	46.6	47.1	244	46.6	47.4	47.0
Standard	19	36.2	38.1	25	42.9	41.2	26	35.7	30.5	70	38.4	36.4	37.4
Alternative	22	37.6	42.0	23	41.0	40.0	18	49.8	42.2	63	43.1	41.4	42.3
None	13	31.4	39.7	17	42.3	47.3	26	44.5	41.2	56	40.8	42.9	41.9

5.3.2 The Chemistry-1 Course

Following the analysis of the General Chemistry course examinations, it was decided to study Chemistry-1 examination results for the same period to compare the findings of both Level-1 Chemistry courses and to use the Chemistry-1 course as a kind of "control group", recognising that it is a very different kind of class.

As always, Chemistry-1 was by far the larger of the two chemistry courses. The variety of qualifications was smaller than that of General Chemistry (the majority of students fall into the Certificate of Sixth Year Studies (CSYS) or Scottish Higher Grade categories). Therefore, the examination results discussed in this section are limited to considering those with Higher Grade and CSYS only. Graphs of the relevant data are shown in Appendices C and D.

Unlike General Chemistry, the number of students involved in Chemistry-1 (see table 5.8) makes the analysis of exam results, according to the different grades of chemistry entrance qualifications, feasible.

Table 5.8: Breakdown of Chemistry-1 Entrance Qualifications

	Passed Grade	94/95 N (% of 540)	95/96 N (% of 490)	96/97 N (% of 398)	97/98 N (% of 519)
Certificate of Sixth Year Studies		**148** (27.4)	**206** (42.0)	**152** (38.2)	**176** (33.9)
	A	**5** (0.9)	**28** (5.7)	**15** (3.8)	**14** (2.7)
	B	**36** (7.7)	**43** (8.8)	**32** (8.0)	**56** (10.8)
	C	**77** (14.3)	**98** (20.0)	**75** (18.8)	**69** (13.3)
	D	**30** (5.6)	**27** (5.5)	**25** (6.3)	**28** (5.4)
Scottish Higher Grade		**218** (40.4)	**216** (44.1)	**180** (45.2)	**242** (46.6)
	A	**37** (6.9)	**47** (9.6)	**46** (11.6)	**69** (13.3)
	B	**133** (24.6)	**137** (30.0)	**122** (30.7)	**153** (29.4)
	C	**36** (6.7)	**10** (2.0)	**10** (2.5)	**20** (3.9)

In the Chemistry-1 course (which never included pre-lectures as defined in section 1.6), an analysis of student performance in examinations showed that the students with high entry qualifications performed better consistently. The average performance of students by entry qualifications is shown in table 5.9.

Table 5.9: Chemistry-1 Students' Performance with Entry Qualifications

Entry Qualification	Pass Grade	Average Mark (%) for sessions							
		94/95		95/96		96/97		97/98	
		Jan	June	Jan	June	Jan	June	Jan	June
Certificate of Sixth Year Studies (CSYS)	A	77	77	81	82	84	81	87	89
	B	55	55	69	70	72	73	76	76
	C	38	40	59	64	65	60	68	66
	D	28	33	45	54	56	50	64	59
Scottish Higher Grade	A	50	53	63	66	68	65	72	71
	B	31	38	48	54	51	51	59	55
	C	23	28	51	56	54	55	58	52

Chemistry-1 exam results (1994/95 to 1997/98) were investigated to ascertain if the results in that course followed the same, or similar, pattern to that of the previous years. All of the January and June exams showed very strong results for each sub-group qualification.

Simple inspection of table 5.9 and the relevant graphs in Appendices C and D show the trend of results, not just from one qualification to another (CSYS to Higher Grade), but also within the different grades of each qualification (e.g. CSYS pass at A). Rather than a series of largely overlapping distributions as was observed in the first two years of the General Chemistry exams detailed so far, Chemistry-1 produced a range of distribution patterns, the central tendencies of which decreased with the grade of that particular grouping. Table 5.10 displays the general trend found in chemistry examination results and shows that the first four sub-groups (CSYS/A, CSYS/B, HA, and CSYS/C) are dominant.

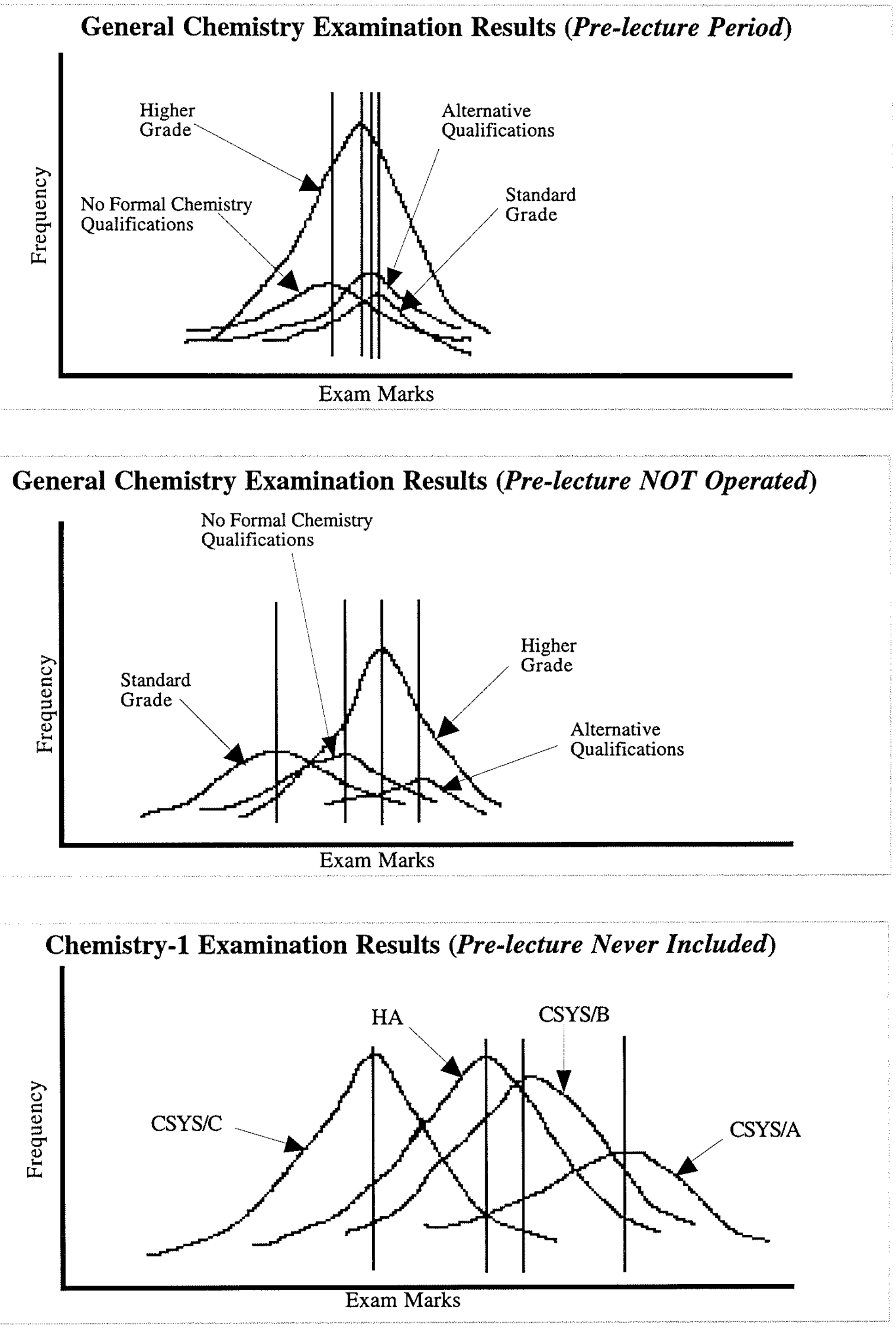
Table 5.10: The General Trend of Chemistry-1 Examination Results

Year	Exam	General Trend						
1994/95	January	CSYS/A	CSYS/B	HA	CSYS/C	HB	CSYS/D	HC
	June	CSYS/A	CSYS/B	HA	CSYS/C	HB	CSYS/D	HC
1995/96	January	CSYS/A	CSYS/B	HA	CSYS/C	HB	CSYS/D	HC
	June	CSYS/A	CSYS/B	HA	CSYS/C	HC	CSYS/D	HB
1996/97	January	CSYS/A	CSYS/B	HA	CSYS/C	CSYS/D	HC	HB
	June	CSYS/A	CSYS/B	HA	CSYS/C	HC	HB	CSYS/D
1997/98	January	CSYS/A	CSYS/B	HA	CSYS/C	CSYS/D	HB	HC
	June	CSYS/A	CSYS/B	HA	CSYS/C	CSYS/D	HB	HC

The evidence from these results clearly supports the hypothesis that exam success in Chemistry-1 is linked to the students standard of entrance qualifications. The same pattern was noticed in the latter three years of the General Chemistry when the pre-lectures were removed.

It could be concluded that the achievement pattern emerging from Chemistry-1 students is similar to those of General Chemistry during the period of absence of pre-lectures. At the same time, the Chemistry-1 achievement pattern disappears in General Chemistry in the presence of pre-lectures. Figure 5.5 also represents the general trend found in Level-1 Chemistry examination results. These are cartoons to illustrate the position of the mean scores and do not imply Standard Deviations.

Figure 5.5: Representation of the General Trend Found in Level-1 Chemistry Courses



5.7 Conclusions

The pattern of results is surprising. Intuitively, it seems unlikely that what appears to be a small change in teaching could make this impact. However, it must be noted that the pre-lectures amounted to about 10% of the total time allocated for lectures, a sizeable proportion of the teaching input.

Nonetheless, it was thought that examining as many other factors as possible would clarify the whole situation. An examination of other features of the course organisation showed that other changes had occurred over the five-year period but none had taken place specifically between 1994/95 and 1995/96. Although the size of the group had risen over the five-year period, the composition of the class in terms of the proportions of students with various entry qualifications showed no discontinuity after year two and, indeed, no trend over the five-year period. Looking at common questions in successive examinations showed little change in overall performance over the five-year period.

It is often tempting to try to cram in more material in order to improve performance. The study by Su (1991) of student habits in lectures shows the folly of this approach. The observations made on this course would seem to suggest that *reducing* the amount of material might be advantageous if the time released was used to prepare the minds of the students to make more complete sense of the new material offered. This is consistent with Garratt's reflections (Garratt, 1998).

The use of pre-lectures may also have been having more subtle effects. The confidence and motivation of more poorly qualified students would almost certainly have been enhanced by learning experiences where their weaknesses were being taken into consideration. Motivation has been shown to be very important in influencing performance (Kempa and Diaz, 1990a and 1990b). In addition, the use of pre-lectures could also have been having a subconscious effect on the lecturers by heightening their sensitivity in checking the pre-knowledge of the students during the presentation of new material.

Chapter Six

CHEMISTRY LEARNING DIFFICULTIES

In the previous chapter, it seems to be clear that, when pre-lectures were removed (as in General Chemistry) or did not exist (as in Chemistry-1), students' performances in the exams were related to their chemistry entrance qualifications. This pattern did not exist in the first two years (1993/94 and 1994/95) of the General Chemistry course when pre-lectures operated. Specifically, students with a lower level of entry qualifications (e.g. Scottish Standard Grade) seemed to benefit from the pre-lecture programme. Therefore, in this chapter, a study has been conducted to monitor the Level-1 Chemistry courses (General Chemistry and Chemistry-1) from inside, to identify the topics perceived to be difficult by students and to find out the possible reasons for these learning difficulties. This has been done by careful observation, examining in detail the tests and exam scripts, and seeking the students' opinions about the difficulties in learning chemistry.

Many questions occur frequently: Why is chemistry difficult to learn? Why cannot students grasp some chemistry concepts easily? Or more practically, why do students have learning difficulties in certain concepts in chemistry? Is it related to intelligence, language, teaching methods, students' attitudes etc? All of these questions are not new or unfamiliar. Teachers and curriculum designers have been aware that some chemistry concepts are perceived as difficult by students and many suggestions have been made regarding the difficulties of chemistry concepts and the remedy for these difficulties (for more detail see section 4.5).

6.1 The Scope and Aims of the Current Study

This study was carried out on over 800 students from Level-1 Chemistry courses (General Chemistry and Chemistry-1) at the University of Glasgow. Students entered these courses with a great variety of different chemistry backgrounds.

This chapter aims to answer the following questions:

(1) *What are the most difficult topics in Level-1 Chemistry courses (Chemistry-1 and General Chemistry) as perceived by students?*

(2) *Are there any differences from those observed by Johnstone (Johnstone, 1974)?*

(3) *What are the reasons behind these difficulties?*

(4) *Is it possible to remedy these difficulties? How?*

6.2 Description of the Procedure

Learning models have been used as a theoretical base for this study, especially Ausubel's model and the Information Processing model. The study has been conducted in three stages, as follows:

(i) *Looking at Level-1 Chemistry courses (Chemistry-1 and General Chemistry) by gathering information through attending lectures and problem solving sessions, meetings with the heads of the classes and members of staff, and direct contact with students in laboratories. The textbooks and handbooks were also carefully studied and reviewed.*

(ii) *Analysing examination results and scripts during the academic year 1997/98.*

(iii) *Applying questionnaires at the end of term-2 (March, 1998).*

As a means of checking that the student opinions about the difficulties are similar to the findings from the analysis of the exams scripts, a comparison will be made between the questionnaire results and the results of the analysis of diagnostic tests and January exam scripts. The comparison between this survey and previous studies (such as Johnstone, 1974) may also give a further indication of the validity of the study.

Each of the above stages is discussed in turn.

6.3 Monitoring Lectures and Problem Solving Sessions

Level-1 Chemistry courses at the University of Glasgow, as previously mentioned in chapter 1, are divided into blocks of lectures, each block covering a major chemistry area. Each block is usually taught by one lecturer, the duration of each lecture being 50 minutes. The lectures are held in two parallel sessions, at 10 am and at 3 pm. This arrangement is necessary because of the increase in the number of students who are studying these courses and to avoid any clashes with other courses.

In the academic year 1997/98, the first lecture of each block of lectures of the General Chemistry course was attended, then at least another two or three lectures from each block were chosen randomly for making observations. The researcher sat through numerous lectures as a member of the audience and, during this time, he looked at some general issues of the teaching and learning process, and at students' behaviour.

The observation during the teaching of some topics showed that some lecturers appeared to cover a specific amount of material during each lecture and, at the same time, there was no change in the style of delivery. Audio-visual aids were rarely used by some lecturers.

In general, the lecture was largely an un-interrupted discourse from a lecturer. Rarely was any discussion or interaction between the lecturer and students seen, and there was little student activity other than listening and taking notes. Thus, the lectures were conventional in the sense that they were content-based, lecturer-controlled, and lecturer-dominated. The method of teaching used by most of the lecturers could be described as teacher-centred (see section 4.3). Students were heavily involved in writing. There was little time for thinking about the delivered material or linking it to previous information. This means that any misconceptions which students may have in advance may be the basis for others to develop. Lectures with laughter and a happy atmosphere were observed on many occasions, while doodling, restlessness, and talking among students were also observed on others.

Problem solving sessions were also monitored. Usually a sheet of paper containing one or two worked examples followed by a list of questions, was given to the students. Firstly, the worked examples were explained and then students were asked to try to solve the questions by themselves. The answers to those questions were given during the sessions. Students were encouraged to try to solve the problems individually and then to discuss the solutions with their colleagues. If they did not understand the problem they could ask any member of staff for help.

Discussions were also held during the academic year with members of staff, especially the heads of the classes (General Chemistry and Chemistry-1). The aim of these discussions was to enrich the information gathered about the teaching/learning situation by exploring staff opinions. This provided useful informal confirmation of the meaning of the data gathered from students.

6.4 Analysis of Tests and Examination Questions

Student examination performances were scrutinised as another source of data in order to monitor Level-1 Chemistry courses (General Chemistry and Chemistry-1). This was done by the analysis of students' examination scripts. It was hoped to build a clear picture of the difficult areas in both courses.

Usually students sat four diagnostic tests (1 hour) during the year (two tests in term-1 and another two in term-2), a January class exam (2 hours) which covered term-1 material, and a June degree exam (3 hours) which covered the whole course.

In this study, scripts for diagnostic tests 2, 3, and 4 along with the January class examination scripts were examined in considerable detail to see whether the actual performance in various topics matched the students' perceptions of difficulties. This is not an exact science in that a topic which students found difficult might lead to a good assessment performance if the questions were straightforward while a topic perceived as easy might lead to problems in a complicated question. Test-1 was not included in this analysis because the students test scripts were returned to students before the researcher had the opportunity to analyse them.

Student performances have been presented for each topic as percentages, because the various questions analysed carried a wide variety of credit. Tables 6.1 and 6.2 display the marks percentages of the questions in General Chemistry and Chemistry-1 respectively, including the related topics which were assessed in that test or exam. Sometimes, the same topics appeared in different questions or in different tests or exams. In this case, the values which will be presented in the tables are the average values.

Table 6.1: General Chemistry (1997/98) Topics Marks Percentages

	Topics	Test-2	Test-3	Test-4	January Exam
*	Draw isomers / inorganic	22			
	Electronegativity	77			
*	Electronic configuration	42			44
	Metal/nonmetal	83			91
	Naming of chemical symbol	99			92
	Naming of ions	63			
*	Oxidation state	11			28
*	Balancing redox equations				17
*	Balancing equations (simple)				18
*	Balancing ionic equations				43
	Corrosion				60
*	Draw diagrams / ligands				16
*	Ligands				26
*	Draw unit cell				30
	Hard/soft acids				56
*	Mole calculations				8
*	Coordination number				40
*	Orbital quantum numbers				35
	$PV=nRT$				50
*	Writing formula for compounds				43
	Writing formula for elements				73
*	Equilibrium constant		45		
	ΔG		51		
*	Rate of reaction		44		
*	Rate constant		48		
*	Rate expression		37		
*	Draw organic compounds			34	
*	Draw chiral			34	
*	Draw cis / trans			22	
*	Draw polymers			18	
	Electrolytes			59	
*	Functional groups			45	
*	Hydrolysis			32	
*	Organic reactions			11	
*	Osmotic pressure			37	
*	van't Hoff '*i*' factor			36	
*	Oxidation			30	
*	pH calculation			9	
*	Polymers			5	
*	Weak acid Ka			35	
*	[A]			13	
*	Solubility			33	
	Solubility in water			53	

* Topics where fewer than 50% of the students answered them correctly

Looking at table 6.1, it can be seen that, in many topics, marks percentages were low, which means that either students did not grasp the topics easily or they still needed more explanation to overcome these difficulties. On the other hand, there were few topics found in Chemistry-1 that produced low marks (see table 6.2). The extracted topics were listed in table 6.3.

Table 6.2: Chemistry-1 (1997/98) Topics Marks Percentages

	Topics	Test-2	Test-3	Test-4	January Exam
	H-bonding	88			
	Intermolecular forces	81			98
	Half-life time	84			
	van der Waals	85			47
	Rate reaction	89			
	Rate law	56			47
	Order of reaction	97			
	Overall reaction	99			68
	Intermediate	98			93
	Molecularity of 1st step	88			87
	Collisions /reactions	97			
	B.p	88			73
	Geometrical isomers / organic		92		68
	Draw organic structure		57		54
	Draw chiral		76		66
	ΔG		58		
	ΔH		72		
	ΔS		74		
	Hydrolysis		83		
	Lone pair electrons		92		76
	Mechanism				37
	Curly arrows				33
*	Cell reaction			42	
	E cell			69	
	Dielectric constant			85	
*	Draw / Ligand			37	
	Isomers / inorganic			81	
	Electronic configurations			63	
	High / low spin d-orbital			73	
	Mole calculations			52	
	Oxidation states			76	
	pH			91	
	pKa			56	
*	Activation energy				33
*	Transition state theory				32
*	Lattice energy				40
	Naming organic compounds				70
	PV=nRT				57
	VSEPR				66

* Topics where fewer than 50% of the students answered them correctly

Table 6.3: Topics Extracted as Difficult From Exam Scripts

Both Courses	*General Chemistry only*	*Chemistry-1 only*
Reaction rate	Writing chemical formulae	Lone-pair electrons
Arrhenius equation	Mole calculations	Lattice energy
Entropy and disorder	Solution concentration	Markovnikov's rule
Enthalpy	Colloidal solutions	Quantum numbers
Free energy changes	Osmotic pressure	Electronic configuration
Buffers	Solvation	Resonance and aromaticity
pH calculations	Drawing unit cells	Half-life time
Isomerism	Corrosion	Common ion effect
Drawing chemical structures	Equilibrium	Nucleophiles and electrophiles
Functional groups	Polarity	Writing mechanisms(eg S_N1)
Nomenclature	Lewis acids and bases	VSEPR rules
Oxidation numbers		
Balancing redox equations		
Electrolytes		

6.5 Questionnaires Employed

From the analysis of the tests and examination scripts, it was noticed that students had difficulties in many areas. Therefore, it was decided to seek the opinions of Level-1 Chemistry students in order to confirm that the extracted topics in table 6.3 were, in fact, the difficult topics. It was also hoped, from this investigation, to continue monitoring Level-1 Chemistry courses (General Chemistry and Chemistry-1), and to seek to develop strategies to help the students to overcome these difficulties.

The questionnaires were designed (two-sides of A-4 sheet) to cover four areas. The first side aimed to collect general information about the students and to measure their attitudes towards their school and university chemistry courses. This side of the questionnaires will be discussed in detail in chapter 7.

The second side of the questionnaire focussed on the difficult topics extracted from the previous analysis in section 6.4. Figures 6.1 and 6.2 show the format of the General Chemistry and Chemistry-1 questionnaires respectively. It aimed to measure the level of difficulty for some chemistry areas. Twenty five topics were listed in each questionnaire, the first fourteen topics were similar for both courses but the last eleven topics were different (see table 6.3 above). Students were asked to rate the various topics taught into one of three categories:

Easy	*"understood without difficulty"*
Moderate	*"had difficulties but I understand it now"*
Difficult	*"still do not understand it"*

If their answers were in the third category (difficult), they were asked to say why they found the topic difficult. Students were also given an opportunity to comment freely about their course and to suggest any improvements they felt would be helpful in order to decrease the difficulties and enhance learning (this will be discussed later in chapter 7).

Figure 6.1: General Chemistry Level of Difficulty Questionnaire

Please tick an appropriate box which indicates your opinion about the chemistry topics:

Easy	understood it without difficulties
Moderate	had difficulties but I understand it now
Difficult	still do not understand it

	Easy	Moderate	Difficult	If difficult, please say **why**
Reaction rate	☐	☐	☐	....
Arrhenius equation	☐	☐	☐	....
Entropy and disorder	☐	☐	☐	....
Enthalpy	☐	☐	☐	....
Free energy changes	☐	☐	☐	....
Buffers	☐	☐	☐	....
pH calculations	☐	☐	☐	....
Isomerism	☐	☐	☐	....
Drawing chemical structures	☐	☐	☐	....
Functional groups	☐	☐	☐	....
Nomenclature	☐	☐	☐	....
Oxidation numbers	☐	☐	☐	....
Balancing redox equations	☐	☐	☐	....
Electrolytes	☐	☐	☐	....
Writing chemical formulae	☐	☐	☐	....
Mole calculations	☐	☐	☐	....
Solution concentration	☐	☐	☐	....
Colloidal solutions	☐	☐	☐	....
Osmotic pressure	☐	☐	☐	....
Solvation	☐	☐	☐	....
Drawing unit cells	☐	☐	☐	....
Corrosion	☐	☐	☐	....
Equilibrium	☐	☐	☐	....
Polarity	☐	☐	☐	....
Lewis acids and bases	☐	☐	☐	....

Please suggest improvements for your chemistry course

....

....

....

Thank you for answering this questionnaire

Figure 6.2: Chemistry-1 Level of Difficulty Questionnaire

Please tick an appropriate box which indicates your opinion about the chemistry topics:

Easy	understood it without difficulties
Moderate	had difficulties but I understand it now
Difficult	still do not understand it

	Easy	Moderate	Difficult	If difficult, please say **why**
Reaction rate	☐	☐	☐	....
Arrhenius equation	☐	☐	☐	....
Entropy and disorder	☐	☐	☐	....
Enthalpy	☐	☐	☐	....
Free energy changes	☐	☐	☐	....
Buffers	☐	☐	☐	....
pH calculations	☐	☐	☐	....
Isomerism	☐	☐	☐	....
Drawing chemical structures	☐	☐	☐	....
Functional groups	☐	☐	☐	....
Nomenclature	☐	☐	☐	....
Oxidation numbers	☐	☐	☐	....
Balancing redox equations	☐	☐	☐	....
Electrolytes	☐	☐	☐	....
Lone pairs of electrons	☐	☐	☐	....
Lattice energy	☐	☐	☐	....
Markovnikov's rule	☐	☐	☐	....
Quantum numbers	☐	☐	☐	....
Electronic configuration	☐	☐	☐	....
Resonance and aromaticity	☐	☐	☐	....
Half-life time	☐	☐	☐	....
Common ion effect	☐	☐	☐	....
Nucleophiles and electrophiles	☐	☐	☐	....
Writing mechanisms (eg S_N1)	☐	☐	☐	....
VSEPR rules	☐	☐	☐	....

Please suggest improvements for your chemistry course

....

....

....

Thank you for answering this questionnaire

These questionnaires were distributed among Level-1 Chemistry students during the last week of term-2 (March, 1998) in the laboratory sessions. 165 first year General Chemistry students (a return rate of 66%) and 410 first year Chemistry-1 students (a return rate of 77%) answered the questionnaires. In the following section, students perceptions of difficulties will be explored in detail.

6.6 Questionnaires' Results and Discussion

An enormous amount of data was gathered from the questionnaires. Table 6.4 shows the complete analysis of the General Chemistry and Chemistry-1 students' responses including the areas which needed more attention. The results were also analysed according to students' comments about why they categorise some topics as difficult. A detailed analysis of the main findings is given in the following sub-sections.

6.6.1 Students Responses

(a) Responses to the Same Topics in Both Courses (General Chemistry and Chemistry-1)

Table 6.4 (a) shows the percentages of students responses, in both courses, to the first fourteen topics listed in the questionnaires. In every case, what is being shown is the percentage of students who have indicated that they found the topic difficult and that they still did not understand it. A much higher proportion found the various topics difficult but managed to make sense of them eventually. In addition, it shows the percentages of students who had indicated that they found the topic easy and they grasped it without difficulty. The following conclusions can be drawn:

(1) *In all cases, as expected, Chemistry-1 students found the topics easier than their counterparts in General Chemistry except "pH calculations" (Chemistry-1 course looks at topics more deeply as the students are more experienced in chemistry).*

(2) *Students indicated some topics as difficult probably due to the need for mathematics, such as "enthalpy", "entropy", "free energy changes", "pH calculations", and "mole calculations".*

(3) *Over 30% of the students in the two classes indicated that they understood the following topics without difficulties: "reaction rates", "drawing chemical structures", "functional groups", and "balancing redox equations".*

(4) *In General Chemistry, seven out of fourteen topics were indicated as difficult (topics where students still did not understand them) by more than 20% of the students. It was also seen that another two topics were showing a noticeable level of difficulty ("isomerism" 19% and "pH calculations" 18%). By contrast, Chemistry-1 students found only two topics difficult, one of them, "buffers", shared with the General Chemistry students.*

Table 6.4: Percentage Responses of Level-1 Chemistry Students 1997/98 (Areas of Perceived Difficulty)

Topics	Easy		Moderate		Difficult		χ^2 between GC&C-1 (sig at)	Topics Causing Greatest Concern	
	GC	C-1	GC	C-1	GC	C-1		GC	C-1
(a) Both Courses									
Reaction rate	32	36	53	50	15	12	1.79		
Arrhenius equation	3	25	58	61	39	11	79.63 (0.1%)	√	
Entropy and disorder	7	35	61	49	32	13	58.98 (0.1%)	√	
Enthalpy	15	41	62	49	23	8	50.41 (0.1%)	√	
Free energy changes	13	30	59	57	28	11	33.26 (0.1%)	√	
Buffers	10	20	70	57	21	22	10.06 (1%)	√	√
pH calculations	24	20	58	51	18	28	6.44 (5%)		√
Isomerism	17	46	64	46	19	7	49.59 (0.1%)		
Drawing chemical structures	31	55	55	41	14	3	44.97 (0.1%)		
Functional groups	33	50	55	46	12	3	28.59 (0.1%)		
Nomenclature	10	65	58	31	31	2	181.10 (0.1%)	√	
Oxidation numbers	19	43	53	47	28	9	52.65 (0.1%)	√	
Balancing redox equations	36	45	50	46	15	8	7.67 (5%)		
Electrolytes	12	14	77	72	12	10	0.95		
(b) General Chemistry Only									
Writing chemical formulae	37		54		9				
Mole calculations	20		58		22			√	
Solution concentration	19		70		11				
Colloidal solutions	4		62		34			√	
Osmotic pressure	16		64		19				
Solvation	7		71		22			√	
Drawing unit cells	33		53		15				
Corrosion	23		62		15				
Equilibrium	20		64		16				
Polarity	16		66		18				
Lewis acids and bases	13		62		25			√	
(c) Chemistry-1 Only									
Lone pairs of electrons		51		42		6			
Lattice energy		26		62		10			
Markovnikov's rule		51		41		7			
Quantum numbers		33		48		16			
Electronic configuration		53		37		8			
Resonance and aromaticity		13		68		15			
Half-life time		47		45		7			
Common ion effect		11		65		15			
Nucleophiles and electrophiles		30		57		11			
Writing mechanisms (eg SN1)		14		56		28			√
VSEPR rules		40		49		9			

Notes: *GC General Chemistry* *C-1 Chemistry-1*

√ *Topics where **OVER** 20% of the sample indicated that they had never understood it.*

For $df = 2$ (two-tailed) χ^2 critical at 5% level = 5.99, at 1% level = 9.21, and at 0.1 % =13.82

(5) *Statistical analysis (χ^2) indicates that the views of General Chemistry and Chemistry-1 students:*

   (a) do not differ significantly in *"reaction rate" and "electrolytes".*

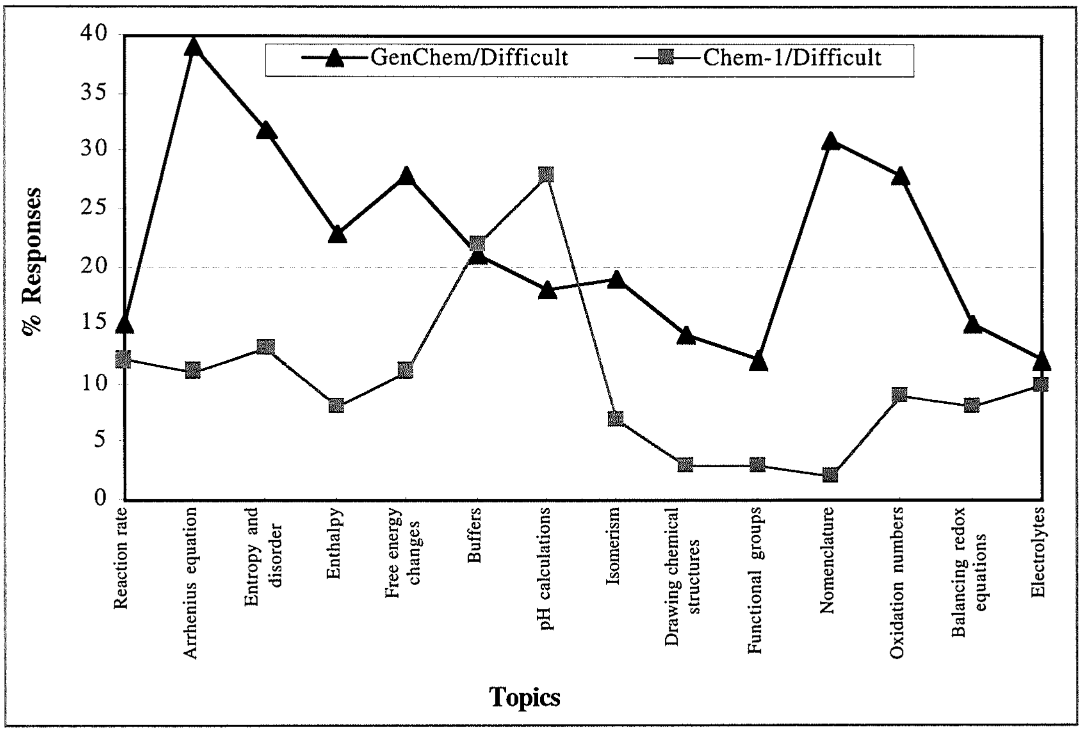
   (b) differ significantly at 5% level in *favour of General Chemistry for "pH calculations" and* in *favour of Chemistry-1 for "Balancing redox equations"*

   (c) differ significantly at 1% level for *"Buffers".*

   (d) differ significantly at 0.1% level in *favour of Chemistry-1 for "Arrhenius equation", "Entropy and disorder", "Enthalpy", "Free energy changes", "Isomerism", "Drawing chemical structures", "Functional groups", "Nomenclature", and "Oxidation numbers".*

The percentage of responses for Level-1 Chemistry students (General Chemistry and Chemistry-1) are presented in figure 6.3.

Figure 6.3: Level-1 Chemistry Students' Responses to the Same Topics (1997/98) (Topics still difficult)



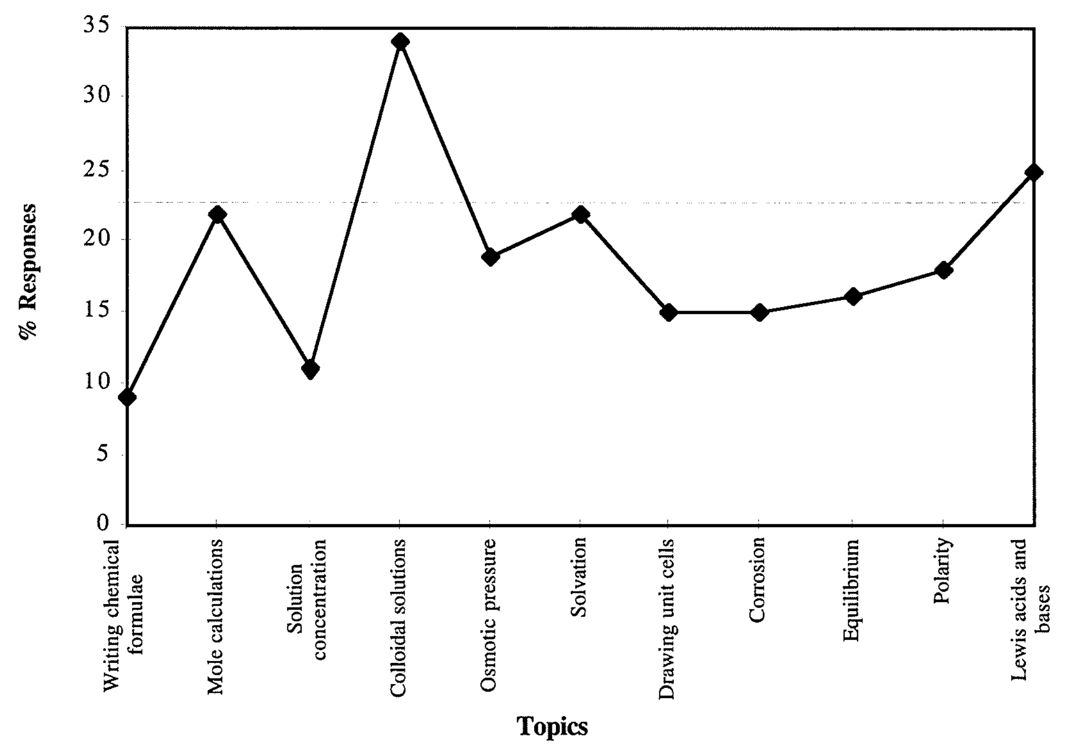
(b) General Chemistry Students' Responses to Their Own Topics

The percentages of the responses to the last eleven topics in the General Chemistry questionnaire were calculated and shown in table 6.4 (b). It was noticed that:

Four topics out of the eleven were seen as difficult. More than 20% of the students indicated that they still did not understand them. These topics are the "mole calculations", "colloidal solutions", "solvation", and "Lewis acids and bases". It was also seen that another two topics were showing a noticeable level of difficulty ("osmotic pressures" 19% and "polarity" 18%).

The percentage responses for General Chemistry students are represented in figure 6.4.

Figure 6.4: General Chemistry Students' Responses to their Own Topics (1997/98) (Topics still difficult)



In general, the following findings are noticed from the General Chemistry course results:

(1) *From twenty five topics, over 30% of the General Chemistry students indicated that they found the following topics easier than others: "reaction rate", "drawing chemical structures", "functional groups", "balancing redox equations", "writing chemical formulae", and "drawing unit cells".*

(2) *In all topics, it can be seen that at least 50% of the General Chemistry students had difficulties, although many managed to grasp them later.*

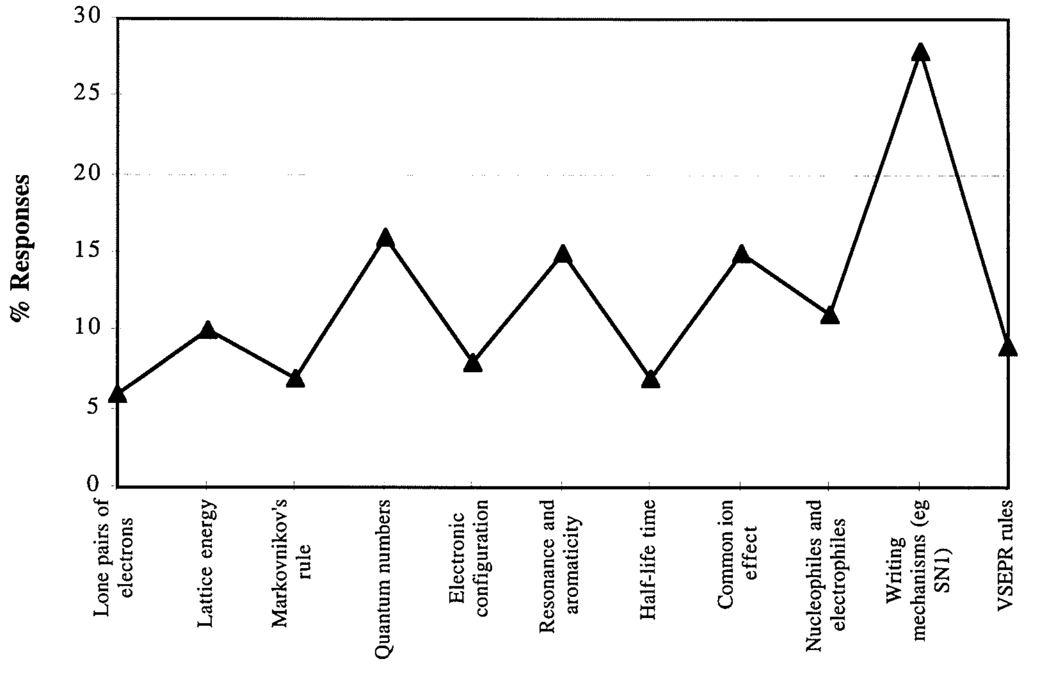
(c) Chemistry-1 Students' Responses to Their Own Topics

The percentages of the Chemistry-1 students responses to the last eleven topics in the Chemistry-1 questionnaire were calculated and shown in table 6.4 (c). It was noticed that:

Only "writing mechanisms (e.g. S_N1)" was seen as difficult by more than 20% of the students. They still did not understand it.

In general, from twenty five topics, over 50% of the Chemistry-1 students indicated that they found the following topics easier than others: *"drawing chemical structures", "functional groups", "nomenclature", "lone-pairs of electrons", "Markovnikov's rule", and "electronic configurations".* The percentage responses for Chemistry-1 students are represented in figure 6.5.

Figure 6.5: Chemistry-1 Students' Responses to their Own Topics (1997/98)
(Topics still difficult)



Looking at the above analysis, it is noticed that some topics need more attention. Table 6.5 displays the topics which were causing concern in both courses based on:

(1) *Students' perceptions where over 20% of the students indicate that they had never understood the topics. 20% was chosen somewhat arbitrarily and indicates a considerable minority having problems.*

(2) *The difference in the values of % responses between students with "easy" responses and those with "difficult" was greater than 5%.*

In chapter 8, these topics will be studied carefully in order to help General Chemistry students to grasp them easily.

Table 6.5: Difficult Topics Causing Greatest Concern (1997/98)

General Chemistry	***Chemistry-1***
Arrhenius equation	Buffers
Entropy and disorder	pH calculations
Enthalpy	Writing mechanisms (e.g. SN1)
Free energy changes	
Buffers	
Nomenclature	
Oxidation numbers	
Mole calculations	
Colloidal solutions	
Solvation	
Equilibrium	
Lewis acids and bases	

In chapter 8, these topics will be studied carefully in order to help General Chemistry students to grasp them easily.

6.6.2 Student Comments on Reasons for Difficulties

In the free response space at the end of each questionnaire, 806 comments were received, many students writing more than one comment. These comments highlighted some sources which caused difficulties:

(1) Curriculum content order.
(2) Overload of working space.
(3) Language and communication.
(4) Concept formation.
(5) Motivation.

Here are some typical comments:

"The concepts are difficult to relate to the questions".
"No clear definitions were provided for the differences between types of isomers".
"Never done it before".
"Not enough information given, not enough time spent".
"I can't visually imagine".
"More examples (needed) with clear calculation steps".
"Too many formulae and equations".
"Too many steps and techniques".
"A lot of technical terms".
"Too many names to remember".
"Similar symbols confusing".
"Course went too quickly, not explained clearly, not enough practice".
"I just can not apply it to examples".
"Topic boring, was not clear".
"Never been able to".
"Hard to remember how to do all calculations".

In many cases, the students' comments were really quite constructive and many lecturers have found this feedback particularly valuable, especially where it identified the problems behind these difficulties which could be easily remedied (more comments in Appendices F1a and F1c).

6.6.3 Main Findings from the Questionnaires

With 575 completed questionnaires, some clear trends did appear to emerge and these have been recorded.

(1) In his early study, Johnstone (1974) found that the most difficult topics for students at school were the mole, chemical formulae, equations, and, in organic chemistry, condensation and hydrolysis reactions. His results showed that difficult topics persist to university level. In this study, many of his findings still occur, despite syllabuses changes at both school and university.

(2) In looking at perceived difficulties, the General Chemistry students identified, as might be expected, more difficult topics than their counterparts in Chemistry-1. As a general impression, physical and inorganic chemistry seem to generate more problems than organic, although it has to be noted that mathematical problems were identified in those topic areas (such as enthalpy, mole calculations, pH calculations). There are also a few specific areas of mathematical difficulty such as logarithms.

(3) In looking overall at the student comments on reasons for topic difficulties, changes to the teaching approach were suggested that might assist in making the topics more accessible. This was perhaps more marked with General Chemistry students.

6.7 Comparison between Exam Results and Questionnaire Findings

It is clear that the views of students supported many of the conclusions that could be drawn from the study of the examination scripts. They were finding topics difficult that they thought were difficult with a considerable measure of consistency (High "easy" ≡ high marks ≡ low "difficult"). These similarities and the patterns of difficulty that emerged can be summarised as follows:

(1) In the General Chemistry course, it is clear that the mark percentages of the students and their responses as "easy" to the same topic are found in few topics, such as: isomerism, drawing unit cells, mole calculations, oxidation numbers, pH calculations, rate of the reaction, writing chemical formulae, and solution concentration.

(2) In the Chemistry-1 course, similarities between students' achievements and responses were shown in some topics such as: activation energy, electronic configuration, naming organic compounds, and lattice energy.

Table 6.6: Comparison Between Topics and Response Percentages (1997/98)

Topics	Examinations				Questionnaire		
	T2	T3	T4	January	Easy	Moderate	Difficult
General Chemistry							
Oxidation state	11			28	19	53	28
Draw isomers / inorganic	22				17	64	19
Writing formula for compounds				43	37	54	9
Draw unit cell				30	33	53	15
[A]			13		19	70	11
Rate of reaction		44			32	53	15
pH calculation			9		24	58	18
Functional groups			45		33	55	12
Mole calculation				8	20	58	22
Balancing redox				17	36	50	15
Chemistry-1							
Activation energy				33	25	61	11
Naming organic compounds				70	65	31	2
Electronic configurations			63		53	37	8
Lattice energy				40	26	62	10
Mechanism				37	14	56	28

Table 6.6 displays the results from the analysis of the exams scripts and students responses in the questionnaires. For more details see Appendix I.

In general, it is clear that, for some topics, exam success (or lack of it) is matched by students' perception of difficulty. For other topics, students' perception does not appear to match performance. In seeking to develop materials to assist students in difficult topics (see chapter 8), the perception of students and their exam performances were both taken into account.

6.8 Conclusions

This study highlights some of the most difficult topics in Level-1 Chemistry courses (General Chemistry and Chemistry-1), as perceived by students. Some of these topics are similar to those observed by Johnstone twenty five years ago. In the General Chemistry course, the lack of previous knowledge and some mathematical skills are areas causing problems. Lack of motivation was also observed. In chapter 8, teaching materials for General Chemistry students are introduced in order to remedy some of these difficulties.

Chapter Seven

STUDENTS' ATTITUDES TOWARDS CHEMISTRY

The attitudes held by Level–1 Chemistry students towards the subject of chemistry, the courses they undertake (Chemistry–1 and General Chemistry), and their approach to that study could make considerable differences in determining success or failure for them.

The General Chemistry course is mainly made up of students who have, by and large, made a conscious decision not to continue chemistry studies beyond that initial university year as well as those with limited chemistry experience, poor or no previous chemistry experience. The backgrounds and future aspirations of such students could potentially generate certain (negative) attitudes to chemistry and their ability to study it, which may hinder their progress in the course.

7.1 Attitude

A great number of publications about attitude studies are reviewed by Gardner (1975) and Schibeci (1984). There is a lack of agreement about the definition for the term attitude. The term is a very broad one and has been the subject of extended debate. Researchers have used it in many different contexts without reaching a consensus. Thurstone (1929) described attitude as the degree of positive or negative affects associated with some psychological objects. This description revealed an affective basis denoted by the predisposition to react negatively or positively in some degree towards an object. Likert (1932) used a much less precise definition, referring to a certain range within which responses move. Allport (1935) gave a definition which combines both Thurstone's and Likert's ideas when he talks about a "mental and neural state of readiness to respond, organised through experience, exerting a directive and/or dynamic influence on behaviour". His definition was an attempt to put together the different contemporary notions, and regards attitude as a variable which predisposes behaviour. It is a long lasting definition.

Many authors define attitude as a product of the cognitive process. Krech (1946) suggested a definition emphasising the aspects of learning as: "an enduring organisation of motivational, emotional, perceptual, and cognitive processes with respect to some aspect of the individual's world". Cook and Sellitz (1964) believed that attitudes, on their own, do not control behaviour but enter into the determination of a variety of behaviours along with other influences.

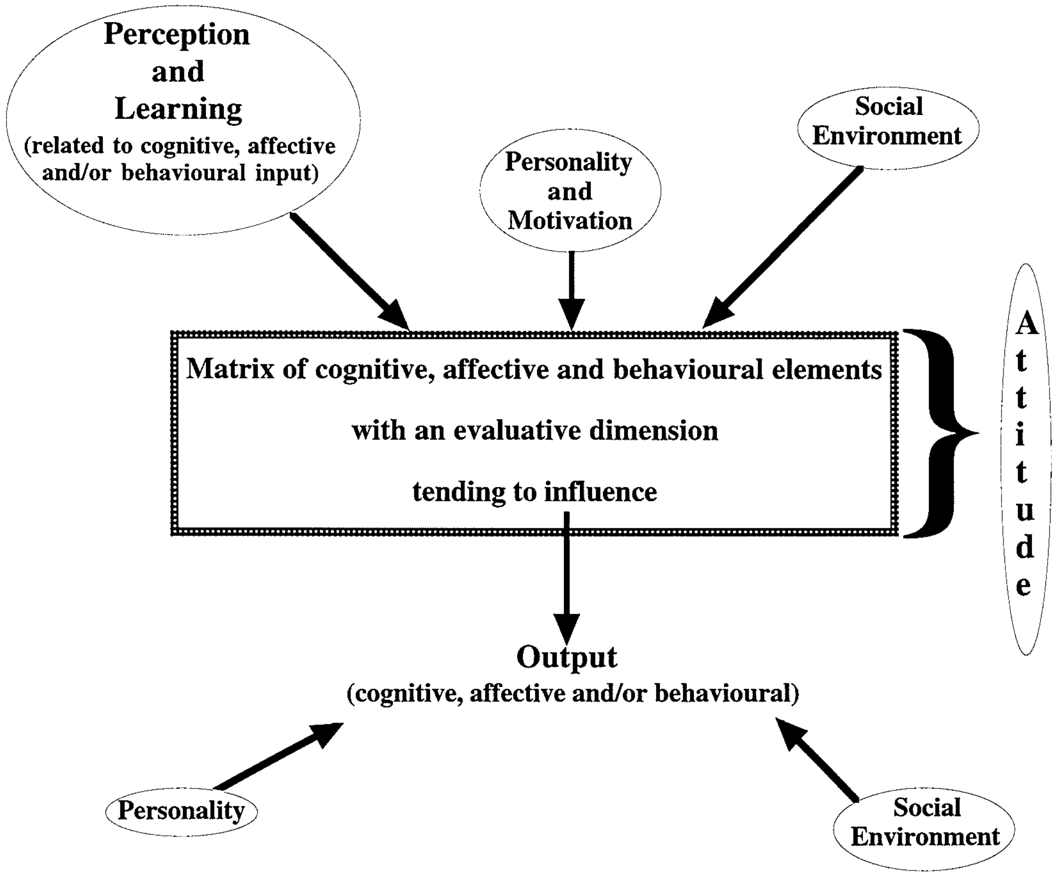
The various definitions reflect the psychological backgrounds of the writers—latent constructs, cognitive processes, or behavioural aspects all being used as bases for definitions.

Reid (1978) reviewed many of the issues about attitude proposed by various researchers and writers over the years. He noted that most of them agreed that attitudes are composed of three components:

Cognitive	*relates to people's knowledge and their thought about the attitude object.*
Affective	*consists of emotions or feelings that people have in relation to the attitude object.*
Behavioural	*encompasses people's actions with respect to the attitude object.*

He came up with a working definition of attitude (figure 7.1).

Figure 7.1: A Working Definition of Attitude



The above figure takes into account the cognitive influences in attitude development, the construct nature of attitudes, and the readiness to respond outcomes. It also warns against deducing an attitude from behaviour patterns. Attitudes have a functional purpose, but circumstances of personality and social environment may so alter behaviour (by, for example, suppressing behaviour, that it may have little obvious connection with any real, underlying attitudes).

Social psychology has moved enormously in the past twenty five years (Eagly and Chaiken, 1993). All knowledge, feelings, and behaviour provide the opportunity to evaluate, the development of an attitude being some form of expression of that evaluation. This has led to the modern understanding of attitudes in terms of evaluations which involve cognitive and affective components.

Gardner (1975) subdivided science-related attitudes into two major categories:

Attitudes to Science	*for which there is always some distinct attitude object (e.g. enjoyment, interest, etc).*
Scientific Attitudes	*styles which the scientist is presumed to display (e.g. openmindness, honesty, skepticism, etc).*

Allport's (1935) statement illustrates the more global nature of earlier definitions. The key feature that goes beyond the Allport type of definition is "evaluation" (making judgments, weighing things up or comparing). Attitude to science (chemistry) is the main theme of this chapter.

7.2 Attitude Measurements

Every aspect featured within the various attitude theories is complicated and this makes measuring attitudes difficult. Many methods have been used to attempt to measure attitudes, but, in an educational context, there are two main methods of measuring a person's attitude, and what determines a person's choice: interviewing or using some form of questionnaire.

It is assumed that the behaviour in responding to the question is an indication of the attitude held by the person. Attitudes are not directly measurable and they must be inferred or deduced from behaviour. There is no certainty that the inference or deduction is correct and no method is perfect. Therefore, it is necessary to use several methods.

The methods used here depend on the work developed many years ago by Likert (1932) and Osgood (1957). Adaptations of their work have stood the test of time.

7.2.1 Likert's Method

This is traditionally used in a scaling methodology but can be more useful when data are handled differently, each item being analysed individually. The modification used here is now well established. Appropriate questions are gathered and tried out with sample groups. Responses typically follow patterns like: strongly agree, agree, uncertain, disagree, strongly disagree. The validity is taken as face validity (views of a few experts were sought) and is not based on statistical correlation. Questions are analysed separately using a statistic like chi-squared. The method gives considerable detail and there is no dependence on uncertain statistical assumptions. The weakness is that the method gives no final score in that each item is analysed apparently (Reid, 1978). Here is an example:

Below is a statement about your chemistry course. Put a tick in the box to indicate your agreement or otherwise.

	Strongly agree	Agree	Disagree	Strongly disagree
Note-taking is easy	☐	☐	☐	☐

Analysis

For this statements, suppose that the following responses were gathered:

General Chemistry	10	60	80	10
Chemistry-1	28	80	190	55

It is possible to compare the frequency distribution from the two classes using chi-squared (χ^2). The value of χ^2 is equal to 17.17 and this indicates that these two distributions could happen by chance less than 0.1% of the time (for df = 3, χ^2 critical at 0.1% level = 16.27).

7.2.2 Osgood's Method

This method was originally not developed for attitude measurement but has subsequently been found to be very useful for this purpose. Phrase pairs that are opposite in meaning are gathered. These phrase pairs (or word pairs) are evaluative comments on the attitude object. A series of unlabelled boxes (anything from 3 to 7 in number) is placed between the word pairs and responses are made by ticking the box that most fits the subject's opinion. Validity is taken as face validity and not based on statistical correlation. Questions are analysed separately using a statistic like chi-squared. It gives considerable detail, but gives no final score. This method is more limited than the Likert approach because words or short phases only are used but it is faster for students to respond (Reid, 1978). Here is an example:

If you had to describe "a racing car" you could do it like this:

quick	√	☐	☐	☐	☐	☐	*slow*
important	☐	☐	√	☐	☐	☐	*unimportant*
safe	☐	☐	☐	☐	√	☐	*dangerous*

The positions of the ticks between the word pairs show that you consider it as very quick, slightly more important than unimportant, and quite dangerous.

7.3 The Scope and Aims of the Current Study

This survey seeks to provide insight into the attitudes and perceptions of Level–1 Chemistry students (Chemistry–1 and General Chemistry) at the University of Glasgow, related to their studies in chemistry. Their attitude towards their previous school chemistry course, their current university chemistry course, and their representative view of the factors influencing students at university are all considered.

This study aims to answer the following questions:

(1) *Is there any difference between Chemistry–1 and General Chemistry students in their attitudes towards chemistry?*

(2) *Are there any gender differences in students' attitudes towards chemistry?*

(3) *What is the relationship between students' attitudes towards their school and university chemistry courses?*

7.4 Questionnaires Employed

The questionnaires distributed among Level–1 Chemistry students in March 1998 were designed to explore two main issues: firstly, students rating of their chemistry topics according to difficulty (the theme of chapter 6). Secondly, in this current chapter, it is envisaged that students' previous chemistry experiences may have had an influence on their attitudes towards university chemistry. Written comments were also analysed in order to look at the courses through the eyes of the students. The attitudes of Level–1 Chemistry students towards their school and university chemistry courses were studied and variations in their chemistry background and gender were investigated. The results will be analysed using simple statistics, tables and graphs.

The questionnaire was designed to explore students' perceptions of the effectiveness of Level–1 Chemistry courses and to highlight specific aspects of any given course. It was designed on a 4 and 6-point rating scale to avoid any totally neutral category which students tend to chose to avoid making a judgment. This questionnaire addressed a number of factors, such as the assessment methods used, preparation and organisation of the course, course pace, etc. Figure 7.2 shows the questionnaire format.

Questions 5, 6, and 7 were designed following Osgood's method while the last one (Q8) followed Likert's method.

In order to fit in with the departmental timetable, it was arranged that questionnaires would be distributed among Level–1 Chemistry students during the last week of term 2 (March, 1998) in the laboratory sessions.

Figure 7.2: Attitudes Towards Chemistry Questionnaire

Centre for Science Education

This questionnaire aims to seek your opinions about your chemistry course.
Your responses are strictly CONFIDENTIAL and will not be seen by any member of staff.

1. Are you: ☐ Male ☐ Female
2. What secondary school did you attend? ....
3. When you first entered Glasgow University, what was your:
   Highest Chemistry Qualifications: ....
   Highest Mathematics Qualifications: ....
   Intended honours subject(s): ....
4. Which other subject(s) are you studying: ....

This is an example. If you had to describe "a racing car" you could do it like this:

quick	☑	☐	☐	☐	☐	☐	*slow*
important	☐	☐	☑	☐	☐	☐	*unimportant*
safe	☐	☐	☐	☐	☑	☐	*dangerous*

The positions of the ticks between the word pairs show that you consider it as very quick, slightly more important than unimportant, and quite dangerous.

Use the same method of ticking to answer the questions 5, 6, 7.

5. What are your opinions about your **School Chemistry Course**?

I liked Chemistry	☐	☐	☐	☐	☐	☐	I hated Chemistry
boring subject	☐	☐	☐	☐	☐	☐	interesting subject
easy subject	☐	☐	☐	☐	☐	☐	complicated subject
prepared me well for University	☐	☐	☐	☐	☐	☐	prepared me badly for University
I disliked the teacher	☐	☐	☐	☐	☐	☐	I liked the teacher
enjoyable lessons	☐	☐	☐	☐	☐	☐	boring lessons

6. What are your opinions about **University Chemistry**?

I feel I am coping well	☐	☐	☐	☐	☐	☐	I feel I am not coping well
I am not enjoying the subject	☐	☐	☐	☐	☐	☐	I am enjoying the subject
I find the subject easy	☐	☐	☐	☐	☐	☐	I find the subject hard
I am growing intellectually	☐	☐	☐	☐	☐	☐	I am not growing intellectually
I am not obtaining new skills	☐	☐	☐	☐	☐	☐	I am obtaining a lot of new skills
I am enjoying practical work	☐	☐	☐	☐	☐	☐	I hate practical work
I am getting worse at the subject	☐	☐	☐	☐	☐	☐	I am getting better at the subject
It is definitely "my" subject	☐	☐	☐	☐	☐	☐	I am wasting my time in this subject

7. How did you find the **Chemistry Course at the University** ?

Lectures boring	☐	☐	☐	☐	☐	☐	Lectures interesting
Laboratories interesting	☐	☐	☐	☐	☐	☐	Laboratories boring
Tutorials helpful	☐	☐	☐	☐	☐	☐	Tutorials waste of time
Course too mathematical	☐	☐	☐	☐	☐	☐	Course not mathematical enough
Course difficult	☐	☐	☐	☐	☐	☐	Course easy
Work level very demanding	☐	☐	☐	☐	☐	☐	Work level undemanding

8. Thinking about your **Chemistry Course**, tick the boxes below to reflect your opinions

	Strongly agree	Agree	Disagree	Strongly disagree
I feel the assessment methods used were good	☐	☐	☐	☐
The time demand was NOT reasonable for me	☐	☐	☐	☐
I found a good support from the academic staff	☐	☐	☐	☐
I found the course well organised	☐	☐	☐	☐
I think chemistry will provide poor career opportunities	☐	☐	☐	☐
I found the course challenging	☐	☐	☐	☐
I found note-taking difficult	☐	☐	☐	☐
The course covered too many topics	☐	☐	☐	☐
The course is a good basis for studying other subjects	☐	☐	☐	☐

7.5 Observations and Results

In this section, the methods used for data analysis and the results of students' evaluation of their Level–1 Chemistry courses will be presented and discussed in detail. 575 students responded to the questionnaire; 165 first year General Chemistry students (return rate 66%) and 410 first year Chemistry–1 students (return rate 77%). Table 7.1 shows the breakdown of Level–1 Chemistry students based on their gender and chemistry entry qualifications. The raw frequencies and percentages of the recorded responses for the questionnaire are presented in tables 7.2 to 7.5. In the questionnaire, the polarity of the statements was varied to encourage students to respond in a more thoughtful way. For example,

> In Q6. What are your opinions about **University Chemistry**?
>
> I feel I am coping well ☐☐☐☐☐☐ I feel I am not coping well
> I am not enjoying the subject ☐☐☐☐☐☐ I am enjoying the subject

Table 7.1: Breakdown of Level–1 Chemistry Students (1997/98)

		Chemistry Entrance Qualifications	Class N	Class (%)	Questionnaire N	Questionnaire (%)
Chem-1	All		519	(100)	410	(100)
	Male		224	(43.2)	165	(40.2)
	Female		295	(56.8)	245	(59.8)
		Certificate of Sixth Year Studies	177	(33.9)	138	(33.7)
		Scottish Higher Grade	242	(46.6)	204	(49.8)
Gen Chem	All		229	(100)	165	(100)
	Male		89	(38.9)	56	(33.9)
	Female		140	(61.1)	109	(66.1)
		Upper Level	119	(52.0)	100	(60.6)
		Lower Level	95	(41.4)	50	(30.3)
		Scottish Higher Grade	109	(47.6)	94	(57.0)
		Scottish Standard Grade	26	(11.4)	20	(12.1)
		Alternative Qualifications	18	(7.9)	6	(3.6)
		No Formal Qualifications	26	(11.4)	15	(9.1)

Level–1 Chemistry courses were compared to each other with regard to gender differences. Whenever the data consists of frequency counts of the number of times different events occur, the χ^2 test can be used to compare the proportions of these events in two independent samples (see Appendix E1). Response frequencies and percentages for each question were used to compare the two courses in order to determine whether the difference between them was statistically significant.

In the following sub-sections the responses to each question will be analysed.

(1) What are your opinions about your School Chemistry Course?

I liked Chemistry	☐	☐	☐	☐	☐	☐	I hated Chemistry
boring subject	☐	☐	☐	☐	☐	☐	interesting subject
easy subject	☐	☐	☐	☐	☐	☐	complicated subject
prepared me well for University	☐	☐	☐	☐	☐	☐	prepared me badly for University
I disliked the teacher	☐	☐	☐	☐	☐	☐	I liked the teacher
enjoyable lessons	☐	☐	☐	☐	☐	☐	boring lessons

The purpose of this question is to find out the effect of the attitudes developed by students during their schooling on their present chemistry study. Six opposed statements were used on a 6-point scale. For each of the Level–1 Chemistry courses in the sample, the frequencies and percentages of responses were calculated (see table 7.2). No responses were received from students who did no chemistry at school.

In General Chemistry, it can be seen that students like their teacher but they find the subject complicated. In general, students' opinions can be summarised as follows: *School chemistry was a complicated and boring subject which prepared them badly for university.*

In Chemistry–1, it can be seen that students like their teacher but they find the subject complicated. In general, students' opinions can be summarised as follows: *School chemistry was an interesting subject with enjoyable lessons. It prepared them well for the university. They liked chemistry and its teacher, but the subject was complicated.*

If we compare the responses of the two groups, it is clear that Chemistry–1 students have more positive attitudes towards their school chemistry courses than their General Chemistry counterparts. The comparison between the responses of Chemistry–1 and General Chemistry students (using chi-squared) revealed that there was a significant difference in favour of Chemistry–1 for all statements at 0.1% level except in 'I like the teacher' which is significant at 5% level.

Gender differences are also explored and the results are analysed by using chi-squared (see table 7.3). The results can be summarised as follows:

In general, female Level–1 Chemistry students found their school chemistry course to be a more complicated subject than male students (significant at 0.1% level). The same results are found for female Chemistry–1 students at 1% level. No other significant differences were found in General chemistry.

Figure 7.3 shows Level–1 Chemistry students' % responses distribution.

Table 7.2: **Level-1 Chemistry Students' (1997/98) Responses to: What are your opinions about your School Chemistry Course?**

Students were asked to respond on a six point scale to various aspects. This is summarised on a three point scale, all questions polarised the same way.

	χ^2 between Chem-1 & Gen Chem		Positive opinion N	(%)	Neutral opinion N	(%)	Negative opinion N	(%)
1.	75.18 (sig at 0.1%)		I liked Chemistry				I hated Chemistry	
		Chem 1	252	(61)	121	(30)	33	(8)
		Gen Chem	38	(23)	69	(42)	46	(27)
2.	58.80 (sig at 0.1%)		Interesting subject				Boring subject	
		Chem 1	213	(52)	157	(38)	34	(8)
		Gen Chem	32	(19)	77	(47)	42	(25)
3.	22.26 (sig at 0.1%)		Easy subject				Complicated subject	
		Chem 1	67	(16)	215	(52)	123	(30)
		Gen Chem	10	(6)	65	(39)	76	(46)
4.	58.16 (sig at 0.1%)		Prepared me well for the University				Prepared me badly for the University	
		Chem 1	206	(50)	148	(36)	50	(12)
		Gen Chem	23	(14)	98	(59)	30	(18)
5.	7.15 (sig at 5%)		I liked the teacher				I disliked the teacher	
		Chem 1	273	(67)	80	(20)	53	(13)
		Gen Chem	85	(52)	45	(27)	21	(13)
6.	27.20 (sig at 0.1%)		Enjoyable lessons				Boring lessons	
		Chem 1	183	(45)	171	(42)	50	(12)
		Gen Chem	33	(20)	87	(53)	31	(19)

Notes: For $df = 2$ (two-tailed) χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1% level = 13.82

Table 7.3: Level-1 Chemistry Students' Responses to "*What are your opinions about your* School Chemistry Course?" Based on Gender Differences (1997/98)

(a) All Level–1 Students

	$\chi 2$ between Males and Females	Responses: Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	1.99	117	173	74	116	25	54
(2)	2.82	100	145	81	153	33	43
(3)	14.69 (sig at 0.1%)	36	41	123	157	56	143
(4)	2.42	97	132	91	155	27	53
(5)	2.02	134	224	55	70	26	47
(6)	3.28	78	138	110	148	27	54

	Response Percentages (%): Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	20.3	30.1	12.9	20.2	4.3	9.4
(2)	17.4	25.2	14.1	26.6	5.7	7.5
(3)	6.3	7.1	21.4	27.3	9.7	24.9
(4)	16.9	23.0	15.8	27.0	4.7	9.2
(5)	23.3	39.0	9.6	12.2	4.5	8.2
(6)	13.6	24.0	19.1	25.7	4.7	9.4

(b) Chemistry-1 Students

	$\chi 2$ between Males and Females	Responses: Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	0.21	104	148	47	74	13	20
(2)	2.46	88	125	57	100	17	17
(3)	11.82 (sig at 1%)	32	35	97	118	34	89
(4)	1.08	88	118	57	91	18	32
(5)	1.09	110	163	35	45	18	34
(6)	1.52	69	114	75	96	19	31

	Response Percentages (%): Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	23.2	22.9	48.2	38.5	21.4	31.2
(2)	21.4	18.3	42.9	48.6	28.6	23.9
(3)	7.1	5.5	46.4	35.8	39.3	49.5
(4)	16.1	12.8	60.7	58.7	16.1	19.3
(5)	42.9	56.0	35.7	22.9	14.3	11.9
(6)	16.1	22.0	62.5	47.7	14.3	21.1

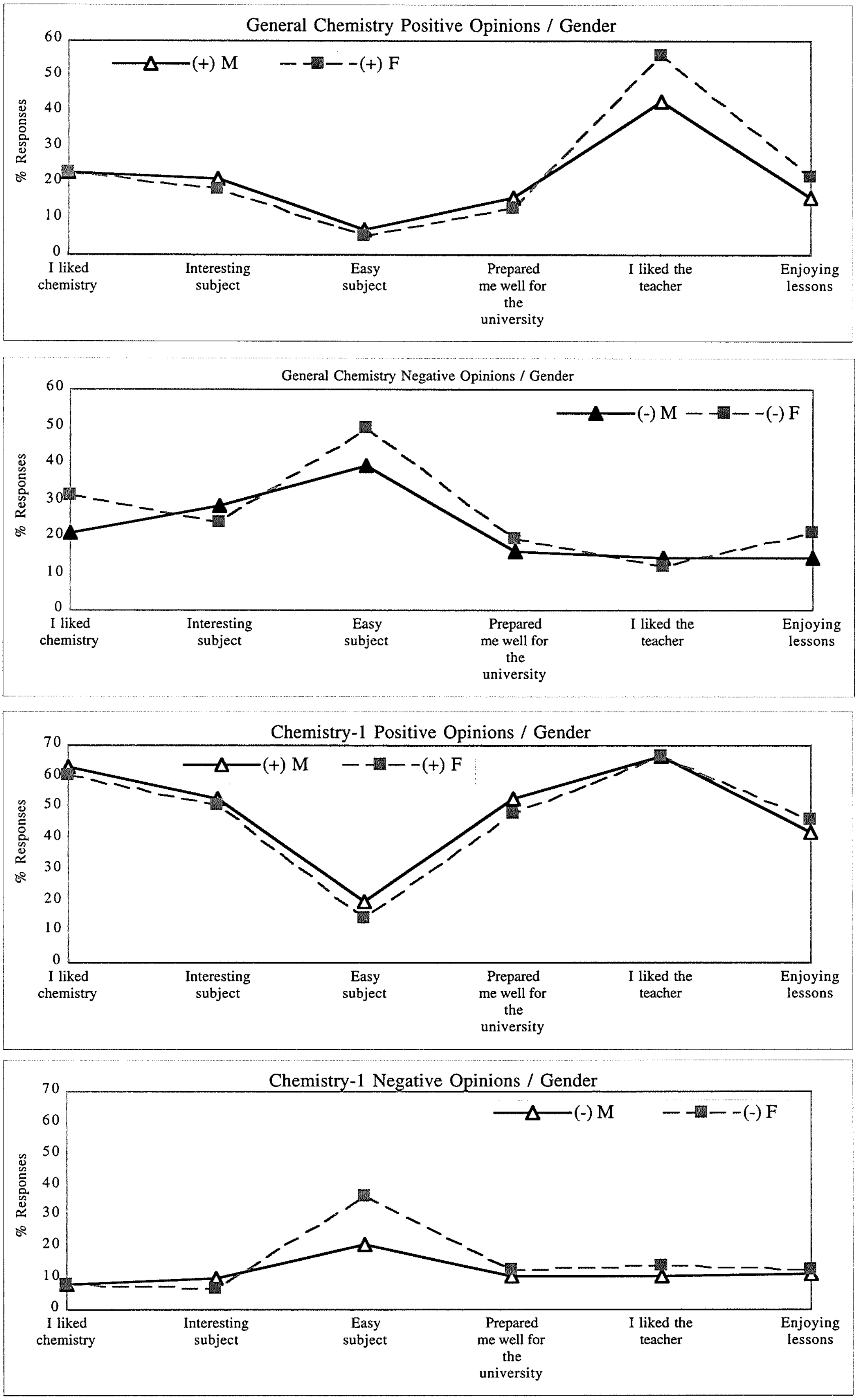
(c) General Chemistry Students

	$\chi 2$ between Males and Females	Responses: Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	2.09	13	25	27	42	12	34
(2)	0.75	12	20	24	53	16	26
(3)	2.04	4	6	26	39	22	54
(4)	0.49	9	14	34	64	9	21
(5)	3.57	24	61	20	25	8	13
(6)	3.07	9	24	35	52	8	23

	Response Percentages (%): Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	23.2	22.9	48.2	38.5	21.4	31.2
(2)	21.4	18.3	42.9	48.6	28.6	23.9
(3)	7.1	5.5	46.4	35.8	39.3	49.5
(4)	16.1	12.8	60.7	58.7	16.1	19.3
(5)	42.9	56.0	35.7	22.9	14.3	11.9
(6)	16.1	22.0	62.5	47.7	14.3	21.1

Notes: For $df = 2$ (two-tailed) χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1% level = 13.82

Figure 7.3: Level–1 Chemistry Students Responses (1997/98) to:
What are your opinions about your School Chemistry Course?



(2) What are your opinions about University Chemistry?

I feel I am coping well	☐ ☐ ☐ ☐ ☐ ☐	I feel I am not coping well
I am not enjoying the subject	☐ ☐ ☐ ☐ ☐ ☐	I am enjoying the subject
I find the subject easy	☐ ☐ ☐ ☐ ☐ ☐	I find the subject hard
I am growing intellectually	☐ ☐ ☐ ☐ ☐ ☐	I am not growing intellectually
I am not obtaining new skills	☐ ☐ ☐ ☐ ☐ ☐	I am obtaining a lot of new skills
I am enjoying practical work	☐ ☐ ☐ ☐ ☐ ☐	I hate practical work
I am getting worse at the subject	☐ ☐ ☐ ☐ ☐ ☐	I am getting better at the subject
It is definitely "my" subject	☐ ☐ ☐ ☐ ☐ ☐	I am wasting my time in this subject

Using statements such as enjoying the subject, the subject is easy, getting better at the subject, and growing intellectually would help in making decisions about students' opinions towards university chemistry. For each of the Level–1 Chemistry courses in the sample, the frequencies and percentages of responses were calculated (see table 7.4).

In General Chemistry, it can be seen that students are getting better at the subject although they still find it hard. In general, students' opinions can be summarised as follows: *Students feel that they are obtaining a lot of new skills, they enjoy practical work, and are getting better at the subject. On the other hand, they feel that they are not coping well, are not enjoying the subject as it is a hard subject, and they are wasting their time in the subject.*

In Chemistry–1, it can be seen that students are getting better at the subject although they still find it hard. In general, students' opinions can be summarised as follows: *Students feel that they are coping well, growing intellectually, obtaining a lot of new skills, they enjoy both the subject and practical work, and are getting better at the subject. On the other hand, the subject was hard for them.*

Statistical analysis using chi-squared test shows that significant results were found between the General Chemistry and Chemistry–1 responses to all statements at 1% level in favour of Chemistry–1 for I am obtaining a lot of new skills, I am enjoying practical work, and I am getting better at the subject. Other statements were differ significantly at 0.1% level.

Looking at Level–1 Chemistry students (see table 7.5), female students feel they are obtaining new skills, not coping well and still find the subject hard. This is the opposite of the male students. In Chemistry–1, the subject is male favoured. They cope well, enjoy it, feel they are growing intellectually and feel it is their subject while females find it harder. In General Chemistry, female students do not enjoy it, are not coping well, feel they are not growing intellectually, and find the subject hard. It is also noticed that both genders have more negative attitudes towards university chemistry than Chemistry–1 students.

Figure 7.4 shows Level–1 Chemistry students' % responses distribution.

Table 7.4: **Level-1 Chemistry Students' (1997/98) Responses to: What are your opinions about University Chemistry?**

Students were asked to respond on a six point scale to various aspects. This is summarised on a three point scale, all questions polarised the same way.

	χ^2 between Chem-1 & Gen Chem		Positive opinion N (%)	Neutral opinion N (%)	Negative opinion N (%)
1.	67.61 (sig at 0.1%)		I feel I am coping well		I am NOT coping well
		Chem 1	200 (49)	166 (40)	42 (10)
		Gen Chem	24 (15)	94 (57)	47 (28)
2.	46.17 (sig at 0.1%)		I am enjoying subject		I am NOT enjoying subject
		Chem 1	151 (37)	196 (48)	61 (15)
		Gen Chem	23 (14)	82 (50)	60 (36)
3.	34.12 (sig at 0.1%)		I find the Subject easy		I find subject hard
		Chem 1	53 (13)	227 (55)	129 (31)
		Gen Chem	4 (2)	70 (42)	91 (55)
4.	22.84 (sig at 0.1%)		I am growing intellectually		I am NOT growing intellectually
		Chem 1	143 (35)	231 (56)	29 (7)
		Gen Chem	32 (19)	104 (63)	29 (18)
5.	10.15 (sig at 1%)		I am obtaining a lot of new skills		I am NOT obtaining new skill
		Chem 1	195 (48)	176 (43)	37 (9)
		Gen Chem	55 (33)	89 (54)	21 (13)
6.	11.03 (sig at 1%)		I am enjoying practical work		I hate practical work
		Chem 1	182 (44)	169 (41)	57 (14)
		Gen Chem	49 (30)	89 (54)	27 (16)
7.	12.80 (sig at 1%)		I am getting better at the subject		I am getting worse at the subject
		Chem 1	211 (51)	172 (42)	25 (6)
		Gen Chem	59 (36)	96 (58)	10 (6)
8.	78.21 (sig at 0.1%)		It is definitely "my" subject		I am wasting time in this subject
		Chem 1	91 (22)	257 (63)	62 (15)
		Gen Chem	6 (4)	80 (48)	78 (47)

Notes: For *df* = 2 (two-tailed) χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1% level = 13.82

Table 7.5: Level-1 Chemistry Students' Responses to "*What are your opinions about* University Chemistry?" Based on Gender Differences (1997/98)

(a) All Level-1 Students

	$\chi 2$ between Males and Females	Responses Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	15.60 (sig at 0.1%)	105	119	94	166	21	68
(2)	8.37 (sig at 5%)	69	105	118	160	33	88
(3)	36.65 (sig at 0.1%)	32	25	137	160	51	169
(4)	5.85	76	99	126	209	15	43
(5)	0.15	95	155	103	162	21	37
(6)	0.28	90	141	99	159	30	54
(7)	2.65	103	167	107	161	9	26
(8)	9.97 (sig at 1%)	48	49	129	205	41	99

	Response Percentages (%) Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	18.3	20.7	16.3	28.9	3.7	11.8
(2)	12.0	18.3	20.5	27.8	5.7	15.3
(3)	5.6	4.3	23.8	27.8	8.9	29.4
(4)	13.2	17.2	21.9	36.3	2.6	7.5
(5)	16.5	27.0	17.9	28.2	3.7	6.4
(6)	15.7	24.5	17.2	27.7	5.2	9.4
(7)	17.9	29.0	18.6	28.0	1.6	4.5
(8)	8.3	8.5	22.4	35.7	7.1	17.2

(b) Chemistry-1 Students

	$\chi 2$ between Males and Females	Responses Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	8.82 (sig at 5%)	93	107	61	105	10	32
(2)	1.66	62	89	82	114	20	41
(3)	25.33 (sig at 0.1%)	31	22	103	124	30	99
(4)	21.73 (sig at 0.1%)	69	74	85	146	7	22
(5)	0.63	76	119	70	106	17	20
(6)	0.45	76	106	65	104	22	35
(7)	1.97	83	128	73	99	7	18
(8)	5.38	46	45	94	160	23	39

	Response Percentages (%) Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	56.4	43.7	37.0	42.9	6.1	13.1
(2)	37.6	36.3	49.7	46.5	12.1	16.7
(3)	18.8	9.0	62.4	50.6	18.2	40.4
(4)	41.8	30.2	51.5	59.6	4.2	9.0
(5)	46.1	48.6	42.4	43.3	10.3	8.2
(6)	46.1	43.3	39.4	42.4	13.3	14.3
(7)	50.3	52.2	44.2	40.4	4.2	7.3
(8)	27.9	18.4	57.0	65.3	13.9	15.9

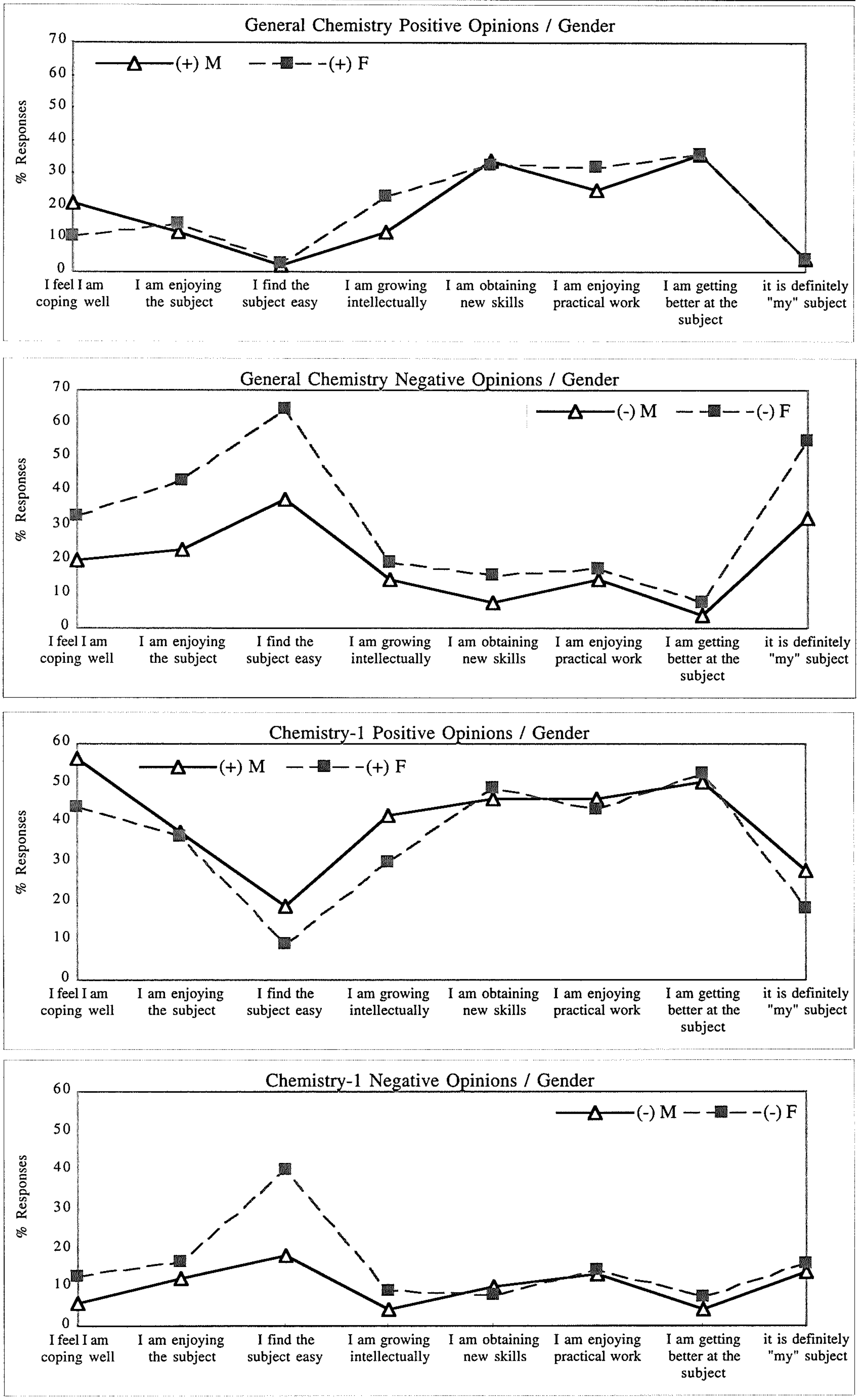
(c) General Chemistry Students

	$\chi 2$ between Males and Females	Responses Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	5.14	12	12	33	61	11	36
(2)	7.74 (sig at 5%)	7	16	36	46	13	47
(3)	11.62 (sig at 1%)	1	3	34	36	21	70
(4)	3.99	7	25	41	63	8	21
(5)	2.48	19	36	33	56	4	17
(6)	1.57	14	35	34	55	8	19
(7)	0.96	20	39	34	62	2	8
(8)	7.57 (sig at 5%)	2	4	35	45	18	60

	Response Percentages (%) Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	21.4	11.0	58.9	56.0	19.6	33.0
(2)	12.5	14.7	64.3	42.2	23.2	43.1
(3)	1.8	2.8	60.7	33.0	37.5	64.2
(4)	12.5	22.9	73.2	57.8	14.3	19.3
(5)	33.9	33.0	58.9	51.4	7.1	15.6
(6)	25.0	32.1	60.7	50.5	14.3	17.4
(7)	35.7	35.8	60.7	56.9	3.6	7.3
(8)	3.6	3.7	62.5	41.3	32.1	55.0

Notes: For $df = 2$ (two-tailed) χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1% level = 13.82

Figure 7.4: Level–1 Chemistry Students Responses (1997/98) to:
What are your opinions about University Chemistry?



(3) How did you find the Chemistry Course at the University?

Lectures boring	☐ ☐ ☐ ☐ ☐ ☐	Lectures interesting
Laboratories interesting	☐ ☐ ☐ ☐ ☐ ☐	Laboratories boring
Tutorials helpful	☐ ☐ ☐ ☐ ☐ ☐	Tutorials waste of time
Course too mathematical	☐ ☐ ☐ ☐ ☐ ☐	Course not mathematical enough
Course difficult	☐ ☐ ☐ ☐ ☐ ☐	Course easy
Work level very demanding	☐ ☐ ☐ ☐ ☐ ☐	Work level undemanding

The purpose of this question about the chemistry course at the university is to explore some aspects of the course and to measure if there are any other changes in students feelings towards chemistry. For each of the Level–1 Chemistry courses in the sample, the frequencies and percentages of responses were calculated (see table 7.6).

In General Chemistry, it can be seen that students find laboratories interesting and the course difficult. In general, students opinions can be summarised as follows: *Students find laboratories interesting. On the other hand, they find the work level very demanding, the course too mathematical, lectures boring, and the course difficult.*

In Chemistry–1, it can be seen that students find laboratories interesting and the course difficult. In general, students opinions can be summarised as follows: *Students find tutorials helpful, and laboratories interesting. On the other hand, they find the work level very demanding, the course too mathematical, lectures boring, and the course difficult.*

Statistical analysis using chi-squared test shows significant differences were found between the General Chemistry and Chemistry–1 responses in favour of Chemistry–1 at:

0.1% level	"laboratories interesting" and "course easy".
1% level	"tutorials helpful".
5% level	"lectures interesting", "course not mathematical enough", and "work level undemanding".

Looking at gender differences between male and female students' responses (see table 7.7), there are significant differences in favour of male students for:

Level–1 Chemistry	*at 0.1% level for "course is difficult" and "work level very demanding".*
Chemistry–1	*at 1% level for "course is difficult" and "work level very demanding".*
General Chemistry	*No significant differences were seen.*

Figure 7.5 shows Level–1 Chemistry students' % responses distribution.

Table 7.6: **Level-1 Chemistry Students' (1997/98) Responses to: How did you find the Chemistry Course at the University ?**

Students were asked to respond on a six point scale to various aspects. This is summarised on a three point scale, all questions polarised the same way.

χ^2 between Chem-1 & Gen Chem		Positive opinion N (%)	Neutral opinion N (%)	Negative opinion N (%)
1. 8.36 (sig at 5%)		Lectures interesting		Lectures boring
	Chem 1	60 (15)	259 (63)	91 (22)
	Gen Chem	14 (8)	98 (59)	53 (32)
2. 27.37 (sig at 0.1%)		Laboratories interesting		Laboratories boring
	Chem 1	180 (44)	188 (46)	42 (10)
	Gen Chem	34 (21)	106 (64)	25 (15)
3. 12.76 (sig at 1%)		Tutorials helpful		Tutorials waste of time
	Chem 1	117 (29)	188 (46)	61 (15)
	Gen Chem	24 (15)	95 (58)	24 (15)
4. 6.36 (sig at 5%)		Course NOT mathematical enough		Course too mathematical
	Chem 1	39 (10)	310 (76)	60 (15)
	Gen Chem	22 (13)	108 (65)	35 (21)
5. 21.60 (sig at 0.1%)		Course easy		Course difficult
	Chem 1	44 (11)	236 (58)	127 (31)
	Gen Chem	9 (5)	71 (43)	85 (52)
6. 6.05 (sig at 5%)		Work level undemanding		Work level very demanding
	Chem 1	39 (10)	265 (65)	105 (26)
	Gen Chem	8 (5)	123 (75)	34 (21)

Notes: For $df = 2$ (two-tailed) χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1% level = 13.82

Table 7.7: Level-1 Chemistry Students' Responses to "*How did you find the* Chemistry Course at the University?" Based on Gender Differences (1997/98)

(a) All Level-1 Students

	$\chi2$ between Males and Females	Responses Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	0.53	28	46	134	223	59	85
(2)	1.77	79	129	111	183	31	36
(3)	1.91	61	80	103	180	32	53
(4)	0.56	35	60	160	258	26	35
(5)	14.88 (sig at 0.1%)	25	28	135	172	60	152
(6)	13.92 (sig at 0.1%)	36	103	161	227	24	23

	Response Percentages (%) Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	4.9	8.0	23.3	38.8	10.3	14.8
(2)	13.7	22.4	19.3	31.8	5.4	6.3
()3	10.6	13.9	17.9	31.3	5.6	9.2
(4)	6.1	10.4	27.8	44.9	4.5	6.1
(5)	4.3	4.9	23.5	29.9	10.4	26.4
(6)	6.3	17.9	28.0	39.5	4.2	4.0

(b) Chemistry-1 Students

	$\chi2$ between Males and Females	Responses Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	0.34	24	36	102	157	39	52
(2)	1.10	70	110	75	113	20	22
(3)	3.76	54	63	67	121	27	34
(4)	0.61	24	36	123	187	18	21
(5)	10.60 (sig at 1%)	23	21	104	132	37	90
(6)	12.03 (sig at 1%)	29	76	114	151	22	17

	Response Percentages (%) Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	14.5	14.7	61.8	64.1	23.6	21.2
(2)	42.4	44.9	45.5	46.1	12.1	9.0
(3)	32.7	25.7	40.6	49.4	16.4	13.9
(4)	14.5	14.7	74.5	76.3	10.9	8.6
(5)	13.9	8.6	63.0	53.9	22.4	36.7
(6)	17.6	31.0	69.1	61.6	13.3	6.9

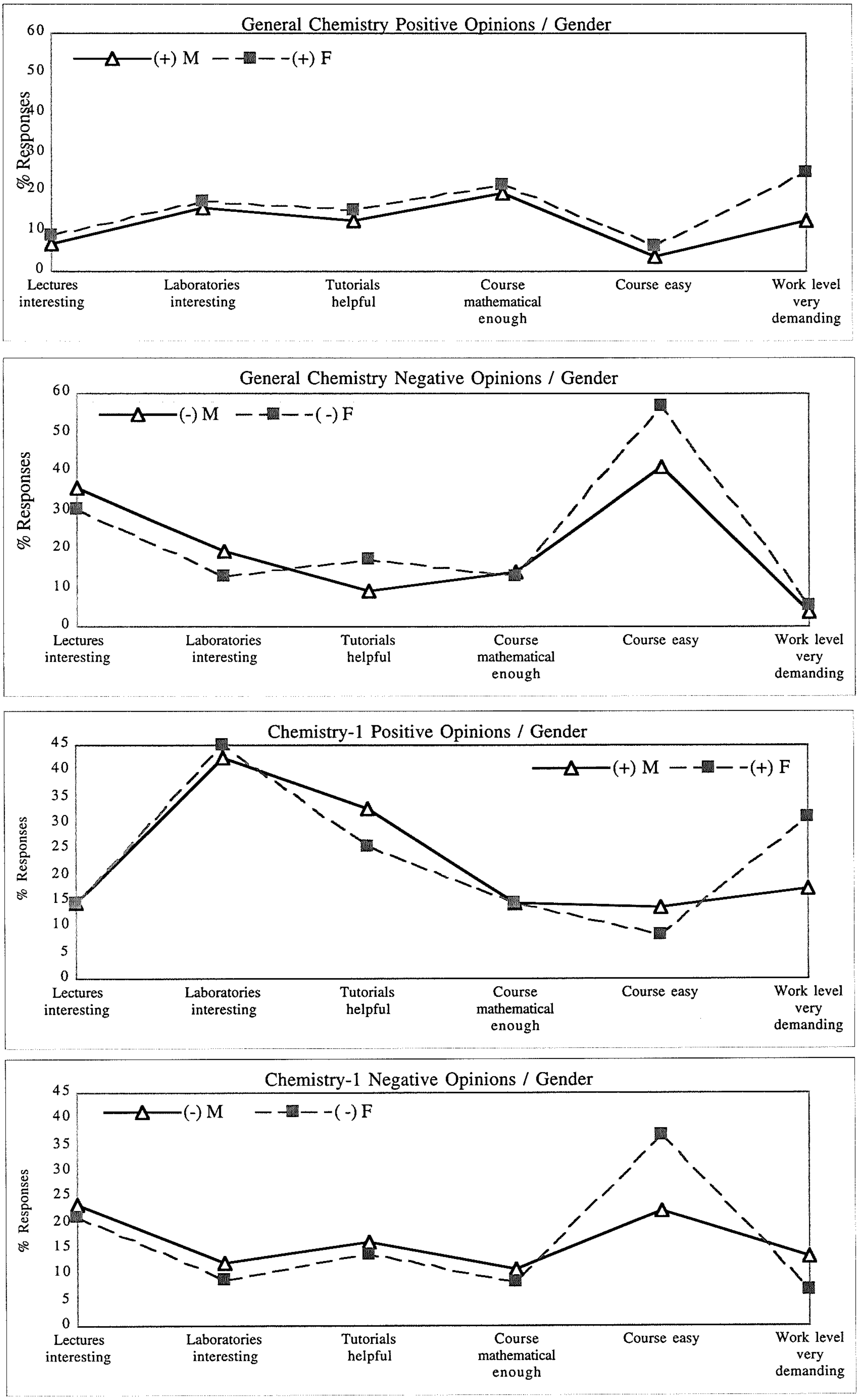
(c) General Chemistry Students

	$\chi2$ between Males and Females	Responses Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	0.59	4	10	32	66	20	33
(2)	1.03	9	19	36	70	11	14
(3)	2.75	7	17	36	59	5	19
(4)	0.16	11	24	37	71	8	14
(5)	5.34	2	7	31	40	23	62
(6)	3.99	7	27	47	76	2	6

	Response Percentages (%) Positive M	Positive F	Neutral M	Neutral F	Negative M	Negative F
(1)	7.1	9.2	57.1	60.6	35.7	30.3
(2)	16.1	17.4	64.3	64.2	19.6	12.8
(3)	12.5	15.6	64.3	54.1	8.9	17.4
(4)	19.6	22.0	66.1	65.1	14.3	12.8
(5)	3.6	6.4	55.4	36.7	41.1	56.9
(6)	12.5	24.8	83.9	69.7	3.6	5.5

Notes: For $df = 2$ (two-tailed) χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1% level = 13.82

Figure 7.5: Level–1 Chemistry Students Responses (1997/98) to:
How did you find the Chemistry Course at the University?



(4) Thinking about the university chemistry course, reflect your opinions?

	Strongly agree	Agree	Disagree	Strongly disagree
I feel the assessment methods used were good	☐	☐	☐	☐
The time demand was NOT reasonable for me	☐	☐	☐	☐
I found a good support from the academic staff	☐	☐	☐	☐
I found the course well organised	☐	☐	☐	☐
I think chemistry will provide poor career opportunities	☐	☐	☐	☐
I found the course challenging	☐	☐	☐	☐
I found note-taking difficult	☐	☐	☐	☐
The course covered too many topics	☐	☐	☐	☐
The course is a good basis for studying other subjects	☐	☐	☐	☐

For each of the Level–1 Chemistry courses in the sample, the frequencies and percentages of responses were calculated (see table 7.8).

Students' responses in both groups to all statements were positive. However, Chemistry–1 students have more positive feelings towards their chemistry course than their General Chemistry counterparts. This relates to assessment methods used, support from academic staff, organisation of the course, and the feeling that the course is a good basis for studying other subjects.

Statistical analysis (using chi-squared) between General Chemistry and Chemistry–1 responses shows that significant differences in favour of Chemistry–1 are found as follows:

0.1% level	*"I felt the assessment methods used were good".*
	"I found good support from academic staff".
	"I found the course well organised".
	"I think chemistry will provide good career opportunities".
	"The course covered enough topics".
	"The course is a good basis for studying other subjects".
5% level	*"The time demand was reasonable for me".*

Looking at gender differences using chi-squared (see table 7.9), significant differences were found between female and male students in favour of female students:

Level–1 Chemistry courses	*at 0.1% for all statements*
Chemistry–1	*at 5% for "the course was challenging".*
General Chemistry	*at 1% for "note-taking is easy".*

Figure 7.6 shows Level–1 Chemistry students' % responses distribution.

Table 7.8: **Level-1 Chemistry Students' (1997/98) Responses to: Thinking about your Chemistry Course, reflect your opinions?**

Statements	χ^2 between Chem-1 & Gen Chem		Strongly agree		Agree		Disagree		Strongly disagree	
			N	(%)	N	(%)	N	(%)	N	(%)
1. I felt the assessment methods used were good	59.4 (sig at 0.1%)									
		Chem 1	**64**	(16)	**332**	(81)	**11**	(3)	**0**	(0)
		Gen Chem	**11**	(7)	**117**	(71)	**34**	(21)	**3**	(2)
2.. The time demand was reasonable for me	4.32(sig at 5%)									
		Chem 1	**25**	(6)	**327**	(80)	**43**	(10)	**2**	(0)
		Gen Chem	**6**	(4)	**127**	(77)	**26**	(16)	**3**	(2)
3. I found good support from academic staff	41.72(sig at 0.1%)									
		Chem 1	**57**	(14)	**310**	(76)	**33**	(8)	**5**	(1)
		Gen Chem	**9**	(5)	**104**	(63)	**43**	(26)	**8**	(5)
4. I found the course well organised	34.62(sig at 0.1%)									
		Chem 1	**71**	(17)	**309**	(75)	**27**	(7)	**2**	(0)
		Gen Chem	**7**	(4)	**117**	(71)	**39**	(24)	**2**	(1)
5. I think chemistry will provide good career opportunities	23.56(sig at 0.1%)									
		Chem 1	**65**	(16)	**299**	(73)	**36**	(9)	**03**	(1)
		Gen Chem	**9**	(5)	**111**	(67)	**34**	(21)	**07**	(4)
6. I found the course challenging	0.00									
		Chem 1	**64**	(16)	**298**	(73)	**42**	(10)	**1**	(0)
		Gen Chem	**28**	(17)	**118**	(72)	**15**	(9)	**2**	(1)
7. I found note taking easy	2.51									
		Chem 1	**48**	(12)	**296**	(72)	**56**	(14)	**8**	(2)
		Gen Chem	**12**	(7)	**118**	(72)	**31**	(19)	**4**	(2)
8. The course covered enough topics	24.28(sig at 0.1%)									
		Chem 1	**28**	(7)	**311**	(76)	**60**	(15)	**7**	(2)
		Gen Chem	**5**	(3)	**101**	(61)	**55**	(33)	**3**	(2)
9. The course is a good basis for studying other subjects	13.32(sig at 0.1%)									
		Chem 1	**39**	(10)	**298**	(73)	**64**	(16)	**4**	(1)
		Gen Chem	**7**	(4)	**107**	(65)	**44**	(27)	**6**	(4)

Notes: For *df* = 1 (two-tailed) χ^2 (critical) at 5% level = 3.84, at 1% level = 6.64, and at 0.1% level = 10.83

Table 7.9: Level–1 Chemistry Students Responses (1997/98) Based on Gender Differences to: ***Thinking about your Chemistry Course, reflect your opinions?***

(a) Level–1 Chemistry Students Responses

	χ^2 between Male and Female	Responses Positive M	Responses Positive F	Responses Negative M	Responses Negative F	Percentage Responses Positive % M	Positive % F	Negative % M	Negative % F
(1)	31.87 (sig at 0.1%)	204	320	48	15	35.5	55.7	8.3	2.6
(2)	36.14 (sig at 0.1%)	186	299	74	31	32.3	52.0	12.9	5.4
(3)	47.32 (sig at 0.1%)	188	292	89	31	32.7	50.8	15.5	5.4
(4)	37.09 (sig at 0.1%)	192	312	70	28	33.4	54.3	12.2	4.9
(5)	37.28 (sig at 0.1%)	178	306	80	38	31.0	53.2	13.9	6.6
(6)	28.84 (sig at 0.1%)	188	320	60	29	32.7	55.7	10.4	5.0
(7)	44.24 (sig at 0.1%)	170	304	99	49	29.6	52.9	17.2	8.5
(8)	57.12 (sig at 0.1%)	171	274	125	48	29.7	47.7	21.7	8.3
(9)	61.88 (sig at 0.1%)	173	278	118	40	30.1	48.3	20.5	7.0

(b) Chemistry-1 Responses

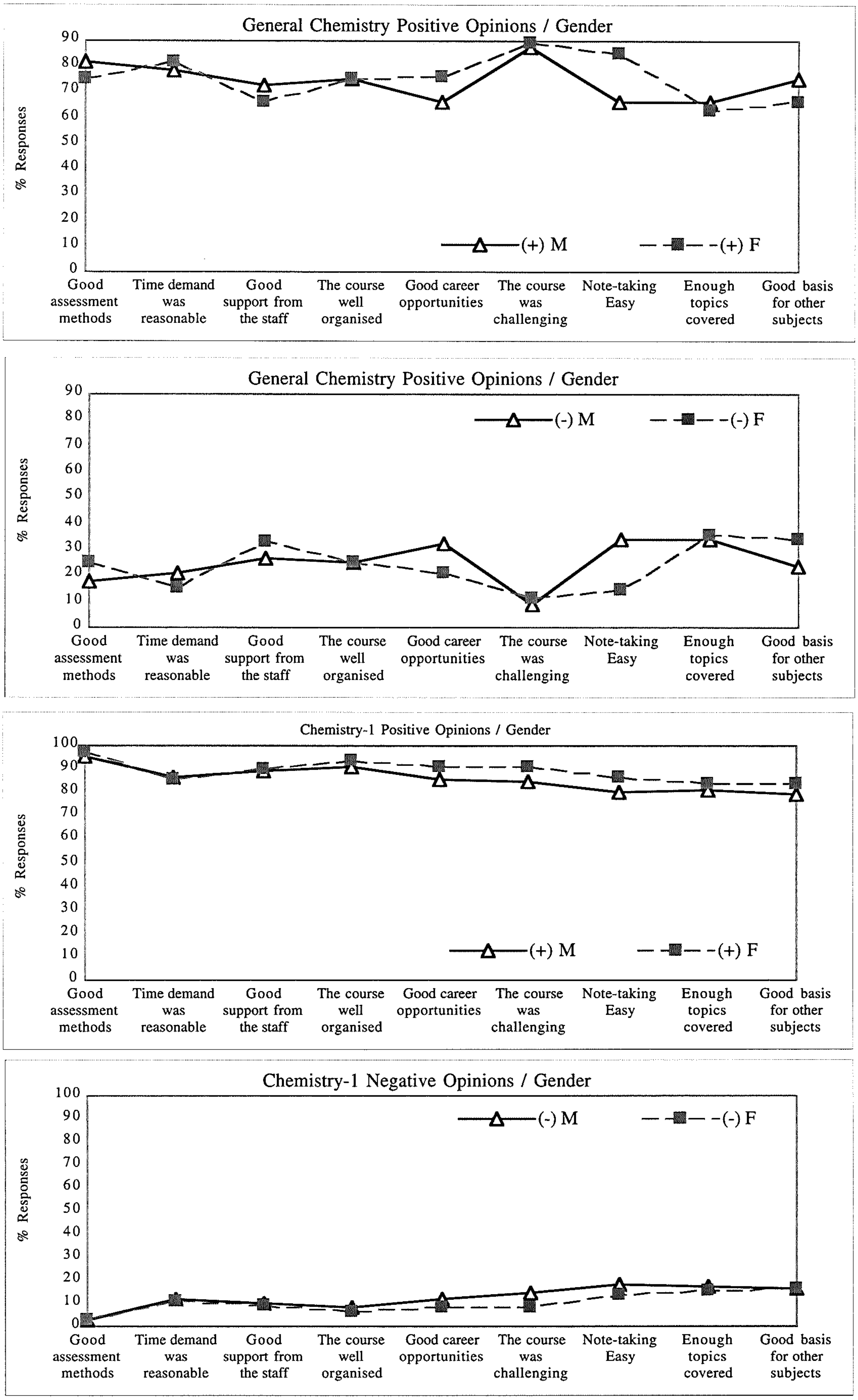
	χ^2 between Male and Female	Responses Positive M	Responses Positive F	Responses Negative M	Responses Negative F	Percentage Responses Positive % M	Positive % F	Negative % M	Negative % F
(1)	0.14	158	238	5	6	95.8	97.1	3.0	2.4
(2)	0.06	142	210	19	26	86.1	85.7	11.5	10.6
(3)	0.06	147	220	16	22	89.1	89.8	9.7	9.0
(4)	0.87	150	230	14	15	90.9	93.9	8.5	6.1
(5)	2.31	141	223	20	19	85.5	91.0	12.1	7.8
(6)	4.85 (sig at 5%)	139	223	24	19	84.2	91.0	14.5	7.8
(7)	1.52	133	211	30	34	80.6	86.1	18.2	13.9
(8)	0.33	134	205	29	38	81.2	83.7	17.6	15.5
(9)	0.02	131	206	27	41	79.4	84.1	16.4	16.7

(c) General Chemistry Responses

	χ^2 between Male and Female	Responses Positive M	Responses Positive F	Responses Negative M	Responses Negative F	Percentage Responses Positive % M	Positive % F	Negative % M	Negative % F
(1)	1.02	46	82	10	27	82.1	75.2	17.9	24.8
(2)	0.72	44	89	12	17	78.6	81.7	21.4	15.6
(3)	0.74	41	72	15	36	73.2	66.1	26.8	33.0
(4)	0.00	42	82	14	27	75.0	75.2	25.0	24.8
(5)	2.32	37	83	18	23	66.1	76.1	32.1	21.1
(6)	0.02	49	97	5	12	87.5	89.0	8.9	11.0
(7)	8.20 (sig at 1%)	37	93	19	16	66.1	85.3	33.9	14.7
(8)	0.08	37	69	19	39	66.1	63.3	33.9	35.8
(9)	1.83	42	72	13	37	75.0	66.1	23.2	33.9

Notes: For $df = 1$ (two-tailed) χ^2 (critical) = 3.84 at 5% level, = 6.64 at 1% level, and = 10.83 at 0.1% level

Figure 7.6: Level–1 Chemistry Students Responses (1997/98) to:
Thinking about your Chemistry Course, reflect your opinions?



Overall results from Q1 (about school chemistry) and the results from Q2 and Q3 (about university chemistry) showed that the General Chemistry students did not enjoy chemistry and found the subject hard, with both lessons and lectures described as boring. Most students felt uncomfortable with their chemistry course. By contrast, Chemistry–1 students had a positive feeling towards both school and university chemistry but they found chemistry a hard subject and were looking for more interesting lectures.

In looking at similar statements about university chemistry in questions 2, 3, and 4, the same responses were noticed. These statements are:

"Work level very demanding" in Q3 and "Time demand reasonable" in Q4.
"Subject hard" in Q2 and "Course difficult" in Q3.
"Enjoying practical work" in Q2 and "Laboratories interesting" in Q3.

7.6 Students' Written Comments

From previous studies in students' general written comments, Braskamp *et al.* (1981) classified over 3000 student comments into twenty two categories. They found that "nearly two thirds of all comments were positive", that "about half of all comments were about the instructor", and that one in four comments related to "the instructor's pedagogical skills".

Su (1991) found many student comments referred to problems of communication. He classified over 500 student comments into fifteen separate categories. Unlike Braskamp, *et al.* found that students comments were largely negative, mainly related to poor communication skills exhibited by the lecturer, and were mainly directed at the less effective lecturers.

In the current study, a blank space was left at the bottom of the second side of the questionnaires, following the difficulty part (see figures 6.1 and 6.2), inviting students to suggest "improvements to the chemistry course". It was found that many students were using this space to make single comments about the lectures, the lecturers, the course organisation, etc.

The students' comments, in many cases, were really quite constructive, and were very helpful in highlighting some particular features of the course or some characteristics of the lecturers. The chemistry department may find this feedback particularly valuable, especially where it identified problems of presentation which could be easily remedied.

The overall written comments of students amounted to almost 252 statements collected from the two courses. After analysis they can be classified into one of these categories:

Lectures, tutorials, labs, textbook, problem sessions, and general comments. Table 7.10 shows the frequency distribution of students' written comments classified by the above categories. The following results have been observed:

Table 7.10: Breakdown of Students' Written Comments (1997/98)

	Chemistry-1	General Chemistry
Total	169	83
Lectures	89	30
Tutorials	22	9
Labs	25	18
Textbook	28	3
General comments	10	45

The following selection of students' written comments highlight some of the most frequently stated opinions expressed by students (for more details see Appendices F2a and F2b):

Lectures

<u>Chemistry–1</u>

"Make lectures more interesting, lively and less boring".

"Less note-taking during lectures and more time spent on explaining theories and giving examples".

"More demonstrations and video in lectures to help visual learners".

"Bigger writing on overhead sheets not leaving it forever, giving handouts to help concentrate on materials not to copying".

"At the end of each lecture block, notes should be handed out, outlining the basic concepts, worked problems, and more examples".

"Instead of speaking through their notes (or overheads), they could write them on the board".

"Some need to speak louder and clearer".

"Some tend to carry out calculations etc. without fully explaining where they are getting their numbers and information from. Entrance of new information without explanations".

"More contact with staff in informal environment to ask questions".

<u>General Chemistry</u>

"Lectures would be much easier to learn if:

lectures were made more interesting by relating the topics to real life.

more variety in teaching methods used.

more examples given with clear calculation steps.

more variation in the lecture delivery".

"Could be more enthusiastic, helpful, and approachable".

"Should try not to move quickly assuming much knowledge available".

"Lecturer's attitude toward general chemistry students needed to be improved".

Tutorials

Chemistry–1

"Have compulsory meetings in small groups (15 students) covering 2-3 weeks lectures block".

General Chemistry

"Compulsory tutorials are needed (twice a month) where more questions can be asked".

Labs

Chemistry–1

"Should be fitted more closely to the lectures".

"Make labs more stimulating and challenging, not having to do what is written in the manual".

"To have better guidance in one lab with more things explained rather than being left to muddle through alone".

General Chemistry

"As some students had no previous knowledge of some topics, lectures must cover lab work before running experiments, or like organic labs, have mini-lectures/discussions at the beginning of the lab (pre-labs)".

General comments

Chemistry–1

"More problem solving sessions with small groups will be more helpful".

General Chemistry

"Summary sheets (or handouts, ...) constructed to show all key points, formulae and equations".

"Less maths should be involved with better explanations".

"Exams (terms or degree) should correspond to class tests and lectures".

"More example sheets of exam-type questions might be given to be more prepared for exams".

"Class tests must be the same standard as either the degree or the term exams".

"Fewer topics with more time spent on the basic aspects of chemistry".

"A gradual build up to the "high level" chemistry by going from one topic to another with more continuity".

Most of the students' written comments, generally, pin-pointed the specific lecturing behaviours which created problems for them in following the taught material, such as illegible writing, overcrowded OHP slides, messy blackboard work, and inaudible speech. The students seemed to know what went wrong and suggested what should be done to improve matters.

Since note taking is probably the main activity of most students during the lectures, students place great importance on what the lecturer says and what is written on the blackboard. Thus, if they cannot always hear what the lecturer is saying, or cannot read what is written on the blackboard or overhead projector slide, they quickly form an adverse opinion of the lecturers' efficiency, and it is very difficult for the lecturer to overcome this initial poor impression.

For many students, the most important criterion of lecturer quality is the efficient communication of information. For other students, the essential criterion may be an interesting style of presentation, an ability to explain things clearly, an enthusiasm for the subject, a friendly approachable manner, or a sense of humour.

7.7 Outcomes of the Study

There were 575 returned questionnaires from students. Each contained responses to over thirty statements, and it is therefore difficult to summarise the information into simple straightforward conclusions. However, some clear trends did emerge and these are recorded below.

(1) Confirming previous studies (such as Johnstone, 1974), the two main factors that influence school pupils towards chemistry are the teacher and the work done in school lessons. Chemistry is still regarded as a complicated school subject.

(2) About one quarter of General Chemistry students recorded that they did not enjoy school chemistry and found it boring. This makes the task of staff teaching these courses rather daunting. Very few Chemistry-1 students held similar views.

(3) At university level, chemistry is still regarded as a hard subject. With General Chemistry students, significant proportions felt that they were not coping well and did not enjoy chemistry. It is clear that many General Chemistry students do not wish to be taking chemistry. Encouragingly, both student groups indicated that they felt they were making progress. With both groups, despite the view that chemistry is a difficult subject, the feeling is that the demand level and time demand of each course is about right.

(4) Laboratory work is regarded positively by both groups although it has to be noted that students wished some adjustments made, with less dependence on laboratory manuals and more open-ended work. This confirms observations made in the past where such changes have been widely appreciated (Johnstone and Letton, 1991). The idea of pre-labs emerges as a positive suggestion. Again previous evidence supports the effectiveness of this approach (Johnstone *et al.*, 1994).

(5) Course organisation and assessment methods receive general approval, with the Chemistry-1 students being particularly positive. There is a hint that the assessment in General Chemistry is not tied closely enough to the work taught.

(6) Looking at lectures, tutorials and laboratories, it is clear that, for both groups, tutorials and laboratories are more favoured than lectures. It is clear that lectures are not always regarded as interesting, and there are the expected difficulties in delivering lectures to such large groups. Students have some practical suggestions for making lectures more effective and these include a greater emphasis on clarity of explanation along with some speed reduction. There are the positive suggestions of post lecture summaries, problem solving sessions, closer application of the chemistry taught to real life situations, and more variation in methods and approaches.

(7) While both courses were regarded as challenging, note taking is not a serious problem area and the topic coverage is about right. However, inconsistently, about one third of the General Chemistry students thought the course covered too many topics. As expected, the relationship of chemistry to other courses varies between Chemistry–1 students and General Chemistry students, the latter not being so positive about this.

(8) The career relevance of chemistry is also an area where the expected difference between the two groups is found to exist, in that General Chemistry students are not expecting to follow any chemistry-based career.

(9) A significant proportion of the General Chemistry students need more staff support.

(10) In General Chemistry, there seems to be a feeling that too much knowledge is assumed, that teaching is too rushed, and that support teaching is needed. Given the background of many of these students with their lack of chemistry experience and their much less positive experiences of chemistry at school, it is to be expected that more support could be very helpful.

(11) There are very few differences in attitudes and perceptions between the sexes although it is matter of concern, in the light of the make up of both classes that the female students are almost universally more negative where such differences do occur.

(12) The main findings about students opinions towards their chemistry courses based on gender differences can be summarised as follows:

(a) *In most areas, there are no significant differences between the opinions of females and males. However, in a small number of areas, differences were observed.*

(b) *In both courses, female students found their university course in chemistry more difficult than their male counterparts and regarded chemistry as less "their" subject than the males.*

(c) *In Chemistry–1, female students felt that school chemistry was more complicated than male students and they felt they were coping less well and not growing intellectually as well as their male counterparts. The females considered that the work level of their university chemistry course was more demanding and challenging than the males and they were less happy about the assessment methods used.*

(d) *In General Chemistry, with smaller samples, areas of significant differences were less obvious. Female students were enjoying their university chemistry less than the males but they found note taking less difficult than the males.*

(e) *Overall, in almost all areas where differences were observed, the female students were at a disadvantage compared to their male counterparts. This is of some concern given that female students make up more than 50% of the classes.*

A complete confidential report was produced including a summary of the main findings, complete analysis of the collected data, and all students' written comments. Copies of this report were sent in August 1998 to the head of the chemistry department, the head of the teaching committee, and to the heads of Level–1 Chemistry classes.

7.8 Conclusions

This study about students' attitudes towards their school and university chemistry courses has helped to build a clear picture of the teaching and learning process. This has assisted in the planning of the teaching materials (to be discussed in chapter 8).

In general, as expected, Chemistry–1 students hold more positive attitudes towards chemistry than their counterparts in the General Chemistry class. Male students' attitudes towards chemistry, in both courses, are more positive than their female counterparts.

Students, in general, find the chemistry courses at school or at university hard and they regard chemistry as a complicated subject. More positive views are noticed in Chemistry–1.

Chapter Eight

INTRODUCING THE CHEMORGANISERS

It has been shown that, in its' first two years (1993/94 and 1994/95), the General Chemistry course gave equal opportunities of success to students with varying backgrounds. In the following three years (1995/96 to 1997/98), the more expected pattern was observed where exam success was related to entry qualifications.

Surveys of students' views and scrutiny of examination scripts pointed out several areas of Level-1 Chemistry courses where difficulties occurred frequently (especially the General Chemistry course). The General Chemistry students' opinions about their school and university chemistry courses indicated that they found chemistry hard, unenjoyable, and complicated.

Following this, new teaching materials were constructed to assist students in those areas which were causing greatest difficulty. Monitoring was continued to assess the impact of these new materials and, in particular, their impact on the lower level group (less well qualified students) was explored in detail.

8.1 The Chemorganisers

Discussions with many school teachers, university lecturers, especially the heads of Level-1 Chemistry classes, Ph.D. research students, and the researchers' own experience led to the decision to design teaching materials called "Chemorganisers". They seek to provide bridges between what the learner already knows and what is to be learned. They are designed to help the learner organise and retrieve material which has already been learned. They also seek to teach by filling the gaps and clearing areas of misconception.

The Chemorganisers were only used by General Chemistry students, and they were based particularly on ideas developed by Ausubel in 1968 (preparing the mind for learning) and Johnstone in 1993 (the information processing model with its overall insight into learning).

8.1.1 The Aims of the Chemorganisers

The Chemorganisers were designed to fulfil the following objectives:

(1) Enhance the preparation of the mind for new learning by:

(a) assisting students to recall important background information.

(b) helping students to organise and relate new information to their previous knowledge.

(c) clearing up misconceptions.

(d) filling gaps.

(2) Ease the load on the "Working Space" by:

(a) presenting material in such a way as to minimise possibility of working space overload.

(b) teaching students how to break down complex areas in to manageable amounts.

(c) enabling students to see interconnections so that knowledge can be "chunked".

(3) Change attitudes towards learning by:

(a) giving students the opportunity to re-inforce understanding and increase their confidence.

(b) enhancing motivation by providing students with summaries, related diagrams, and tables to be used for examination revision.

(c) encouraging students to become aware of their own learning processes, and as far as possible, to be in control of them.

8.1.2 Design Features

Some sixty Chemorganisers were developed, covering those topics which had been found previously to be causing difficulties for students. Although very different from pre-lectures (explained earlier in section 1.6), their underlying aim to develop materials which might mimic pre-lectures in preparing the minds of learners.

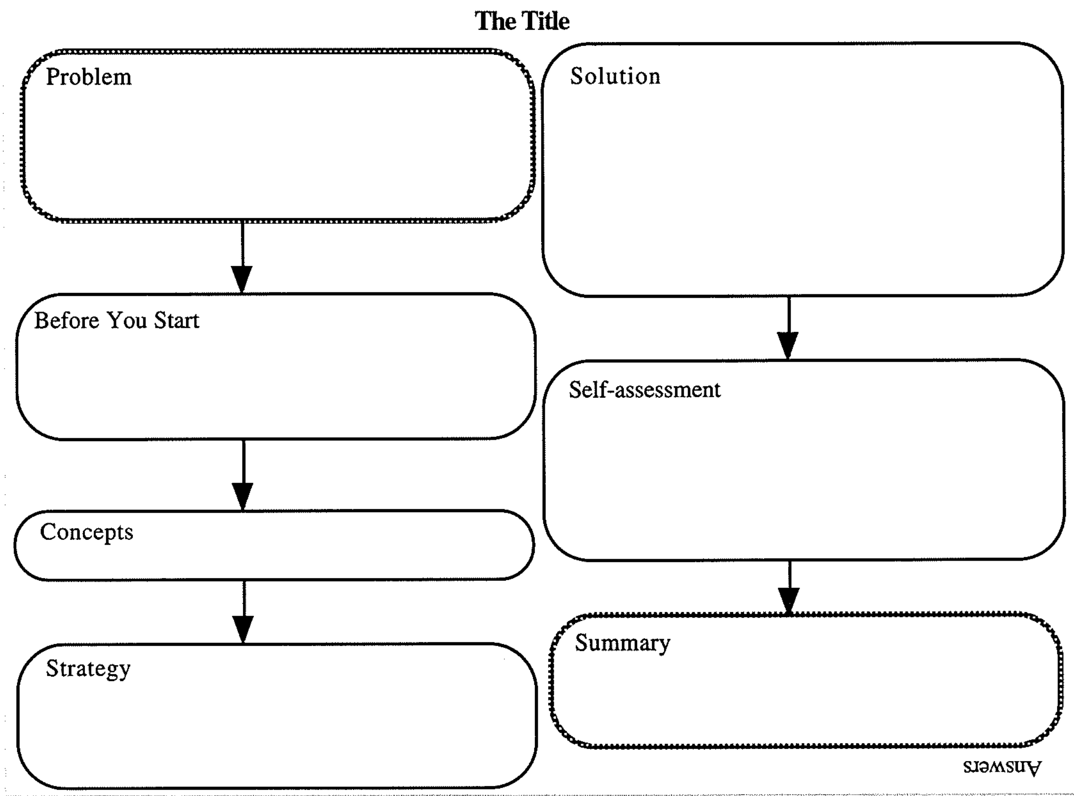
Practical considerations led to a paper-based format, although computer-based materials are discussed in chapter 9. Each Chemorganiser was designed to fit on to one A4 page in landscape orientation, making it easier for the students to see all the parts of the presentation at one time. The style, language and terminology was made consistent with the way individual lecturers presented the topics. Extensive use of variable typescript formats and shading was introduced to aid ease of use and to emphasise key points.

Each Chemorganiser started by introducing the topic or presenting the problem, followed by a list of the background information which the student would need (entitled: "Before You Start"). The topic was explained, often using an example, a general strategy was outlined and students were given opportunities to try out their skills, with answers provided. Although each Chemorganiser covered a single topic or idea, links between Chemorganisers were provided so that students could move from one to another logically or could move back to a previous one to clarify underlying ideas.

Each Chemorganiser was constructed with a clear single focus in mind. The aim was to reduce demands on "Working Space" by minimising unnecessary "noise". They also aimed to develop an idea and then allow students to apply it in an unthreatening way to build confidence and provide useful feedback.

Chemorganisers can be used in many ways and the design allowed for use in groups or individually. They were offered to students as a resource. The format of the Chemorganisers and an example are shown in figures 8.1 and 8.2 respectively. The complete set of the Chemorganisers is presented in Appendix K.

Figure 8.1: The Chemorganisers' Format



The Mole and Solutions

Problem

How many mL of 2 M H_2SO_4 will be required to neutralise 25 mL of 1 M NaOH?

Before you start

- The millilitre (mL) is one thousandth of a litre: 1000mL = 1 litre

  If a solution contains 1 mole of dissolved material per litre it is said to be a **Molar** solution and the symbol used is **M**. Thus a 2 M solution contains 2 moles per litre.

- Neutralization is complete when all the H^+ (aq) of an acid have joined with exactly the same number of OH^- (aq) of an alkali:

$$2\,H^+(aq) + 2\,OH^-(aq) \longrightarrow 2\,H_2O\,(l)$$

- The reaction of a strong acid with strong alkali (base) gives new material called a **salt**:

H_2SO_4	+	2 NaOH	⟶	Na_2SO_4	+	2 H_2O
acid		alkali (base)		a **salt**		water

Concepts

Strong acid, strong alkali (base), concentration, mole, neutralisation, salt, molar solution, molarity, neutralization point.

Strategy

(1) Imagine the alkali in a beaker: How many moles of OH^- in the beaker?
Number of moles OH^- = Volume in litres x Molarity x Number of OH^- in the formula

(2) Imagine the acid in a beaker: How many moles of H^+ in the beaker?
Number of moles H^+ = Volume in litres x Molarity x Number of H^+ in the formula

(3) When an acid neutralises an alkali. The number of H^+ = the number of OH^-

Solution

(1) Number of moles OH^- = Volume in litres x Molarity x Number of OH^- in the formula
= 25 ÷ 1000 L x 1 x 1 (i.e. 1 OH^- in NaOH)
= 0.025 moles OH^-

(2) Number of moles H^+ = Volume in litres x Molarity x Number of H^+ in the formula
Suppose that the volume of the acid is **V**
= (**V** ÷ 1000 L) x 2 x 2 (i.e. 2 H^+ in H_2SO_4)
= (0.004 **V**) Litres

(3) The number of H^+ = the number of OH^-
0.004 **V** = 0.025
V = 0.025 ÷ 0.004 = 0.00625 Litres = 6.25 mL

Thus: 6.25 mL volume of H_2SO_4 is needed.

Self assessment

(a) What is the molarity of $Ca(OH)_2$ when 100 mL of it can be exactly neutralised by 12.5 mL of 0.50 M HCl ?

(b) 100 mL of 0.20 M HCl are placed in a flask. How many millilitres of 0.40 M NaOH are required to bring the solution to the neutralisation point?

Summary

- Number of Moles OH^- = Volume (L) x Molarity ($mol.L^{-1}$) x Number of OH^-
- Number of Moles H^+ = Volume (L) x Molarity ($mol.L^{-1}$) x Number of H^+
- In our problem above:

At neutralisation point,

	Number of moles OH^- (alkali)	=	Number of moles H^+ (acid)
Therefore,	V x M x Number of OH^-	=	V x M x Number of H^+
Or ,	**V_1 x M_1 x P_1 (alkali)**	=	**V_2 x M_2 x P_2 (acid)**

[P stands for ***power*** (H^+ or OH^- per formula)]

Answers: 0.031 M 50 mL

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8.1.3 Description of the Chemorganisers in Use

The Chemorganisers were used by the General Chemistry students in two ways:

(a) Introductory sessions at the beginning of the academic year 1998/99:

The head of the General Chemistry class chose to use twelve of the Chemorganisers (mainly those with fundamental mathematical emphases such as logarithms), in the lab sessions. These twelve were used on three occasions, the classes being optional for students. The procedure was as follows:

> *At the beginning of each class, the Chemorganiser sheets were distributed by the staff member who asked the students to look at each sheet. A discussion session was then started by explaining the theoretical background behind each problem, "Before you start", and then the worked example was gone through step by step. When students were satisfied, they were asked to try on their own (or with their partner) to solve the self-assessment question(s).*

In many ways, this use of the Chemorganisers directly reflects the way the former pre-lectures operated. The atmosphere was unthreatening, involved no assessment and allowed students to be involved in cooperative learning.

(b) Distributed at the beginning of each block of lectures

After the introductory sessions were over, the other three parts of the Chemorganisers (forty two sheets), inorganic, physical, and organic, were offered to students throughout the course. There was no pressure on students to take them, use them, or use them in a specific way.

8.2 Measurements Made

In order to assess the effect of the Chemorganisers, the following steps were taken during the academic year 1998/99:

(1) Monitoring the effect of the Chemorganisers on the *General Chemistry* students by:

- *(a) Analysing all the formal assessment (tests and exams) scripts and students' performances through out the session 1998/99 in order to compare the results with those of the five previous academic years (1993/94 to 1997/98).*
- *(b) Applying a questionnaire to explore the General Chemistry students' impression of the effect of the Chemorganisers to compare the results of students who used the Chemorganisers and with others who did not use them.*
- *(c) Interviewing a small sample of General Chemistry students to explore their feelings about the Chemorganisers.*
- *(d) Direct communication with students during problem solving and lab sessions.*

(2) Employing the same questionnaires which were used during the previous academic year (1997/98) by General Chemistry and Chemistry-1 students in order to:

(i) explore the students' (and their lecturers') views about the difficult areas in chemistry.

(ii) measure students' attitudes towards their chemistry courses.

The outcomes are discussed in detail in the following sub-sections:

8.2.1 Examination Results

The relationship between entrance qualifications and ultimate success achieved by students in formal assessment procedures was explored in order to build up a whole picture about Level-1 Chemistry courses during the period from 1993/94 to 1998/99. All percentages quoted in the tables are in terms of the students who completed the course and sat the June exams. This followed the pattern set in chapter 5 to allow comparisons to be consistent.

(a) The General Chemistry Course

The results of January and June exams over the academic years 1993/94 to 1998/99 are shown in table 8.1. It shows the results for students with upper and lower level of entry qualifications in each year, and it also shows the results of the main sub-groups.

Table 8.1: Average Marks for General Chemistry Examinations Based on Chemistry Entry Qualifications

Year	Exam	All	*Main groups*		*Sub-groups*			
			Upper level	Lower level	Higher Grade	Standard Grade	Alternative Qualifications	No formal chemistry
93/94	January	53.3	54.4	51.3	53.5	55.2	50.3	44.5
	June	47.3	47.4	46.3	47.2	50.2	42.7	44.1
94/95	January	48.7	49.5	49.3	48.4	50.8	50.5	46.1
	June	48.6	48.8	48.7	49.2	49.3	50.7	45.2
95/96	January	40.7	44.3	37.1	44.4	36.2	37.6	31.4
	June	45.2	49.4	40.3	49.6	38.1	42.0	39.7
96/97	January	45.8	50.3	42.0	49.4	42.9	41.0	42.3
	June	43.4	46.1	41.9	45.0	41.2	40.0	47.3
97/98	January	45.1	46.8	43.9	46.6	35.7	49.8	44.5
	June	43.2	46.1	38.7	47.1	30.5	42.2	41.7
98/99	January	47.4	48.6	46.7	48.8	50.7	43.3	45.0
	June	49.4	50.9	48.6	51.0	51.3	48.6	50.8

It is clear that, in the first two years (1993/94 and 1994/95), students with lower levels of chemistry entry qualifications obtained similar average marks as their colleagues with the upper levels. In the following three years (1995/96 to 1997/98), this trend could not be recognised: lower level entry qualifications were linked to lower marks. On the other hand, when the Chemorganisers were introduced in the academic year 1998/99, the results show that students with lower levels of entry qualifications obtained similar average marks to those students with upper levels. For example, the average mark of students with Scottish Standard Grades or students with no formal chemistry qualifications was similar to that of students with Scottish Higher Grades (the graphs in Appendices A and B show the distributions of the average marks for the main groups and sub-groups).

Table 8.2: Relationship Between Entry Qualifications and Examination Success

	January	***June***
Pre-lectures (93/94 and 94/95)	*No significant differences* between *groups based on entry qualifications.*	*No significant differences between groups based on entry qualifications.*
No pre-lectures (95/96 to 97/98)	Significant differences *between* (i) *Upper and lower levels in 95/96 and 96/97* *(ii) Scottish Standard Grade and Upper level in 95/96 all groups in 97/98*	Significant differences between (i) *Upper and lower levels in 95/96 and 97/98* *(ii) Scottish Standard Grade and Upper level in 95/96 and 97/98 Lower level groups in 97/98*
Chemorganisers (98/99)	*No significant differences between groups based on entry qualifications.*	*No significant differences between groups based on entry qualifications.*

The Mann-Whitney test was applied to all exams in all years and table 8.2 summarises the main findings. These findings confirmed the previous results which were drawn from table 8.1 and the graphs in Appendices A and B, and indicated that General Chemistry students' performances in the January and June exams were related to their chemistry entry qualifications only during the period where the pre-lectures did not operate. It can be concluded that introducing the Chemorganisers to the General Chemistry course restored the original pattern where students' examination performance is not related with entry qualifications.

Discussion

From the previous section, clear cut results were shown using the Mann-Whitney test. Students' performances did not relate to their entrance qualifications in the pre-lecture and the Chemorganiser periods, but it did relate in the absence of them. To be sure about the findings of the Mann-Whitney test (which applied in a situation where there is no assumption of normal distribution), students performances (the main two groups, upper and lower levels of entry qualifications) were also analysed under the assumption of normal distribution by using the t-test. Table 8.3 displays the findings of both tests (Mann-Whitney and t-test).

Table 8.3: Results of Statistical Analysis of General Chemistry Students' Examination Performances Based on Chemistry Entry Qualifications

Year	N	Exam	Average Marks			t-test	Mann-Whitney test
			Class	Upper	Lower		
1993/94	110	January	53.3	54.4	51.3	not sig.	not sig.
		June	47.3	47.4	46.3	not sig.	not sig.
1994/95	180	January	48.7	49.5	49.3	not sig.	not sig.
		June	48.6	48.8	48.6	not sig.	not sig.
1995/96	169	January	41.0	44.3	37.1	sig. at 0.1%	sig. at 1%
		June	45.2	49.4	40.3	sig. at 0.1%	sig. at 1%
1996/97	163	January	45.8	50.3	42.0	sig. at 1%	sig. at 1%
		June	43.4	46.1	41.9	not sig.	not sig.
1997/98	229	January	45.1	46.8	43.9	not sig.	not sig.
		June	43.2	46.6	38.7	sig. at 0.1%	sig. at 0.1%
1998/99	192	January	47.4	48.6	46.7	not sig.	not sig.
		June	49.4	50.9	48.6	not sig.	not sig.

The findings of both tests (Mann-Whitney and t-test) made it clear that no matter the assumption of distribution normality, General Chemistry students' performances were affected by the presence of pre-lectures or Chemorganisers.

Another Way of Looking at the Data

Another way of looking at the main findings emerging from the previous analysis was to calculate the *differences* in the average marks of the main two groups (upper and lower level of entry qualifications) in all exams (January and June) over the six-year period (1993/94 to 1998/99). For example, looking at table 8.4, in the academic year 1998/99, the differences in the average marks for the upper and lower level groups in the January exam is 1.9 and in the June exam is 2.3. Therefore, the average differences over the whole year in the two exams is 2.1. These calculations were run for the same students who sat both January and June exams.

Table 8.4: General Chemistry Main Groups Performances (Upper and Lower)

Year	Number of pre-lectures	% of Students		January			June			Average differences between Upper and Lower in January and June Exams
				Average Marks		Differences	Average Marks		Differences	
		Upper	Lower	Upper	Lower	Upper - Lower	Upper	Lower	Upper - Lower	
93/94	8	50.9	42.7	54.4	51.3	3.1	47.4	46.3	1.1	2.1
94/95	6	50.0	40.0	49.5	49.3	0.2	48.8	48.7	0.2	0.2
95/96	0	50.9	40.8	44.3	37.1	7.2	49.4	40.3	9.2	8.2 (sig at 0.1%)
96/97	0	43.2	48.4	50.3	47.0	8.3	46.1	41.9	4.2	6.3 (sig at 0.1%)
97/98	0	52	41.4	46.8	43.9	2.9	46.6	38.7	7.9	5.4 (sig at 0.1%)
98/99	0	39.6	56.8	48.6	46.7	1.9	50.9	48.6	2.3	2.1

Looking at table 8.4, it is clear that the difference in average marks is little between the performances of students with upper and lower level of entry qualifications in the years 1993/94, 1994/95, and 1998/99. On the other hand, in the years 1995/96 to 1997/98, the performances of students with upper and lower level of entry qualifications is statistically better in all three years. These findings confirm the pattern that emerged from the analysis of General Chemistry students' performances using Mann-Whitney and t-tests.

A Look at Sub-groups

The results of the four main sub-groups of General Chemistry students were also compared following the same method used in page 67. Table 8.5 shows the weighted average marks for the main four sub-groups in three periods (1993/94 and 1994/95, 1995/96 to 1997/98, and 1998/99), taking in consideration, for each sub-group, the number of students in each year and their average marks. These four main sub-groups involve the majority of the students. The data from table 8.5 again confirms the pattern emerging from the previous approaches.

Table 8.5: General Chemistry Sub-Groups' Performances

(a) The first two years (The presence of pre-lectures)

Groups	1993/94 N	1993/94 January	1993/94 June	1994/95 N	1994/95 January	1994/95 June	Two years N	Two years January	Two years June	Two years Average
Higher	52	53.5	47.2	85	48.4	49.2	137	50.3	48.4	49.4
Standard	21	55.2	50.2	23	50.8	49.3	44	52.9	49.7	51.3
Alternative	16	50.3	42.7	28	50.5	50.7	44	50.4	47.3	48.9
None	10	44.5	44.1	21	46.1	45.2	31	45.6	44.9	45.2

(b) The intermediate three years (No pre-lectures)

Groups	1995/96 N	1995/96 January	1995/96 June	1996/97 N	1996/97 January	1996/97 June	1997/98 N	1997/98 January	1997/98 June	Three years N	Three years January	Three years June	Three years Average
Higher	77	44.4	49.6	58	49.4	45.0	109	46.6	47.1	244	46.6	47.4	47.0
Standard	19	36.2	38.1	25	42.9	41.2	26	35.7	30.5	70	38.4	36.4	37.4
Alternative	22	37.6	42.0	23	41.0	40.0	18	49.8	42.2	63	43.1	41.4	42.3
None	13	31.4	39.7	17	42.3	47.3	26	44.5	41.2	56	40.8	42.9	41.9

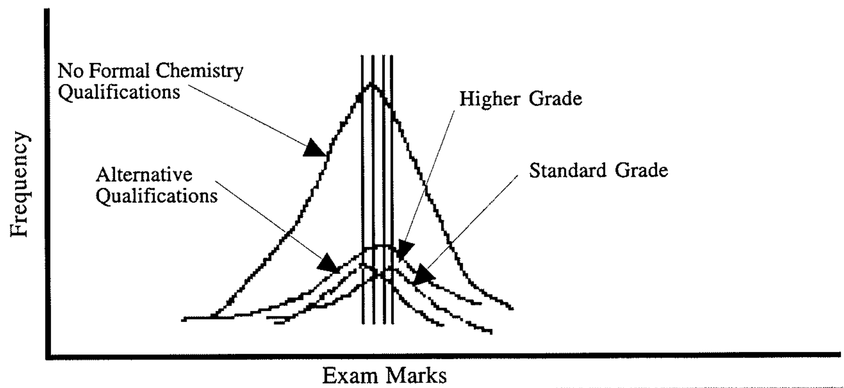
(c) The last year (Introducing the Chemorganisers)

Groups	1998/99 N	1998/99 January	1998/99 June	One year N	One year January	One year June	One year Average
Higher	73	48.8	51.0	73	48.8	51.0	49.9
Standard	22	50.7	51.3	22	50.7	51.3	51.0
Alternative	37	43.3	48.6	37	43.3	48.6	46.0
None	19	45.0	50.8	19	45.0	50.8	47.9

It can be clearly seen that the average marks of the sub-groups during the Chemorganisers and the pre-lectures periods overlap while, in the absence of the pre-lectures, there are noticeable differences between the average marks. Figure 8.3 represents the general trend of examination results found in General Chemistry during the period of the Chemorganisers (see figure 5.5, page 70 for comparison). It seems that the same trend of the pre-lectures is now restored. This is a cartoon to illustrate the position of the mean score and does not imply Standard Deviation.

Figure 8.3: Representation of the Trend in the General Chemistry Course (1998/99)

General Chemistry Examination Results (*The Chemorganisers Period*)



(b) The Chemistry-1 Course

A parallel analysis was conducted with the Chemistry-1 class. The examination results discussed in this section are limited to considering those with only Scottish Higher Grade (H) and Certificate of Sixth Year Studies (CSYS), since the majority of Chemistry-1 students fall into these categories. Graphs of the relevant data are shown in Appendices C and D.

In the Chemistry-1 course (which never included pre-lectures as defined in section 1.6 and never used Chemorganisers), analysis of student performance in examinations showed that students with high entry qualifications performed better consistently. The average performance of students by entry qualifications is shown in table 8.6.

Table 8.6: Chemistry-1 Students' Performance with Entry Qualifications

Entry Qualification	Pass Grade	Average Mark for sessions									
		94/95		95/96		96/97		97/98		98/99	
		Jan	June	Jan	June	Jan	June	Jan	June	Jan	June
Certificate of Sixth Year Studies (CSYS)	A	77	77	81	82	84	81	87	89	90	85
	B	55	55	69	70	72	73	76	76	84	76
	C	38	40	59	64	65	60	68	66	68	62
	D	28	33	45	54	56	50	64	59	60	53
Scottish Higher Grade (H)	A	50	53	63	66	68	65	72	71	76	68
	B	31	38	48	54	51	51	59	55	63	55
	C	23	28	51	56	54	55	58	52	55	46

The evidence from these results supports the idea that exam success in Chemistry-1 is linked to the students' standard of entrance qualifications. The same pattern has been noticed in the years of the General Chemistry course when the pre-lectures were removed.

8.2.2 Chemorganisers' Questionnaire

In addition to the results received from the above methods, it was decided to look for more evidence about the influence of the Chemorganisers on students' performances in one of the class tests. A 4-point Likert-type questionnaire with ratings from high to low was designed (figure 8.4 shows the format of the questionnaire). The statements used were:

"Used, essential to understand topics"
"Used, helpful to understand topics"
"Used, not very helpful to understand topics"
"Did not use"

Figure 8.4: The Chemorganisers' Questionnaire 1998/99 (for Test 4)

Centre for Science Education
The Chemorganisers' Questionnaire
(for Test 4)

Matriculation number : ....

Chemorganisers (hand-outs) were available for each of the topics below, many of these topics appeared in Test 4.

Please, tick the box which best indicates your use of each Chemorganiser to understand the topic.

	Used, essential to understand topic	Used, helpful to understand topic	Used, not very helpful to understand topic	Did not use
Solubility	☐	☐	☐	☐
van't Hoff "*i*" factor	☐	☐	☐	☐
Osmotic pressure	☐	☐	☐	☐
pH	☐	☐	☐	☐
pOH	☐	☐	☐	☐
Weak acid	☐	☐	☐	☐
K_a	☐	☐	☐	☐
K_b	☐	☐	☐	☐
Hydrogen ion concentration, $[H^+]$	☐	☐	☐	☐
Functional groups (alcohol, ketone, etc.)	☐	☐	☐	☐
Hydrolysis	☐	☐	☐	☐
Geometric isomers (cis-trans)	☐	☐	☐	☐
Naming organic compounds	☐	☐	☐	☐

Do you have any comments about the Chemorganisers?

....

....

....

....

....

Thank you for your co-operation

The questionnaire focussed on the benefit of having and using the Chemorganisers before answering the questions of one of the class tests (test-4, which was held at the end of term-2, and assessed the material given in blocks 6 and 7). The questionnaire was distributed among students during the following laboratory sessions. A total of 100 students responded to the questionnaire (a return rate of 64%). Table 8.7 displays students' responses to the Chemorganisers' questionnaire.

Table 8.7: General Chemistry Students' Responses to the Chemorganisers' Questionnaire (1998/99)

Topics	A Used, essential to understand topics	B Used, helpful to understand topics	C Used, not very helpful to understand topics	D Did not use	E No Response	F Usefulness = A + B	G Use = A + B + C	H $\frac{(A + B)}{(A + B + C)} \times 100$
Solubility	19	55	9	14	3	74	83	89
van't Hoff "*i*" factor	16	48	9	24	3	64	73	88
Osmotic pressure	18	51	11	18	2	69	80	86
pH	20	53	10	13	4	73	83	88
pOH	18	53	10	14	5	71	81	88
Weak acid	16	45	13	22	4	61	74	82
Ka	25	43	15	15	2	68	83	82
Kb	24	41	14	18	3	65	79	82
$[H^{+}]$	22	49	9	16	4	71	80	87
Functional groups	29	48	8	12	3	77	85	91
Hydrolysis	21	51	9	16	3	72	81	89
Cis-trans isomers	24	38	11	21	6	62	73	85
Naming organic compounds	35	39	4	19	3	74	78	95
Mean	**22**	**47**	**10**	**17**	**3**	**69**	**79**	**87**

Notes: N = Number of students responses = 100, therefore N = %

It can be concluded from table 8.7 that, in most topics, about 80% of General Chemistry students used the Chemorganisers, of which, typically, 87% said they found them useful.

A space was provided at the foot of the questionnaire for free responses which were analysed to see if there was a pattern of response which might give hints about the problems and the deficiencies in this teaching and learning approach. 71 students' general comments were identified and typical comments were as follows:

"They were helpful in giving good examples, with a step by step guide to calculations".

"The wording was simple to understand".

"Essential as much of the lecture material is not easily understand by students with no chemistry background".

"Helpful as use as a form of study guide".

"Very useful for reinforcement and consolidation of learning".

"Very useful-recommended using them for every year".

"Couldn't do some parts of the course without them".

"I would like to have had them for all topics".

From the above findings, it was noticed that students liked to work with the Chemorganisers and they found them essential, helpful, and they were asking for more. Almost all comments were positive (see Appendix F3 for the full list of students' comments).

8.2.3 Student Interviews

Interviewing the General Chemistry students was a good opportunity to gather information about the effectiveness of the Chemorganisers in their own words. It gave useful insights into the way General Chemistry students feel about the Chemorganisers, and provided some evidence about the questionnaire validity. Other insights were also gained such as students' study habits and their attitudes towards chemistry.

The interviews were carried out during the last two weeks of the final term (May, 1999). By this time, all the written Chemorganisers had been handed out to students, and the overall picture of the course was clear for them. Through direct contact with students during laboratory sessions, a representative sample of students, in terms of chemistry entrance qualifications, was chosen randomly to reproduce the General Chemistry class. The interview group was asked to participate, but time only allowed for 14 students to be interviewed (around 30 minutes for each). The interview group came from different chemistry entry backgrounds, the majority from the lower level group. Table 8.8 indicates the class and interview group breakdown in terms of qualifications.

Table 8.8: Breakdown of the Composition of the General Chemistry Class and the Interview Group by Entry Qualifications (1998/99)

	Students in Class		Students in Interview Group	
	N	(% of 192)	N	(% of 14)
Upper Level	**76**	(39.6)	**4**	(28.6)
Lower Level	**109**	(56.8)	**8**	(57.1)
Scottish Higher Grade	**73**	(38.0)	**4**	(28.6)
Scottish Standard Grade	**22**	(11.4)	**5**	(35.7)
Alternative Qualifications	**37**	(19.3)	**2**	(14.3)
No Formal Chemistry	**19**	(9.9)	**1**	(7.1)
Others	**7**	(3.6)	**2**	(14.3)

Notes: **Alternative Qualifications** (Mainly those with entry Access and Modules)
Others (Overseas, USA or Irish qualifications)

The interview covered three main areas: students' study habits, attitudes towards chemistry, and their experiences with the Chemorganisers. A checklist was designed to record students' responses (see Appendix G1). The responses were analysed and the interview findings are as follows:

(a) STUDY HABITS

The first part of the interview was about the students' study habits and was intended to allow the students to relax with the interviewer. Students were not asked to think about the Chemorganisers but merely to give insight into their approach to study. The following conclusions can be drawn from the first part:

(1) *Students preferred to use examples (related exam questions) and/or to start the lecture with a short quiz to prepare their minds for new information.*

(2) *The preferred place for study is at home and then the library comes next.*

(3) *Students considered that they made mathematical errors in answering chemistry questions rather than conceptual ones.*

(4) *Students claimed that they first looked at their notes, then the textbooks, when they faced difficult questions.*

Looking at students' approaches to study, it can be concluded that the Chemorganisers match their needs. The Chemorganisers used realistic worked examples. They can be used at any time, any where, and as an additional source of organised notes. The first part of the Chemorganisers was designed, in some cases, to clarify the fundamental mathematical areas which seemed to be necessary for the General Chemistry students.

(b) ATTITUDES TOWARDS CHEMISTRY

The second part of the interview sought students' opinions about their attitudes towards chemistry. The responses were analysed and summarised as follows:

(1) *Students said that they were affected by the method of teaching more than they were affected by the lecturer.*

(2) *Students preferred organic chemistry because they saw it as more useful in everyday life, and it was conceptual not mathematical. Most of them liked to continue with the same order of lectures, starting with inorganic then physical and end with organic (students did not experience any other teaching order).*

(3) *In looking at ways to answer chemistry questions, students held a variety of views, some preferring to stick to familiar approaches while others were willing to consider new approaches, seeking an easy way to success.*

Looking at the above findings, the Chemorganisers sought to present the necessary information in a way that reflected the logic of chemistry while taking into account the psychology of the learner. Many of the students are doing degrees with a biological flavour and it is not surprising to find organic chemistry more to their taste.

(c) THE CHEMORGANISERS

The main part of the interview was about the Chemorganisers. It was hoped to gather more evidence about their effectiveness and to look for any deficiencies.

(1) When the students were asked about their experience with the Chemorganisers, their responses were very positive and the idea of the Chemorganisers appealed to them. Typical comments were:

"They are very useful, preparing for exams (before lecture block, would be good preparation)".

"I find Chemorganisers very clear and precise. They guide me through a problem step by step".

"I found them helpful as an extra set of notes which we would be come to".

"They are very helpful, like working with a friend".

"Gives more confidence in learning".

"Summary of what done, foundation to build on".

(2) Students believed that using the Chemorganisers in their studies helped them in different areas. Typical comments were:

"Helps to focus my study on a particular area of chemistry".

"They backup lecture ideas and mathematical ideas".

"Have a quick read for issues that do not need a full covering. Also, important as a summary of the ideas that must be retained".

"Gives you experience in doing actual questions which is helpful for exams. Also gives you another source other than lecture notes or textbook".

"Reinforced knowledge from lectures".

(3) Critical comments were rare but they were constructive. Typical comments were:

"Only a few more questions, one other worked examples".

"Not enough of them".

"The self-assessment questions are not explained-only the answer is given".

"They only give foundation information which is not enough to know-could refer you to textbook".

(4) Students thought that the Chemorganisers were well presented in a logical order which is easy to understand and clear as one page per topic. Typical comments were:

"Can relate problems and method of solution easily".

"Feel a sense of achievement when you realise you can do the problem".

"Gives you basic ideas and then builds on them".

"As an individual problem".

"Focused on what I needed, easy access".

(5) Students felt that the Chemorganisers strategies were different from what they were used to. Typical comments were:

"More understandable, doesn't assume chemistry background".

"More clear".

"The Chemorganisers lay it out in steps which are easier to learn".

"Not in a confusing way".

(6) Students claimed that self-assessment was helpful. Typical comments were:

"It gives student the chance to see how much he/she knows about the topic".

"It gives different difficulty levels in the questions".

"It shows that what the strategy can be applied to".

"Good backup to test the knowledge gained".

(7) Students recommended the use of the Chemorganisers by lecturers next year. Typical comments were:

"Give student more confidence when revising and looking over lecture notes".

"Builds on notes from lectures".

"Backup the work the lecturer is doing".

"Help students to understand clearly therefore easier for lecturer to get concept access".

"Good for learning, practising and revising basic concepts".

"Would be able to come into the lecture prepared for the subject being taught".

(8) Students indicated that the Chemorganisers helped them and illuminated unclear areas such as logarithms, pH calculations, naming organic compounds, organic functional groups, and aqueous solutions.

(9) Some students used the Chemorganisers separately, others used them as a set. Student opinions about the most suitable time for distributing the sheets were varied; some suggested before, others during and others after the end of each block of lectures.

Main findings for the interviews

It is difficult to distil down so many comments into simple conclusions but the Chemorganisers were given almost universal support by the interview group. Students said they enjoyed the opportunity to work with the Chemorganisers. They believed that introducing a brief theoretical background gave them the confidence and the familiarity to react positively with the topics. It allowed them opportunity not offered elsewhere to practice individual questions. No critical comments other than constructive comments were found. Overall, the interviews confirmed the pattern emerging from the Chemorganisers' questionnaire, where the Chemorganisers were found to be widely used, and students found them helpful.

8.2.4 Chemistry Learning Difficulties

Following the methods used earlier in chapter 6, students' examination performances and their opinions about chemistry topics' level of difficulties were scrutinised as another source of data, in order to continue monitoring Level-1 Chemistry courses, and particularly to measure the effect of introducing the Chemorganisers to the General Chemistry course. This was done by the analyses of student exam scripts and employing the same questionnaire used in the academic year 1997/98. It was hoped to build a clear picture about the difficult areas which still need more care.

(a) Analysis of Tests and Examination Scripts

In this study, scripts for the diagnostic tests 1, 2, 3, and 4, along with the January class examination scripts for the academic year 1998/99 were examined in considerable detail. The performance has been presented for each topic as percentages because the various analysed questions carried a wide variety of credit. Tables 8.9 and 8.10 display the marks percentages of the questions in the General Chemistry and Chemistry-1 courses respectively including the related topics which were assessed in that particular test or exam. The tables also show the marks of the previous academic year 1997/98 for comparison.

Table 8.9: General Chemistry Students' Examination Results

Topics	Examinations								
	1997/98				1998/99				
	Test-2	Test-3	Test-4	Class	Test-1	Test-2	Test-3	Test-4	Class
Balancing equations (simple)				**18**	**36**				
Calculations			11					20	
Draw chiral			34					21	
Draw cis/trans isomers			**22**					**47**	
Draw isomers / inorganic	**22**					**31**			**58**
Draw organic compounds			**34**					**56**	
Draw polymers			18					46	
Draw unit cell				30		31			19
Electronegativity	77					70			
Electronic configuration	**42**			**44**		**74**			**83**
Equilibrium constant		**45**					**40**		
Functional groups			**45**					**63**	
ΔG		51					66		
Hydrolysis			**32**					**56**	
Mole calculation				**8**					**30**
Naming of ions	**63**					**76**			
Organic reactions			11					31	
Osmotic pressure			**37**					**77**	
Oxidation state	**11**			**28**		**54**			**58**
pH			**9**					**20**	
Rate constant		48					13		
Rate expression		37					28		
Rate of reaction		44					7		
Solubility			**43**					**72**	
van't Hoff i factor			**36**					**48**	
Writing formula for compounds				**43**	**54**				**52**
[A]			13					30	

Looking at table 8.9 (**Bold** indicates where the Chemorganisers were employed), it is noticed that, in many topics, 1998/99 marks percentages were greater than that in 1997/98. As tests were the same in both years, this suggests that the introduction of Chemorganisers is helping to clarify some difficult points such as functional groups, mole calculations, balancing equations, hydrolysis, solubility, and osmotic pressure.

Looking at table 8.10 (**Bold** indicates where similar results were seen), it can be seen that the results for the two years are similar.

Table 8.10: Chemistry-1 Students' Examination Results

Topics	Examinations							
	1997/98				1998/99			
	Test-2	Test-3	Test-4	Class	Test-2	Test-3	Test-4	Class
Activation energy				33				22
Boiling point	**88**			**73**	**86**			
Cis / trans				68				56
Collisions /reactions	**97**				**95**			
Curly arrows		81		33		86		64
Dielectric constant			85				68	
Draw / Ligand			**37**				**36**	
Draw chiral		**76**		**66**		**77**		**75**
Draw organic structure		57		54		66		71
Electronic configurations			**63**				**63**	
ΔG		58				85		
Geometrical isomers / organic		92				71		
ΔH		**72**				**70**		
H-bonding	**88**				**88**			
Half-life	84				91			
High / low spin d-orbital			73				81	
Hydrolysis draw		83				29		
Intermediate	**98**			**93**	**97**			**55**
Intermolecular forces	**81**			**98**	**83**			
Isomers / inorganic			**81**				**79**	
Kw			65				77	
Lone pair electrons		92		76		86		57
Mechanism		82		37		64		62
Mole calculation			**52**				**57**	
Molecularity of 1st step	**88**			**87**	**92**			
Naming organic compounds				**70**				**73**
Order of reaction	97				95			39
Overall reaction	99			68	97			45
Oxidation states			**76**				**71**	**35**
pH			**91**				**89**	
pKa			**47**				**42**	
PV=nRT				57				38
Rate formation/ disappearance	**81**				**78**			
Rate law	**56**			**47**	**55**			**32**
Rate reaction	**97**				**93**			
ΔS		**74**				**71**		
van der Waals	85			47	76			29
VSEPR draw				**66**			**72**	

(b) Questionnaires Employed

In addition to the analysis of the tests and exam scripts, it was decided to seek the students' (and their lecturers') opinions in order to confirm the previous findings. It was also hoped, from this investigation, to continue monitoring Level-1 Chemistry courses (General Chemistry and Chemistry-1), and to measure the effect of introducing the Chemorganisers to the General Chemistry course.

(i) Students Questionnaires

The same questionnaires which were employed in the academic year 1997/98 (see section 6.5) were distributed among Level-1 Chemistry students during the last week of term-2 (March, 1999) in the laboratory sessions. 152 first year General Chemistry students (return rate 79%) and 401 first year Chemistry-1 students (return rate 79%) answered the questionnaires.

(a) General Chemistry

An enormous amount of data was gathered from the questionnaires. Table 8.11 shows the complete analysis of the General Chemistry students' percentage responses, including the areas which still need more attention. Students' perceptions of difficulties will be explored in detail.

Looking at table 8.11, it is clear that, in the Chemorganisers' year (1998/99), a high measure of achievement was found in many areas, especially the areas which were covered by the Chemorganisers such as in: buffers, pH calculations, isomerism, nomenclature, oxidation numbers, mole calculations, osmotic pressure, and solvation.

Table 8.11: % Responses of General Chemistry Students (Areas of Perceived Difficulty)

χ^2 values are comparing the frequencies of responses between 1997/98 and 1998/99.

Topics	χ^2	Easy		Moderate		Difficult		Better Year	
		98/99	97/98	98/99	97/98	98/99	97/98	98/99	97/98
Reaction rate	13.6 (sig at 1%)	**18**	(32)	**59**	(53)	**22**	(15)		(√)
Arrhenius equation	4.2	**3**	(3)	**58**	(58)	**29**	(39)	√	
Entropy and disorder	4.4	**9**	(7)	**52**	(61)	**38**	(32)		(√)
Enthalpy	9.1 (sig at 5%)	**11**	(15)	**55**	(62)	**33**	(23)		(√)
Free energy changes	4.3	**10**	(13)	**53**	(59)	**34**	(28)		(√)
Buffers	8.0 (sig at 5%)	**16**	(10)	**65**	(70)	**16**	(21)	√	
pH calculations	6.5 (sig at 5%)	**32**	(24)	**54**	(58)	**13**	(18)	√	
Isomerism	6.3 (sig at 5%)	**23**	(17)	**62**	(64)	**14**	(19)	√	
Drawing chemical structures	6.1 (sig at 5%)	**39**	(31)	**46**	(55)	**13**	(14)		
Functional groups	5.3	**40**	(33)	**49**	(55)	**10**	(12)		
Nomenclature	6.6 (sig at 5%)	**16**	(10)	**56**	(58)	**18**	(31)	√	
Oxidation numbers	25.7 (sig at 0.1%)	**33**	(19)	**51**	(53)	**15**	(28)	√	
Balancing redox equations	15.4 (sig at 0.1%)	**28**	(36)	**59**	(50)	**12**	(15)		
Electrolytes	1.7	**12**	(12)	**72**	(77)	**14**	(12)		
Writing chemical formulae	5.8	**46**	(37)	**45**	(54)	**9**	(9)		
Mole calculations	7.0 (sig at 5%)	**28**	(20)	**53**	(58)	**18**	(22)	√	
Solution concentration	5.5	**22**	(19)	**63**	(70)	**14**	(11)		
Colloidal solutions	7.3 (sig at 5%)	**3**	(4)	**65**	(62)	**22**	(34)	√	
Osmotic pressure	6.5 (sig at 5%)	**21**	(16)	**65**	(64)	**12**	(19)	√	
Solvation	2.8	**7**	(7)	**75**	(71)	**16**	(22)	√	
Drawing unit cells	7.1 (sig at 5%)	**42**	(33)	**46**	(53)	**11**	(15)	√	
Corrosion	3.3	**16**	(23)	**66**	(62)	**14**	(15)		
Equilibrium	1.9	**24**	(20)	**61**	(64)	**14**	(16)		
Polarity	6.6 (sig at 5%)	**22**	(16)	**63**	(66)	**13**	(18)		
Lewis acids and bases	2.4	**13**	(13)	**66**	(62)	**19**	(25)	√	

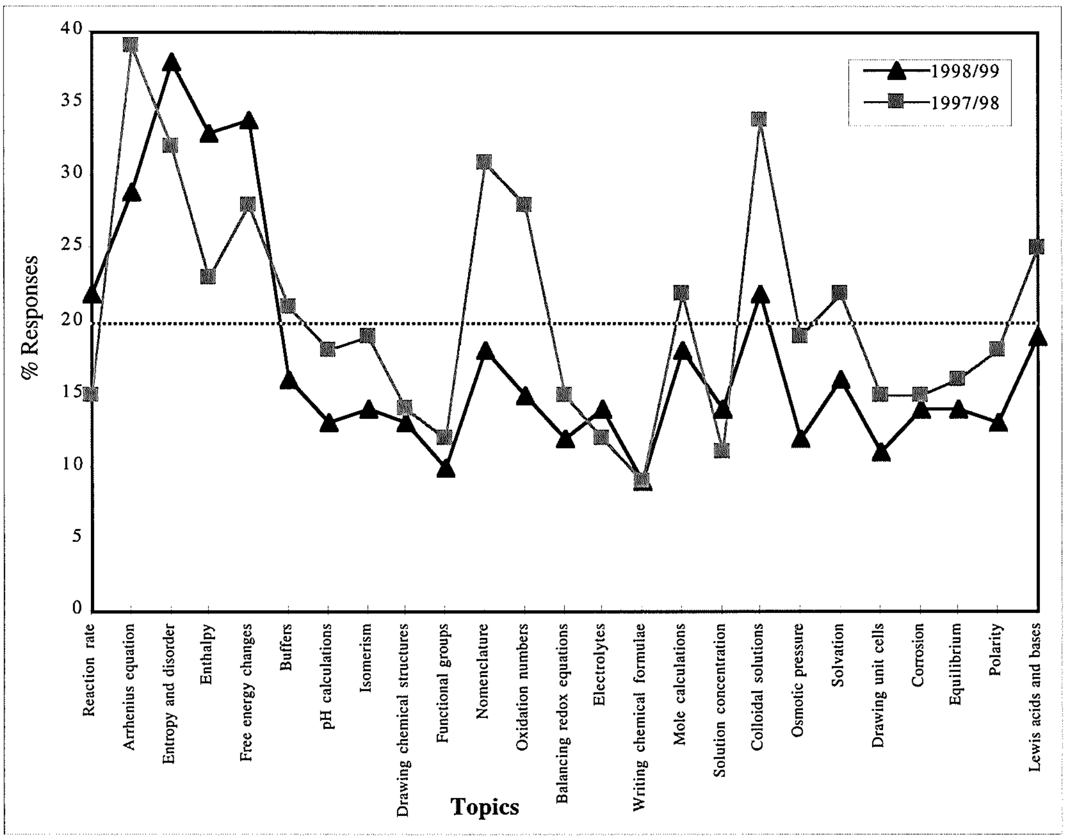
Notes: For df = 2 χ^2 critical at 5% level = 5.99, at 1% level = 9.21 and at 0.1% = 13.82

In some other areas, students still had difficulties, such as reaction rate, enthalpy, entropy and disorder, and free energy changes. The Chemorganisers which covered these areas were not distributed to students because of a delay outside the researcher's control. A few of these were given to students who asked for them later during the interviews.

Some areas covered by the Chemorganisers show little change, such as in solution concentrations and equilibrium. This means that more work must be done on these areas to help students to overcome the learning difficulties either by decreasing the amount of material given to students or by more tutorial sessions.

The findings of both instruments: the study of examination scripts and examination marks, and students' views about topics difficulties, strongly supported each other: General Chemistry students were finding topics difficult that they thought were difficult. In looking at the areas which were covered by the Chemorganisers, it is clear from the results from tables 8.9 and 8.11 that students benefited most in the following topics: Isomerism, functional groups, hydrolysis, mole calculations, nomenclature, solubility, pH calculations, osmotic pressure, oxidation numbers, and writing formulae for compounds. On the other hand, other similarities were found with topics which students expected to be difficult but they performed even worse than expected (e.g. solution concentration). Figure 8.5 shows the pattern of difficulties for the General Chemistry class.

Figure 8.5: % Responses of General Chemistry Students (Topics still difficult)



(b) Chemistry-1

Similar analyses for the Chemistry-1 students' responses were carried out. The percentage responses of students who had studied the topics and recorded them as difficult were calculated and summarised in table 8.12.

Table 8.12: % Responses Chemistry-1 Students (Areas of Perceived Difficulty)

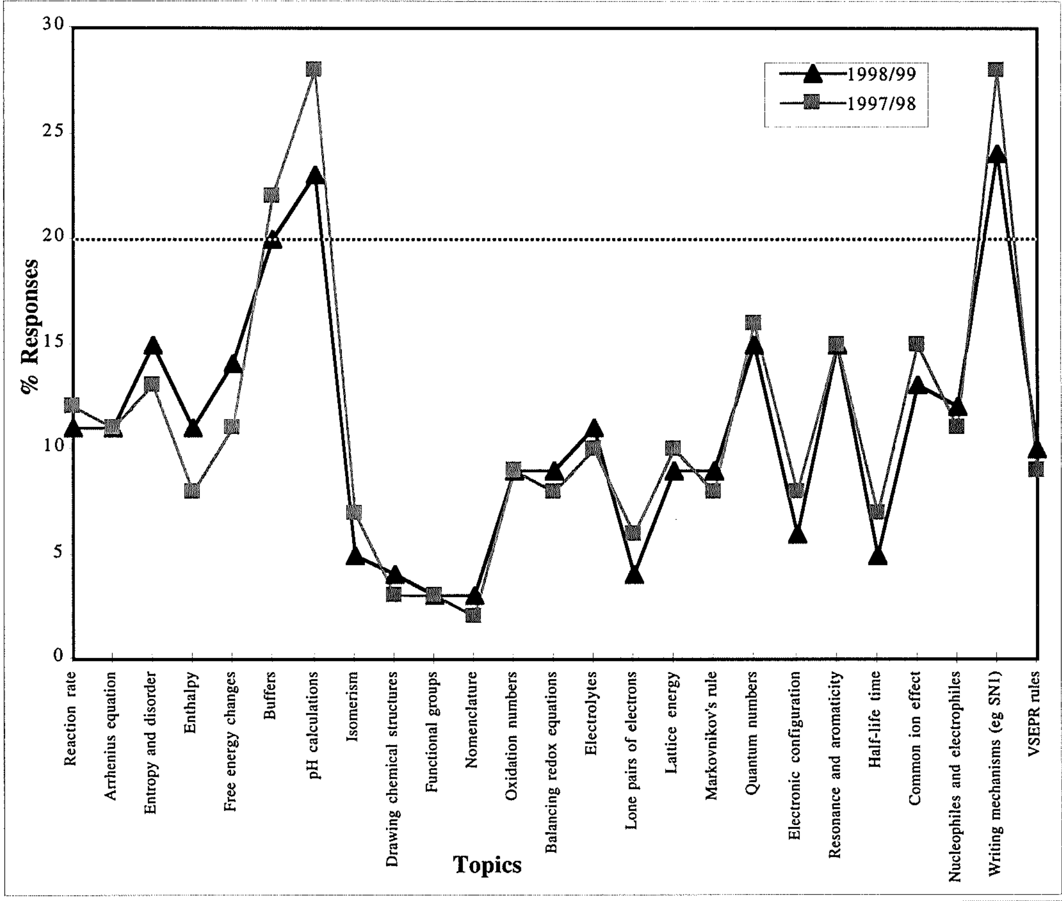
χ^2 values are comparing the frequencies of responses between 1997/98 and 1998/99.

Topics	χ^2	Easy		Moderate		Difficult		Better Year	
		98/99	97/98	98/99	97/98	98/99	97/98	98/99	97/98
Reaction rate	6.7 (sig at 5%)	**31**	(36)	**56**	(50)	**11**	(12)		
Arrhenius equation	3.7	**20**	(25)	**63**	(61)	**11**	(11)		
Entropy and disorder	4.8	**31**	(35)	**53**	(49)	**15**	(13)		
Enthalpy	3.2	**37**	(41)	**53**	(49)	**9**	(8)		
Free energy changes	8.2 (sig at 5%)	**25**	(30)	**54**	(57)	**14**	(11)		
Buffers	3.4	**18**	(20)	**62**	(57)	**20**	(22)		(√)
pH calculations	5.0	**19**	(20)	**55**	(51)	**23**	(28)	√	(√)
Isomerism	2.2	**43**	(46)	**47**	(46)	**5**	(7)		
Drawing chemical structures	4.0	**55**	(55)	**37**	(41)	**4**	(3)		
Functional groups	3.4	**52**	(50)	**41**	(46)	**3**	(3)		
Nomenclature	2.1	**65**	(65)	**28**	(31)	**3**	(2)		
Oxidation numbers	5.5	**67**	(43)	**41**	(47)	**9**	(9)		
Balancing redox equations	1.1	**44**	(45)	**43**	(46)	**9**	(8)		
Electrolytes	2.6	**11**	(14)	**70**	(72)	**11**	(10)		
Lone pairs of electrons	2.7	**54**	(51)	**38**	(42)	**4**	(6)		
Lattice energy	4.8	**30**	(26)	**57**	(62)	**9**	(10)		
Markovnikov's rule	1.8	**46**	(51)	**42**	(41)	**8**	(7)		
Quantum numbers	24.1 (sig at 0.1%)	**22**	(33)	**59**	(48)	**15**	(16)		
Electronic configuration	3.4	**51**	(53)	**39**	(37)	**6**	(8)		
Resonance and aromaticity	1.4	**11**	(13)	**66**	(68)	**15**	(15)		
Half-life time	1.6	**47**	(47)	**43**	(45)	**5**	(7)		
Common ion effect	5.5	**8**	(11)	**70**	(65)	**13**	(15)		
Nucleophiles and electrophiles	0.6	**29**	(30)	**55**	(57)	**12**	(11)		
Writing mechanisms (eg SN1)	24.8 (sig at 0.1%)	**23**	(14)	**49**	(56)	**24**	(28)	√	(√)
VSEPR rules	2.0	**40**	(40)	**45**	(49)	**10**	(9)		

Notes: For df = 2 χ^2 critical at 5% level = 5.99, at 1% level = 9.21 and at 0.1% = 13.82

Figure 8.6 shows the pattern of difficulties for the Chemistry-1 class. There is a high measure of consistency over the two academic years (1997/98 and 1998/99).

Figure 8.6: % Responses of Chemistry-1 Students (Topics still difficult)



(ii) Lecturers' Responses

Lecturers were also offered questionnaires containing the same topics as those listed in the students' questionnaires (see Appendix H1 for the lecturer questionnaires' format). They were asked to mark the topics which caused trouble to their students. 10 Lecturers responded, of whom 7 were actually involved in teaching the first year chemistry courses and 3 former first year lecturers. The analysis of their views indicated that lecturers believed that the main factor causing trouble to students is the lack of mathematical background. Few of them mentioned the conceptual problems. Therefore, student and lecturer views did not correspond although the lecturers often did pick out the most troublesome topics. Detailed comments from some lecturers as to why some topics are difficult are shown in Appendix H2.

8.2.5 Attitudes Towards Chemistry

Monitoring the changes in Level-1 Chemistry students' attitudes towards their school and university chemistry courses was continued. In the third week of March 1999, the same questionnaires which were employed in the previous year (1997/98) were distributed among the students during laboratory sessions (see section 7.4). The % responses of students to the same questions are shown in tables 8.13 to 8.16. In general, it seems that the changes in first year university chemistry students' opinions towards school and university chemistry courses in two successive years were small but in favour of the academic year 1998/99. The main shifts are included below each table as follows:

Table 8.13: Percentage Responses of Level-1 Chemistry Students to: What are your opinions about your **School Chemistry Course**?

Six factors were offered on a six point scale. These are summarised on a three point scale all polarised positively in the same direction, for each of the two groups of chemistry students. χ^2 values are presented to compare student response frequencies between 1997/98 and 1998/99 in each course.

	χ^2			Positive opinion (%)		Neutral opinion (%)		Negative opinion (%)	
				1998/99	1997/98	1998/99	1997/98	1998/99	1997/98
1.				I liked Chemistry				I hated Chemistry	
	2.0		*Chem 1*	**59**	(61)	**31**	(30)	**9**	(8)
	4.2		*Gen Chem*	**16**	(23)	**46**	(42)	**24**	(27)
2.				Interesting subject				Boring subject	
	0.0		*Chem 1*	**52**	(52)	**38**	(38)	**8**	(8)
	0.8		*Gen Chem*	**19**	(19)	**45**	(47)	**22**	(25)
3.				Easy subject				Complicated subject	
	4.7		*Chem 1*	**16**	(6)	**48**	(52)	**35**	(30)
	3.5		*Gen Chem*	**7**	(6)	**30**	(39)	**49**	(46)
4.				Prepared me well for the University				Prepared me badly for the University	
	8.6	(sig at 5%)	*Chem 1*	**44**	(50)	**43**	(36)	**12**	(12)
	17.2	(sig at 0.1%)	*Gen Chem*	**11**	(14)	**45**	(59)	**30**	(18)
5.				I liked the teacher				I disliked the teacher	
	1.8		*Chem 1*	**64**	(67)	**21**	(20)	**15**	(13)
	18.8	(sig at 0.1%)	*Gen Chem*	**38**	(52)	**25**	(27)	**23**	(13)
6.				Enjoyable lessons				Boring lessons	
	4.7		*Chem 1*	**40**	(45)	**47**	(42)	**13**	(12)
	8.5	(sig at 5%)	*Gen Chem*	**17**	(20)	**42**	(53)	**26**	(19)

Notes: For $df = 2$ and (two-tailed) χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1 level = 13.82

The main shifts are

(a) In Chemistry-1, no major changes towards school chemistry course were found.

(b) In General Chemistry, students felt that their school chemistry course prepared them badly for the university, they disliked their chemistry teachers, and they found chemistry lessons were boring.

Table 8.14: Percentage Responses of Level-1 Chemistry Students to: What are your opinions about **University Chemistry**?

Students were asked to respond on a six point scale to various aspects. This is summarised on a three point scale. In quite a few areas, there were differences between the two year groups. χ^2 values are presented to compare student response frequencies between 1997/98 and 1998/99 in each course.

	χ^2			Positive opinion (%) 1998/99	1997/98	Neutral opinion (%) 1998/99	1997/98	Negative opinion (%) 1998/99	1997/98
1.				I feel I am coping well				I am NOT coping well	
	2.5		*Chem 1*	**52**	(49)	**39**	(40)	**8**	(10)
	0.1		*Gen Chem*	**14**	(15)	**58**	(57)	**27**	(28)
2.				I am enjoying subject				I am NOT enjoying subject	
	12.7	(sig at 1%)	*Chem 1*	**45**	(37)	**40**	(48)	**15**	(15)
	4.6		*Gen Chem*	**18**	(14)	**53**	(50)	**28**	(36)
3.				Subject is very easy				I find subject hard	
	1.1		*Chem 1*	**13**	(13)	**57**	(55)	**29**	(31)
	9.9	(sig at 1%)	*Gen Chem*	**6**	(2)	**35**	(42)	**58**	(55)
4.				I am growing intellectually				I am NOT growing intellectually	
	0.3		*Chem 1*	**35**	(35)	**56**	(56)	**8**	(7)
	2.1		*Gen Chem*	**22**	(19)	**64**	(63)	**13**	(18)
5.				I am obtaining a lot of new skills				I am NOT obtaining new skills	
	2.0		*Chem 1*	**51**	(48)	**39**	(43)	**9**	(9)
	6.2	(sig at 5%)	*Gen Chem*	**42**	(33)	**46**	(54)	**10**	(13)
6.				I am enjoying practical work				I hate practical work	
	4.3		*Chem 1*	**49**	(44)	**36**	(41)	**14**	(14)
	6.7	(sig at 5%)	*Gen Chem*	**36**	(30)	**43**	(54)	**20**	(16)
7.				I am getting better at the subject				I am getting worse at the subject	
	5.6		*Chem 1*	**56**	(51)	**39**	(42)	**4**	(6)
	12.1	(sig at 1%)	*Gen Chem*	**30**	(36)	**56**	(58)	**13**	(6)
8.				It is definitely "my" subject				I am wasting time in this subject	
	3.8		*Chem 1*	**22**	(22)	**65**	(63)	**11**	(15)
	11.2	(sig at 1%)	*Gen Chem*	**5**	(4)	**60**	(48)	**34**	(47)

Notes: For $df = 2$ and (two-tailed) χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1 level = 13.82

The main shifts are

(a) In Chemistry-1, students were enjoying the subject more than in the last year 1997/98.

(b) In General Chemistry, fewer students stated that they were obtaining a lot of new skills but getting worse at the subject.

Table 8.15: Percentage Responses of Level-1 Chemistry Students to: How did you find the **Chemistry Course at the University**?

Students were asked to respond on a six point scale to various aspects. This is summarised on a three point scale.

χ^2 values are presented to compare student response frequencies between 1997/98 and 1998/99 in each course.

	χ^2			Positive opinion (%) 98/99	(97/98)	Neutral opinion (%) 98/99	(97/98)	Negative opinion (%) 98/99	(97/98)
1.				Lectures interesting				Lectures boring	
	1.2		*Chem 1*	**16**	(15)	**61**	(63)	**22**	(22)
	16.3	(sig at 0.1%)	*Gen Chem*	**17**	(8)	**49**	(59)	**34**	(32)
2.				Laboratories interesting				Laboratories boring	
	0.3		*Chem 1*	**44**	(44)	**44**	(46)	**11**	(10)
	34.1	(sig at 0.1%)	*Gen Chem*	**39**	(21)	**46**	(64)	**14**	(15)
3.				Tutorials helpful				Tutorials waste of time	
	9.8	(sig at 1%)	*Chem 1*	**34**	(29)	**41**	(46)	**11**	(15)
	17.7	(sig at 0.1%)	*Gen Chem*	**27**	(15)	**52**	(58)	**12**	(15)
4.				Course not mathematical enough				Course too mathematical	
	3.9		*Chem 1*	**15**	(10)	**72**	(76)	**12**	(15)
	8.9	(sig at 5%)	*Gen Chem*	**28**	(13)	**63**	(65)	**7**	(21)
5.				Course easy				Course difficult	
	1.7		*Chem 1*	**13**	(11)	**57**	(58)	**30**	(31)
	1.3		*Gen Chem*	**3**	(5)	**43**	(43)	**51**	(52)
6.				Work level undemanding				Work level very demanding	
	11.1	(sig at 1%)	*Chem 1*	**9**	(10)	**72**	(65)	**18**	(26)
	6.5	(sig at 5%)	*Gen Chem*	**5**	(5)	**64**	(75)	**28**	(21)

Notes: **For** df = 2 and two-tailed χ^2 (critical) at 5% level = 5.99, at 1% level = 9.21, and at 0.1 level = 13.82

The main shifts are

(a) In Chemistry-1, students thought that the work level was undemanding and tutorial helpful.

(b) In General Chemistry, students found the lectures and laboratories interesting, the course not mathematical enough, the work level very demanding, and tutorials helpful.

Table 8.16: Percentage Responses of Level-1 Chemistry Students to: Thinking about your **Chemistry Course,** reflect your opinions?

χ^2 values are presented to compare student response frequencies between 1997/98 and 1998/99 in each course.

Item	χ^2		Course	strongly agree 98/99	strongly agree 97/98	agree 98/99	agree 97/98	disagree 98/99	disagree 97/98	strongly disagree 98/99	strongly disagree 97/98
1 I felt the assessment methods used were good											
	1.0		Chem 1	**28**	(16)	**68**	(81)	**3**	(3)	**0**	(0)
	14.6	(sig at 0.1%)	Gen Chem	**9**	(7)	**81**	(71)	**7**	(21)	**2**	(2)
2. The time demand was reasonable for me											
	0.2		Chem 1	**8**	(6)	**79**	(80)	**10**	(10)	**0**	(0)
	11.9	(sig at 0.1%)	Gen Chem	**3**	(4)	**68**	(77)	**26**	(16)	**2**	(2)
3. I found good support from academic staff											
	0.5		Chem 1	**21**	(14)	**70**	(76)	**7**	(8)	**1**	(1)
	2.9		Gen Chem	**11**	(5)	**63**	(63)	**21**	(26)	**3**	(5)
4. I found the course well organised											
	15.2	(sig at 0.1%)	Chem 1	**25**	(17)	**71**	(75)	**2**	(7)	**0**	(0)
	4.7	(sig at 5%)	Gen Chem	**7**	(4)	**76**	(71)	**14**	(24)	**3**	(1)
5. I think chemistry will provide good career opportunities											
	10.0	(sig at 1%)	Chem 1	**21**	(16)	**62**	(73)	**13**	(9)	**1**	(1)
	11.1	(sig at 0.1%)	Gen Chem	**9**	(5)	**75**	(67)	**12**	(21)	**1**	(4)
6. I found the course challenging											
	0.1		Chem 1	**15**	(16)	**74**	(73)	**9**	(10)	**1**	(0)
	4.2	(sig at 5%)	Gen Chem	**25**	(17)	**68**	(72)	**5**	(9)	**0**	(1)
7. I found note taking easy											
	1.3		Chem 1	**11**	(12)	**70**	(72)	**13**	(14)	**4**	(2)
	3.2		Gen Chem	**9**	(7)	**64**	(72)	**21**	(19)	**6**	(2)
8. The course covered enough topics											
	0.1		Chem 1	**5**	(7)	**78**	(76)	**13**	(15)	**2**	(2)
	2.7		Gen Chem	**3**	(3)	**55**	(61)	**33**	(33)	**9**	(2)
9. The course is a good basis for studying other subjects											
	0.9		Chem 1	**11**	(10)	**73**	(73)	**14**	(16)	**0**	(1)
	5.3	(sig at 5%)	Gen Chem	**11**	(4)	**67**	(65)	**20**	(27)	**1**	(4)

Notes: For $df = 1$ (two-tailed) χ^2 (critical) at 5% level = 3.84, at 1% level = 6.64, and at 0.1% level = 10.83

The main shifts are

(a) In Chemistry-1, students found the course well organised and challenging and they thought that chemistry will provide good career opportunities.

(b) In General Chemistry, students felt that the assessment methods used were good, the course well organised and challenging and a good basis for studying other subjects, and they think chemistry will provide good career opportunities but the time demand is not reasonable.

8.3 Conclusions

From the previous sections, the findings of the following sources were considered as the major evidence that the Chemorganisers achieved their aims in preparing the minds of the students and improving confidence:

(1) *Students' ratings and comments.*

(2) *The questionnaire which gave detailed feedback on all aspects of the Chemorganisers and the way they were presented.*

(3) *Examination achievements of students.*

(4) *Student interviews.*

(5) *The approval of the content of the Chemorganisers by members of the academic staff.*

(6) *In addition, working as a demonstrator in Level-1 Chemistry laboratory sessions provided the opportunity to interact with Level-1 Chemistry students, especially the General Chemistry students, which gave insights into what they thought about the course in general, and about the Chemorganisers in particular.*

From these sources of evidence, the following conclusions can be drawn:

(1) *When the Chemorganisers were used, the less-well qualified students performed as well as the better-qualified students in examinations.*

(2) *The Chemorganisers were presumably preparing the minds of General Chemistry students (pre-learning) for the materials to come.*

(3) *The layout, the presentation, and the amount of given information were largely acceptable. The Chemorganisers were found to be a relatively easy, time-saving, and friendly tool.*

(4) *The use of applications (self-assessment) were appreciated as it gave students the opportunity to test the knowledge gained and to develop confidence.*

(5) *The evidence suggests that students used the Chemorganisers in a variety of ways (such as for exam revision, study guidance) and found their flexibility very useful. It is possible that the Chemorganisers can be used for distance learning. Each sheet contains a target and encourages further exploration of issues.*

Chapter Nine

GENERAL CONCLUSIONS

When faced with new experiences (such as laboratory work or solving problems), it is not always easy for unprepared learners to find strategies to cope successfully. Pre-learning is necessary to prepare the mind to recognise the expected changes, to be surprised when something different occurs, and to have the requisite theory to guide what is going to be experienced.

The Information Processing Model (as a predictive model of learning) highlights the following key points:

(1) *Long-term memory (LTM) controls what we attend to and how we perceive new information.*

(2) *Existing material drawn from LTM controls how we process new information.*

(3) *Previous knowledge allows information to be chunked and shortcuts to be developed, to increase the efficiency of the restricted working space.*

(4) *Storage processes control the retrieval of knowledge, meaningful learning being easier to access than rote learning.*

(5) *Poor storage and retrieval will affect all other steps in learning by introducing errors of perception and processing. This leads to further poor storage.*

If what is already in the students' long-term memory is so crucial to the processing of new material, then the preparation of long-term memory before learning is absolutely essential to enhance learning and minimise mislearning. This is the point emphasised so strongly by Ausubel.

The Information Processing Model led to the idea of pre-learning. This approach was used to modify teaching laboratories, which led to pre-labs. These pre-lab exercises were developed to alert students to relevant material they would meet and prepare their minds to handle the new tasks. The success of the pre-lab exercises had suggested the idea of introducing pre-lecture sessions in the new General Chemistry course.

The General Chemistry course is mainly made up of students who have, by and large, made a conscious decision not to continue chemistry studies beyond that initial university year, as well as those with limited chemistry experience, poor or no previous chemistry experience. The backgrounds and future aspirations of such students could potentially generate certain (negative) attitudes to chemistry and their ability to study it, which may hinder their progress in the course.

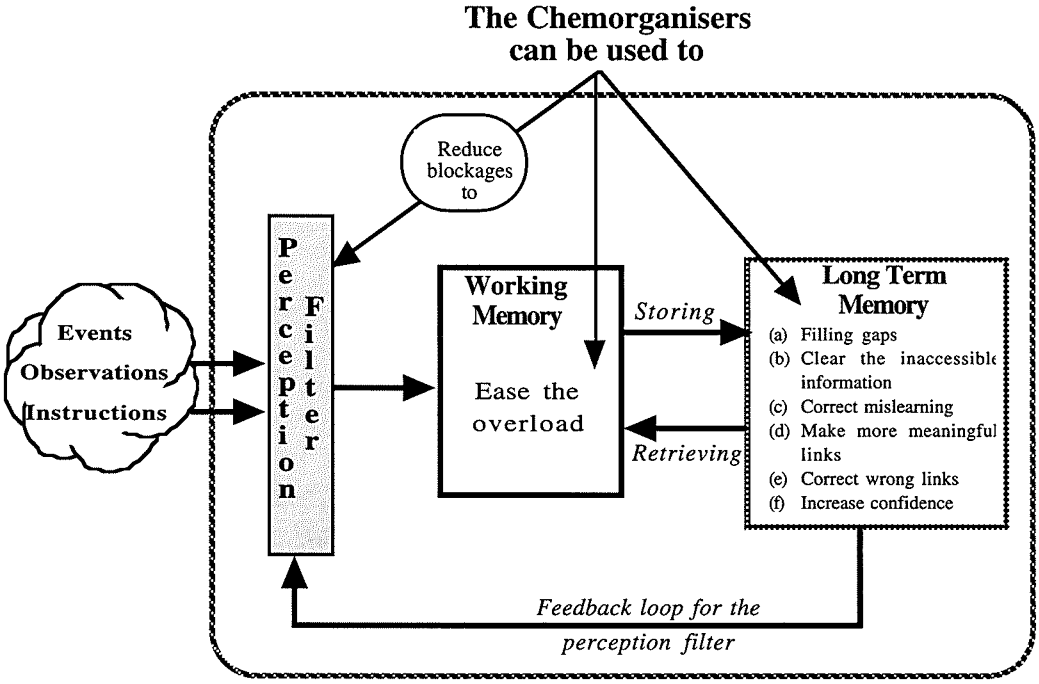
Surprisingly, for two years when pre-lectures were operated, no significant link was found between entrance qualifications held by students and their examination results in the General Chemistry course. This meant that success in this course was unrelated to the previous chemistry experience of the students. This was not the case for the Chemistry-1 course (which did not operate pre-lectures), where success was related to the previous chemistry experiences. When pre-lectures were not used in the General Chemistry course, it was found that the exam results were related to students' past experience.

Chemorganisers were designed to assist General Chemistry students in areas of chemistry where difficulties were known to exist. Although they had wider functions, these teaching materials were constructed to mimic features of pre-lectures. On introducing Chemorganisers in the academic year 1998/99, it was found that performance in exams was not related to entry qualifications. The pattern was similar to the years 1993/94 and 1994/95 when pre-lectures operated. From the evidence gained, it appears that many of the Chemorganisers' goals were realised. They mimic the pre-lectures, preparing the mind of the learner, and supporting students with the necessary key elements to understand topics.

The aim was to allow Chemorganisers to assist long-term memory by reducing problems such as correcting mislearning, making more meaningful links, correcting wrong links, filling gaps, making previously held knowledge more accessible, and increasing confidence. The Chemorganisers were also designed to minimise problems caused by limitations of working space, so that the perception filter would work as the students faced new material.

The Chemorganisers could form the basis for helping students to identify how they learn and how they could learn better. The possible ways in which this is occurring are presented in figure 9.1. In this, the Information Processing Model is seen to make sense of why the Chemorganisers helped the less-well qualified students more, providing a basis for understanding the observations made in this work.

Figure 9.1: The effect of the Chemorganisers



9.1 Messages

The results do suggest a number of key messages which, if appropriately noted, would improve the effectiveness and efficiency of the teaching/learning process. These key points are:

(a) The Importance of Previous Knowledge

While appropriate knowledge and skills must be present in the learners' mind, it is important to recognise that they must be accessible (able to be retrieved in a meaningful form) at the time when new material is presented. The new material also must be presented in a manner consistent with the way the previous knowledge and skills have been laid down in long-term memory. It is, therefore, important that the minds of the students are prepared for lectures if the learning is to be meaningful.

(1) Students' previous knowledge should be taken seriously. The teachers should assess students' prior knowledge before introducing new material.

(2) There is no point in putting a student into a situation without mental preparation. The nature of that preparation has to be as carefully considered as the course itself.

(3) Moreover, teachers should carefully match instructional activities with student's current levels of knowledge. The learning material needs to be organised and to be made explicit to the students so that they have an overall sense of direction and can see the logical order of the material and how the information relates to the learning task.

(4) Changes to the teaching approach could be made which might assist in making the topics more accessible. Reducing the amount of material might be advantageous if the time released was used to prepare the minds of the students to make more complete sense of the new material offered.

(5) The teaching of strategies, or the encouragement of students to develop their own, is an essential part of the teaching/learning process. It should include pre-learned concepts which enable incoming ideas (demands) to be processed and meaningfully learned.

(6) Each piece of new chemical information needs to be explicitly linked to what the student already knows. The more meaningful linkages the student can make for each piece of knowledge, the deeper his/her understanding will be and the easier to be recalled later. Students need to construct these links for themselves by being challenged to engage their minds with this problem.

(b) Limitations of the " Working Space"

When processing information, usually a person can attend to only one thing at a time. The working space, at any one time, can hold only about 7 'chunks', on average, of information processing. Lecturers should use strategies, wherever possible, to minimise working space demands. It is important to avoid excessive content where students have little chance of mastery (or even understanding) because of limited working space.

(c) Importance of attitudes

Positive attitudes towards chemistry, style of teaching, style of learning, and usefulness (as perceived) leads to better motivation and then on to better learning.

(1) Students' motivation is an important factor for encouraging meaningful learning. Students should be actively involved in the exercise and have time to reflect on the exercise afterwards, to consider what they have learned, how

they learned it, and how it fits with what else they know. The confidence and motivation of more poorly qualified students will almost certainly be enhanced by learning experiences where their weakness are being taken into consideration.

(2) Teaching is creating situations and challenges that encourage students in active constructions of meaning. Learning occurs when there is a change in what we think, and good teaching should be about helping learners to construct and to reconstruct their ideas. The teaching materials should be presented in such a way that they will be understood by students, and students feel that they get answers to questions they asked, or could have asked themselves.

9.2 Suggestions for Teaching

(1) Chemorganisers were successfully used for preparing the mind of students and decreasing some chemistry learning difficulties. Two further applications may need exploring:

(a) as a pre-test for students to provide good indications of students' preconceptions and prior knowledge in a particular area (developing the ability of self-evaluation).

(b) in a computer-based form. If each Chemorganiser could be used on screen or downloaded as a single page, students could select those which are relevant to their needs. In this way, students could control their own pace of study, the location of study and, to some extent, even the order by which materials are studied.

(2) Another approach is to allow students to share knowledge in small group discussions prior to beginning new, and possibly unfamiliar, tasks either in tutorial or problem solving sessions.

(3) Replace the traditional method of lecturing by introducing the material in the form of Chemorganisers, then hold discussion sessions.

(4) In some areas, Chemorganisers seemed to have little effect. Perhaps, other approaches need to be developed here.

9.3 Further Studies

Like any other research studies, questions have been raised from this study and each one of them can be a point of departure for further research. Some of them are offered below:

(1) *The data gathered show that not all students with a lower level of entry qualifications (e.g., Scottish Standard Grade) seemed to benefit from the pre-lectures and the Chemorganisers. This needs exploration.*

(2) *Some Chemorganisers had large effects, others minimum. They do not work in all areas at the same level. The reasons for this need exploration.*

(3) *Is it possible to study the effect of using the Chemorganisers as a post-learning device?*

(4) *What is the difference between using the Chemorganisers by individuals and by groups?*

(5) *What is the difference between the use of the Chemorganisers by teachers as compulsory or as optional?*

(6) *What is the difference between using the Chemorganisers in paper-based or computer-based forms?*

(7) *Is it possible to apply the idea of the Chemorganisers in another field, for instance in biology or physics?*

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List of Appendices

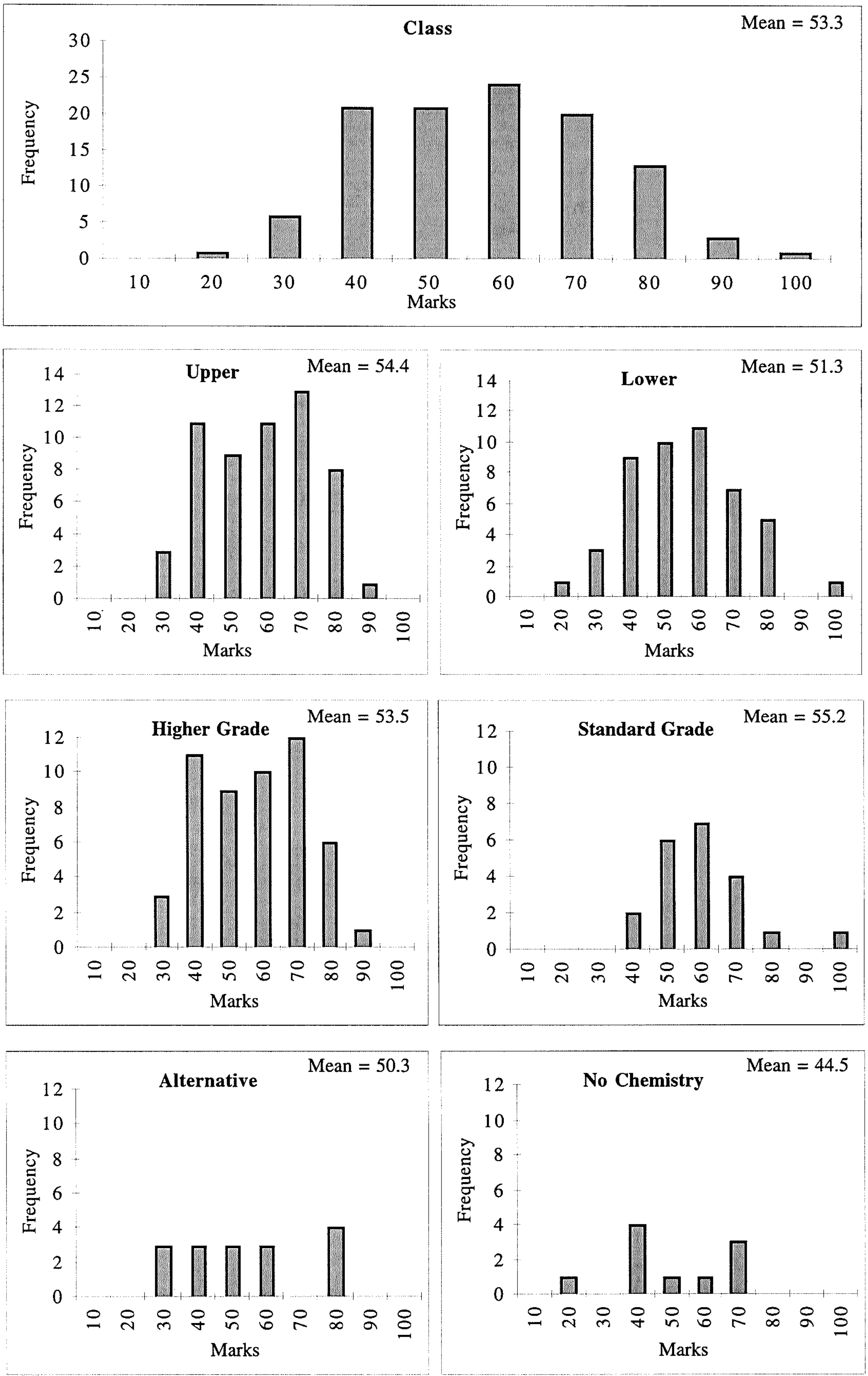
Appendix A

General Chemistry

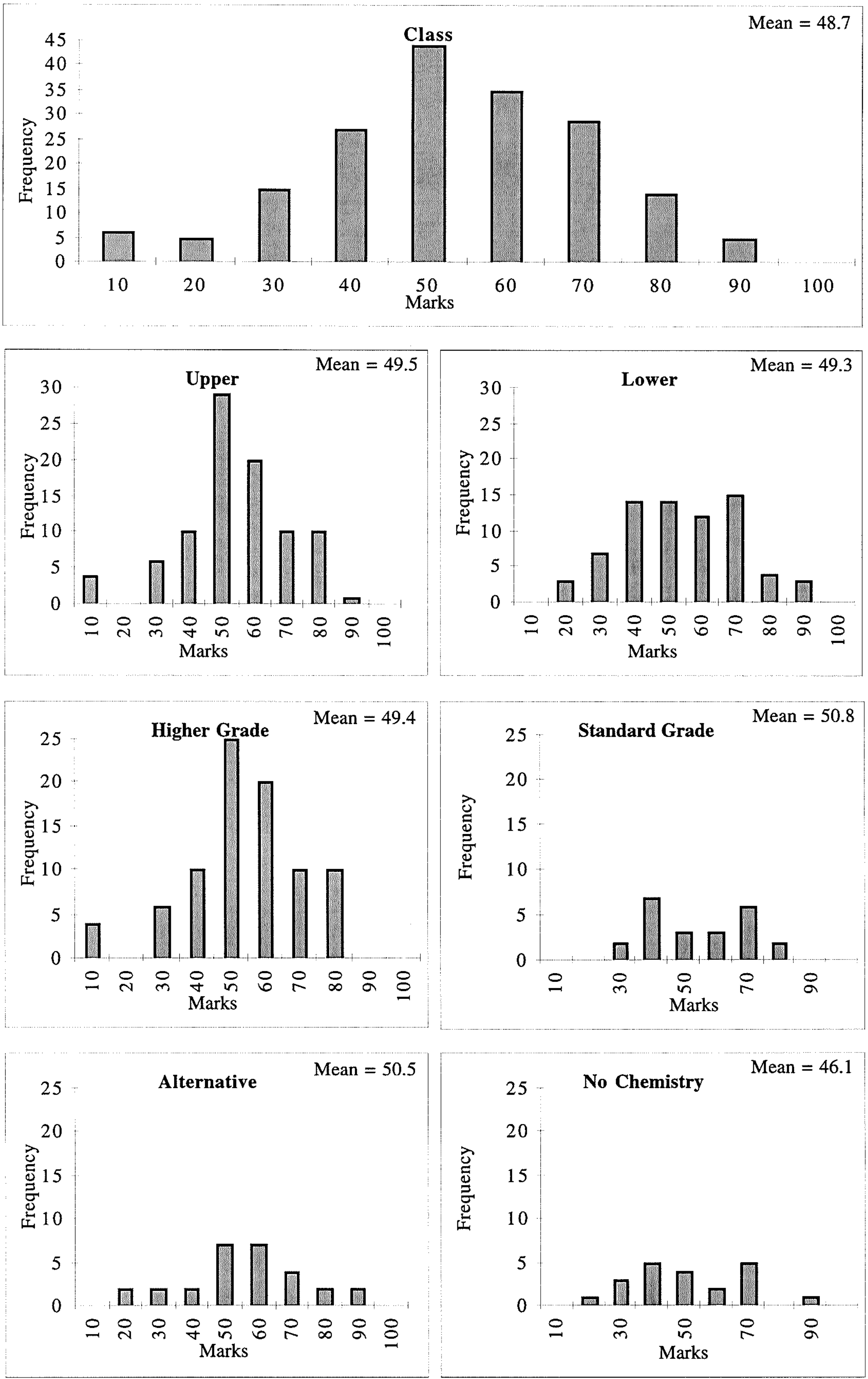
January Examination Results

(1993/94 to 1998/99)

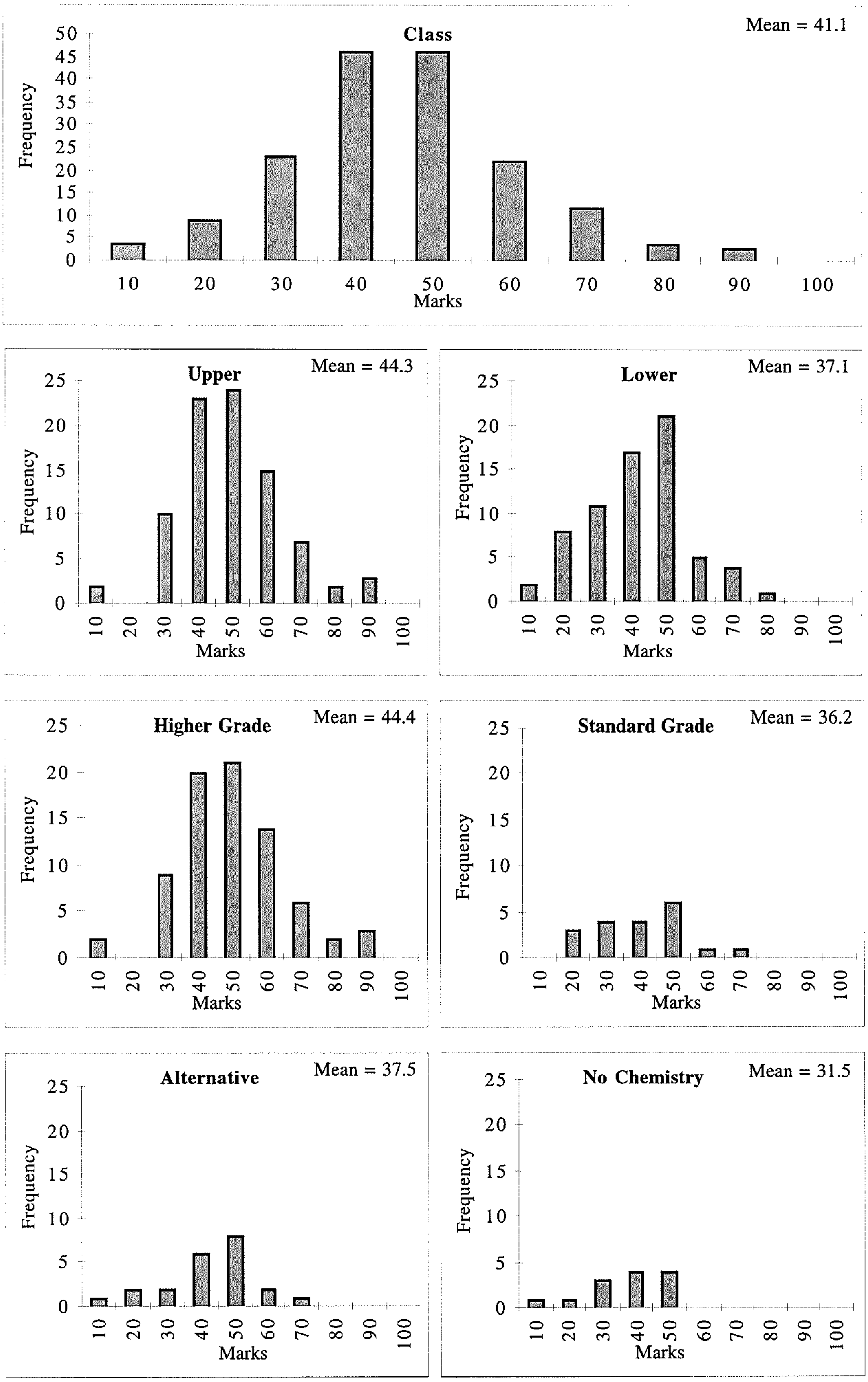
Graph A1: Distribution of General Chemistry (1993/94) January Exam Marks



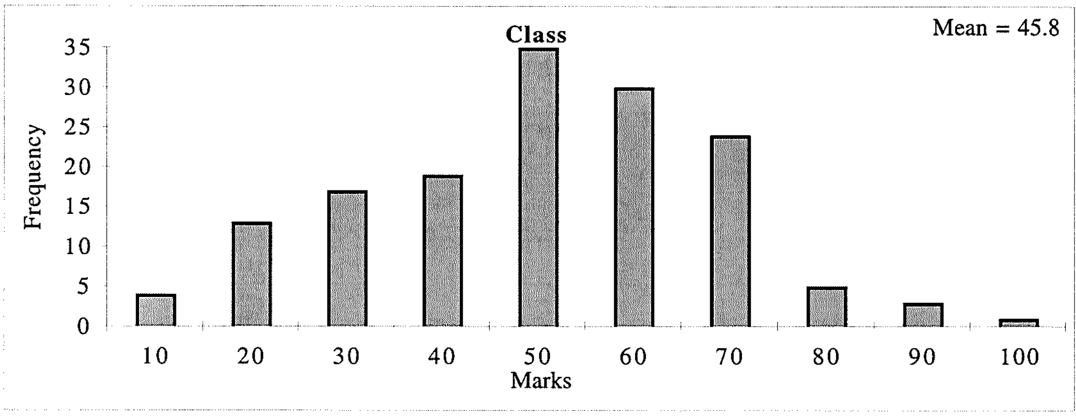
Graph A2: Distribution of General Chemistry (1994/95) January Exam Marks

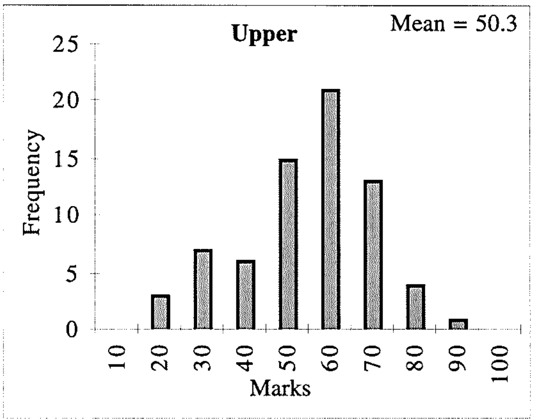


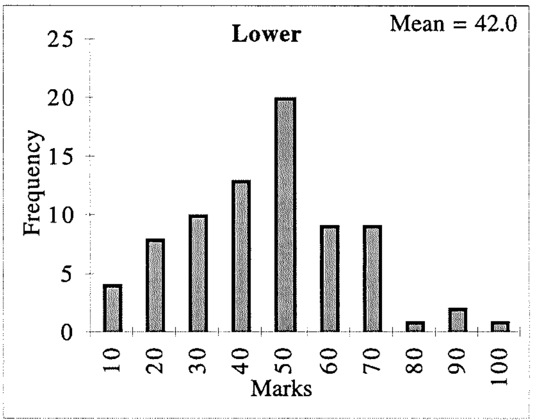
Graph A3: Distribution of General Chemistry (1995/96) January Exam Marks

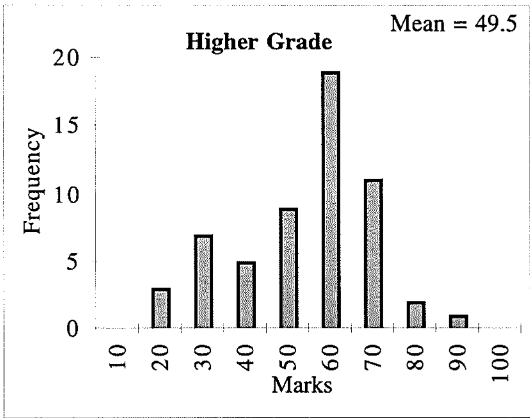


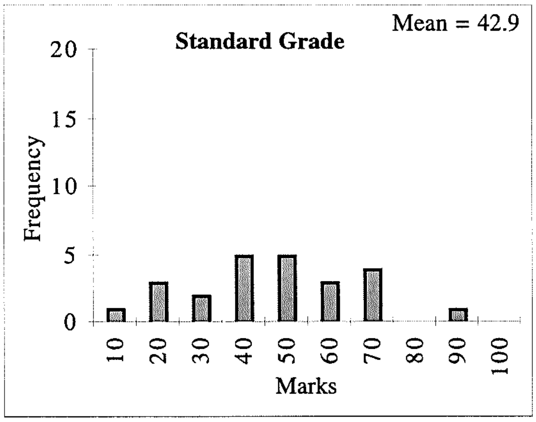
Graph A4: Distribution of General Chemistry (1996/97) January Exam Marks

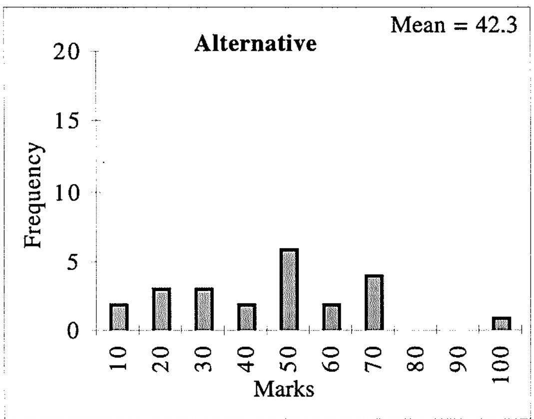


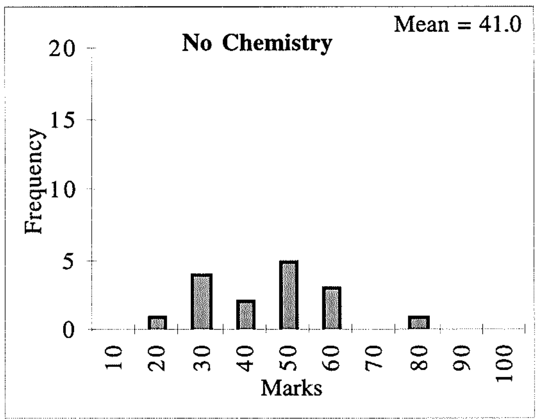




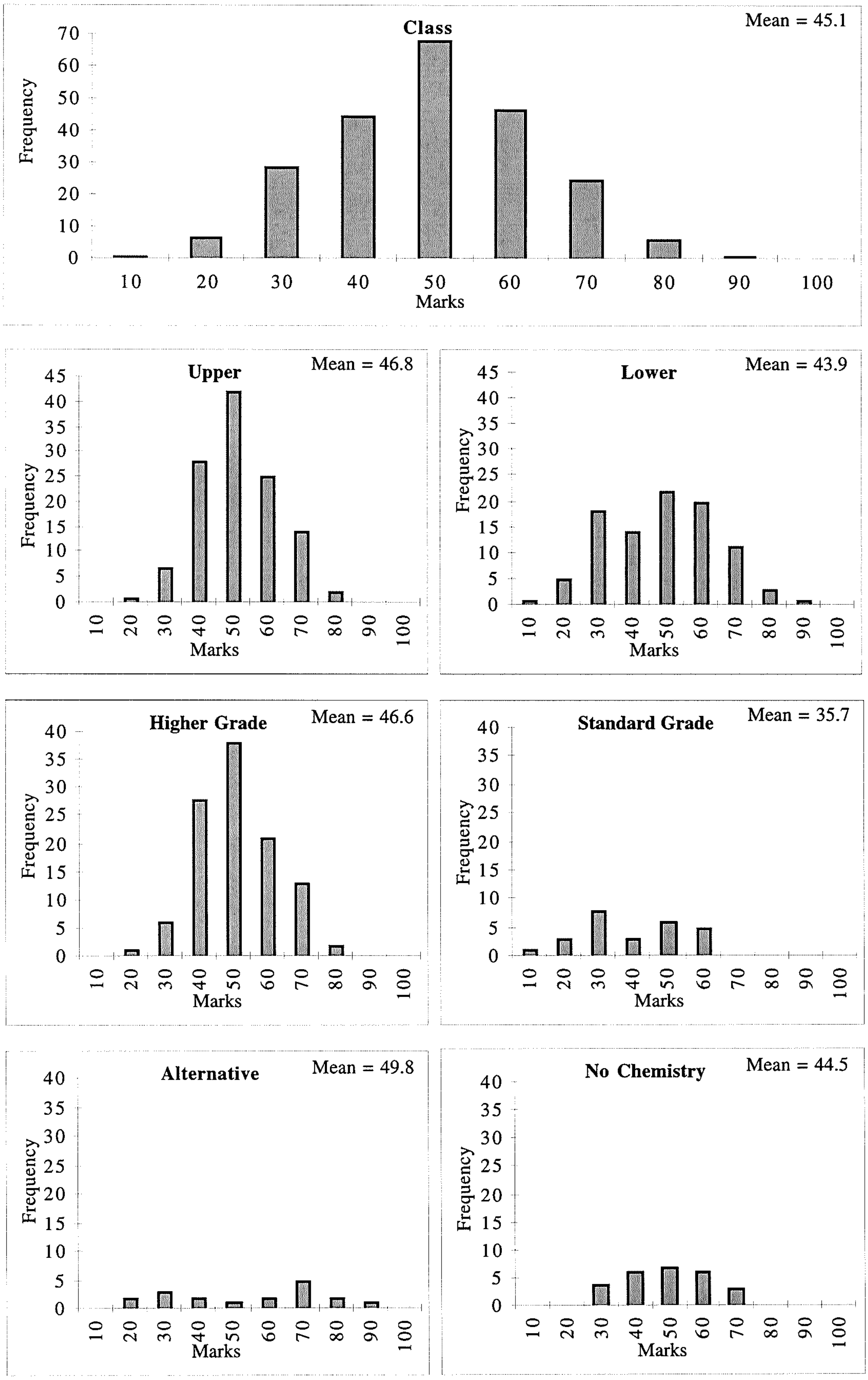




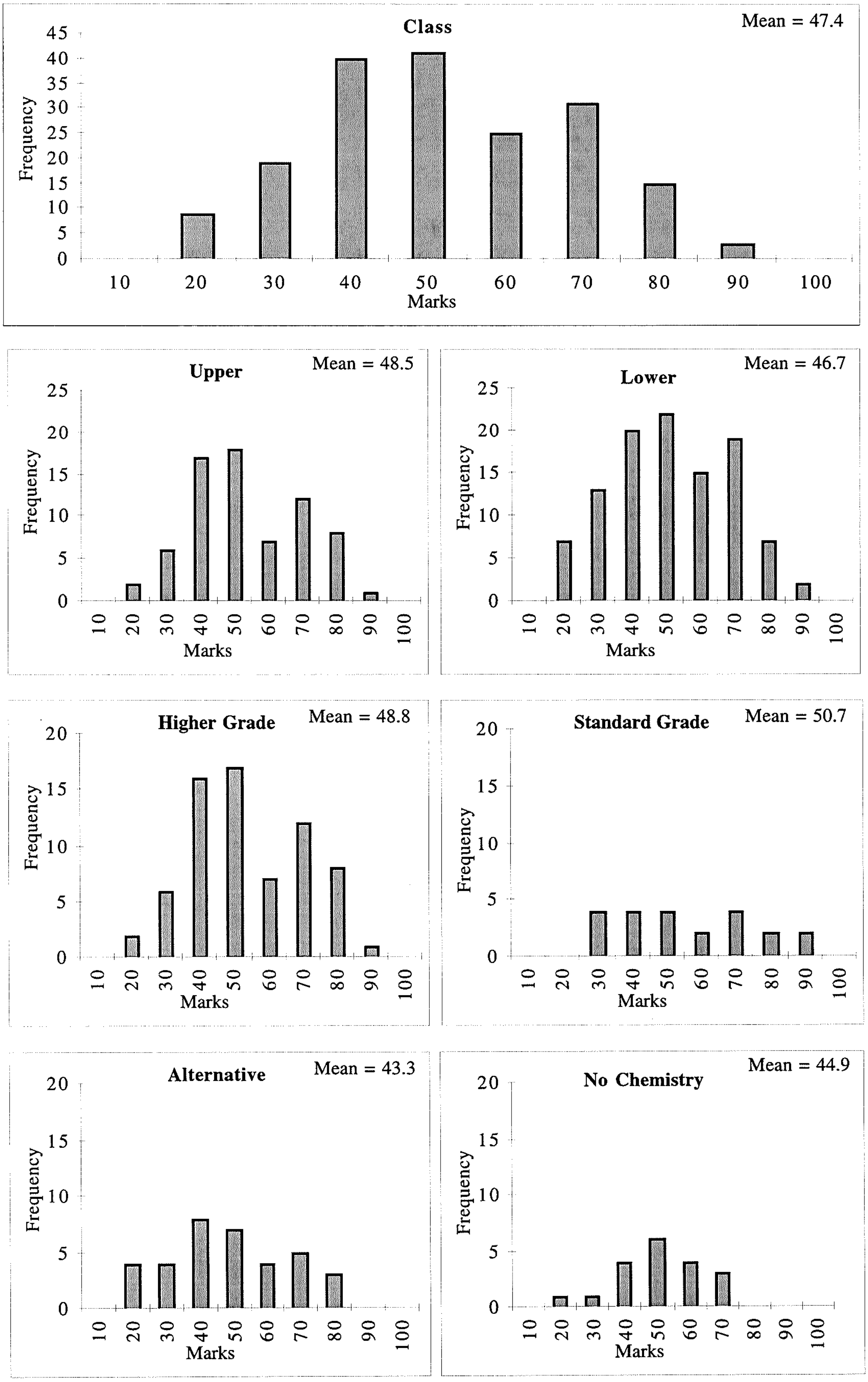




Graph A5: Distribution of General Chemistry (1997/98) January Exam Marks



Graph A6: Distribution of General Chemistry (1998/99) January Exam Marks



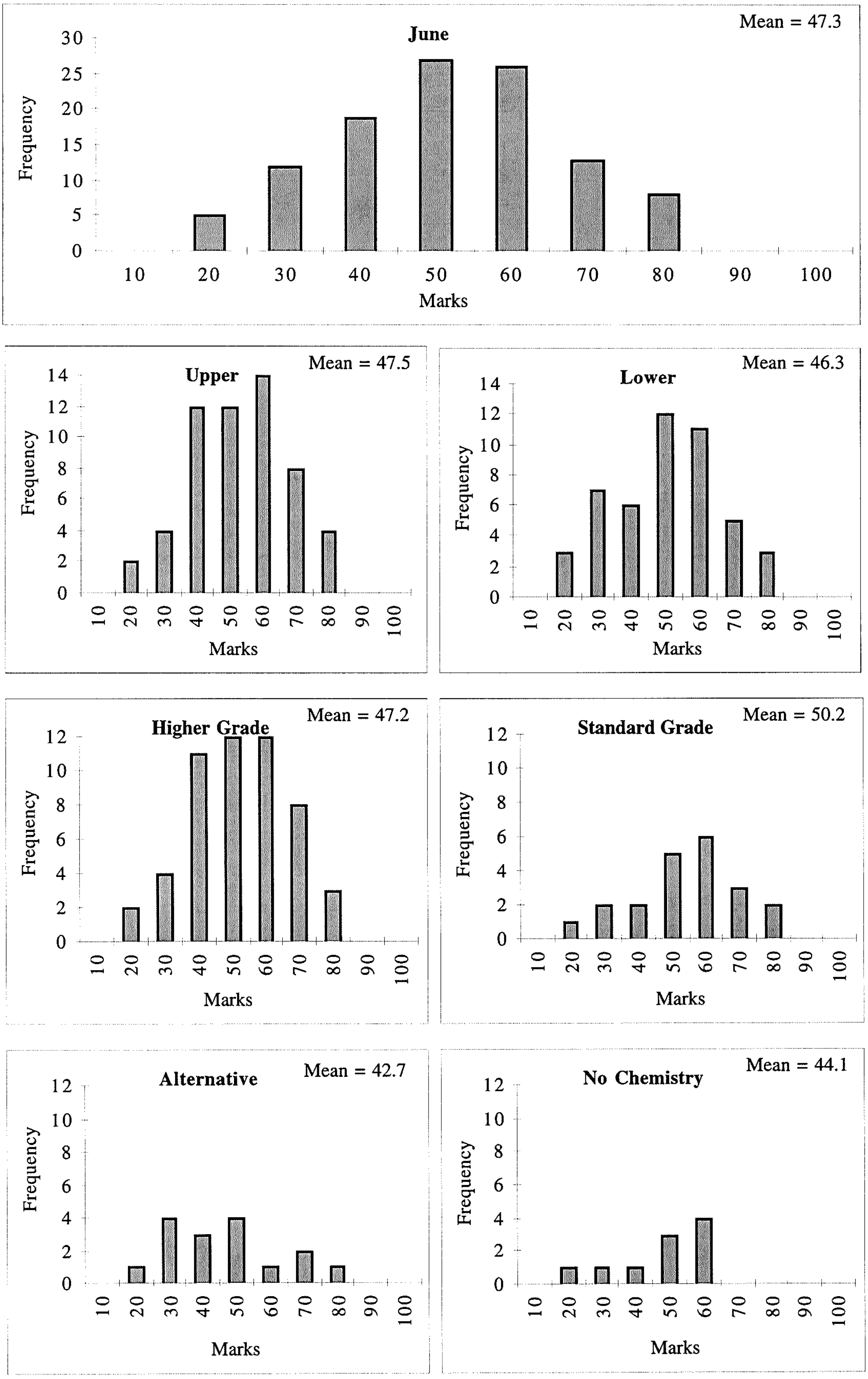
Appendix B

General Chemistry

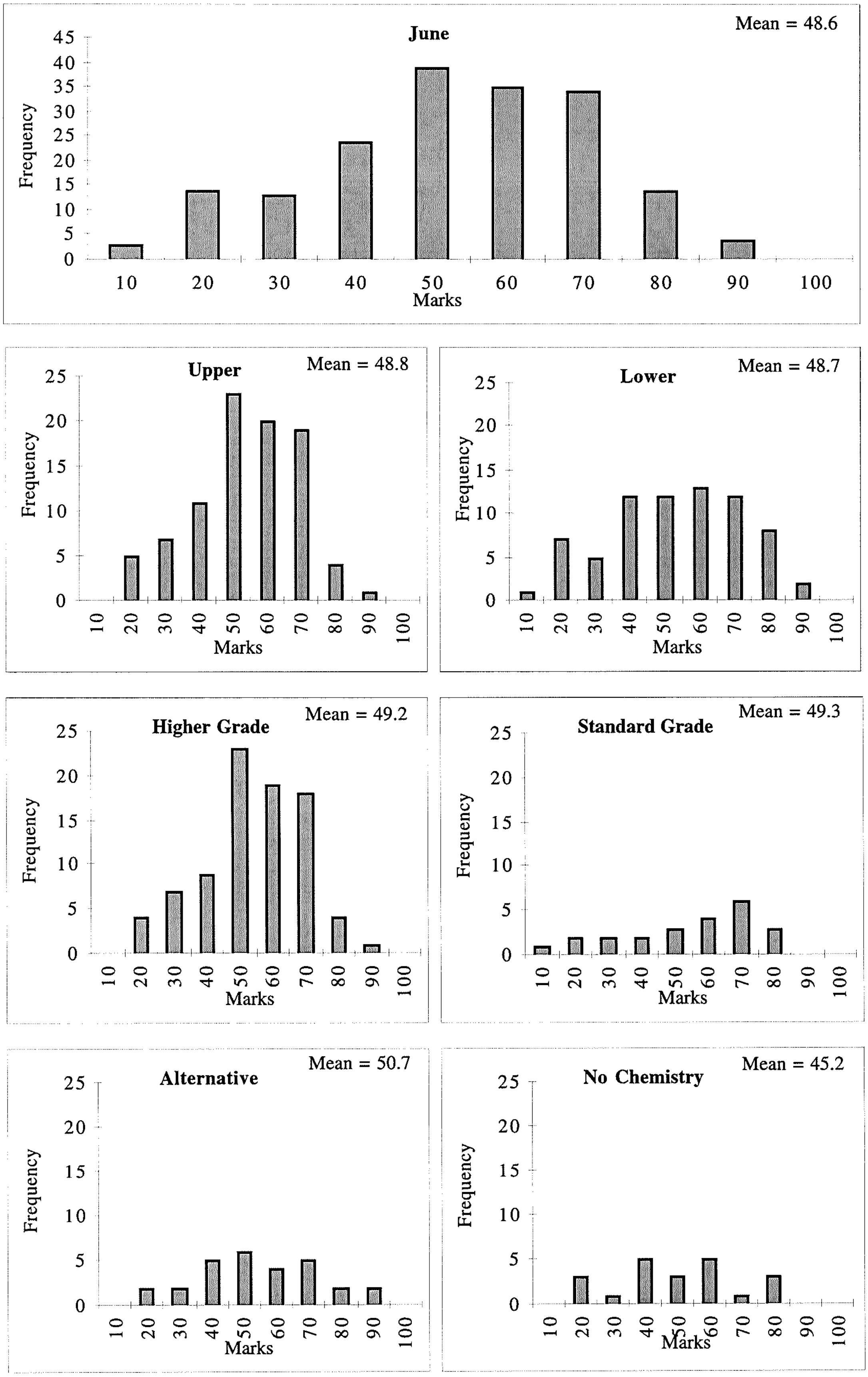
June Examination Results

(1993/94 to 1998/99)

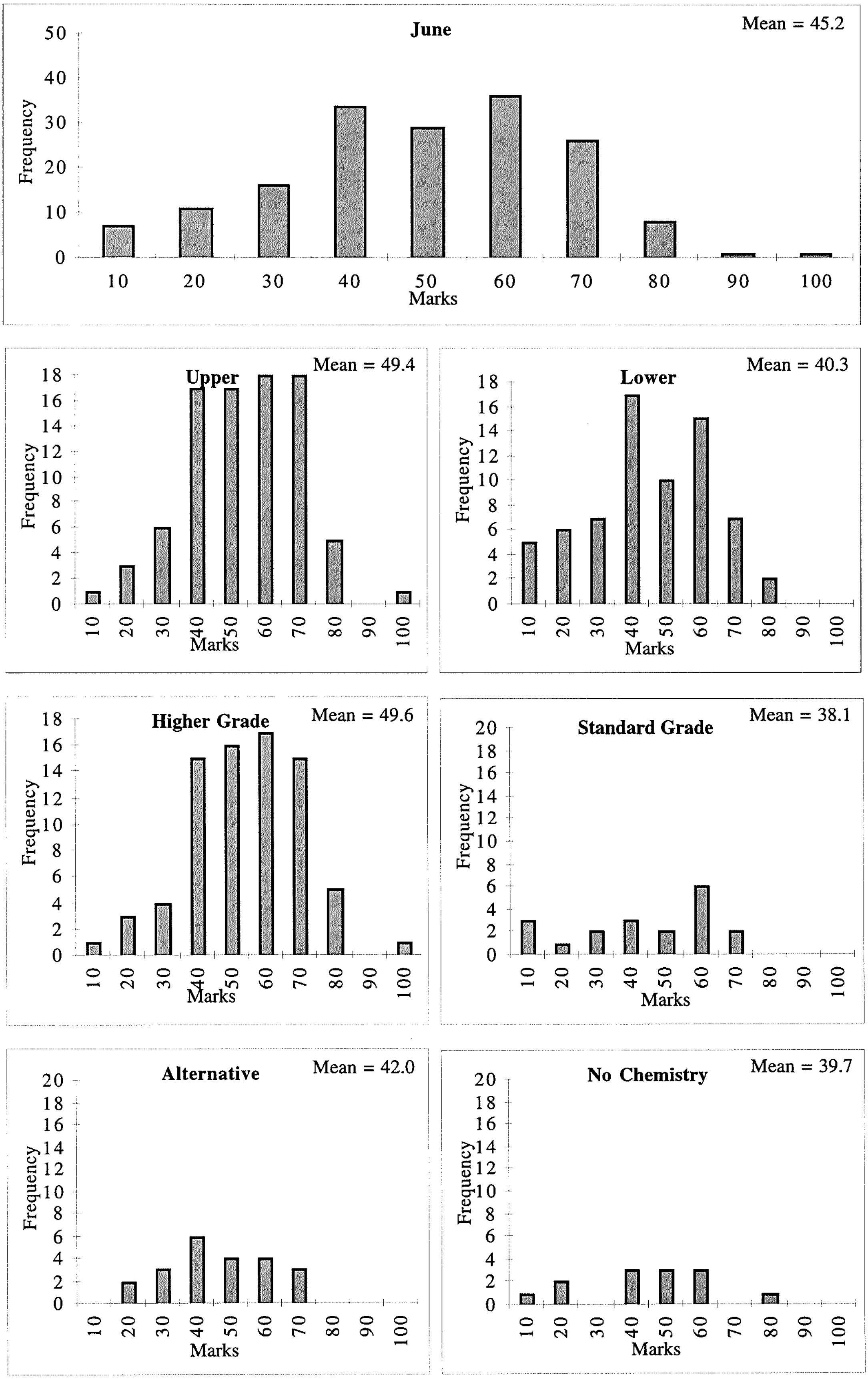
Graph B1: Distribution of General Chemistry (1993/94) June Exam Marks



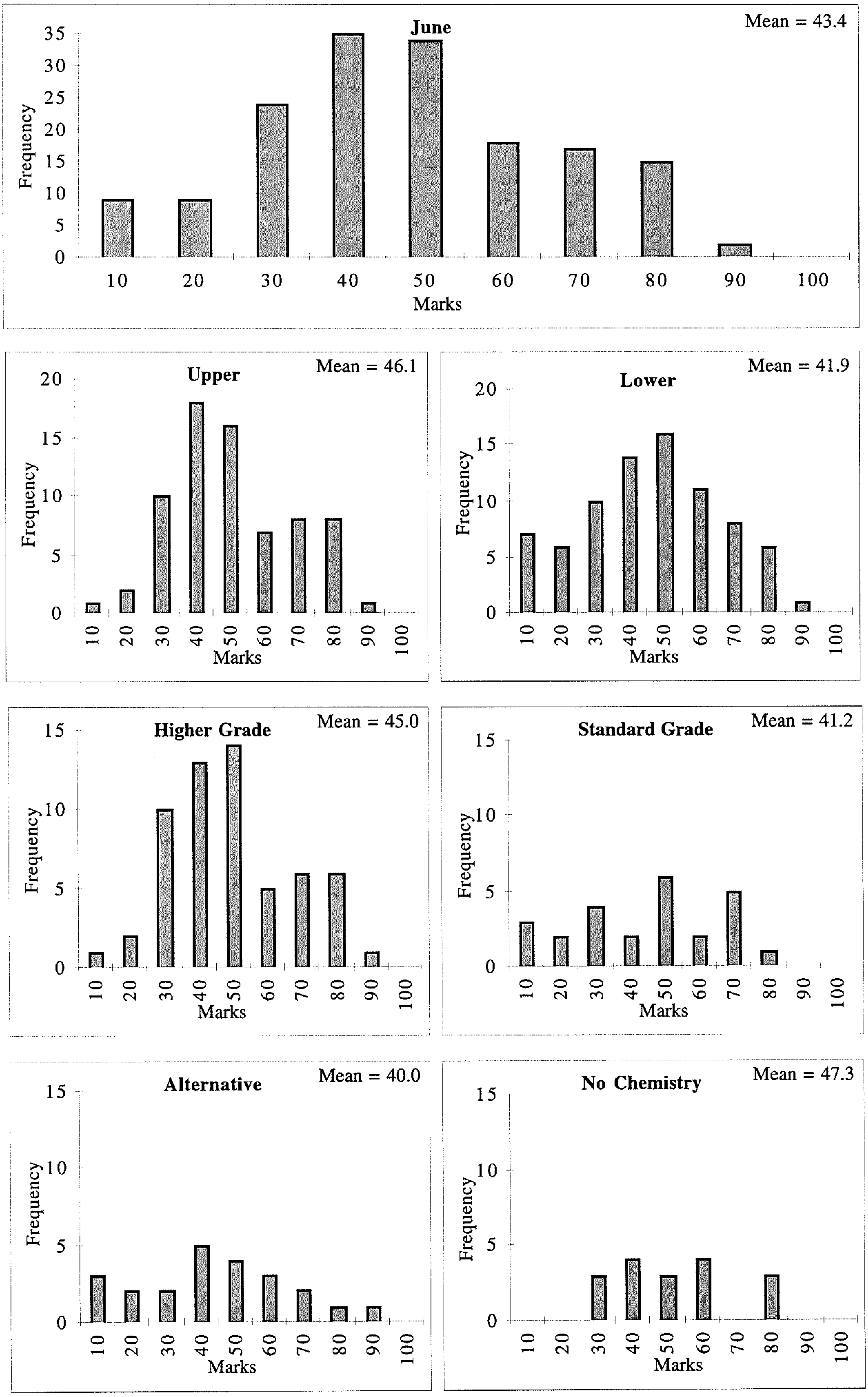
Graph B2: Distribution of General Chemistry (1994/95) June Exam Marks



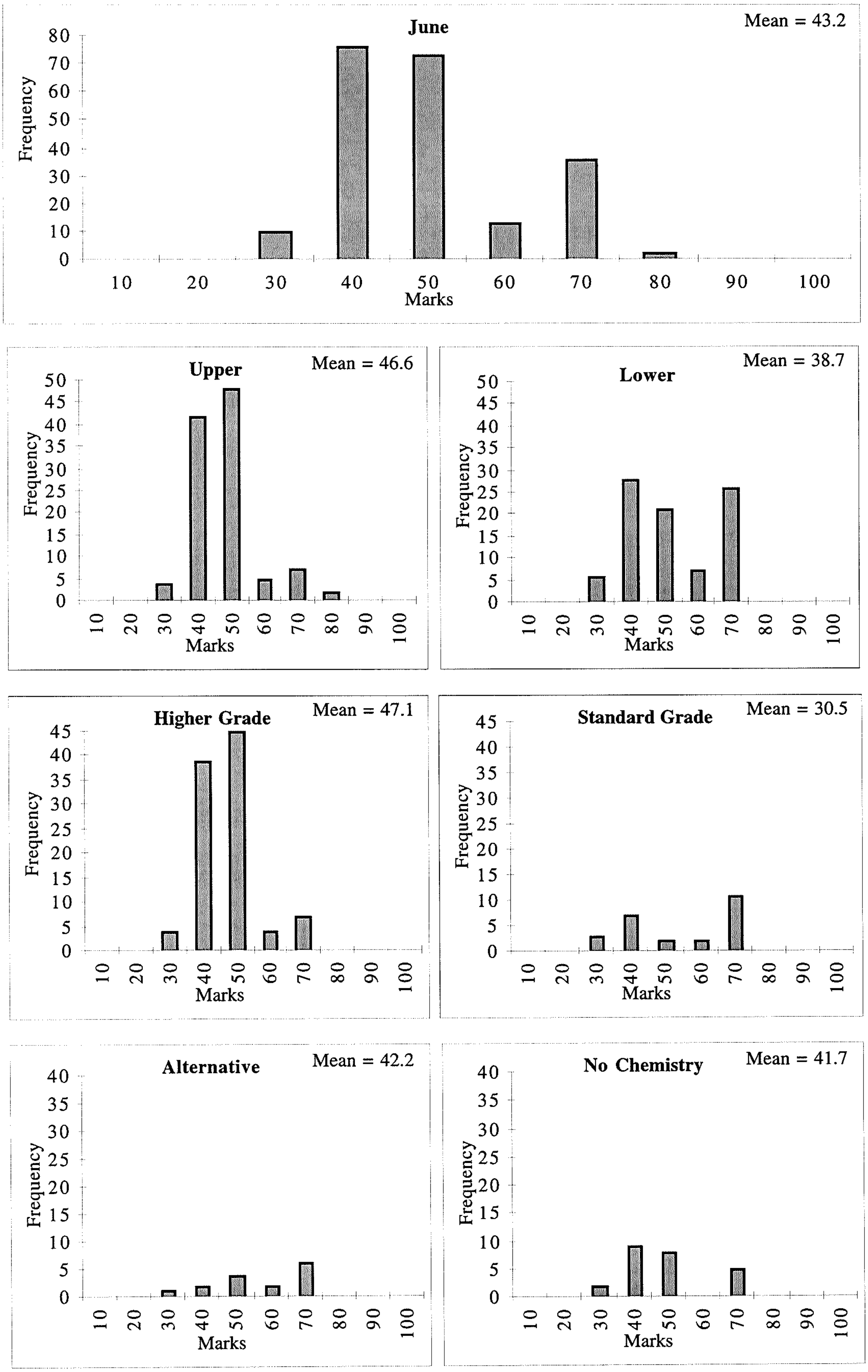
Graph B3: Distribution of General Chemistry (1995/96) June Exam Marks



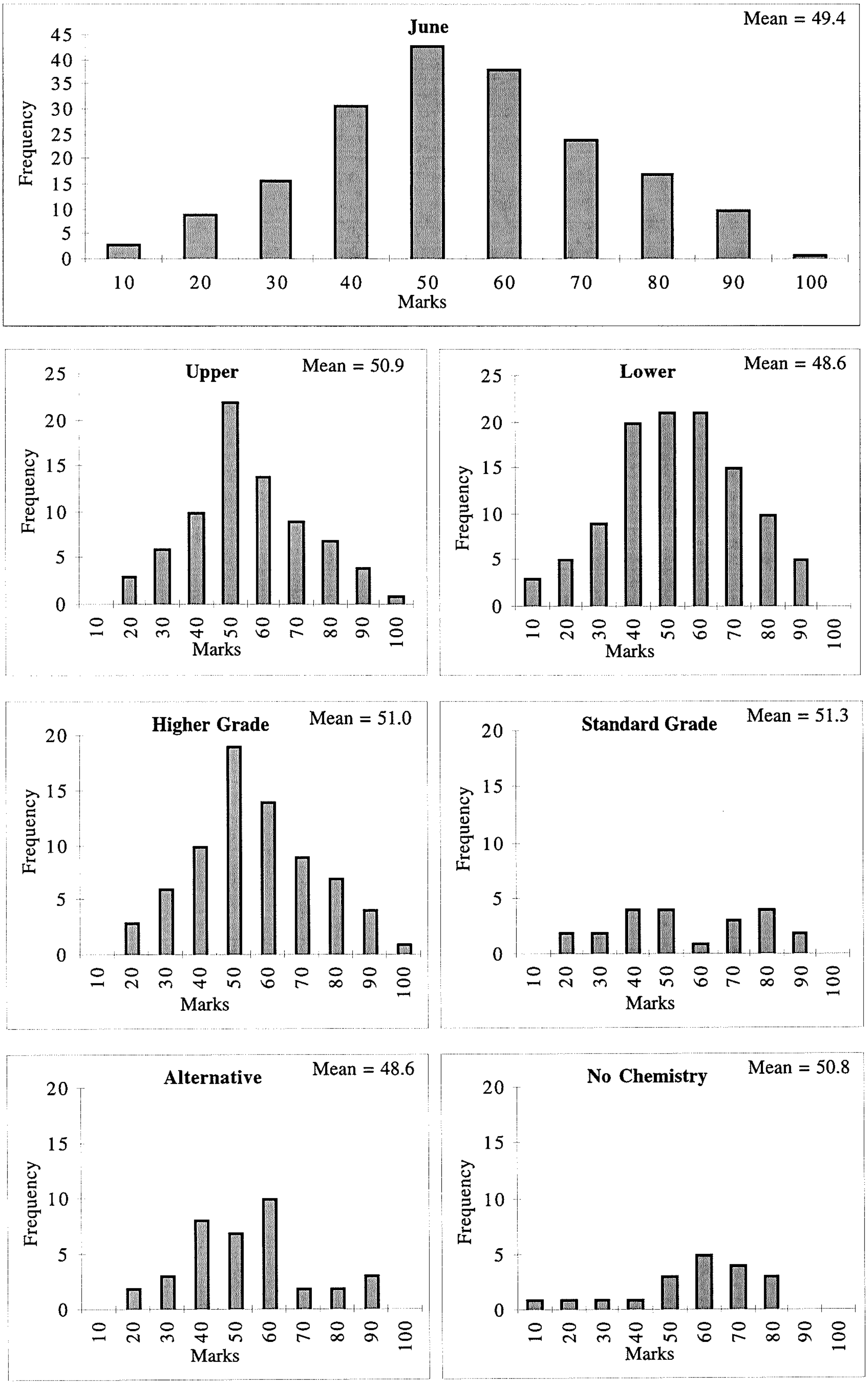
Graph B4: Distribution of General Chemistry (1996/97) June Exam Marks



Graph B5: Distribution of General Chemistry (1997/98) June Exam Marks



Graph B6: Distribution of General Chemistry (1998/99) June Exam Marks



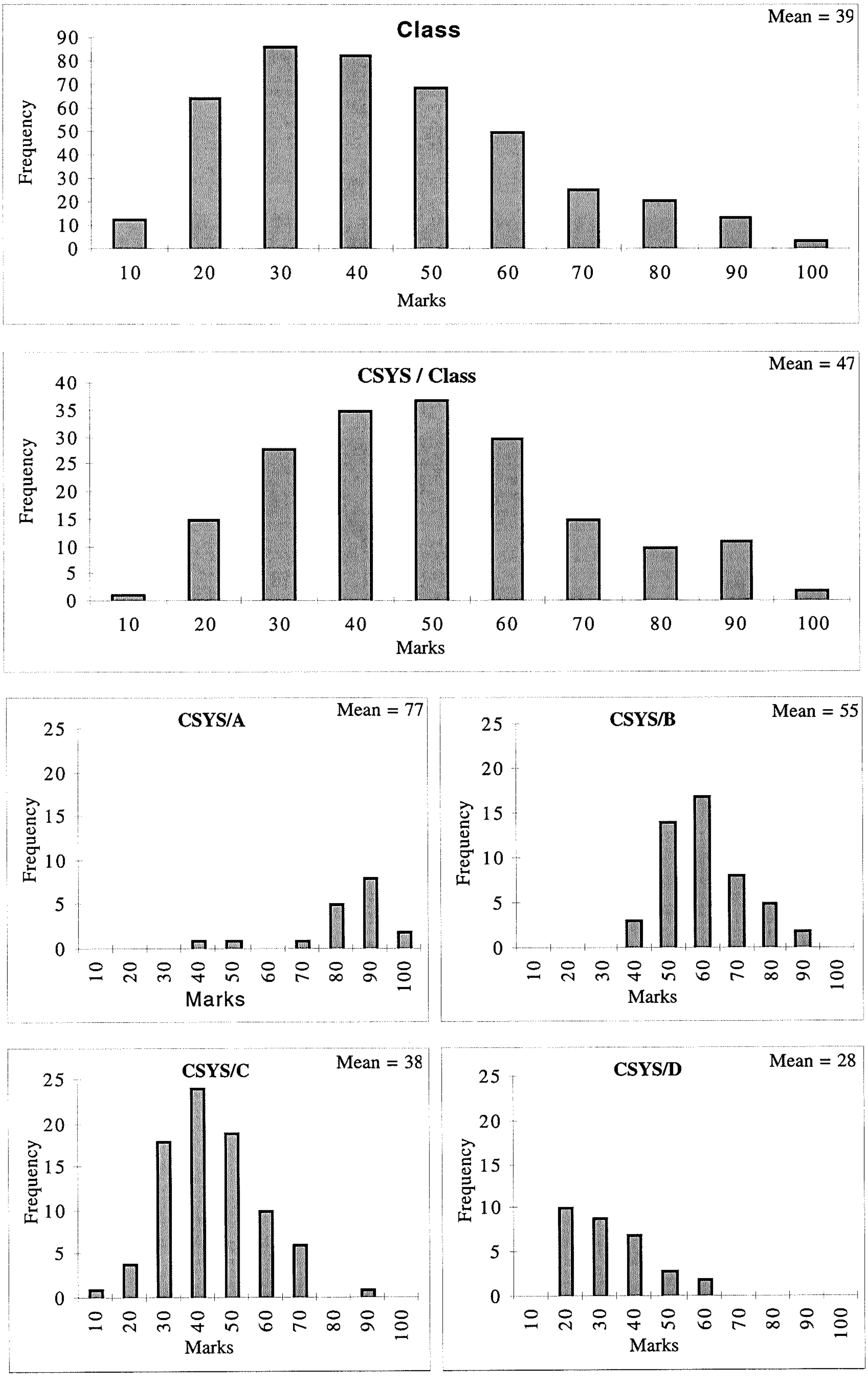
Appendix C

Chemistry-1

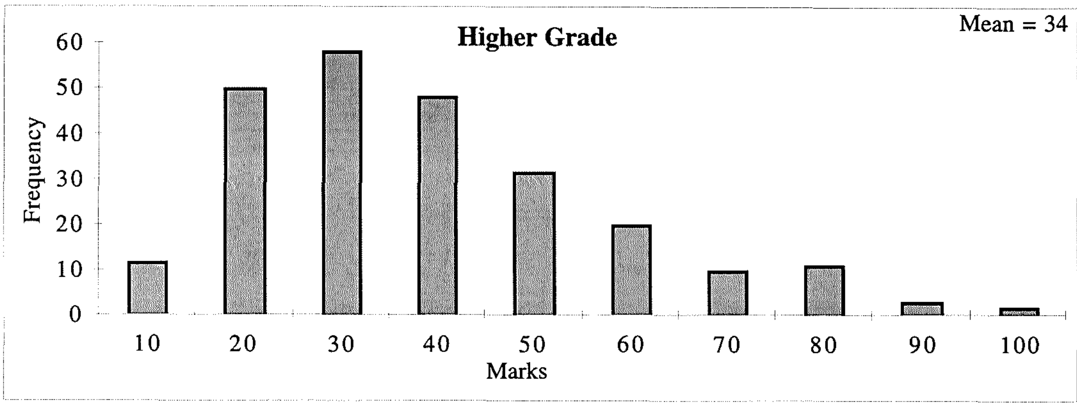
Class Examination Results

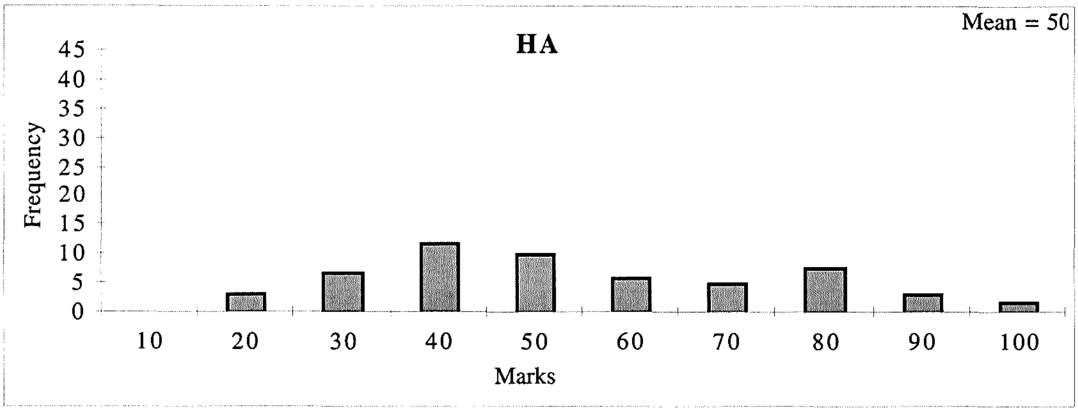
(1994/95 to 1998/99)

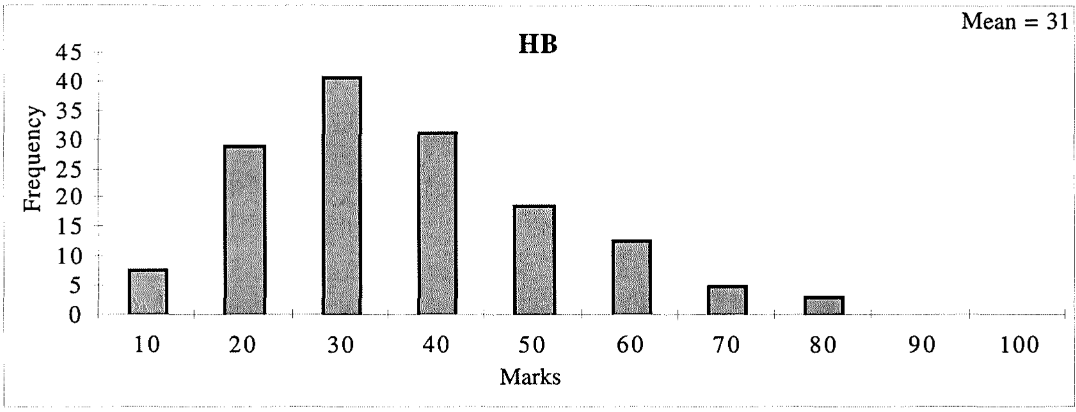
Graph C1a: Distribution of Chemistry-1 (1994/95) January Exam Marks

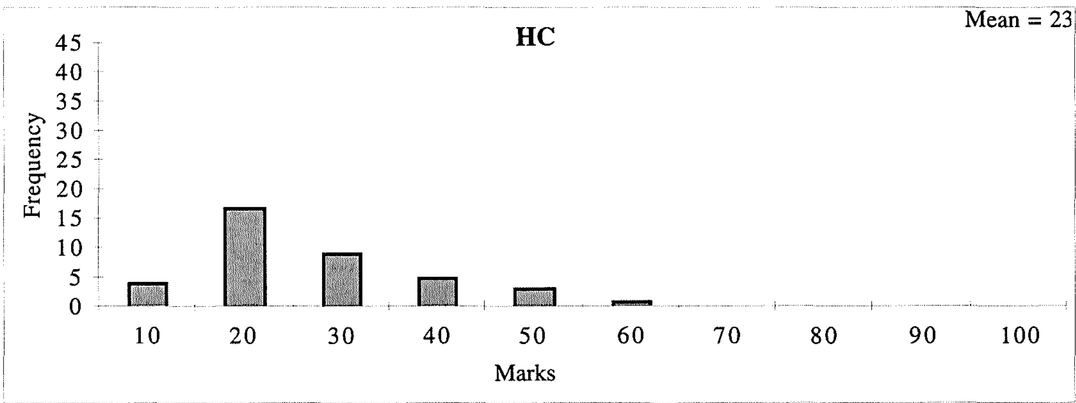


Graph C1b: Distribution of Chemistry-1 (1994/95) January Exam Marks

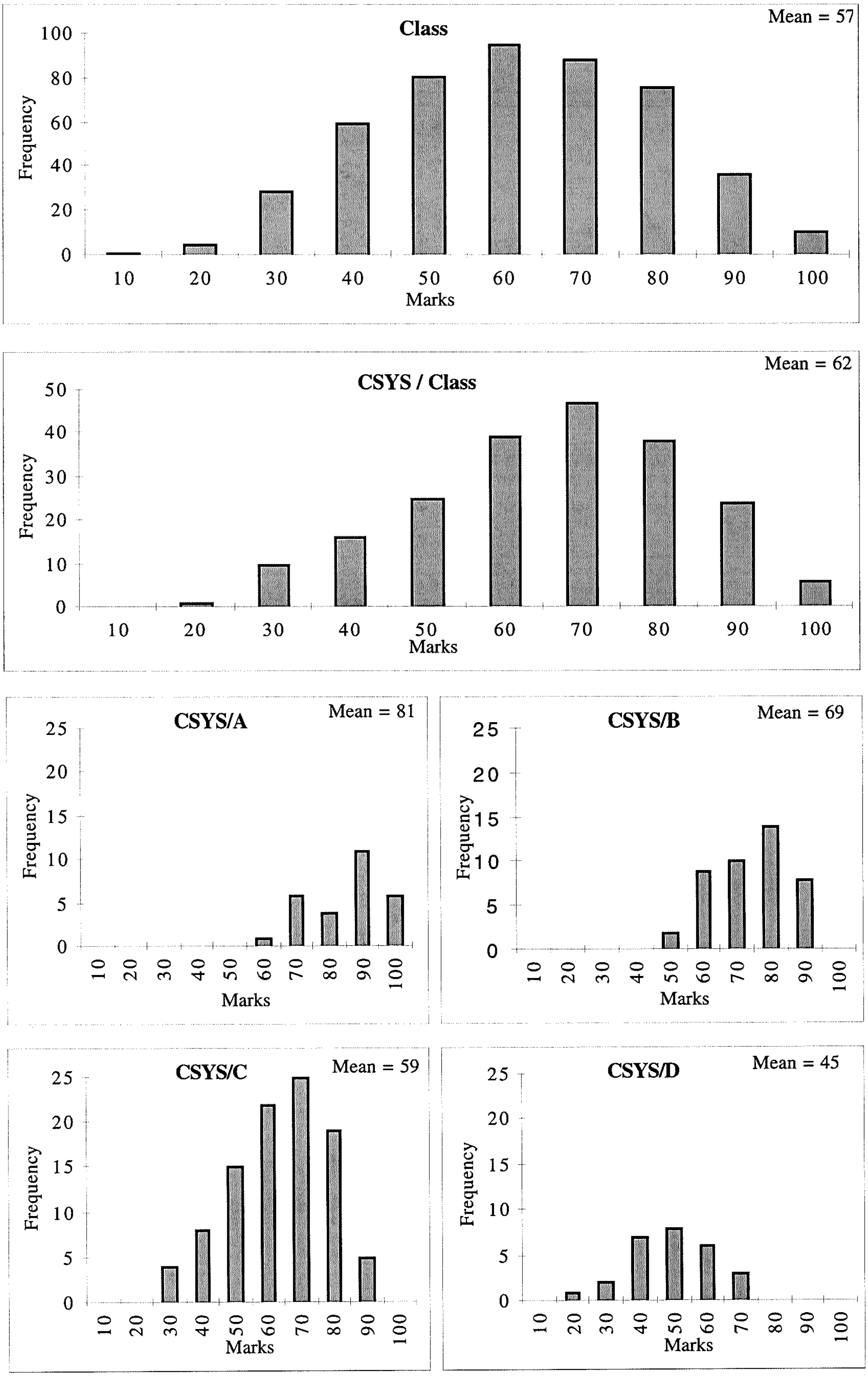




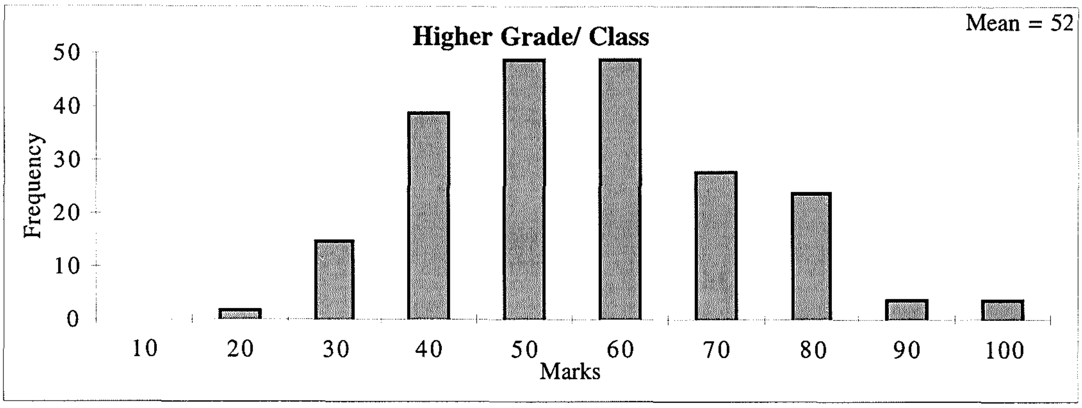


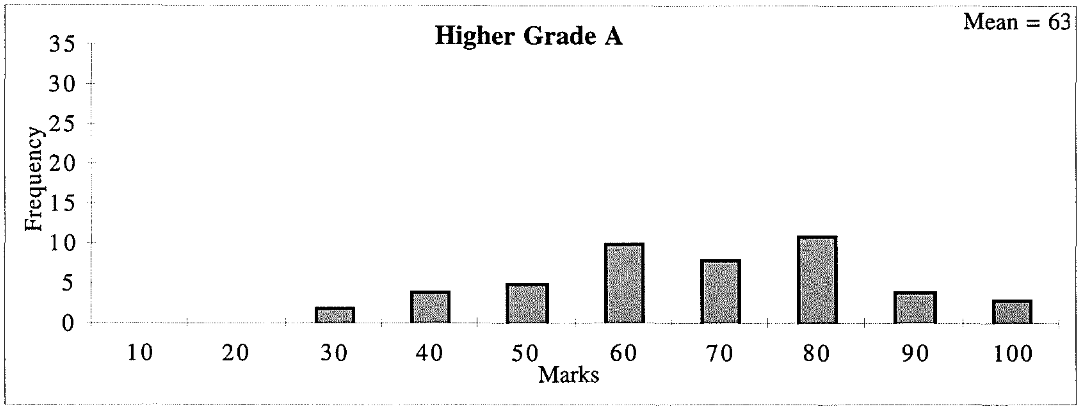


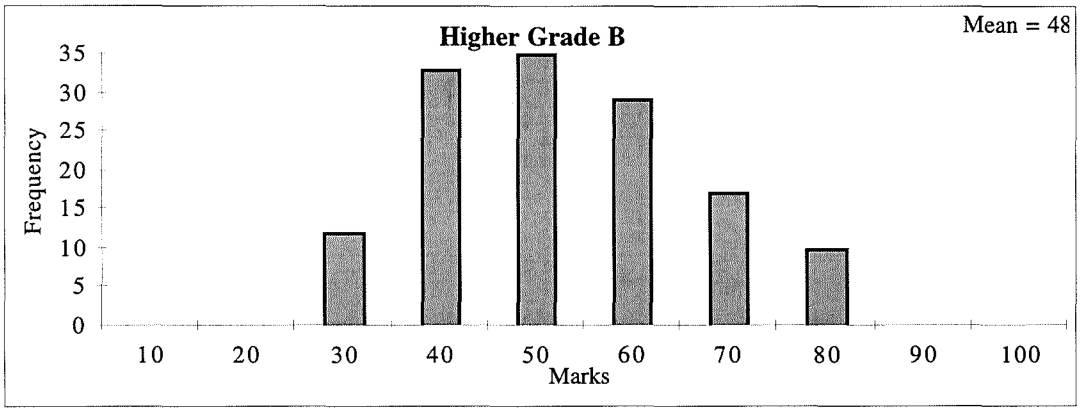
Graph C2a: Distribution of Chemistry-1 (1995/96) January Exam Marks

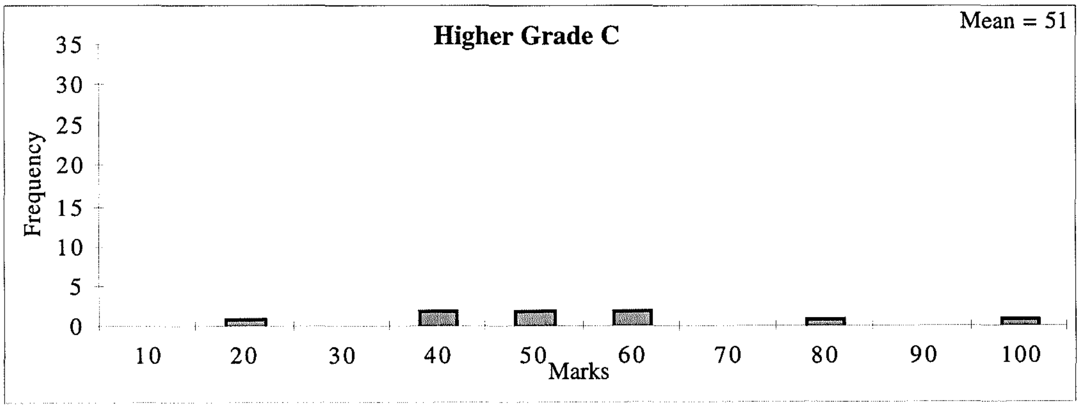


Graph C2b: Distribution of Chemistry-1 (1995/96) Class Exam Marks

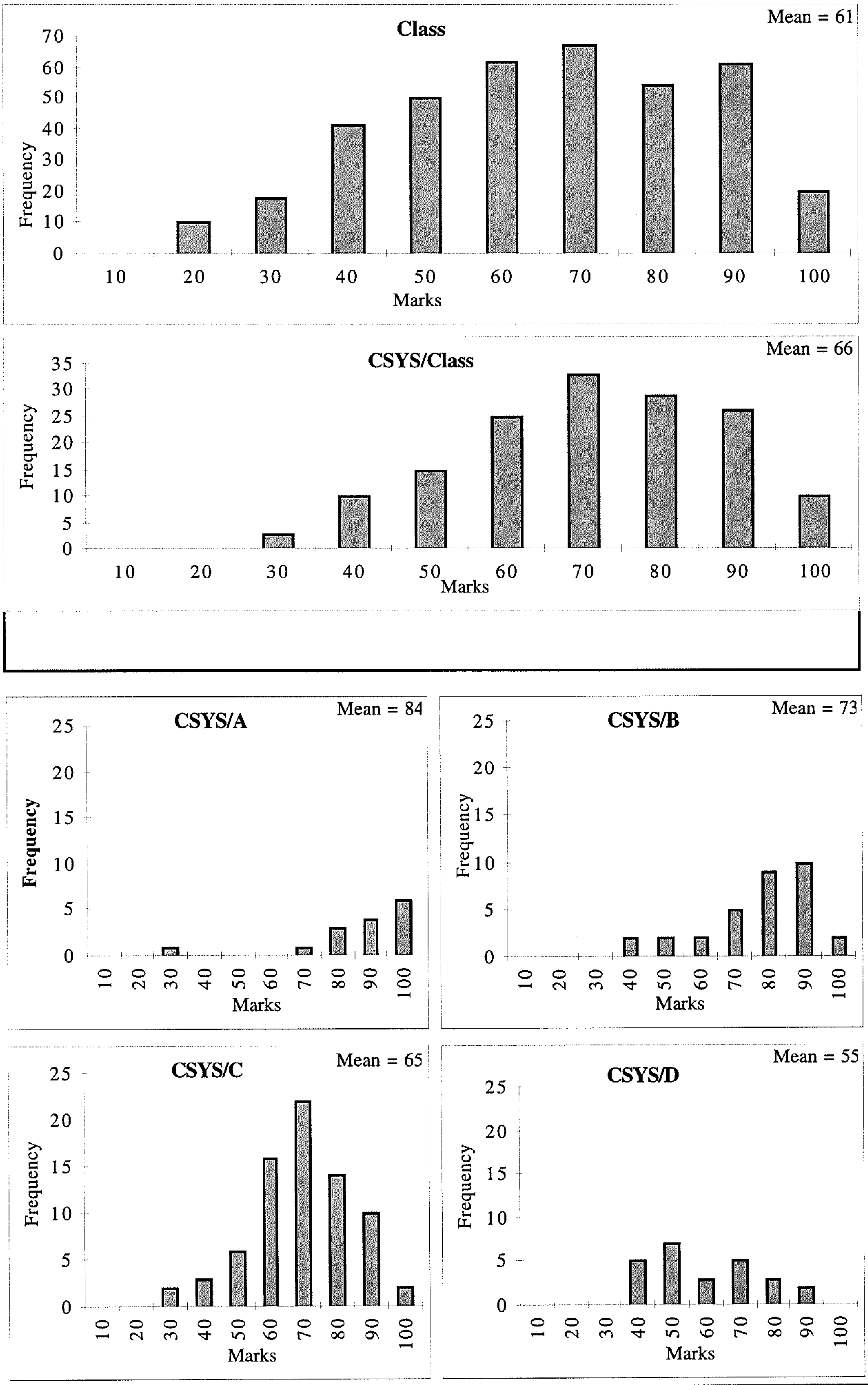




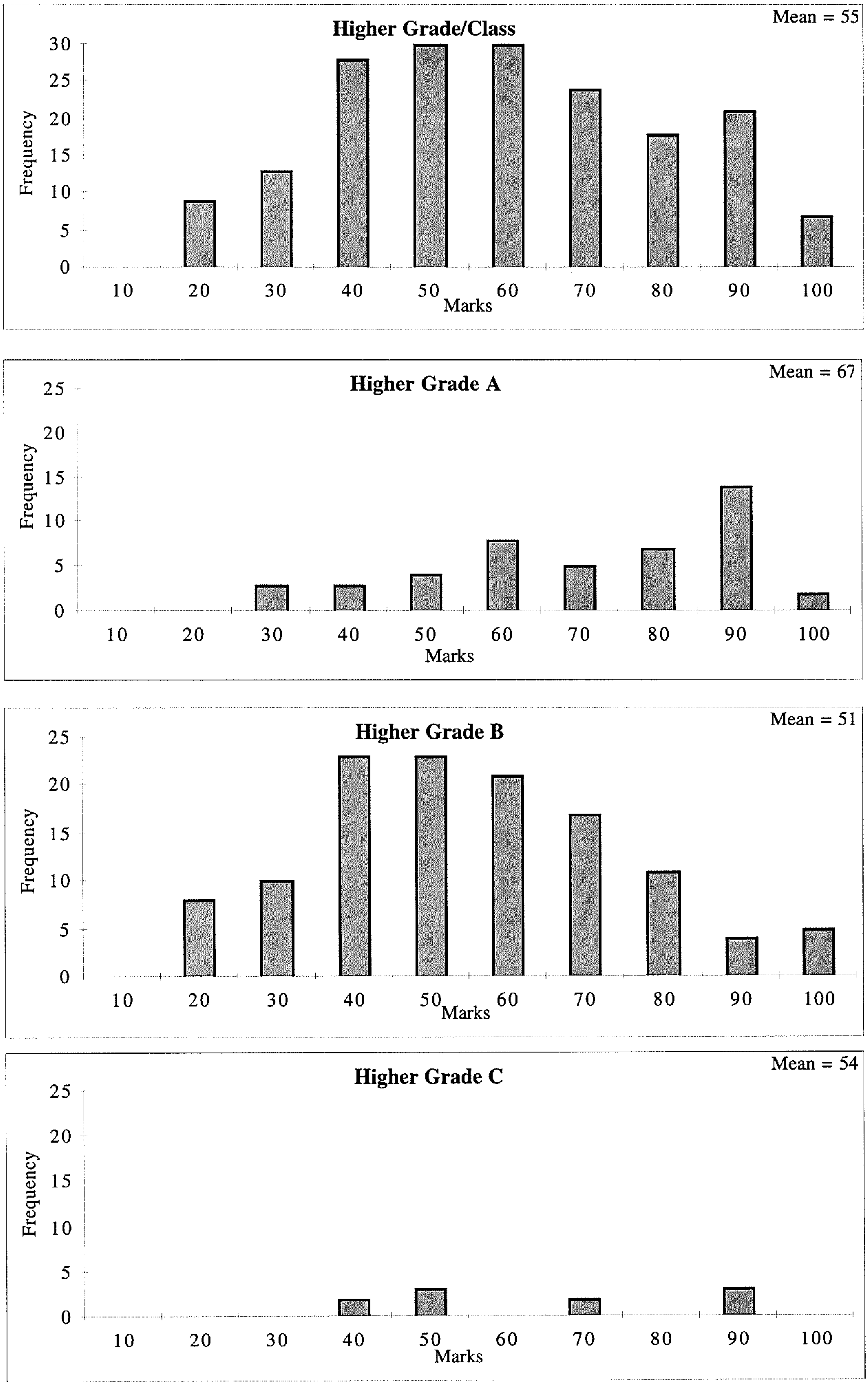




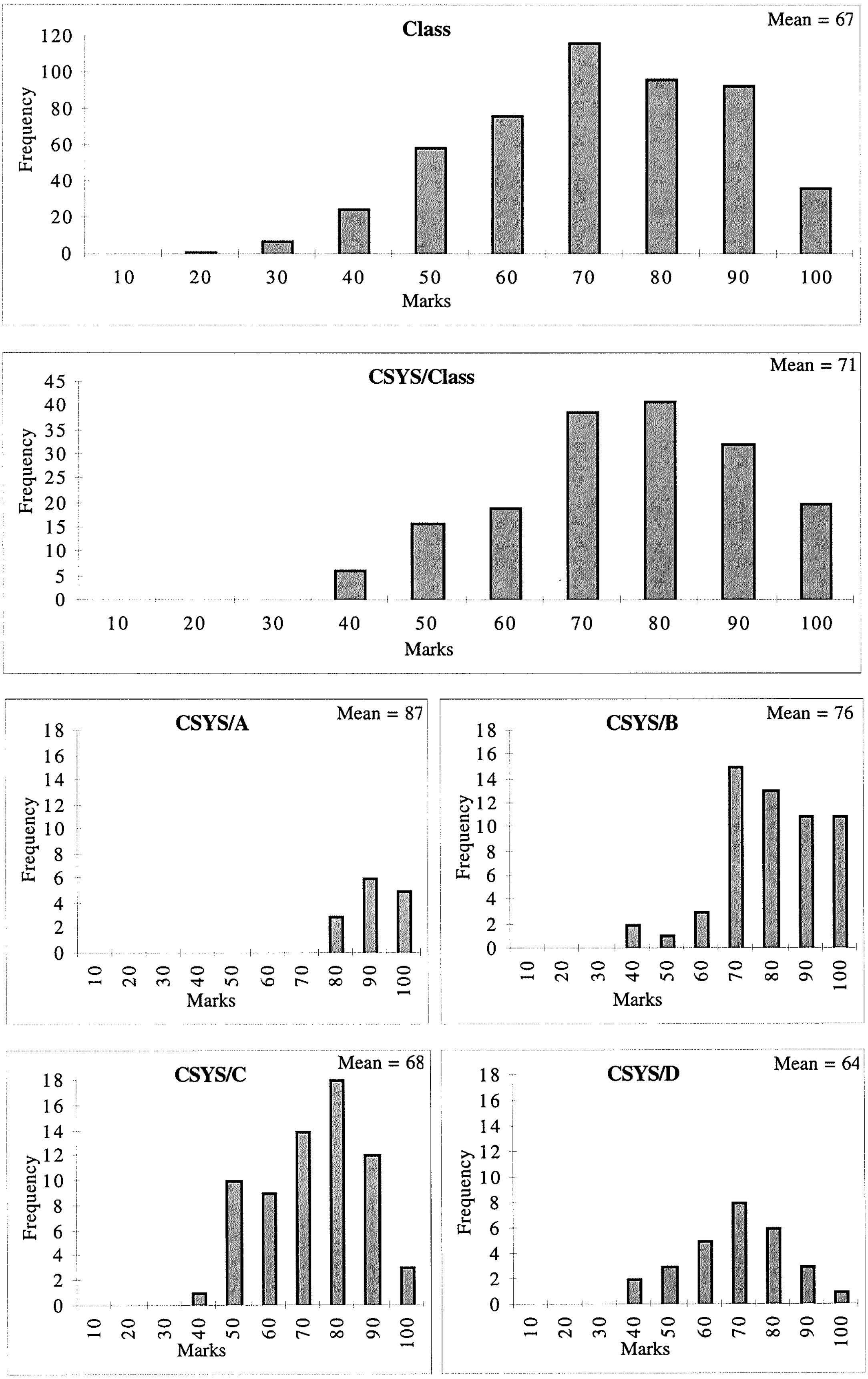
Graph C3a: Distribution of Chemistry-1 (1996/97) January Exam Marks



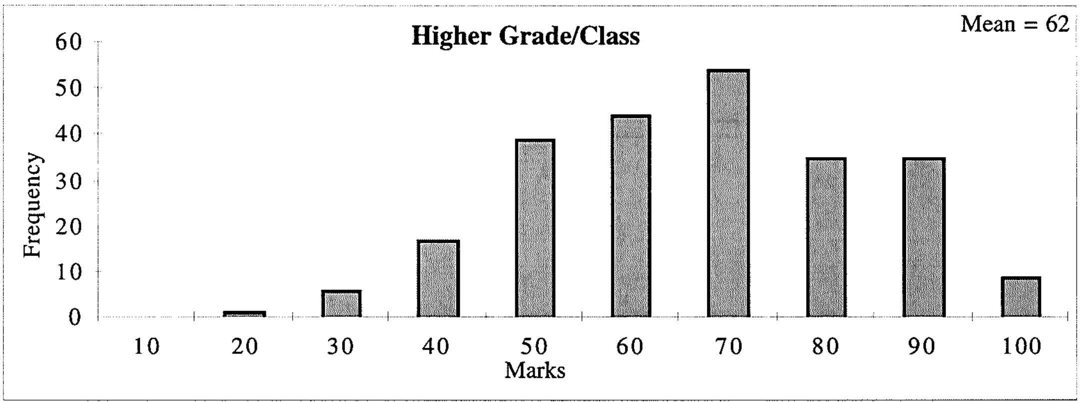
Graph C3b: Distribution of Chemistry-1 (1996/97) January Exam Marks

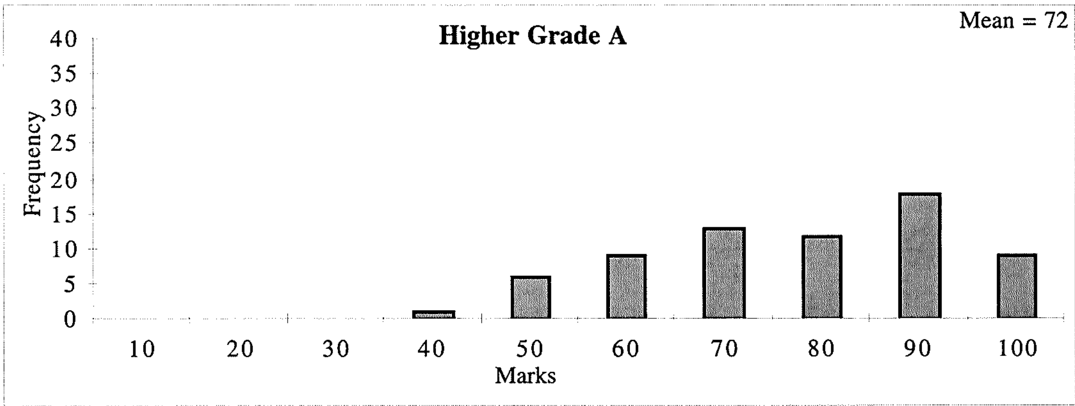


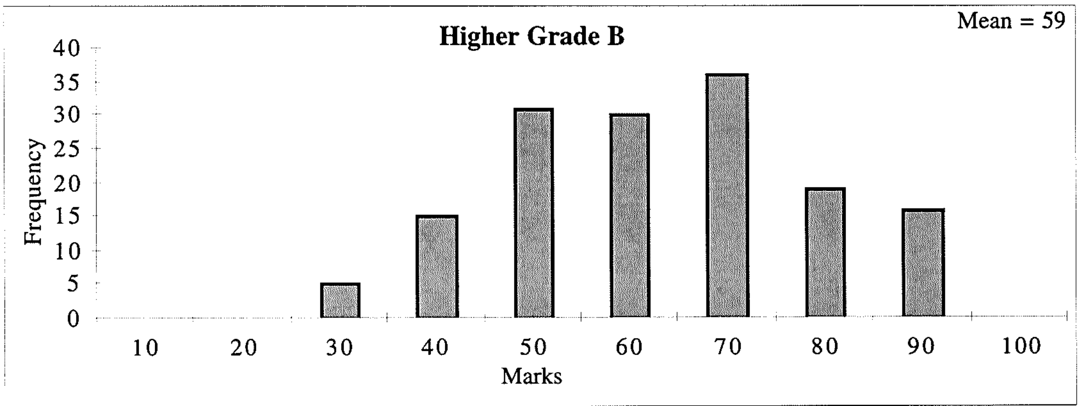
Graph C4a: Distribution of Chemistry-1 (1997/98) January Exam Marks

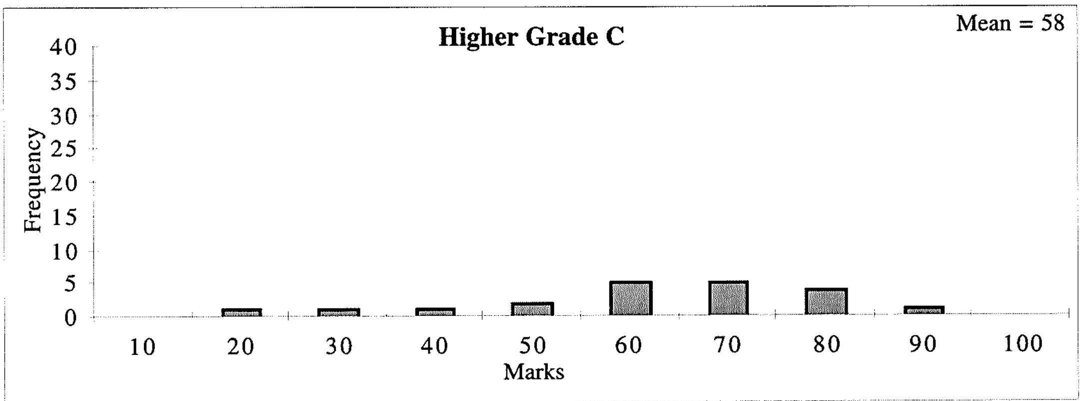


Graph C4b: Distribution of Chemistry-1 (1997/98) January Exam Marks

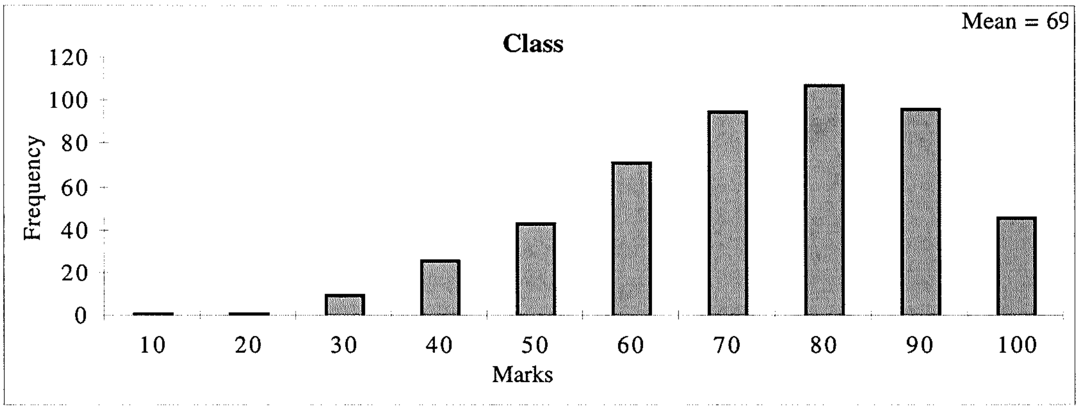


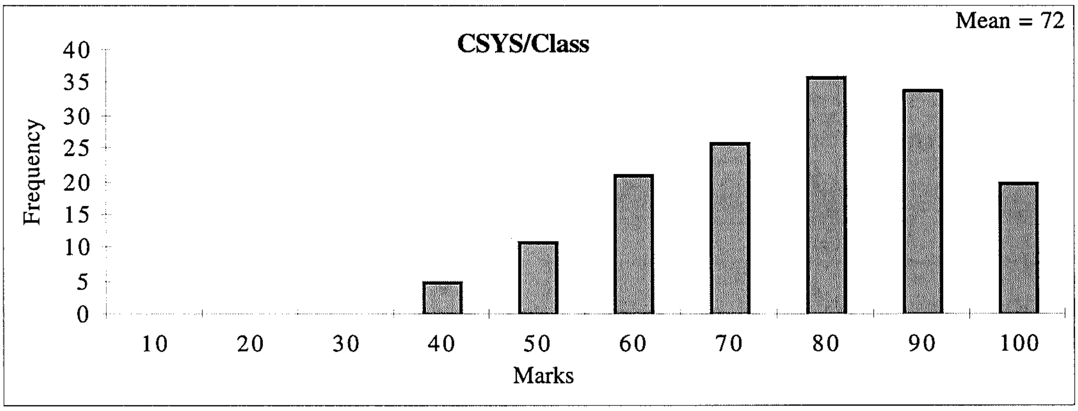


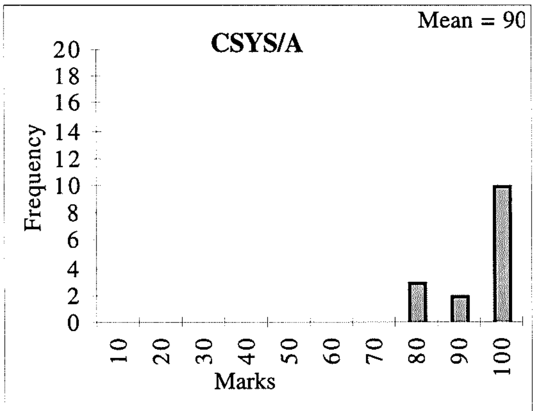


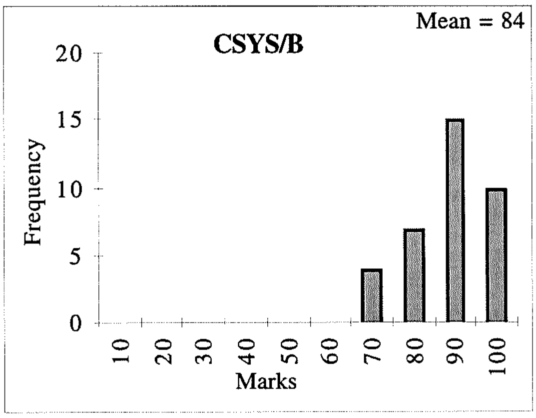


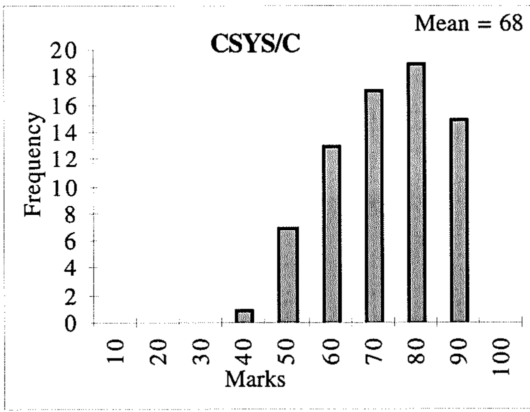
Graph C5a: Distribution of Chemistry-1 (1998/99) January Exam Marks

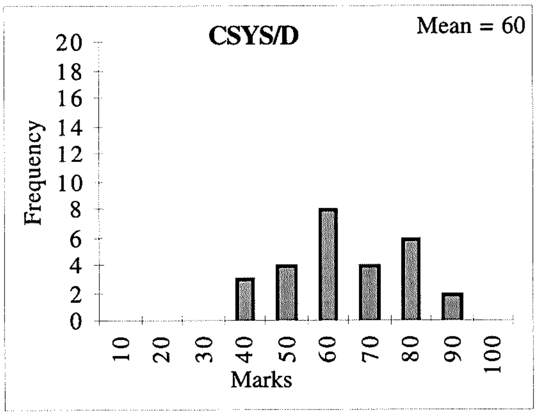




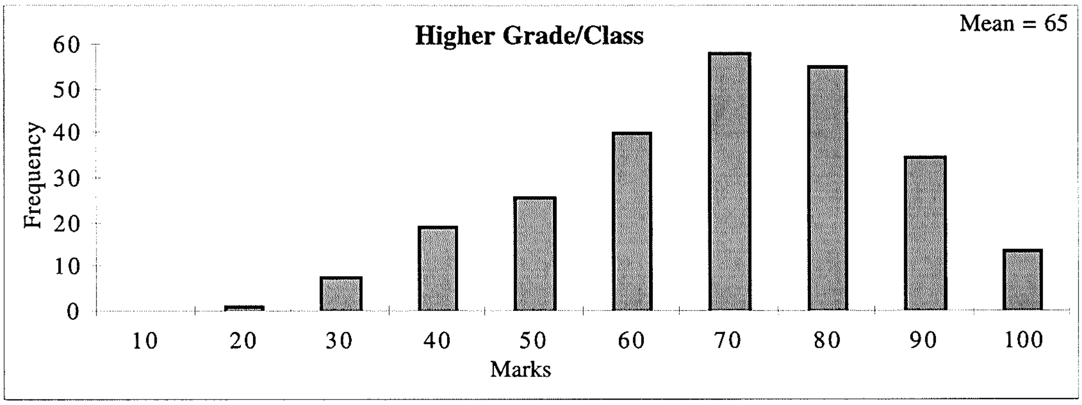


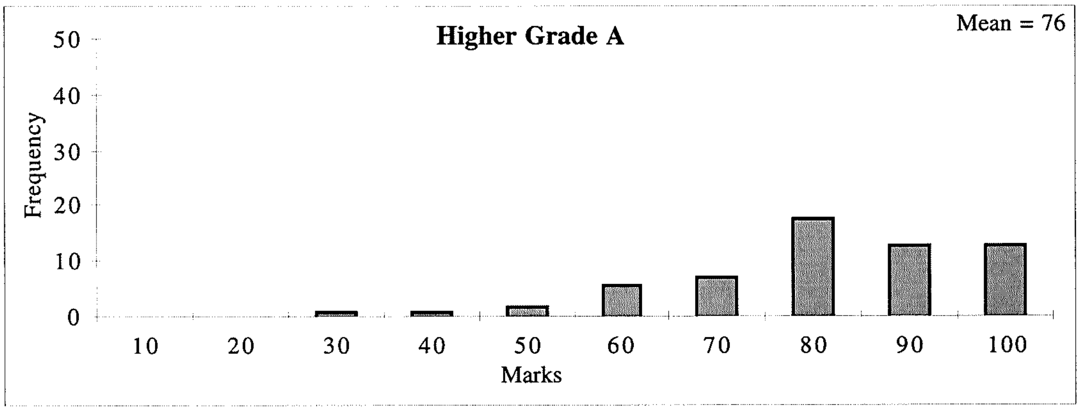


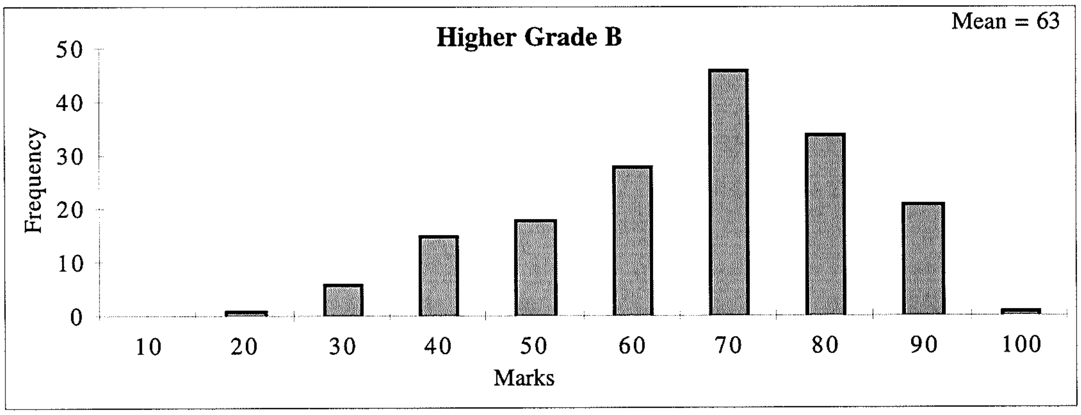


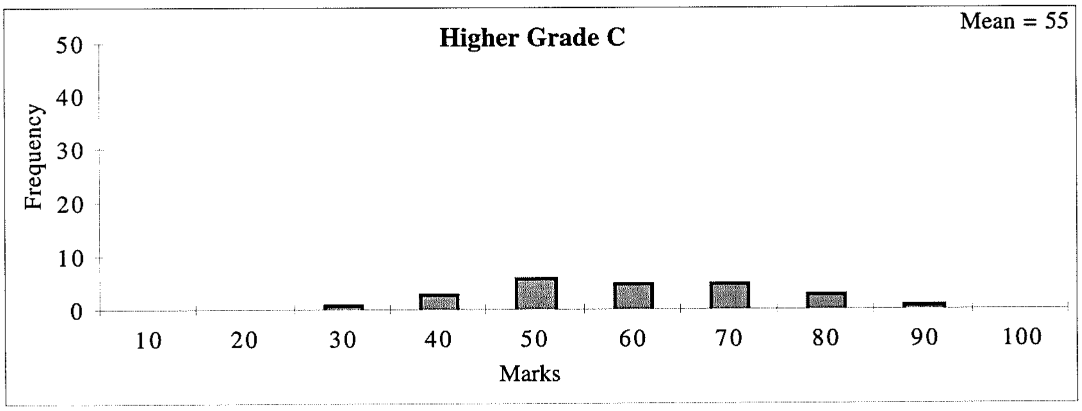


Graph C5b: Distribution of Chemistry-1 (1998/99) January Exam Marks









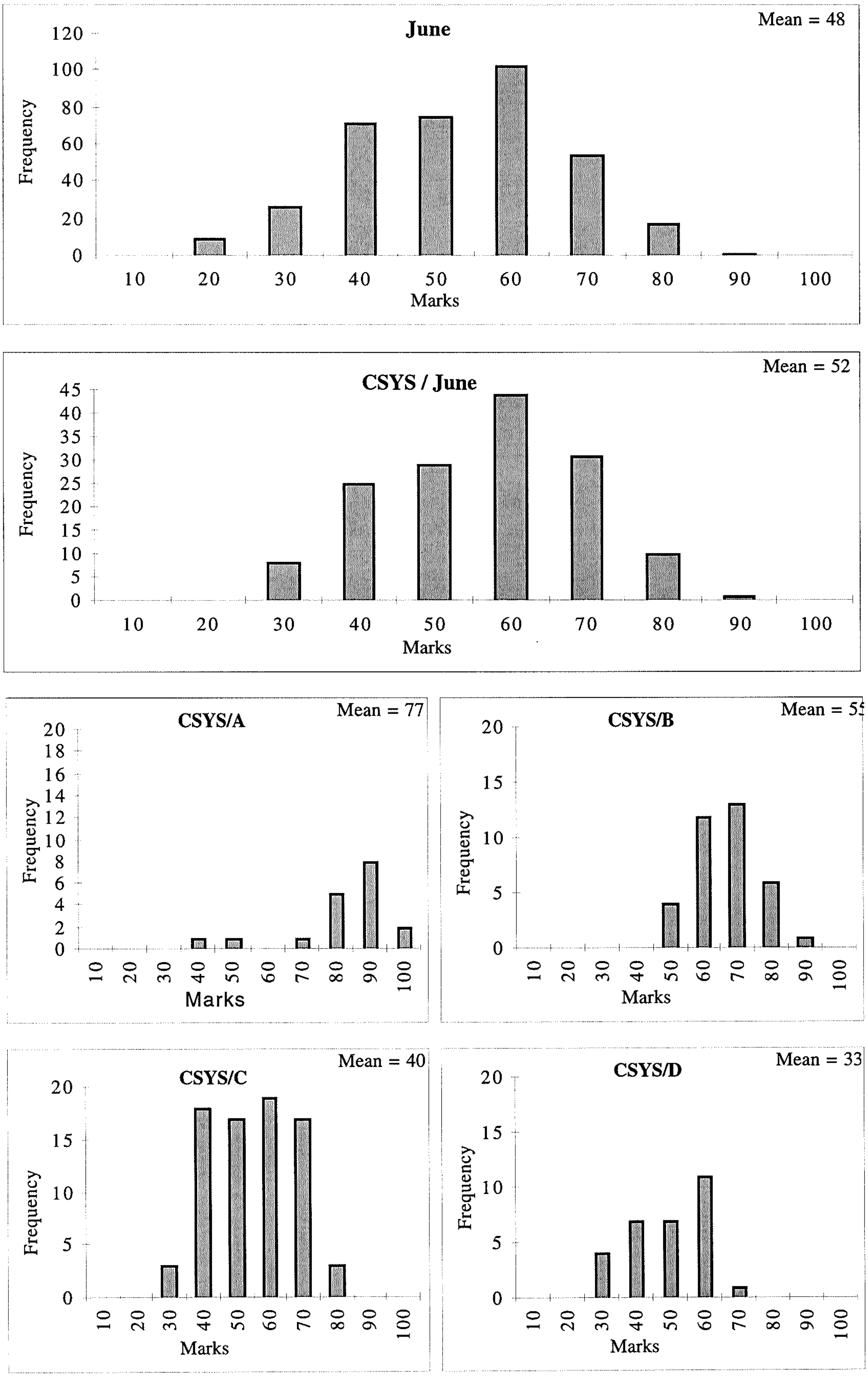
Appendix D

Chemistry-1

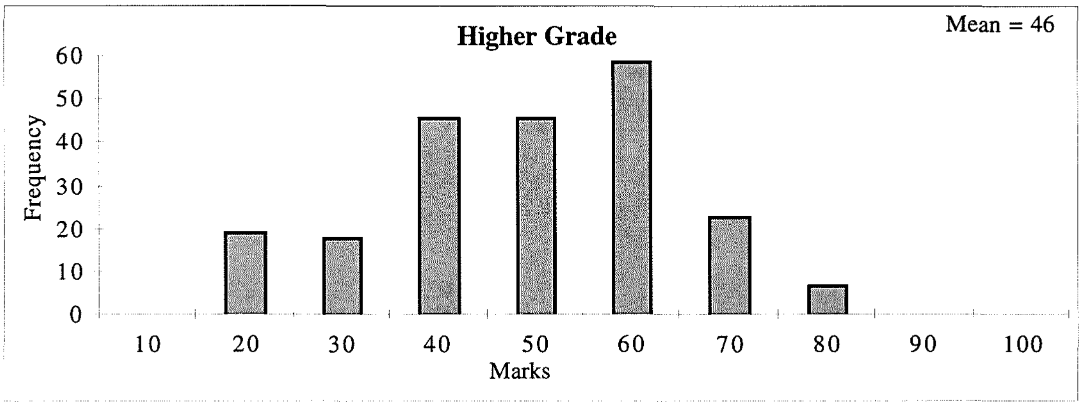
June Examination Results

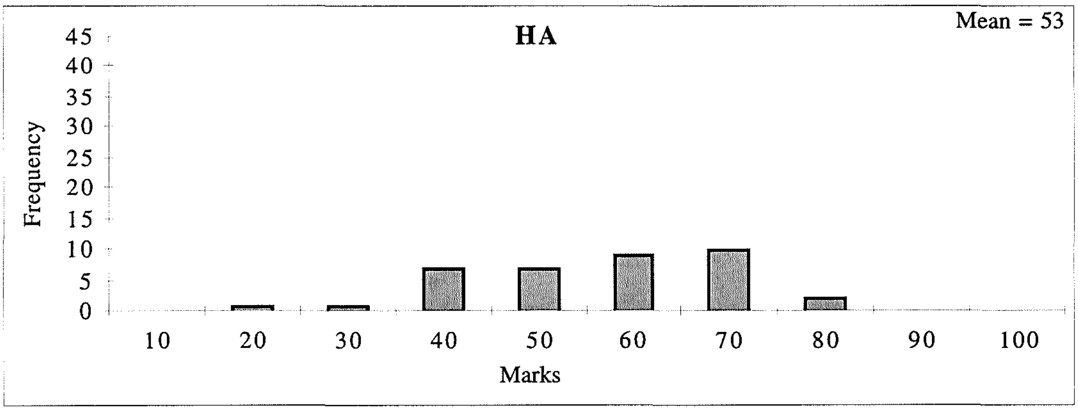
(1994/95 to 1998/99)

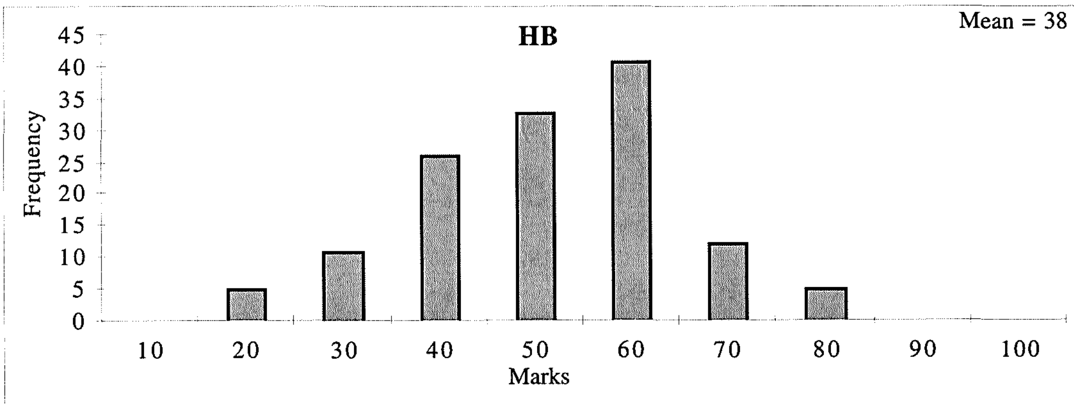
Graph D1a: Distribution of Chemistry-1 (1994/95) June Exam Marks

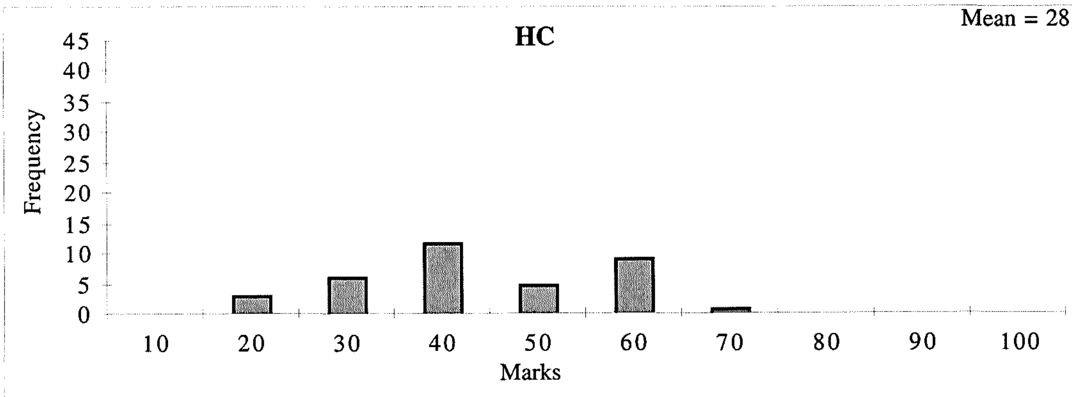


Graph D1b: Distribution of Chemistry-1 (1994/95) June Exam Marks

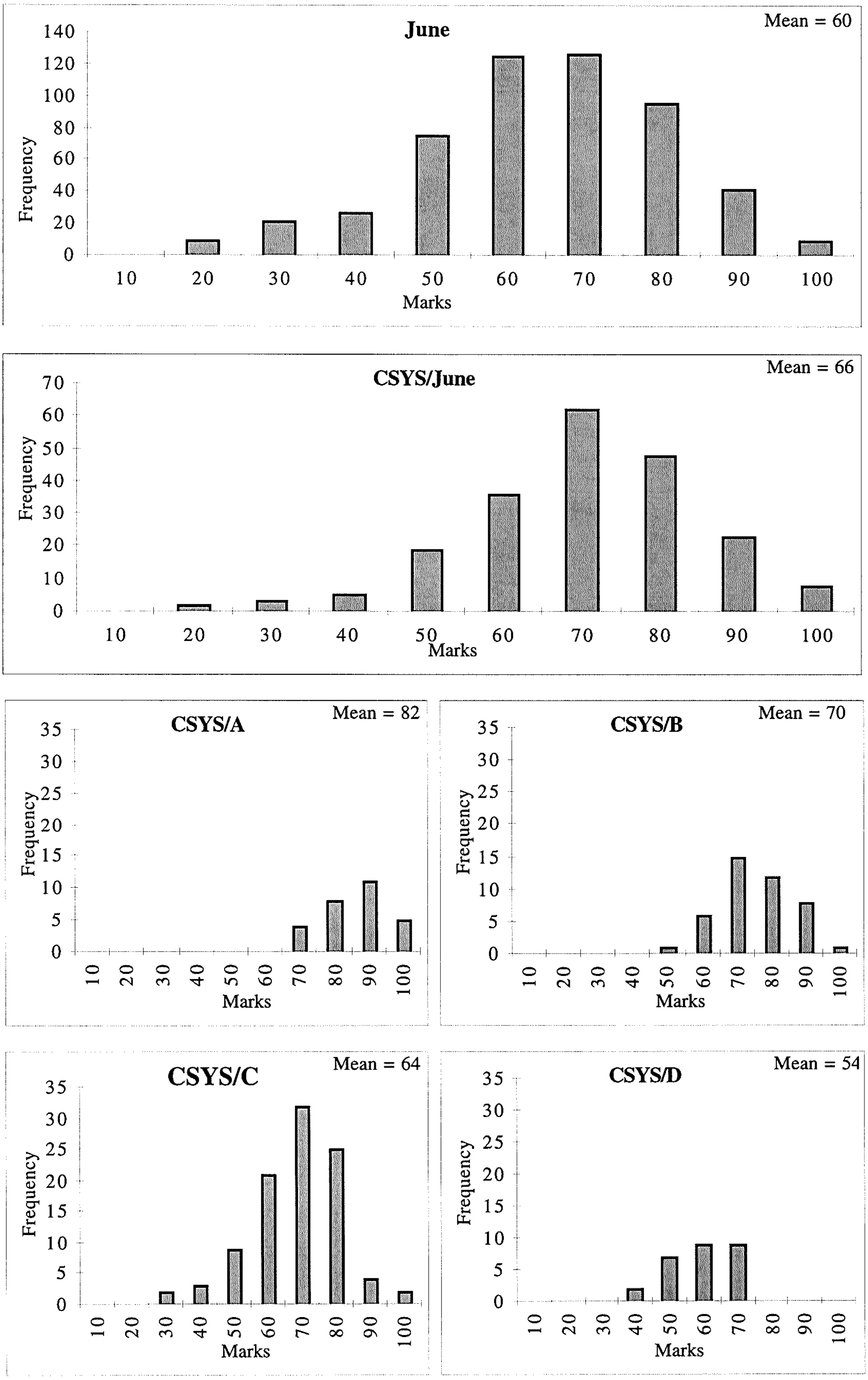




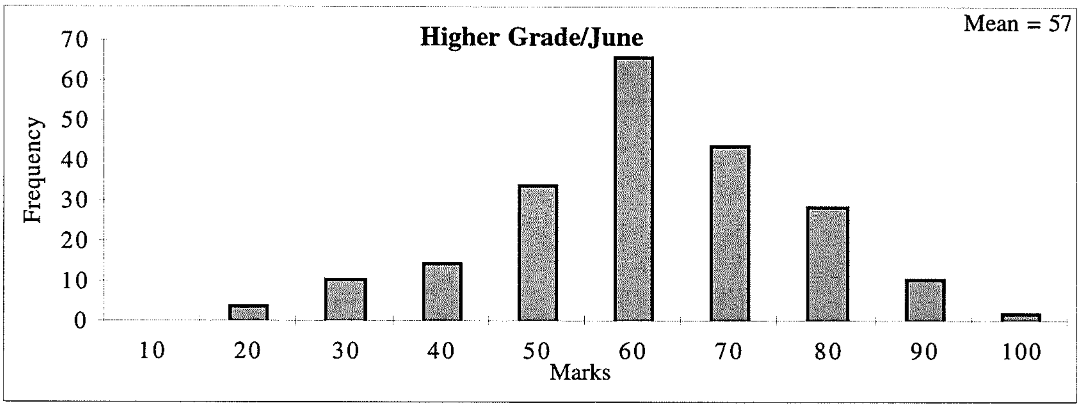


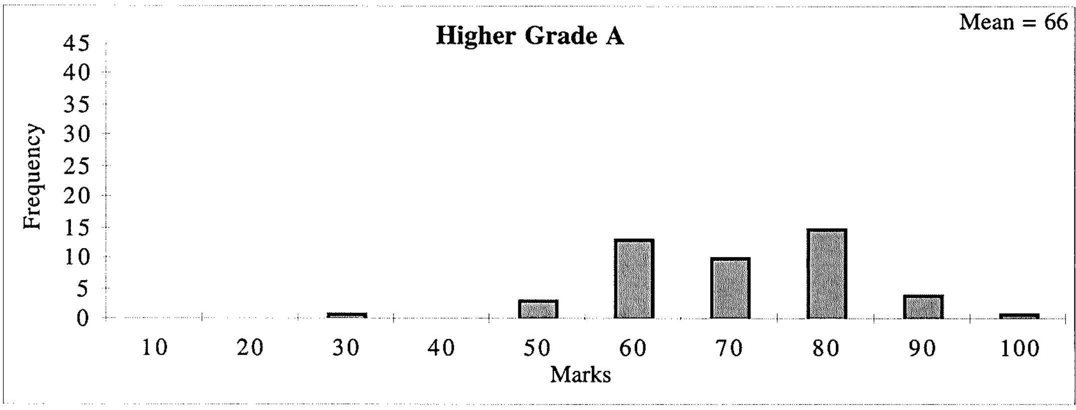


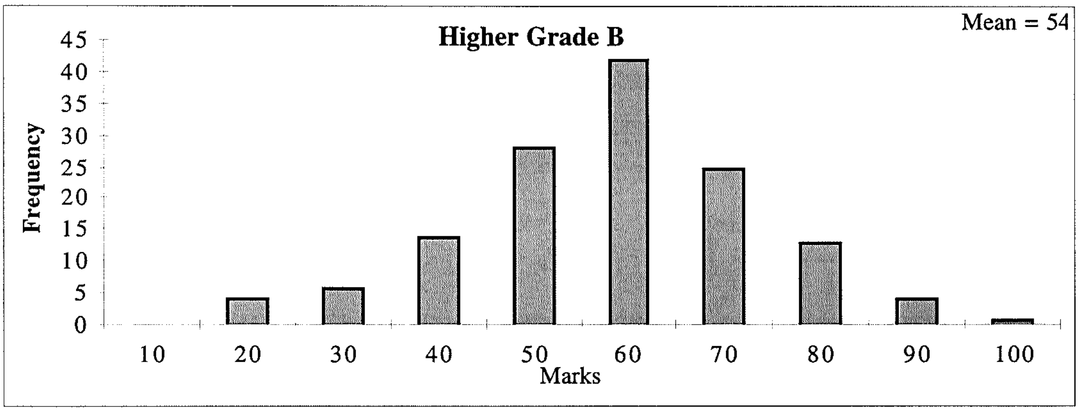
Graph D2a: Distribution of Chemistry-1 (1995/96) June Exam Marks

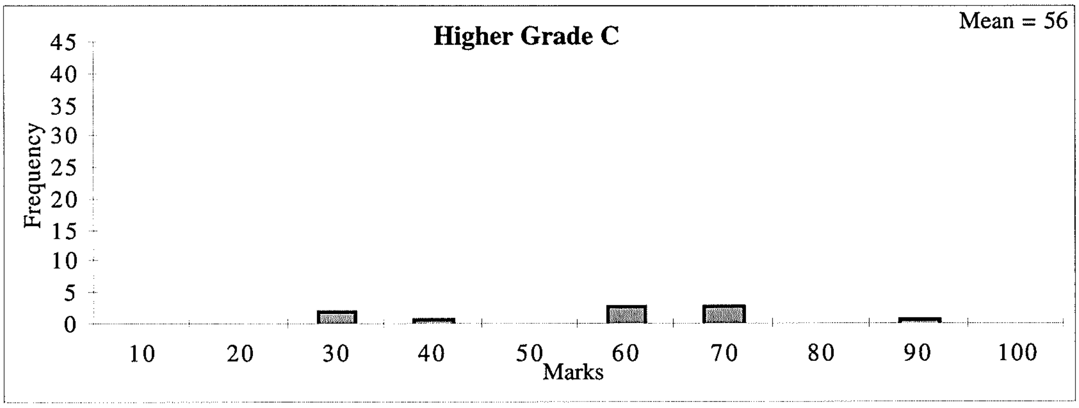


Graph D2b: Distribution of Chemistry-1 (1995/96) June Exam Marks

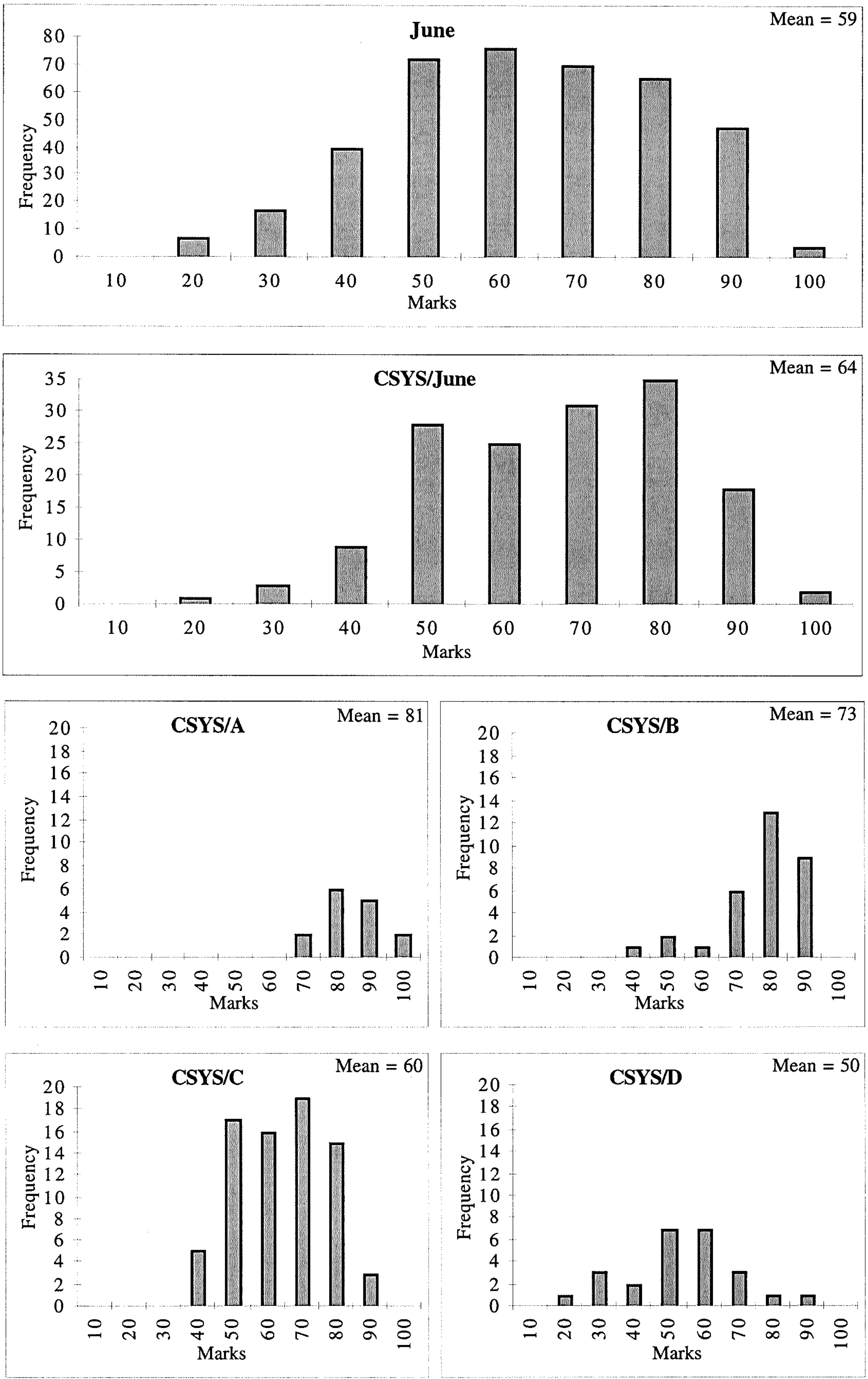




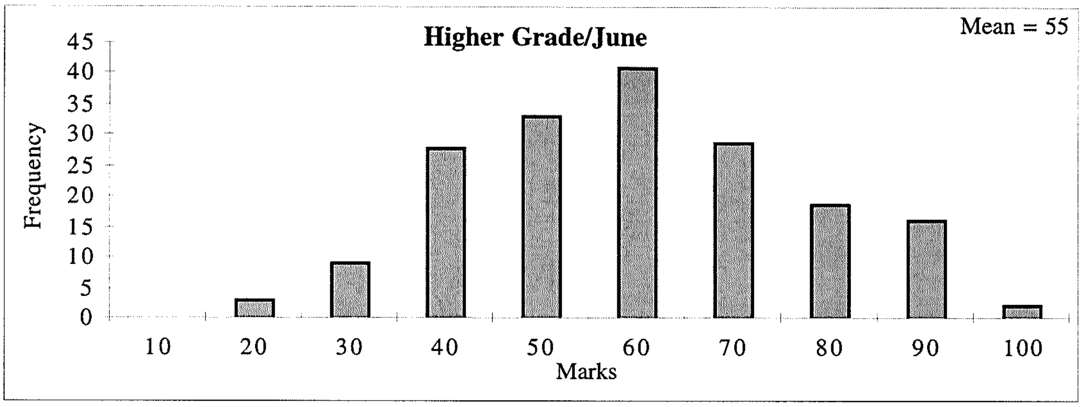


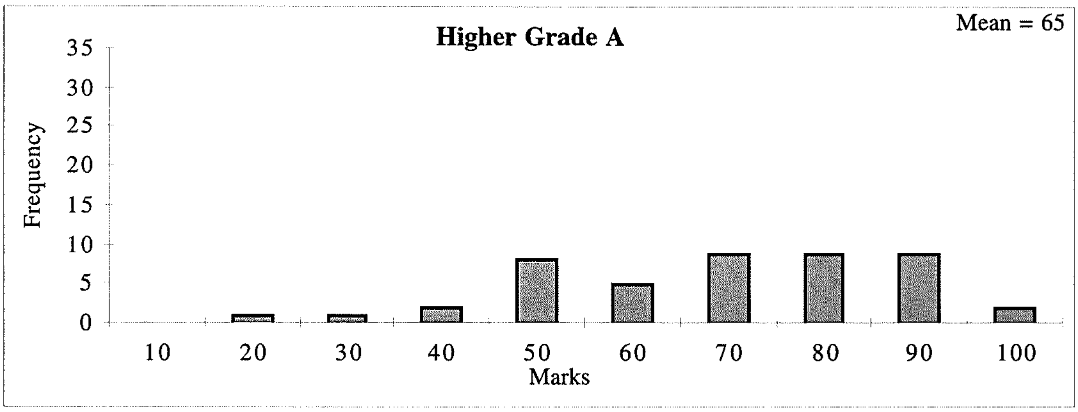


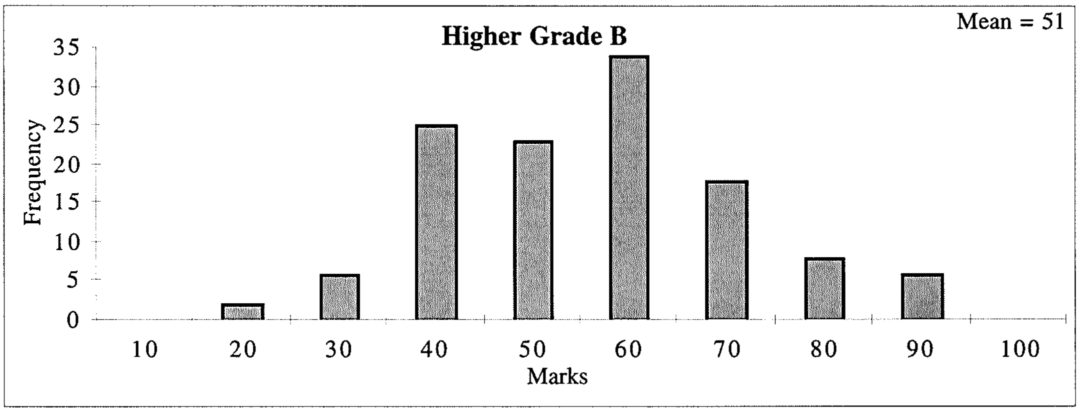
Graph D3a: Distribution of Chemistry-1 (1996/97) June Exam Marks

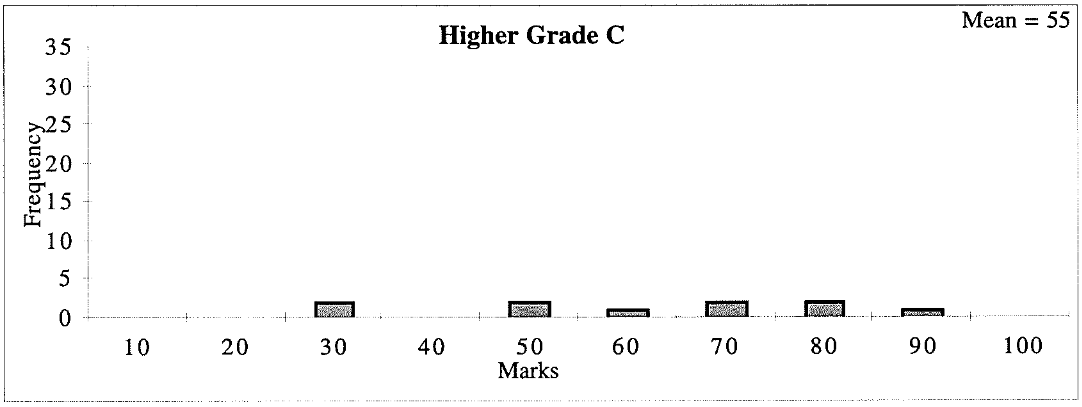


Graph D3b: Distribution of Chemistry-1 (1996/97) June Exam Marks

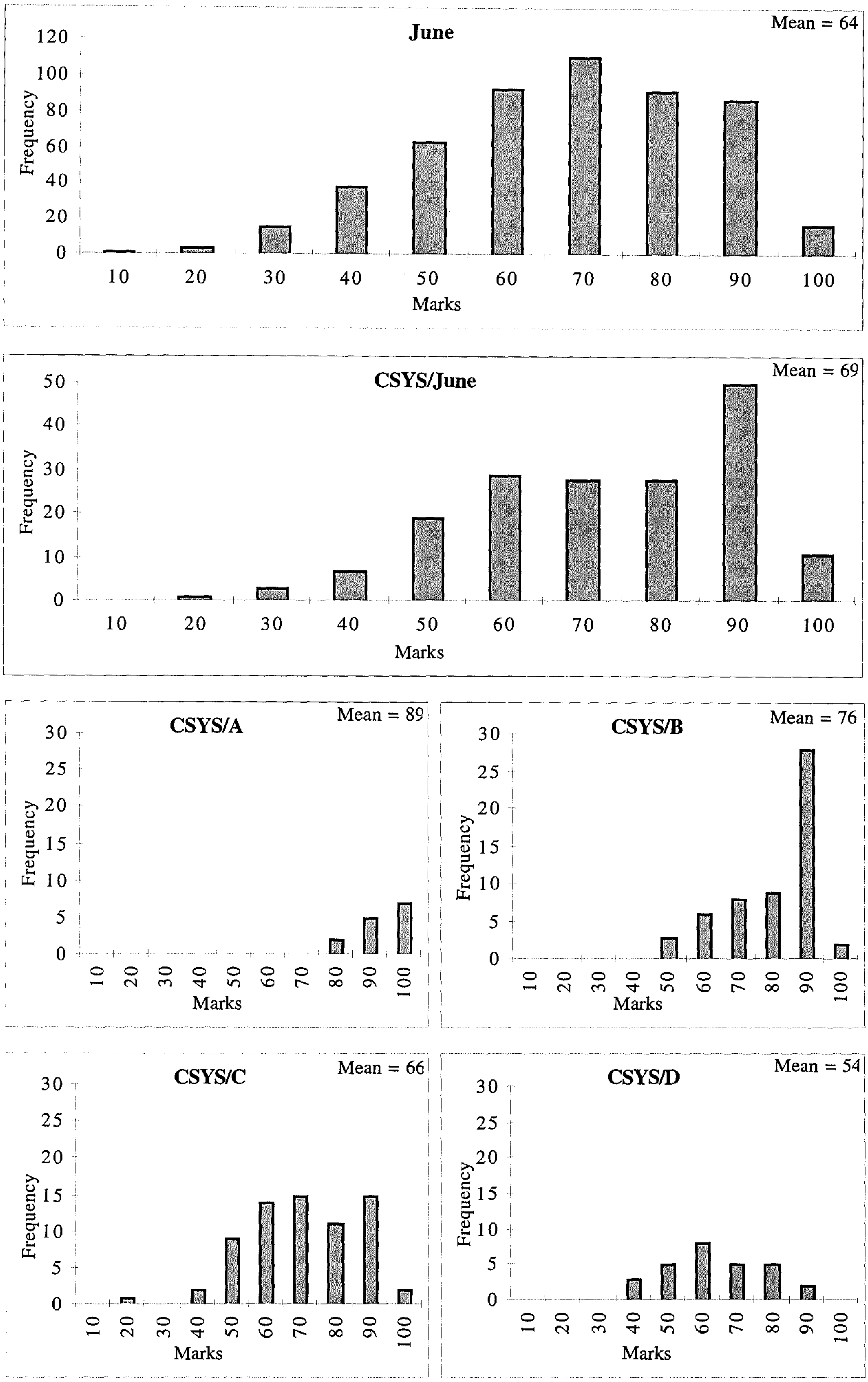




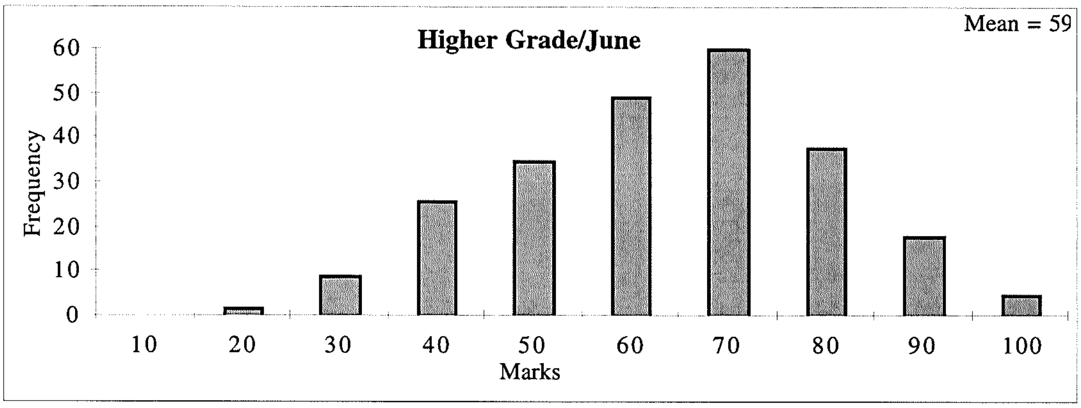


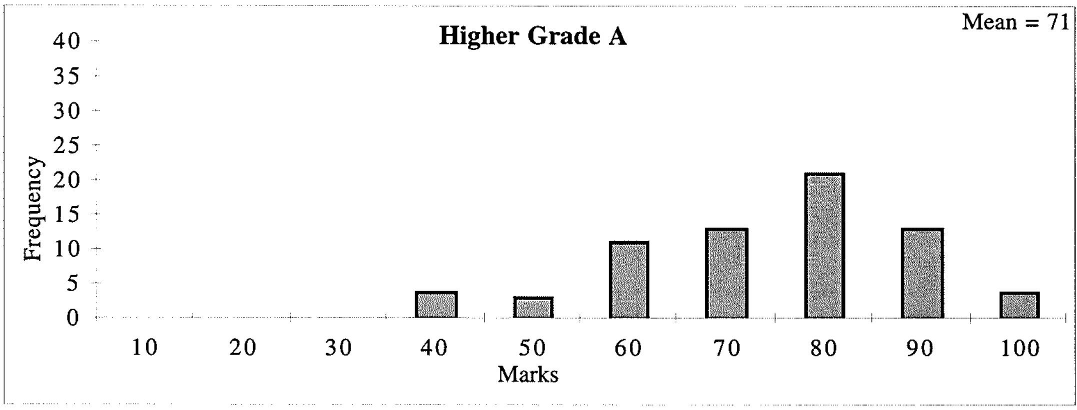


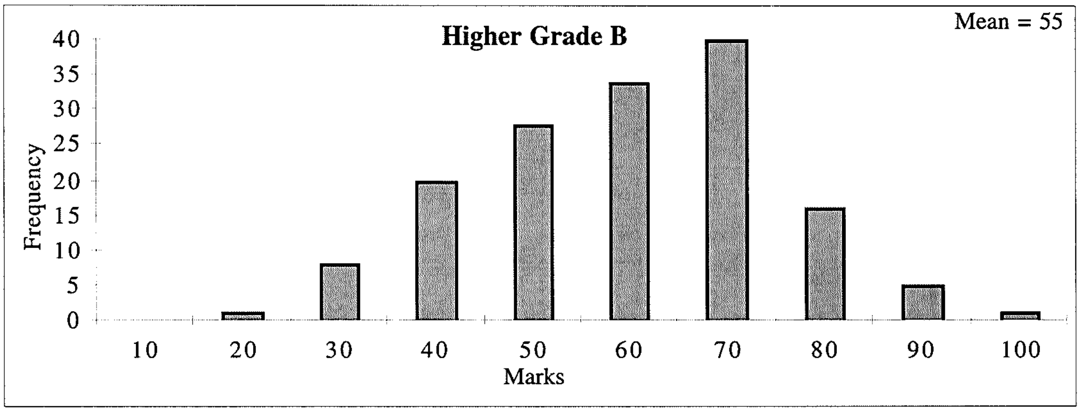
Graph D4a: Distribution of Chemistry-1 (1997/98) June Exam Marks

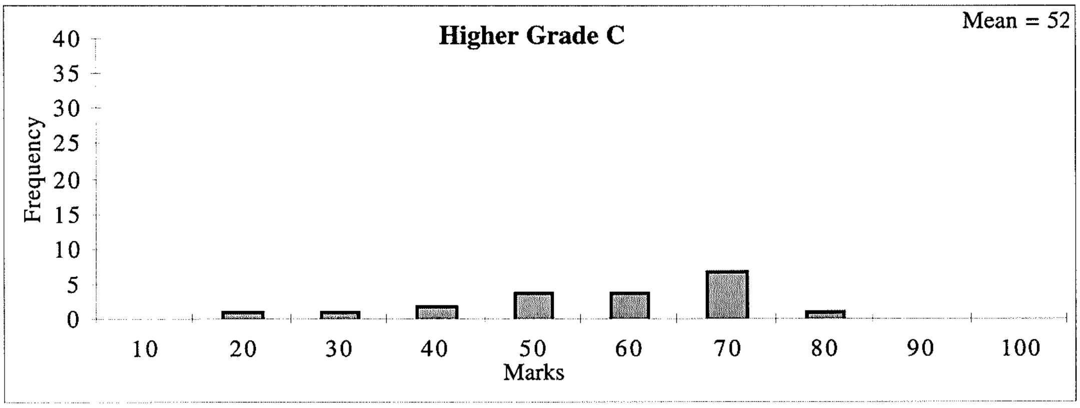


Graph D4b: Distribution of Chemistry-1 (1997/98) June Exam Marks

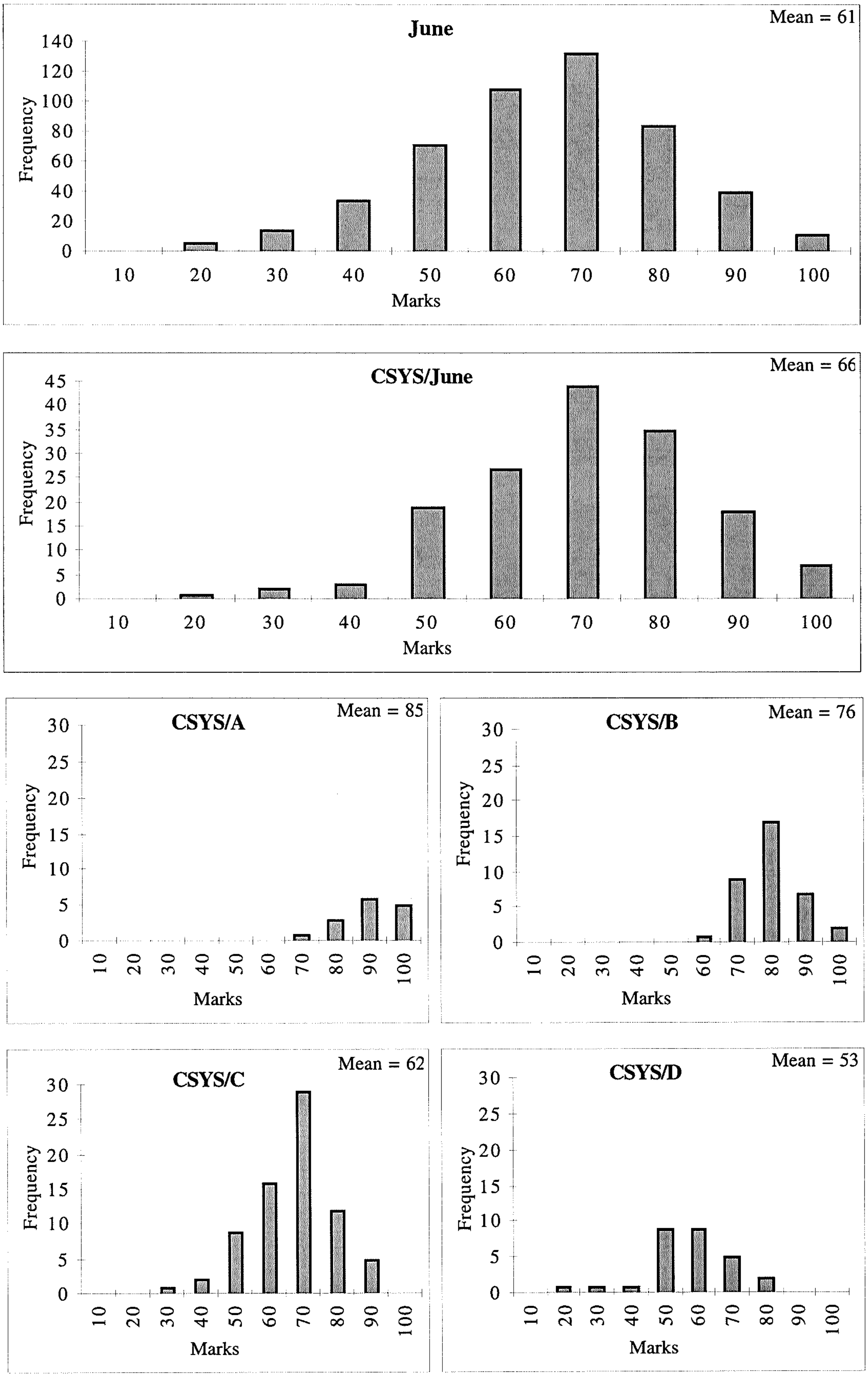




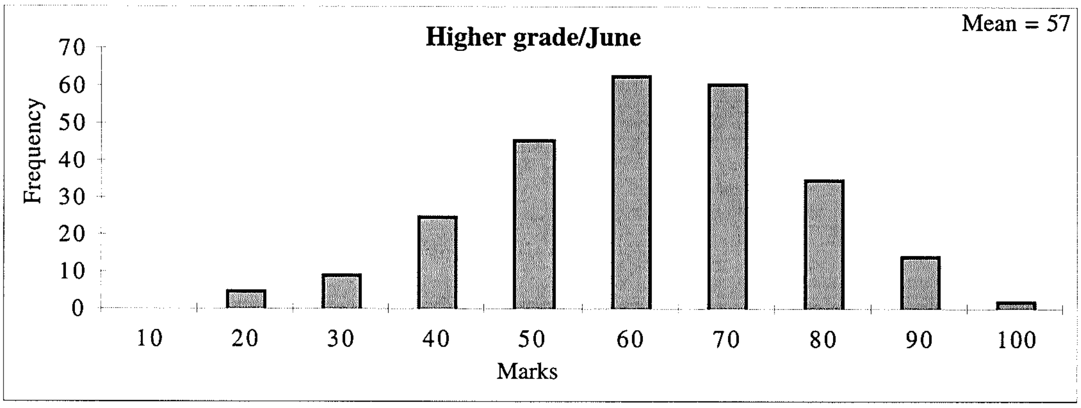


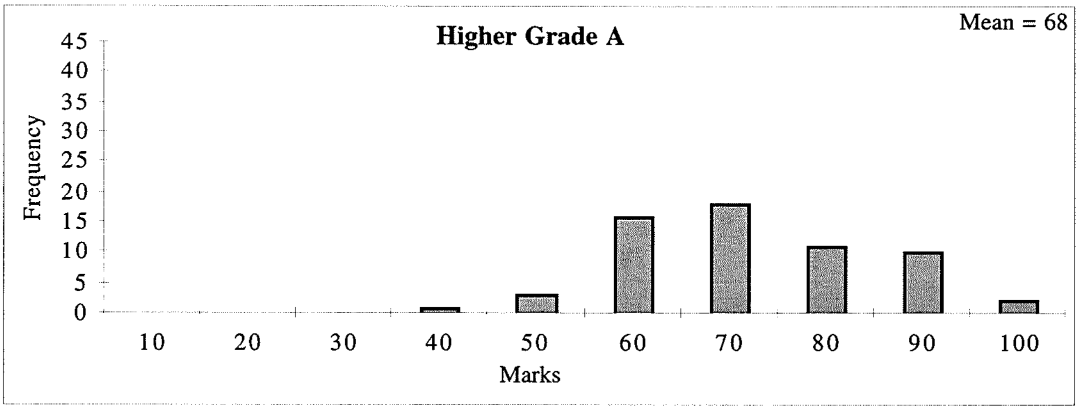


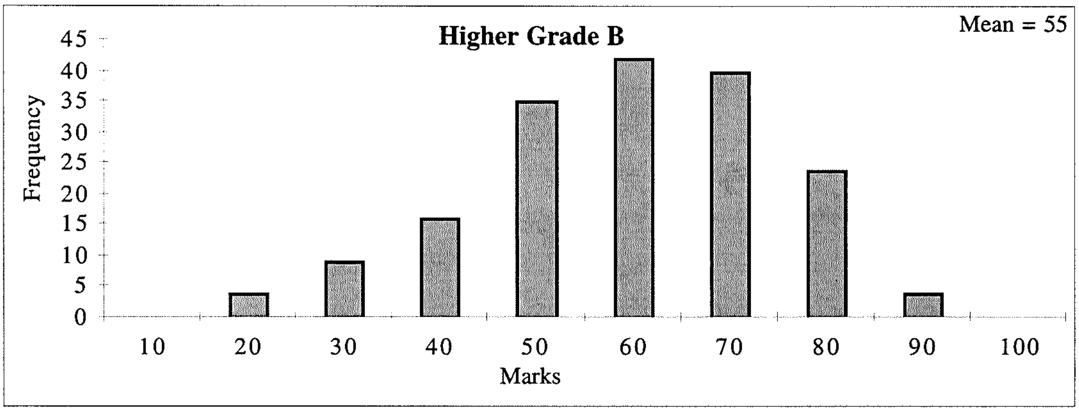
Graph D5a: Distribution of Chemistry-1 (1998/99) June Exam Marks

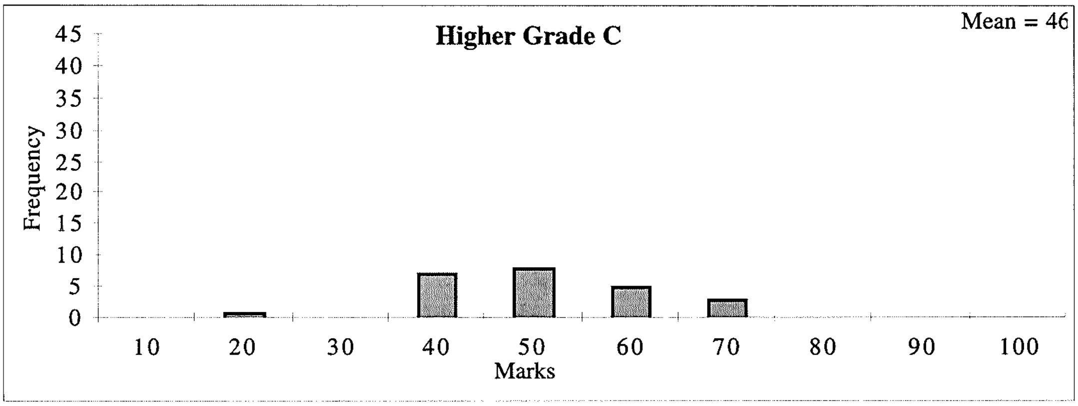


Graph D5b: Distribution of Chemistry-1 (1998/99) June Exam Marks









Appendix E

Statistical Tests

Appendix E1: Chi-squared Test

Chi-squared Test

There are two distinct applications of Chi-squared test. Both are employed in this study.

(a) *Goodness of Fit Tests*

It is a binomial distribution to test simple hypotheses, it is a "goodness of fit test". In this, an experimentally observed array of responses is compared to a control array of responses. This technique is used to compare experimental distributions to control group distributions.

For example,

	Easy	Moderate	Difficult	
Experimental	43	81	27	N (Experimental) = 152
Control	33	96	36	N (Control) = 165
				(using raw numbers)
This leads to				
	Easy	Moderate	Difficult	
fo = observed frequency	43	81	27	
fe = expected frequency	30.4	88.3	33.1	

and, f_e = (152/165) x (control data)

$$\chi^2 = \sum \frac{(f_o - f_e)^2}{f_e}$$

$$\chi^2 = \frac{(43 - 30.4)^2}{30.4} + \frac{(81 - 88.3)^2}{88.3} + \frac{(27 - 33.1)^2}{33.1}$$

$$\chi^2 = 6.94$$

At two degrees of freedom, this is significant at greater than 5%. (χ^2 critical at 5% level = 5.99)

(b) *Contingency Test*

This use of chi-squared is frequently applied in analysing data comparing two groups of a population. For example, it was used in this study to compare males and females responses. There is no reason to suppose either is a control.

For example,

	Positive	Neutral	Negative	
Male Experimental	31	103	30	
Female Experimental	22	124	99	
			(actual data)	
	Positive	Neutral	Negative	N
Male Experimental	31	103	30	164
Female Experimental	22	124	99	245
	31 (21)	103 (91)	30 (52)	164
	22 (32)	124 (136)	99 (77)	245
	53	227	129	409

The expected frequencies are shown in brackets, and are calculated thus: e.g. 21 = (164/409) x 53

$$\chi^2 = \frac{(31 - 21)^2}{21} + \frac{(103 - 91)^2}{91} + \frac{(30 - 52)^2}{52} + \frac{(22 - 32)^2}{32} + \frac{(124 - 136)^2}{136} + \frac{(99 - 77)^2}{77}$$

χ^2 = 0.52 + 1.58 + 9.31 + 3.13 + 1.06 + 0.29 = 16.43

At two degree of freedom, this is significant at 0.1%. (χ^2 critical at 0.1% level = 13.82)

Before chi-squared can be compared with the calculated values, the degrees of freedom (*df*) must be known.

For analysing the tables the degree of freedom (*df*) are always given by:

df = (R-1)(C-1)

Where R is the number of rows and C is the number of columns in the contingency tables.

For the example above there are 2 rows and 3 columns therefore we have (2-1)(3-1)= 2 *df*.

Appendix E2: Mann-Whitney and T-tests

Mann-Whitney Test

It is an appropriate static by which to test whether two independent groups have been drawn from the same population. The test requires that, at least, the data should be at the ordinal level of measurement.

For example, exam marks of two groups were as follows:

A	23 (1)	36 (7)	34 (6)	25 (2)	42 (10)		$N_A = 5$
B	48 (11)	27 (3)	38 (8)	41 (9)	31 (5)	29 (4)	$N_B = 6$

Rank the combined set of $N_A + N_B$ scores from the lowest to highest value. Use rank 1 for the lowest, 2 for the next lowest, and so on. The rank values are shown in brackets.

R_A = the sum of the ranks for the smaller group = 1 + 7 + 6 + 2 + 10 = 26

$U = [(N_A \times N_B) + \{N_A(N_A + 1)/2\}] - R_A$

$U = [(5 \times 6) + \{ (5 \times 6) / 2\}] - 26 = 14$

$U' = (N_A \times N_B) - U = 30 - 26 = 4$

When $N_A = 5$ and $N_B = 6$, the critical value of U for 5% significance (two-tailed) is 3.

Conclusion: As the (smaller) observed U is greater than the critical value of U for 5% significance, it can be concluded that there is no significance difference between the two groups.

T- test for Independent Samples

This is a parametric test of the difference between the means of two independent samples. It might be used, for example, to determine whether a random sample of five students with Higher Grade are performed better than six students with Standard Grade. The t-test assumes that the two sets of scores come from normal population with equal variance, but the test is not affected by minor violations of these rules. It is also assumed that the measurements are on an interval scale.

Let us used the above example,

A	23	36	34	25	42		$\Sigma NA = 160$	$\Sigma(NA)^2 = 5370$
B	48	27	38	41	31	29	$\Sigma NB = 214$	$\Sigma(NB)^2 = 7960$

General procedure

(1) *Calculate the two sample means*

$$\bar{X}_A = \frac{\Sigma NA}{NA} = \frac{\Sigma NA}{NA} = \qquad \bar{X}_B = \frac{\Sigma NB}{NB} = \frac{\Sigma NB}{NB} =$$

(2) *Calculate the two sample variances*

$$S_A^2 = \frac{\Sigma(NA)^2}{NA} - \bar{X}_A^2 = \qquad S_B^2 = \frac{\Sigma(NB)^2}{NB} - \bar{X}_B^2 =$$

(3) *Substitute the values of the means and variances*

$$t = \frac{(\bar{X}_A - \bar{X}_B)\sqrt{(N_A + N_B - 2)N_A N_B}}{\sqrt{N_A S_A^2 + N_B S_B^2) + (N_A + N_B)}}$$

$$t = \frac{(32 - 35.7)\sqrt{(5 + 6 - 2)(5 \times 6NB)}}{\sqrt{(5 \times 50 + 6 \times 52.7) + (5 + 6)}} = 0.75$$

(4) *Find the number of degrees of freedom* $\qquad df = N_A N_B - 2$

For 9 degrees of freedom the value of t required for 5% level of significance (two-tailed) is 2.262

Conclusion: As the observed t is less than 2.262 the probability that the difference between the means arose by chance is greater than 5% that the results could not have arisen by chance.

Appendix F

Students' Comments

Appendix F1a: General Chemistry Students' Comments / Reasons of Difficulty (1997/98)

Reaction rate [11]	Lectures difficult.[4] Too mathematical.[7]
Arrhenius equation [17]	Too mathematical.[3] Have not done them before.[6] Not explained well.[5]
Entropy and disorder [14]	Too many equations (formulas) got mixed up.[5] Not explained clearly enough in lectures.[3] Difficult to understand,need to concentrate in principles behind it.[6]
Enthalpy [10]	Lots of formulas.The concepts are difficult to relate to the questions.[3] Not very well taught to beginners.[3]
Free energy changes [12]	Confusing, too mathematical.[5] Lots of formulas and didn't understand any of it.[6]
Buffers [9]	Not explained well (mixed lectures).[3] It is difficult to know when to use different equations.[4]
pH calculations [12]	Too mathematical (logs).[5] Lectures confusing (many formulas).[4]
Isomerisms [8]	Confused easily because it is difficult to picture.[4] Don't know how to draw isomers.[3]
Drawing chemical structures [9]	Complicated explanations- lecturers told us different things.[3] Difficult to picture chemical structures.[3]
Functional groups [4]	Confusing and complicated explanations.[3]
Nomenclature [11]	Don't know what this is.[7]
Oxidation numbers [17]	Was not explained clearly enough.[6] Don't know which methods to use.[6]
Balancing redox equations [7]	Difficult to remember, confusing, I get mixed up .[3]
Electrolytes [2]	
Writing chemical formulae [4]	Many rules need more practice.[3]
Mole calculations [18]	Complicated maths involved.[8] Confused, never know which methods to use.[4] Never been able to.[4]
Solution concentration [5]	Hard to remember how to do all calculations.[3]
Colloidal solutions [15]	Never heard of it.[12]
Osmotic pressure [7]	Complicated, wasn't explained well enough.[3]
Solvation [5]	Don't know what it is.[4]
Drawing unit cells [7]	Difficulty in imagining 3D structures.[3] Not enough time spend in this area, less practice (rushed when taught).[3]
Corrosion [5]	Much theory involved, not covered well.[3]
Equilibrium [7]	Too many equations.[3]
Polarity[4]	
Lewis acids and bases [11]	Don't spend enough time on it.[5] Not enough information given.[4]

Appendix F1b: General Chemistry Students' Comments / Reasons of Difficulty (1998/99)

Reaction rate [25]	Lectures difficult, gone through too quickly.(3)
	Confusing, I can't visually imagine. (3)
	Too mathematical, too many formulae and equations. (11)
	Not clearly shown, show up as a series of unexplained equations(6)
Arrhenius equation [21]	Could not apply it, very difficult to pick up, and not clearly shown.(5)
	Lecturer slightly confusing couldn't relate lectures to labs. (3)
	Lectures were confusing and difficult.(3)
	Too much maths.(9)
Entropy and disorder [36]	Lecturer couldn't understand him, slightly confusing, seemed to just talk not teach, weren't easy to follow, didn't help, and the material in lectures didn't appear to have anything in common with the labs.(8)
	Confusing, too mathematical, and very difficult to pick up.(8)
	New topics, a lot of technical terms, could have taken longer to explain.(7)
Enthalpy [30]	Lecturer: couldn't understand him, weren't easy to follow, slightly confusing couldn't relate lectures to labs, gone through too quickly in lectures, and didn't help.(8)
	New topics and allot of information to take in.(3)
	Many of the lectures given were just a series of unexplained equations and show up in notes as a list of equations with no explanation of where figures came from or how they were derived, they are confusing.(3)
	Complicated topic, not clearly shown, and very difficult to pick up.(7)
	Too mathematical, too many figures and equations.(10)
Free energy changes [29]	Lecturer: couldn't understand him, seemed to just talk not teach, weren't easy to follow, didn't help, and slightly confusing couldn't relate lectures to labs.(7)
	Not explained well, gone through too quickly.(8)
	Too mathematical.(9)
	Very complicated topic and difficult to pick up, and no previous knowledge.(5)
Buffers [22]	Lecturer slightly confusing couldn't relate lectures to labs, hard to understand, and weren't easy to follow.(5)
	Too complex, confusing, and no enough time spent on it.(3)
	The content was challenging and difficult, and no previous knowledge.(6)
	Very mathematical.(5)
pH calculations [14]	Difficult calculations, confusing, and I don't understand relevance of equations.(9)
	Lecturer couldn't understand him, not clear, and slightly confusing couldn't relate lectures to labs.(4)
Isomerism [5]	Not explained well, didn't understand cis, trans etc.(3)
	Drawing chemical structures (4)
	Lectures difficult.(3)
Functional groups [3]	Complicated.(3)
Nomenclature [4]	Lectures difficult and too many exemption.(3)
Oxidation numbers [8]	Find hard to work out and need to be talked about a little larger in lectures.(5)
Balancing redox equations [14]	Not explained well, and not enough practise.(4)
	The material in lectures didn't appear to have anything in common with the labs.(3)
	Very long, slightly confusing, and complicated.(4)
Electrolytes [10]	Lectures difficult, slightly confusing, and couldn't relate lectures to labs.(4)
	Not much information on them.(4)
Writing chemical formulae [10]	Not enough advice given on topic. (3)
	Lectures difficult, slightly confusing, and the material in lectures didn't appear to have anything in common with the labs.(5)
Mole calculations [16]	Maths.(8)
	Too complicated, more practice needed and no previous knowledge.(3)
	Too many different examples, have always found mole confusing, and don't know what to use and when.(3)
Solution concentration [8]	Lecturer difficult to follow, slightly confusing, and couldn't relate lectures to labs.(3)
	Maths.(3)
Colloidal solutions [5]	Difficult to follow, slightly confusing, and not related to labs.(3)
Osmotic pressure [10]	Difficult and slightly confusing lectures.(6)
	Very mathematical.(3)
Solvation [8]	Difficult and confusing.(4)
Drawing unit cells [6]	Confusing and difficult lectures.(4)
Corrosion [3]	Difficult, no previous knowledge.(3)
Equilibrium [18]	Too mathematical, difficult to understand and to remember equations.(4)
	Just couldn't get head round it and not fully explained.(3)
	Confusing couldn't relate lectures to labs.(9)
Polarity [8]	Not explained in enough detail, found difficult, and confusing.(3)
	Lecturer vague and too fast.(4)
Lewis acids and base [11]	Lecturer vague, slightly confusing, too fast, couldn't relate lectures to labs, and seemed to just talk not teach.(6)
	Difficult lectures and not fully explained.(4)

Appendix F1c: Chemistry-1 Students' Comments / Reasons of Difficulty (1997/98)

Reaction rate [42]	too much maths.[12] not explained clearly, too difficult to take notes.[10] too fast, not enough examples, too much information.[8]
Arrhenius equation [24]	too mathematical.[5]; fast, not explained clearly.[6] hard to understand and very hard to remember.[13]
Entropy and disorder [30]	lecturer was fast, material unclear.[6] not explained enough, bad notes, not enough notes on board.[8] didn't understand where ideas came from, get confused easily.[14]
Enthalpy [14]	too many equations.[4]; not explained enough.[6]
Free energy changes [17]	not explained well, not enough notes on board.[5]; complex, hard to understand.[6]
Buffers [55]	lectures was not clear, too many notes in short time.[12] not enough explanations.[11]; topic boring.[10] many equations and calculations during lectures are confusing and make it difficult to follow.[16]
pH calculations [78]	confusing.[7]; topic boring, wasn't clear.[8] not explained well enough, go through very fast.[20] too much maths.[15]; not enough examples.[5] many equations and calculations are confusing.[14] didn't understand lectures.[15]; very complicated, too many steps and techniques.[13]
Isomerism [20]	all different isomers are confusing.[7] no clear definitions were provided us to the differences between different types of isomers.[4]
Drawing chemical structures [5]	easily confused, hard to remember rules.[5]
Functional groups [7]	too many to remember-confusing.[7]
Nomenclature [5]	hard to remember naming system.[5]
Oxidation numbers [23]	difficult to understand, get confused easily.[11]; not explained well.[6]
Balancing redox equations [17]	confusing calculations and complex ideas.[7] it is hard to understand where electrons should go.[4]
Electrolytes [14]	notes confusing not more information on it.[5]
Lone pairs of electrons [12]	course went too quickly, not explained clearly, not enough practice.[5]
Lattice energy [15]	too many calculations, hard to remember them all, not explained enough how to get it.[6]
Markovnikov's rule [12]	complicated and confusing.[5]
Quantum numbers [31]	not explained properly.[6]; extremely confusing and not entertaining.[7] difficult to grasp especially in 1st week of term.[6]
Electronic configuration [14]	done quickly, needs to be explained.[5] notes hard to understand, confused me, where electrons came from (i.e. 4s,4d), needs more examples.[7]
Resonance and aromaticity [16]	not enough information given, not enough time spent.[6]
Half-life time [12]	lectures were too fast, not explained enough, poor lecture notes.[6]
Common ion effect [21]	don't know what this is.[20]
Nucleophiles and electrophiles [18]	I can't apply it to examples, easily confused getting +ve and -ve mixed up.[6]
Writing mechanisms [55]	confusing and complicated.[10]; not explained clearly.[4]; never done it before.[4] I just can't apply it to examples.[5]; found it hard to use only arrows.[6]
VSEPR rule[18]	very confusing-did not give enough examples.[7] didn't understand lecture notes, poor explanations in the textbook.[5]

Appendix F1d: Chemistry-1 Students' Comments / Reasons of Difficulty (1998/99)

Reaction rate [26]	Not well taught, poor lecture notes[9]
	Found it confusing, difficult to know exactly what is needed to answer question correctly. [8]
	Too mathematical, too many equations to learn, and not enough time spent on examples. [11]
Arrhenius equation [30]	Complicated to remember, confusing to grasp. [5]
	Not well taught. [8]
	Quite a lot of maths, not enough time spent on examples. [8]
Entropy and disorder [49]	Involves maths. [6]
	Confusing lectures, didn't understand basics before moved into higher level. [6]
	Found it hard to read lecturers writing and still follow what he was saying, very fast. [9]
	Lectures were incomprehensible which discouraged me. They were not very well explained which made it difficult to understand. [8]
	Poor lecture notes, v. disorganised, difficult to follow not very informative. [7]
Enthalpy [35]	Found it hard to read lecturers writing and still follow what he was saying. [5]
	Found notes confusing and slightly inadequate. [7]
	No enough explanations, the topic was not put correctly no little examples. [4]
	Lectures very confusing. [3]
	Too mathematical with similar symbols confusing. [7]
	The lecturer didn't explain things properly. [11]
Free energy changes [37]	Confusing and mathematical. [8]
	Difficult to take notes, listen and understand what's going on! [5]
	Found notes confusing and slightly inadequate. [9]
	The lecturer didn't explain things properly, very hard to follow. [9]
Buffers [31]	Difficult to take notes, listen, and understand what's going on. [4]
	Don't understand and can't grasp concept. [4]
	Not well taught, easily get confused. [3]
	Its very complicated - too much maths and equations look a like. [11]
	This is not explained very well, no enough examples given. [9]
pH calculations [68]	Not well taught, too much covered at once, and confusing teaching methods. [16]
	Maths too complicated, vague calculations (no examples). [18]
	Notes are not clear, difficult to understand explanations. [5]
	Slightly complicated with the equations and logs. [9]
	Hard to remember. [3]
Isomerism [13]	Difficult to see which are same and different. [8]
	I don't feel it has been very well taught (no enough examples). [3]
Drawing chemical structures [11]	Not explained well, get mudded. [4]
	Needs more time to spend on examples. [4]
Functional groups [10]	Difficult to remember. [3]
	Easily confused, not enough explanation and time spent on examples. [6]
Nomenclature [4]	Complicated, difficult to grasp. [3]
Oxidation numbers [18]	Can't understand how to figure it out. [6]
	Find it confusing. [3]
	Wasn't explain in details. [7]
Balancing chemical equations [18]	Not explained well, easily get confused. [5]
	Never get the equation right, complicated rules, and lots to remember. [9]
Electrolytes [10]	Never quite got the hang of it. Not well covered. [4]
Lone pairs of electrons [11]	Difficult to remember rules, easily confused. [4]
	Find hard to understand. [3]
	I don't feel it has been very well taught. [3]
Lattice energy [11]	Not well taught. [3]
	I find it very difficult as lectures confusing. [3]
	Not enough time covering topics. [4].
Markovnikov's rule [11]	Find it confusing, too complicated, and not well explained. [6]
Quantum numbers [28]	Conceptually difficult. [3]
	Could have been explained more easily. [9]
	Lecturer went too fast don't understand "shells"/"orbitals". [6]
	Never done before. [4]
Electronic configuration [10]	Difficult to understand. [4]
	Not explained well enough. [5]
Resonance and aromaticity [15]	Too many names to remember. [3]
	Hard to understand, lots of rules to learn. [5]
	I don't feel it has been very well taught. [4]
Half-life time [9]	Not enough explanation. [3]
	Difficult calculations and confusing equations. [3]
Common ion effect [18]	I don't feel it has been very well taught. [3]
	I don't know what this is. [8]
	Difficult concept. [6]
Nucleophiles and electrophiles [20]	Get mixed up which is which. [8]
	Find hard to understand. [3]
	Find it confusing. [3]
	Found it hard to remember. [4]
	Poorly explained. [2]
Writing mechanisms [47]	Confusing curly arrows, not sure what way arrows go. [17]
	Could not grasp it. [6]
	Mechanisms always different. [3]
	Not explained well, not enough practice. [8]
	There are many of them to learn. [4]
VSEPR rule [24]	Confusing. [3]
	Difficulty drawing shapes and many exceptions to the rules. [5]
	Don't understand. [3]
	Need to practise more! [3]
	Not covered fully enough, felt it was rushed slightly. [7]

Appendix F2a: General Chemistry Students' General Comments

(1997/98)

Lectures [30]	Lectures should be put in a better order, i.e.- learning from periodic table should come before any thing else as it provides basis.[3]
	Lectures would be much easier to learn if:
	lectures were made more interesting by relating the topics to real life.[6]
	more variety in teaching methods used.[3]
	more examples given with clear calculation steps.[3]
	more variation in the lecture delivery.[5]
	Lecturers could be more enthusiastic, helpful, and approachable.[7]
	Lecturers should try not to move quickly assuming much knowledge available.[4]
	Lecturer's attitude toward general chemistry students needed to be improved.[4]
	Staff-student committee is needed.[3]
Tutorials [9]	Compulsory tutorials are needed (twice a month) where more questions can be asked.[9]
Text book [3]	Very unclear and difficult to study from or not easily understood at all.[3]
Labs [18]	Lab time should be made shorter.[3]
	As some students had no previous knowledge of some topics, lectures must cover lab work before running experiments, or like organic labs, have mini-lectures/discussions at the beginning of the lab.[11]
	More percentage of year work for lab.[3]
General [45]	Summary sheets (or handouts, ...) may be constructed to show all key points, formulas and equations.[10]
	Less maths should be involved with better explanations.[7]
	Exams (terms or degree) should correspond to class tests and lectures.[9]
	More example sheets of exam-type questions might be given to be more enough prepared for exams.[4]
	Class tests must be the same standard as either the degree or the term exams.[4]
	Fewer topics with more time spent on the basic aspects of chemistry.[10]
	A gradual builds up to the "high level" chemistry by going from one topic to another with more continuity.[10]

(1998/99)

Explanations [7]	More structure and explanation in lectures such as an introduction to the topic.[3]
	More interesting lectures and better explanation of mathematical topics.[3]
Handouts [10]	A pre package for people who have never done chemistry before.[3]
	Sheets giving main points-summary, homework (as games) that will get checked once a week.. List of e.g. at the end of 'x' you should know 'y'.[5]
Lab [6]	Lecturers should cover the lab work in the lectures before the labs so we understand the information somewhat before the labs.[5]
Lectures [41]	More interesting lectures and better explanation of mathematical topics.[3]
	Perhaps revision lectures before class tests so students have the opportunity to ask questions.[5]
	More structure and explanation in lectures such as an introduction to the topic.[4]
	Lecturers should use more detail in explaining calculations and explain in detail even the obvious calculations.[4]
	Lecturers too fast, seems to be aimed at students with previous chemical knowledge.[3]
	More interesting lectures. Lecturers should have more energy enthusiasm and give more interesting lectures.[5]
	Certain members of staff seem unapproachable.[4]
	Each lecturer start lectures with outline for lecture- often they start and we have no idea what the lecture is about.[5]
Organisation [45]	Need to use of microphones so the lecturers can be heard.[3]
	Need to cater more for people who have no previous experience.[6]
	Make it more interesting, i.e. use experiments to demonstrate.[3]
	After each topic have a couple of general sessions to see where problems lie and to sort them out.[3]
	Lecturers should explain, repeat new topics more clearly especially to those without A level chemistry.[3]
	Reduce calculations, formulas etc.[4]
	Lower content and concentrate more on the subjects covered.[4]
	More time should be spent on fewer topics as it seemed to just skim over every thing not concentrating on understanding all of the basics.[3]
	Some tutorials are needed to find out whether people are actually understanding the lectures or not.[3]
	Perhaps getting on the web to post notices answers to workshops and class exams.[4]
	The majority of all lecture material should be on overheads making it easier to take notes.[4]
Previous knowledge [15]	Lecturers should be better at explaining complex subjects to people who have never taken it before. Too much is assumed![9]
Summary [6]	Sheets giving main points-summary. List of e.g. at the end of 'x' you should know 'y'.[6]
Tests [5]	The first 2 class tests should be harder, they did not prepare me for the shock of the exam. Also, the course is too hard for people without higher chem.[5]
Textbook [3]	I don't find the text book very helpful.]3]
Tutorials [17]	Taking small groups (6-8 students) and going over areas of difficulty would be better than workshops.[6]
	More help for people who have done no chemistry at all - extra tutorials.[5]
	Tutorial groups 1 a week would be good to cover the lecture work.[5]
Web [4]	All lecture material should be available on internet.[4]
Workshops [4]	More help is required in workshops and perhaps some help with maths also.[4]

Appendix F2b: Chemistry-1 Students' General Comments

1997/98

Lectures [80]	make lectures more interesting, lively and less boring.[14]
	examples should be available during lectures with same difficulties as the exams.[11]
	less note-taking during lectures and more time spent on explaining theories and giving examples.[8]
	more demonstrations and video in lectures to help visual learners.[7]
	topics (pH, kinetics, entropy and buffers) should be covered in more depth and slower.[9]
	bigger writing on overhead sheets not leaving it forever, giving handouts to keep concentrate on materials not to copying.[16]
	at the end of each lecture block, notes should be handed out, outlining the basic concepts, worked problems, and more examples.[15]
Lecturers [39]	some tend to rush through simply "cooling of their notes". I'm too busy in writing notes to either and understand that the teacher is trying to explain.[10]
	instead of speaking through their notes (or overheads), they could write them on the board.[10]
	some need to speak louder and clearer.[6]
	some tend to carry out calculations etc. without fully explaining where they are getting their numbers and information from. Entrance new information without explanations.[8]
	more contact with staff in informal environment to ask questions.[7]
Labs [25]	should be fitted more closely to the lectures.[10]
	make labs more stimulating and challenging, not having to do what is written in the manual.[2]
	to have better guidance in one lab. more things explained rather than being left to muddle through alone.[4]
	boring.[5]
Tutorials [22]	have compulsory meetings in small groups (15 students) covering 2-3 weeks lectures block.[18]
	tutorial sheets are very useful with more questions given out to go over difficulties from start.[10]
	more interaction with staff at tutorials.[4]
	it is much more interesting and helpful working with a partner in the labs.[3]
Textbook [28]	the textbook is quite complicated and does not cover some of the things in the topics and unhelpful.[28]
Problem sessions [10]	more sessions with small groups will be more helpful.[10]

1998/99

Previous knowledge [6]	Assumed knowledge in many aspects of the course (e.g. electron configurations and pKa) is far beyond that obtained at higher chemistry level.[6]
Problem sessions [6]	More problem sessions or longer problem sessions (More availability of test problems and solutions, not just one sheet in each problem session).[6]
Tutorials [13]	Compulsory tutorials (more tutorials to aid learning) in small groups of people.(10)
	Tutorials should be on a one-to-one basis, and help overcome individual's difficulties.[3]
Labs [23]	I think the pre-lab work for some of the labs was too difficult (organic labs) and time consuming.[4]
	Inorganic lab was a waste of time and I didn't understand what was happening.[3]
	Less labs, slow the lab down to make it a learning experience.[4]
	Try to make the labs and course work match up more.[6]
OHP [8]	I would suggest greater use of overheads.[3]
	More specific overheads, rather than pages and pages of information - very hard to take in anything when worrying about missing bits and keeping up with the lecturer.[5]

to be continued

Appendix F2b: Chemistry-1 Students' General Comments (Continued)

Lectures [83]	Better structure to lectures on chemical changes, pH, and solutions.(6) More explanation would help me in lectures (more examples) rather than just stating a fact or just copying overheads.(3) Some of the lectures could be more enthusiastically taught, and presented more imaginatively. Liven up lectures.(3) Access to notes that are understandable and clearly on board.(5) Academic staff being more helpful and less prejudice! (3) The lecturer for X should improve his lectures and writing. He did not seem aware that he was standing in front of 250 people. He was very boring causing people to sneak out of his lectures early. He gave very unclear, poor, and very difficult to understand lectures. He didn't introduce any of his topics; he mumbled; doesn't make himself heard. (7) If possible lecturers should speak up and not mumble!! Use of microphones. (5) Lecturers could explain calculations and some difficult terms more. More examples to be done by student and then answers explained.(4) Lecturers should use less than ten slides, don't just read exactly off overheads, more work on board and handouts so students can process information in lecture or at least have a basic understanding of topics.(10) Make the topic more interesting, break up the lecture with break or jokes-these keep your attention and increase attendance - I liked the lecturers on organic chemistry, they were the best, clear, and well presented.(6) Some lecturers writing is difficult to read and a clear definition of each section of topics using were headings is required.(4) Some of the lecturers do not make topic easy to understand which would help- even if topic is difficult- rush through easy levels to get levels of more they like. One especially could speak up, and prepare better.(5) The lecturer for Y did not speak clearly (could not understand him) and could not read his writing.(5) Some lecturers need to speak slower and in a way that students are interesting and understanding.(8) Handouts or a comprehensive reference to the textbook should be included next to the learning outcomes in the course information booklet. Revision notes for subjects. e.g. list of important facts. (5)
Organisations [56]	More exam type questions and answers in lectures. Make class tests more challenging so that you must learn about subject, despite it giving us a good continual assessment mark. The course work should not count as 50% towards the end mark.(6) A slow introduction initially would make the first few weeks more interesting, could include some maths lectures for chemistry (e.g. logs, rearranging equations (3) It would be helpful to have background in lectures to make the lab sessions and pre-lab easier to understand.(8) The number of labs should be cut down. Make labs more interesting, slow the lab down to make it a learning experience, think about time limits on labs. Sometimes feel rushed towards the end and end up not really thinking about what writing.(5) Tell us what we're meant to learn more clearly- we will be learning about something and then suddenly an equation or something will appear out of thin air with little explanation as to what it is for and this confuses me.(5) Course covers too many topics. Bear in mind that most 1st year students take 3 subjects. It could be quite helpful during exam time.(3) Less reliance on maths.(7) Material covered in January exam should not be covered in June exam. Split course into modules as with biology. I think we should cover "solutions and pH" before organic chemistry as pKa 's were mentioned and I didn't know what it meant. I feel organic course is too complicated. If it was broken it two blocks it would have helped us.(3) I think a text-book should be prepared which contain all the information needed without extra information. That way, you wouldn't have to rake through books such as Ebbing and organic chemistry.(4) Get another lecture theatre, decent projector, and sound system.(4) Availability of sample tests/ problems and brief tutorial notes via web page. Lecture notes and better communication over the web as in IBLS this is very helpful.(3)

Appendix F3: The Chemorganiser's Questionnaire General Comments (1998/99)

71 Students general comments were categorised as follows:

Clear (4)	*Each topic was very clearly explained.* *I found them clear and well layout explained the calculations and working well making it easier to understand.* *I found them clear.* *They are very clear and make it much easier to understand.*
Essential (3)	*Couldn't do some parts of course without them.* *Essential as much of the lecture material is not easily Understand by students with no chemistry background.*
Helpful (22)	*Found them extremely helpful (5).* *Generally very helpful.* *Good.* *Help to understand topics very well.* *Helpful as use as a form of study guide.* *I found all the handouts very useful, I miss 2 of the lectures when some was given at.* *I think they are very helpful for understanding the course.* *Overall, good!* *Quite good, quite helpful. Can't really remember what I used them for though I can remember using them and they were quite helpful.* *Reasonably helpful quite difficult to understand some of the topics* *The Chemorganisers proved helpful as they presented the formulae for equations clearly as opposed to my lecture notes which don't.* *The ones I received were fairly helpful.* *The organic chemistry one is extremely helpful.* *They are helpful because they give questions to answer as you work through them.* *They helped to clarify some aspects of lectures that were not understood.* *They were helpful in giving good examples, with a step by step guide to calculations.* *They were very helpful although it would have helped if the second packet given out to us was explained and taught to us as in the beginning of the year.* *Yes, very effective in showing and demonstrating the ideas.*
Layout	*I found them well layout.*
Like	*I did like the functional group section.*
Need more (3)	*Didn't cover every thing.* *I would like to have had them for all topics.* *I would prefer more topics to be covered.*
Didn't get any	*I did not get any.* *Didn't have Chemorganisers just used notes and text book.*
Easy	*I found the tables easy to understand but difficult to learn.*

To be continued

Appendix F3: The Chemorganiser's Questionnaire General Comments (1998/99) Continued

Presentation (5)	*Examples good and show how to work through step by step* *I found them explained the calculations and working well making it easier to understand.* *The warding was simple to understand.* *They were okay. It was good that you got the answers at the bottom and given other examples.* *Well-organised/presented.*
Revision	*I did not really use the Chemorganisers as I went along I am using them now to revise and they are mainly very helpful.*
Summary (3)	*Good summary of the essentials* *They were helpful in summarising the key points.* *Very helpful summaries and calculations etc.*
Tutor	*Could have more tutorials than before with more times.*
Useful (14)	*Extremely useful for revision purposes.* *I found them very useful and straight forward.* *I think that the organisers were extremely useful for studying with.* *In general I find all the handouts useful to use in conjunction with lecture notes.* *They are useful at backing up topics done in lectures and workshops* *They are useful for study. Give some questions on each topics and answers which is useful when studying specific topics.* *Useful as a starting for studying the variance topics.* *Useful as a general synthesis.* *Useful as an extra reference into understanding many topics.* *Useful if used.* *Useful what it did cover.* *Very useful for reinforcement and consolidation of learning.* *Very useful-recommended using them for every year.* *Were useful-helped to reinforce the topics covered in the lectures.*
Suggestions (11)	*A sheet of useful formulae would be great as its difficult to learn so many and its easy to get confused.* *Allocate more time to go through Chemorganisers with lectures.* *Could do with more varied questions and solutions for each topic.* *Could possibly have more simple definitions for people who have no chemistry experience what so ever.* *If they include more definitions of key words that would be of more help.* *May be a little more detail on the organic Chemorganisers.* *Some topics-such as difficult calculations could have been explained in more detail, otherwise quiet a good idea, and generally helpful.* *The self-test answers at the end of each page should be explained more clearly.* *They need more range of examples.* *Those without Higher chemistry should not be permitted to take the course. I did not have Higher and I found the course depressingly difficult.* *Topics which involved difficult calculations and equations could have been explained better.*

Appendix G

General Chemistry Students' Interview

Appendix G1: General Chemistry 1998/99 Interview Checklist

Centre For Science Education
Interview Checklist

Matriculation Number: ....

STUDY HABITS

1) By what method do you find that you most easily get hold of new concepts in chemistry?

....

....

2) How do you most easily solve your chemistry problem?
   by working on your own　　with a friend　　by using textbook
   by worked examples　　others ....

3) Where do you prefer to study?
   at home　　in the library　　with a friend
   others ....

4) What kind of errors do you commonly make in problems?
   conceptual　　mathematical

5) What do you do when you get really difficult problems?
   ask a friend　　ask the lecturer　　read the text
   read the notes　　others ....

ATTITUDES TOWARDS CHEMISTRY

6) Do you like chemistry?
   Yes　Why? ....
   No　Why? ....

7) Why are you doing chemistry?

....

8) Do you find chemistry easy?

....

9) The way you feel about chemistry affected by:
   your lecturer　　the method of teaching

....

10) What area of chemistry do you prefer?
   inorganic　　physical　　organic
   Why? ....

11) Do you consider the possibility of more than one method being possible to solve a problem?

....

To be continued ...

Appendix G1: General Chemistry 1998/99 Interview Checklist (Continued)

<u>THE CHEMORGANISERS</u>

12) What is your opinion of working with the Chemorganisers?

....

....

13) Does the idea appeal to you?

    Yes Why? ....

    No Why? ....

14) Do you see any advantages in learning with the Chemorganisers?

....

....

15) What criticisms would you like to make?

....

....

16) What do you think of the way that the material in the Chemorganisers was presented?

    The layout

    The sequence of the material

17) Did working with Chemorganisers satisfy you?

    Yes Why? ....

    No Why? ....

18) Did you read everything in the Chemorganiser sheet?

....

19) Does the problem solving strategy of the Chemorganisers differ from what you are used to?

....

20) Was the self-assessment helpful?

....

21) Are you willing to ask lecturers to use the Chemorganisers next year?

    Yes Why? ....

    No Why? ....

22) Did the Chemorganisers help you—did it illuminate any area which was previously unclear?

....

23) Did you feel that the Chemorganisers are related to each other?

....

Appendix G2: General Chemistry Students' Reply to the Interview Questions

STUDY HABITS

Q1 By what method do you find that you most easily get hold of new concepts in chemistry?

I rewrite my notes each night checking the concepts. If not understood look at textbook.
Problem solving approach, using examples and explain. Relate problem exam questions.
Giving short quiz at start of lecture to refresh my memory. Helps to focus mind on upcoming lecture.
For definitions I find it easier if they are put on the overhead. For calculations I find it easier if the lecturer goes through it on the blackboard.
To read the information and then to rewrite the information.
Written dawn step by step instructions with discussion.
Using overheads. Give definition first.
By reading the lecture notes. Concepts are more easily grasped if the basic definitions are gone over first and then examples given. If only examples are given, the concept is not understood.
With an explanation followed by an example.
If the lecturer relates his new concepts to ones in life.
Use of blackboard, easier to follow lecturer's through start from examples to the theory. use history background.
By working examples. Access to tutorial (small group).
Need concepts explained clearly first. Giving examples is helpful but only once the concepts have been clearly explained. Giving examples first gets confusing.
Overheads and explanation from lecturers. Usually need to go over examples a few times, Tutorials.

Q2	How do you most easily solve your chemistry problem?			
your own	a friend	using textbook	examples	others
4	3	2	1	5 Fiends doing postgraduates or in 3rd or 4th year.
1	4	3	2	
3	4	2	1	
1	4	3	2	5 Lecturer.
5	2	3	1	4 look at other textbooks.
3	4	2	1	
4	1	2	3	
5	3	2	1	4 Friends from higher years.
2	3	1	4	5 Someone who done chemistry.
4	1	3	2	
1	4	1	3	
2	3	4	1	
5	3	2	1	4 Friends in second/third year.

Q3	Where do you prefer to study?		
at home	in the library	with a friend	others
4	1	2	3 Parental home
1	2		
1	2	3	
1	2		
1	2	3	
2	1	3	
3	2	1	4 Park.
2	3	1	
1	3	4	2 In the library with a friend.
3	1	2	
1	3	2	
1	2	3	
1	3	2	

Q4	What kind of errors do you commonly make in problem
conceptual	mathematical
2	1
	1
2	1
1	
	1
1	2
	1
2	1
2	1
2	1
2	1
	1
1	2

Q5	What do you do when you get really difficult problems?			
ask a friend	ask the lecturer	read the text	read the notes	others ....
3	4	2	1	5 Older friends, school teacher.
3		2	1	4 Dr. Morris.
3	4	2	1	
3	4	2	1	
2	1	3	5	4 read other text.
4	3	2	1	
3	4	1	2	
3	5	1	2	4 Friends in higher years.
3	4	2	1	5 Ask someone else who has done chemistry.
1	4	3	2	
4	3	1	2	5 Other textbooks.
3	1	4	2	
4	5	2	1	3 Friends in second/third year.

To be continued

Appendix G2: General Chemistry Students' Reply to the Interview Questions (Continued)

ATTITUDES TOWARDS CHEMISTRY

Q6 Do you like chemistry?

Yes Why?	No Why?
Yes, very useful in understanding biology.	
	No, it is very difficult to grasp and understand.
Yes, to help future work in biology and other subjects.	
Yes, find it interesting as it is in the world around-need to know why things happen around us.	
Yes, I fell it is universal subject it links to all subjects. I find it interesting but difficult.	
Yes, logical, useful for other subjects.	
	No, too much mathematics.
	No, difficult to understand. Too much information if concepts are not grasped at beginning then its very difficult to understand later on.
	No, hard to understand. Not part of my chosen course. Not as related to life as other subjects.
Yes, find some of the concepts for fetched.	No, can't apply them to everyday life.
Yes, it's very related to life (at school), but too much issues covered and not in enough depth (chemistry at university).	
Yes, related to life.	
	No, find it extremely difficult, have not really grasped it from the start. A lot of work to cover in one year with no background.

Q7 Why are you doing chemistry?

I have prior knowledge of chemistry and have enjoyed learning about it. Also as a course requirement.
I'll need it to study physiology.
To help further my studies in biology.
Recommended for the course I'm doing.
I need a background in chemistry for doing my degree.
Important in access to many 2nd year science subjects.
Required subject.
Recommended to do as also doing biology.
I need it to do the course I chose for honours.
Because I had to, for designated degree.
Liked it at high school. Compulsory for my degree/honours.
It is needed for future biological studies.
Recommended if doing biology.
Need it for future use.

Q8 Do you find chemistry easy?

Reasonably easy to understand concepts. Logic and reasoning.
No
I can cope fairly well with it.
Not particularly, I find it difficult making links between the concepts and the problems.
No, I find it difficult the maths and sometimes new concepts.
No.
Difficult-due to mathematical aspects of course.
I find chemistry difficult because the basics of new concepts are not always explained before the lecture goes into examples.
No.
No.
Yes.
No.
Very difficult, have not managed to keep up with all the new topics feel I'm becoming more confused.
Sometimes it can be, not always.

Q9 The way you feel about chemistry affected by:

your lecturer	he method of teaching
	1
	1
2	1
	1
	1
2	1
2	1
2	1
2	1
2	1
1	1
	1
2	1

To be continued

Appendix G2: General Chemistry Students' Reply to the Interview Questions (Continued)

ATTITUDES TOWARDS CHEMISTRY (continued)

Q10 What area of chemistry do you prefer?		
inorganic	physical	organic
3	2	1
2	3	1
1	2	3
3	2	1
2	3	1
2	3	1
1	3	2
2	3	1
1	3	1
2	3	1
3	1	2
2	3	1
1	3	2

Q10Why?

Is more useful in everyday life, picture, three dimensional. Stay same order.
Organic relates more to existing knowledge. Stick to same order.
Easier to learn inorganic because it is more factual. Physical was a little harder due to mathematics. Organic was too much based on pictures/drawings.
Related to general every day life. To start-inorganic.
It is the easiest way to understand. The way the course is given is good to start with inorganic and finish with organic.
Conceptual more than mathematical. Start with organic, inorganic.
In organic-Theory was easier to grasp. Stick to the same layout.
The way in which the lecturer (Dr. M) gives the lecturers and explains the material is very clear and is very easy to understand.. If it had been possible to give us physical chemistry before Christmas and put it in that exam instead of in the final exam then it would have been much easier. I feel it is irrelevant where organic and inorganic chemistry goes.
They are more interested than physical chemistry. Arrange in the same order.
Can relate organic to life.
Mainly thermodynamics. Structure of lectures: physical-inorganic-organic.
Relative to my future studies.
Inorganic chemistry was a lot easier to understand, I found physical chemistry very hard, organic chemistry is interesting but I am so lost how that I don't really enjoy it.
More relevant to future course.

Q11 Do you consider the possibility of more than one method being possible to solve a problem?

Conceptual method.

Yes, but leads to confusion when more than one way to solve problems.
I use the method which I find the easiest to apply to the problem.
Yes
Yes.
Accept that.
Yes.
If I trust the person who gave me the other method then I would use it.
I'd consider it but stick to the method I was taught.
Yes.
Yes.
Yes.
Accept another method but tend to use method that I understand most.
Sometimes there can be more than one way to answer a problem.

To be continued

Appendix G2: General Chemistry Students' Reply to the Interview Questions (Continued)

THE CHEMORGANISERS

Q12 What is your opinion of working with the Chemorganisers?
They are very useful, preparing for exams (before lecture block, would be good preparation)
Excellent. Set at step by step. So understanding the problem is easier. Also summary to help remember for future. Help understand lecture material.
I think they are useful as a starting point in learning the appropriate topics.
Very helpful.
They are useful as they work through problems step by step.
Quite easy to understand, useful.
Make complex ideas easier to understand.
I find Chemorganisers very clear and precise. They guide me through a problem step by step.
I found them helpful as an extra set of notes which I new would be come to.
Very helpful.
Use them as the last option (as an introduction/guidance to the course and as a summary to make sure that all the important points were covered).
Helpful, friendly, and easy to grasp.
Helpful, taken through problems step by step.
They are very helpful, like working with a friend.

Q13 Does the idea appeal to you?
Yes WHY?
Yes, to help understand concepts easily.
Yes, help with revision and understanding.
Yes, gives more confidence in learning.
Yes, easy to understand topics.
Yes, easy to understand.
Yes, summary of what done, foundation to build on.
Yes, what you need to know is in front of you.
Yes, takes me easily through some difficult problems.
Yes, as an extra set of notes.
Yes, gives background into subject.
Yes, to guide students' study.
Yes, convenient/easy.
Yes, very simple, easily to understand.
Yes, they are convenient.

Q14 Do you see any advantages in learning with the Chemorganisers?
You have worked examples to look at and problems to try and solve with answers.
Yes. Help understanding. Also as a back up to refer back to were stuck
Helps to focus my study on a particular area of chemistry.
Yes, contains what you need to know in the course able to base rest of study on it.
They backup lecture ideas and mathematical ideas.
Plenty of examples, easier to grasp concepts.
Plain facts not excessive examples where you lose the original idea.
They take me through the original problem step by step and show me how they get the answer. The language is simple and easy to understand.
Yes, they are clear and concise and make the problems seem more simple and make them seem easier to learn.
It makes it easier to grasp the main concepts.
Have a quick read for issues that do not need a full covering. Also, important as a summary of the ideas that must be retained.
To have in conjunction with lectures. Helps to understand and remember.
Gives you experience in doing actual questions which is helpful for exams. Also gives you another source other than lecture notes or textbook.
They are a good aid to have in tandem with the lectures. Also useful when revising for exam-time.

Q15 What criticisms would you like to make?
Only a few more questions, one other worked examples.
Not enough of them. Should be given out before lecture course.
I would prefer Chemorganisers to be given at the start of each topic.

Sometimes wording can be bit confusing.
The self-assessment questions are not explained-only the answer is given.
They only give foundation information which is not enough to know-could refer you to textbook etc.

Helpful, cover in more detail, give a sequence to.
Good to have earlier rather than at the end of set of lectures.

To be continued

Appendix G2: General Chemistry Students' Reply to the Interview Questions (Continued)

THE CHEMORGANISERS (continued)

Q16 ***What do you think of the way that the material in the Chemorganisers was presented?***
The layout
1 I recommend the shade.
Logical-easier to understand. Clear as one page/topic.
The boxes should be shaded.
Yes, good.
The layout is clear.
1
1
1 Keep to same style. Shaded layout of organiser is much better.
1
Yes, it would be better if they laid out up and down A4.
Vertical as full text. Two sides, the small one (title) shaded.
Fine.
1 Same style, same layout. Prefer shaded boxes.
Very clear.

The sequence of the material
1 Good
Step by step. Prefer the set out as it is.
The sequence is quite good.
Yes, good.
It is well presented.
1 Good, logical.
1
1 Keep to same style.
1

Same way but concepts after the problem and the self assessment at the end. Also in before you start analysis of the concepts.
Fine.
1 With arrows, same sequence.
Good.

Q17 ***Did working with Chemorganisers satisfy you?***
Yes WHY?
Yes, for having problems to try.
Yes, it is helping with understanding.
Yes, reinforced knowledge from lectures. Some topics require Chemorganisers, i.e. symmetry (unit cells).
Yes, I found it very useful.
Yes, they helped clear things up and understanding.
Yes, felt that I had learned concepts.
Yes, can relate problems and method of solution easily.
Yes, feel a sense of achievement when you realise you can do the problem.
Yes, good as a revision aid.
Yes, gives you basic ideas and then builds on them.
Yes, as an individual problem.
Yes, focused on what I needed, easy access.
Yes, makes questions easy.
Yes, good backup to lecture material.

Q18 ***Did you read everything in the Chemorganisers sheet?***
Yes
Yes and take at information for a study note book.
Yes.
Yes. Most things.
Yes.
Yes.
Yes.
Yes.
No, usually I only read the necessary parts.
No, I would look at the summary to see if I knew the information. covered on the sheet. If not I would then look at the whole sheet.
Without self-assessment.
Yes.
Yes.
Yes, looked at relevant bits at the time needed. Recall all things on one sheet.

Q19 ***Does the problem solving strategy of the Chemorganisers differ from what you are used to?***
Does differ, more information to enable me to understand the question is there.
Different from lectures, but more understandable. Doesn't assume chemistry background.
I am not sure.
No.
No, they work through the problem step by step.
Yes, more organised.
Yes-don't have guidelines to relate problems to.
Occasionally Chemorganisers differ but I find them more clear.
No major differences-although sometimes the problems were not complex enough compared to lectures.
There is not much difference, but the Chemorganisers lay it out in steps which are easier to learn.
Yes, when it's satisfactory.
Mostly similar
Sometimes different but not in a confusing way.
Yes.

To be continued

Appendix G2: General Chemistry Students' Reply to the Interview Questions (Continued)

THE CHEMORGANISERS (continued)

Q20 ***Was the self-assessment helpful?***

Yes
Yes, to check if you understandable then to remember because you understand.
Yes, because it gives student the chance to see how much he/she knows about the topic.
Yes.
Yes, it helps you see if you have really understood the problem.
Test yourself, useful.
Yes.
The self-assessment is useful.
Yes, gave practice.
Yes, it gives different difficulty levels in the questions.
Yes, as it shows that the strategy can be applied to.
Yes.
Yes.
Yes, good backup to test the knowledge gained.

Q21 ***Are you willing to ask lecturers to use the Chemorganisers next year?***

Yes WHY?
Yes, to take the course more organised, ordered.
Yes, they have helped and are useful.
Yes, give student more confidence when revising and looking over lecture notes.
Yes, builds on notes from lectures.
Yes, they backup the work the lecturer is doing.
Yes.
Yes, make sure everything is referred to.
Yes, help students to understand clearly therefore easier for lecturer to get concept access.
Yes, good for learning, practising and revisions basic concepts.
Yes, You would be able to come into the lecture prepared for the subject being taught.
Yes, if it includes a previous guidance.
Yes, find very useful in conjunction with lectures.
1
Yes, useful in tandem with lectures.

Q22 ***Did the Chemorganisers help you - did it illuminate any area which was previously unclear?***

Yes, ideal gas equation and logarithms.
Yes, all areas that were covered by the Chemorganisers
Helped to clarify how to do the pH calculations.
Yes, able to quickly finds something that you may be unsure about.
Yes. I used them during physical chemistry for all topics and they helped clear up many problems especially with equations.
Yes.
Yes, PV=nRT
Helped me very much, unclear areas were explained step by step, very useful for revision.
Yes, mainly concerning the functional groups.
Naming (organic) clarified this area.
Some areas.
Yes.
Yes, helpful explain many problems (organic functional groups). It was good having inorganic first as it was quite basic and a good introduction. I did like having physical in the middle as it really put me off. However, if it was put at the end it would be very difficult to study for the exam.
Helped with more calculations and aqueous solutions.

Q23 ***Did you feel that the Chemorganisers are related to each other?***

Yes, suggest of other related problems would be helpful though. To be given during lecture blocks.
Same format in each. Relate new problems to previous sheets.
I didn't go back and look at previous Chemorganisers. I used them separately to study for the relevant topics for each class test. I would like to see more references given to each Chemorganiser, to return to previous Chemorganisers to reinforce topics.
Yes, prefer to get Chemorganiser after the block of lectures relevant to it-you are able to relate the concepts as you already have had the information about it.
Yes, they sometimes refer back to previous organisers. Chemorganisers should be given during the block of lectures.
Yes, continuity was good.
Each one works separately.
Yes, I feel the Chemorganisers would be better given before block of lectures.
Would probably help if you were referred to other Chemorganisers.
Yes, if there were a footer at the bottom telling you related subjects.
Not really as lectures are given as separate subjects. Include footnotes referred to other Chemorganisers.
Yes, but can be used independently.
Yes, given our during lectures, if given before it could be confusing and if given out after it's too late.
Yes, but can be used separately.

Appendix H

Lectures' Views of Topics Difficulties

Appendix H1 a: General Chemistry Lecturers' Questionnaire

Centre for Science Education

Dear Lecturer

The list of topics below contains the main themes taught in General Chemistry. From your experience as a lecturer, please tick an appropriate box which reflects your views of student difficulty.

Easy	**students understand without difficulties**
Moderate	**students have difficulties but understand it eventually**
Difficult	**students never seen to understand it**

	Easy	Moderate	Difficult	If difficult, please say **why**
Reaction rate	☐	☐	☐	....
Arrhenius equation	☐	☐	☐	....
Entropy and disorder	☐	☐	☐	....
Enthalpy	☐	☐	☐	....
Free energy changes	☐	☐	☐	....
Buffers	☐	☐	☐	....
pH calculations	☐	☐	☐	....
Isomerism	☐	☐	☐	....
Drawing chemical structures	☐	☐	☐	....
Functional groups	☐	☐	☐	....
Nomenclature	☐	☐	☐	....
Oxidation numbers	☐	☐	☐	....
Balancing redox equations	☐	☐	☐	....
Electrolytes	☐	☐	☐	....
Writing chemical formulae	☐	☐	☐	....
Mole calculations	☐	☐	☐	....
Solution concentration	☐	☐	☐	....
Colloidal solutions	☐	☐	☐	....
Osmotic pressure	☐	☐	☐	....
Solvation	☐	☐	☐	....
Drawing unit cells	☐	☐	☐	....
Corrosion	☐	☐	☐	....
Equilibrium	☐	☐	☐	....
Polarity	☐	☐	☐	....
Lewis acids and bases	☐	☐	☐	....

Thank you for answering this questionnaire

Appendix H1 b: Chemistry-1 Lecturers' Questionnaire

Centre for Science Education

Dear Lecturer

The list of topics below contains the main themes taught in Chemistry-1. From your experience as a lecturer, please tick an appropriate box which reflects your views of student difficulty.

Easy	**students understand without difficulties**
Moderate	**students have difficulties but understand it eventually**
Difficult	**students never seen to understand it**

	Easy	Moderate	Difficult	If difficult, please say **why**
Reaction rate	☐	☐	☐	....
Arrhenius equation	☐	☐	☐	....
Entropy and disorder	☐	☐	☐	....
Enthalpy	☐	☐	☐	....
Free energy changes	☐	☐	☐	....
Buffers	☐	☐	☐	....
pH calculations	☐	☐	☐	....
Isomerism	☐	☐	☐	....
Drawing chemical structures	☐	☐	☐	....
Functional groups	☐	☐	☐	....
Nomenclature	☐	☐	☐	....
Oxidation numbers	☐	☐	☐	....
Balancing redox equations	☐	☐	☐	....
Electrolytes	☐	☐	☐	....
Lone pairs of electrons	☐	☐	☐	....
Lattice energy	☐	☐	☐	....
Markovnikov's rule	☐	☐	☐	....
Quantum numbers	☐	☐	☐	....
Electronic configuration	☐	☐	☐	....
Resonance and aromaticity	☐	☐	☐	....
Half-life time	☐	☐	☐	....
Common ion effect	☐	☐	☐	....
Nucleophiles and electrophiles	☐	☐	☐	....
Writing mechanisms (e.g. S_N1)	☐	☐	☐	....
VSEPR rules	☐	☐	☐	....

Thank you for answering this questionnaire

Appendix H1 c: Lecturers' of Level-1 Chemistry Courses Questionnaire

Centre for Science Education

Dear Lecturer

The list of topics below contains the main themes taught in chemistry-1 and general chemistry courses. From your experience as a lecturer, on either of these courses, please tick an appropriate box which reflects your views of student difficulty.

Easy	**students understand without difficulties**
Moderate	**students have difficulties but understand it eventually**
Difficult	**students never seen to understand it**

	E	M	D	If difficult, please say **why?**
Reaction rate	☐	☐	☐	....
Arrhenius equation	☐	☐	☐	....
Entropy and disorder	☐	☐	☐	....
Enthalpy	☐	☐	☐	....
Free energy changes	☐	☐	☐	....
Buffers	☐	☐	☐	....
pH calculations	☐	☐	☐	....
Isomerism	☐	☐	☐	....
Drawing chemical structures	☐	☐	☐	....
Functional groups	☐	☐	☐	....
Nomenclature	☐	☐	☐	....
Oxidation numbers	☐	☐	☐	....
Balancing redox equations	☐	☐	☐	....
Electrolytes	☐	☐	☐	....
Writing chemical formulae	☐	☐	☐	....
Mole calculations	☐	☐	☐	....
Solution concentration	☐	☐	☐	....
Colloidal solutions	☐	☐	☐	....
Osmotic pressure	☐	☐	☐	....
Solvation	☐	☐	☐	....
Drawing unit cells	☐	☐	☐	....
Corrosion	☐	☐	☐	....
Equilibrium	☐	☐	☐	....
Polarity	☐	☐	☐	....
Lewis acids and bases	☐	☐	☐	....
Lone-pair electrons	☐	☐	☐	....
Lattice energy	☐	☐	☐	....
Markovnikov's rule	☐	☐	☐	....
Quantum numbers	☐	☐	☐	....
Electronic configuration	☐	☐	☐	....
Resonance and aromaticity	☐	☐	☐	....
Half-life time	☐	☐	☐	....
Common ion effect	☐	☐	☐	....
Nucleophiles and electrophiles	☐	☐	☐	....
Writing mechanisms(eg S_N1)	☐	☐	☐	....
VSEPR rules	☐	☐	☐	....

Thank you for answering this questionnaire

Appendix H2: Lecturers' Reasons of Topics Difficulties

GC & C-1

Reaction rate	Maths-calculas. Mathematical difficulties. Maths and logs. Concept, maths
Arrhenius equation	Maths-calculas.[2]
Entropy and disorder	Maths-calculas. Concept [3]
Enthalpy	Calculations expected are easy but implications not were grasped
Free energy changes	Mixed with entropy and enthalpy Poor maths skills. Concept
Buffers	Maths. Not numerate, concept difficult Concept and maths. Students can no longer calculate molarites reliably and seeing few of them understand logarithms.
pH calculations	Maths [3] Not numerate, concept difficult Thinking out what the situation is and so what equations to use Students can no longer calculate molarites reliably and seeing few of them understand logarithms.
Nomenclature	Organic ok, inorganic complex. Good student have little difficulty.
Oxidation numbers	Good student have little difficulty.
Balancing redox equations	Like all equations-don't know products. Good student have little difficulty. Required knowledge of oxidation states. Don't know.
Electrolytes	Don't know.

GC only

Writing chemical formulae	Probably scored at school. Good student have little difficulty.
Mole calculation	Maths/overload. Fail to distinguish single compounds from solutions Good student have little difficulty. Lack of clear system
Solution concentration	Fail to distinguish single compounds from solutions Confusion of systems
Osmotic pressure	At level asked i causes problems Don't know, concept difficult?
Drawing unit cells	3-D visualisation, ok with models. Depends on what is asked Don't know, concept difficult?
Equilibrium	confusion with Physics.
Polarity	Understand when explained can't work out for themselves. Don't relate to periodic table.
Lewis acids and base	Good student have little difficulty.

C-1 only

Lone-pair electrons	Don't relate to periodic table.
Lattice energy	Difficult to visualise.
Quantum number	Totally unvisualisable. Concept
Electronic configuration	ok with a P.T., otherwise confusing. Don't relate to periodic table.
Resonance and aromaticity	Aromaticity will be taken out next year. Frequent misconceptions, poor presentation
Half-life time	Maths [2]
Common ion effect	Teachers as confused as students. Not covered very much in course.
Nucleophiles and electrophiles	Difficulty with electronic configuration (see above) Which is which?
Writing mechanisms (e.g. SN1)	Difficult to visualise. Difficulty with electronic configuration and polarity. Curly arrows!

Appendix I

Analysis of Exam Scripts and Students' Responses to the Questionnaires

Appendix Ia: General Chemistry (1997/98) Topics and Response Percentages

Topics	Examinations				Questionnaire		
	T2	T3	T4	January	Easy	Moderate	Difficult
Naming compounds					10	58	31
Naming of chemical symbol	99			92			
Naming of ions	63						
Oxidation state	11			28	19	53	28
Draw isomers / inorganic	22				17	64	19
Metals / nonmetals	83			91			
Electronegativity	77						
Electronic configuration	42			44			
Mole calculation				8	20	58	22
Balancing redox				17	36	50	15
Corrosion				60	23	62	15
Writing formula for compounds				43	37	54	9
Writing formula for elements				73			
Balancing equations (simple)				18			
Balancing ionic equations				43			
Hard/soft acids				56			
Coordination number				40			
Orbital quantum numbers				35			
PV=nRT				50			
Draw unit cell				30	33	53	15
Draw diagrams ligands				16			
Ligands				26			
ΔG		51			13	59	28
Equilibrium constant		45			20	64	16
Rate of reaction		44			32	53	15
Rate constant		48					
Rate expression		37					
Osmotic pressure			37		16	64	19
van't Hoff i factor			36				
Organic reactions			11				
Oxidation			30				
Electrolyts			59		12	77	12
Draw organic compounds			34				
Draw chiral			34				
Draw cis			22				
Draw polymers			18				
Weak acid Ka			35		13	62	25
Solubility			33		7	71	22
Solubility in water			53				
pH calculation			9		24	58	18
Functional groups			45		33	55	12
[A]			13		19	70	11
Hydrolysis			32				
Polymers			5				

Appendix Ib: Chemistry-1 (1997/98) Topics and Response Percentages

Topics	Examinations				Questionnaire		
	T2	T3	T4	January	Easy	Moderate	Difficult
B.p	88			73			
H-bonding	88						
Intermolecular forces	81			98			
Half-life time	84				47	45	7
van der Waals	85			47			
Rate reaction	89				36	50	12
Rate law	56			47			
Order of reaction	97						
Overall reaction	99			68			
Intermediate	98			93			
Molecularity of 1st step	88			87			
Collisions /reactions	97						
Activation energy				33	25	61	11
Lattice energy				40	26	62	10
Naming organic compounds				70	65	31	2
PV=nRT				57			
Transition state theory				32			
VSEPR draw				66	40	49	9
Geometrical isomers / organic		92		68	46	46	7
Draw organic structure		57		54			
Draw chiral		76		66			
ΔG		58			30	57	11
ΔH		72			41	49	8
ΔS		74			35	49	8
Hydrolysis draw		83					
Lone pair electrons		92		76	51	42	6
Mechanism		82		37	14	56	28
Curly arrows		81		33			
Cell reaction			42		14	72	10
E cell			69				
Dielectric constant			85				
Draw / Ligand			37				
Isomers / inorganic			81				
Electronic configurations			63		53	37	8
High / low spin d-orbital			73		33	48	16
Mole calculation			52				
Oxidation states			76		43	47	9
pH			91		20	51	28
pKa			56		20	57	22

Appendix J

General Chemistry Course

Statistical Analysis (1997/98 and 1998/99)

Appendix J1: Results of Analysis of Difference in General Chemistry January Examination Performance Based on Chemistry Qualifications

		Upper	Higher Grade	Standard Grade	Alternative Qualifications	No formal chemistry
Lower	93/94	not sig	not sig	not sig	not sig	not sig
	94/95	not sig	not sig	not sig	not sig	not sig
	95/96	sig at 1%	sig at 1%	not sig	not sig	not sig
	96/97	sig at 1%	sig at 1%	not sig	not sig	not sig
	97/98	not sig	not sig	sig at 5%	not sig	not sig
None	93/94	not sig	not sig	not sig	not sig	
	94/95	not sig	not sig	not sig	not sig	
	95/96	sig at 1%	sig at 1%	not sig	not sig	
	96/97	not sig	not sig	not sig	not sig	
	97/98	not sig	not sig	sig at 5%	not sig	
A	93/94	not sig	not sig	not sig		
	94/95	not sig	not sig	not sig		
	95/96	not sig	not sig	not sig		
	96/97	sig at 5%	sig at 5%	not sig		
	97/98	not sig	not sig	sig at 5%		
S	93/94	not sig	not sig			
	94/95	not sig	not sig			
	95/96	sig at 5%	sig at 5%			
	96/97	not sig	not sig			
	97/98	sig at 0.1%	sig at 0.1%			
H	93/94	not sig				
	94/95	not sig				
	95/96	not sig				
	96/97	not sig				
	97/98	not sig				

Appendix J2: Results of Analysis of Difference in General Chemistry June Examination Performance Based on Chemistry Qualifications

		Upper	Higher Grade	Standard Grade	Alternative Qualifications	No formal chemistry
Lower	93/94	not sig	not sig	not sig	not sig	not sig
	94/95	not sig	not sig	not sig	not sig	not sig
	95/96	0.0026 (1%)	0.0026 (1%)	not sig	not sig	not sig
	96/97	not sig	not sig	not sig	not sig	not sig
	97/98	0.0005 (0.1%)	0.0003 (0.1%)	0.0359 (5%)	not sig	not sig
None	93/94	not sig	not sig	not sig	not sig	
	94/95	not sig	not sig	not sig	not sig	
	95/96	not sig	not sig	not sig	not sig	
	96/97	not sig	not sig	not sig	not sig	
	97/98	not sig	not sig	0.0222 (5%)	not sig	
A	93/94	not sig	not sig	not sig		
	94/95	not sig	not sig	not sig		
	95/96	not sig	not sig	not sig		
	96/97	not sig	not sig	not sig		
	97/98	not sig	not sig	not sig		
S	93/94	not sig	not sig			
	94/95	not sig	not sig			
	95/96	0.0382 (5%)	0.0381 (5%)			
	96/97	not sig	not sig			
	97/98	0.0000 (0.1%)	0.0000 (0.1%)			
H	93/94	not sig				
	94/95	not sig				
	95/96	not sig				
	96/97	not sig				
	97/98	not sig				

Appendix K

The Chemorganisers

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Kelvin building
Faculty of Science
University of Glasgow

Chemorganisers

by
Ghassan Sirhan

Each covers one topic from level one chemistry

Essential background knowledge is provided

A strategy to obtain the right answer is given

Practice problems, with answers, are offered

Re-arranging Equations

Problem

Rearrange in the form " x = ..." the equation: $a = 9x + 27$

Before you start

* An equation expresses a relationship involving variables (things which can vary) and constants (things which do not vary)

e.g. Density = mass ÷ volume

or d = m ÷ v

or density is a <u>function</u> of mass and volume.

* To solve an equation, it is necessary to rearrange it first so that the variable you want is by itself on one side and all the other variables and constants are on the other side.

Concepts

Variable, function, addition, subtraction, multiplication, division.

Strategy

(1) Your aim is to move all terms containing your variable to one side and all other terms to the other side.

(2) Do this by adding, subtracting, multiplying or dividing.

(3) **Remember:** What you do to one side must be done to the other side.

Solution

(1) Your variable (x) is in the right side.

(2) As your variable is added to 27, subtract 27 from the two sides

$a = 9x + 27$

$a \mathbf{- 27} = 9x + 27 \mathbf{- 27}$

$a - 27 = 9x$

(3) Your variable multiplied by a constant (9), so you must divide the two sides by 9

$a - 27 = 9x$

$(a - 27) \mathbf{\div 9} = (9x) \mathbf{\div 9}$

$(a - 27) \div 9 = x$

$x = (a - 27) \div 9$

Self Assessment

(1) In your chemistry course you will use the following formulas, try to rearrange them to the required variable?

(i) $PV = nRT$ solve for n

(ii) $V_1 \div T_1 = V_2 \div T_2$ solve for T_1

(iii) °F = 1.8 °C + 32 solve for °C

(2) Solve for y $2x + 10 = 3y - 6$

Reminder

Multiplying two positive quantities gives a <u>positive</u> quantity: $(+4)(+2) = +8$

Multiplying two negative quantities gives a <u>positive</u> quantity $(-4)(-2) = +8$

Multiplying a positive quantity by a negative quantity gives a <u>negative</u> quantity

$(-4)(+2) = -8$ or $(+4)(-2) = -8$

Answer: (1) i) $n = PV \div RT$ ii) $T_1 = (V_1T_2) \div V_2$ iii) °C = (°F - 32) ÷ 1.8

(2) $y = (2x + 16) \div 3$

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Chemorganisers

Temperature Measurements

Problem

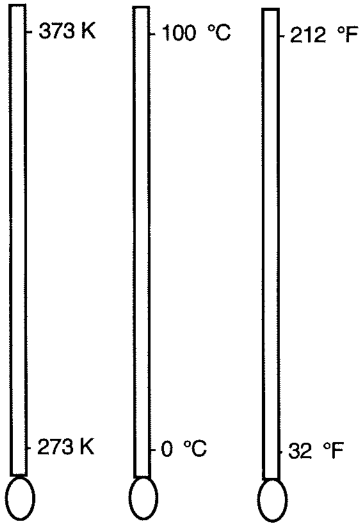
Normal body temperature is 37 °C.

What is this in: (a) Kelvins (b) Fahrenheit degrees ?

Before you start

* In temperature measurements, you will use Kelvin (K), Celsius (°C) and Fahrenheit (°F) scales.
* The Kelvin, K (notice that the abbreviation is K, not °K) is the name of the degree on the Kelvin scale, and it is identical in size with the Celsius degree (100 degree between freezing and boiling water in both scales).
* 0 °C corresponds to 273 K, while 100 °C corresponds to 373 K.
* To convert the given temperature to Celsius or Kelvin, use the equation:

  K = °C + 273



* The degree Celsius (°C) is 1.8 times the size of the degree Fahrenheit (°F), (1 °C = 1.8 °F).
* To convert the given temperature to Celsius or Fahrenheit, use the following equation: °F = (1.8 x °C) + 32
* To convert from Kelvin (K) to Fahrenheit (°F) or the opposite you must convert the given temperature to Celsius (°C) then to the required temperature.

Concepts

Kelvin scale, Celsius scale, Fahrenheit scale, temperature, degree.

Strategy

1 Determine the scale of the known temperature,

2 Determine the scale of the unknown temperature,

3 Use the suitable equation for conversion

Celsius to **Kelvin** **use** K = °C + 273

Celsius to **Fahrenheit** **use** °F = (1.8 x °C) + 32

Solution

a) To convert 37 °C to Kelvin K = °C + 273

therefore, K = 37 + 273 = 310 K

b) To convert 37 °C to Fahrenheit °F = (1.8 x °C) + 32

therefore, °F = (1.8 x 37) + 32 = 98.6 °F

Self assessment

Fill in the missing spaces:

Common temperature readings	C°	°F	K
Very cold day	-20	.....	.....
Room temperature	.....	.....	293
Normal body temperature	.....	.....	310
Very hot day	38	.....	.....
Hottest temperature the hands can stand	.....	120	.....

Summary

* To convert from

Kelvin AND **Celsius** K = °C + 273

Fahrenheit AND **Celsius** °F = (1.8 X °C) + 32

Kelvin AND **Fahrenheit** always convert to **Celsius** first

* One degree on the Kelvin scale is the same size as one degree on the Celsius scale.

Answer: [-20 -4 253] ; [20 68 293] ; [37 98.6 310] ; [38 100.4 311] ; [48.9 120 321.9]

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Chemorganisers

Scientific Notation (Exponantial Notation)

Problem

Express each number in scientific notation:-

(a) 57800000 (b) 0.00000001

Before you start

* Chemists have to deal with numbers which are either extremely large or extremely small.
  For convenience they express the numbers in scientific notation or exponential notation form: **N** x **10^x** e.g. 150 = 1.5×10^2
  [**N** is a number between 1 and 10, and **x** is the power (index) of 10]
* The power (index) of 10 indicates how many moves the decimal point is to be shifted to the right or the left.
* For each shift of the decimal point one place to the left, the power (index) increases by 1. e.g. $2.35 \times 10^2 = 0.235 \times 10^3$
* For each shift of the decimal point one place to the right, the power (index) decreases by 1. e.g. $2.35 \times 10^2 = 23.5 \times 10^1$

Concepts

Scientific notation, power (index), decimal number, non-zero digit, sign

Strategy

(1) Count the number of moves of the decimal point so that you obtain a number which lies between 1 and 10.

(2) If you have to move the decimal point to the left, the power (index) of 10 is the number of moves with a positive sign.

(3) If you have to move the decimal point to the right, the power (index) of 10 is the number of moves with a negative sign.

Solution

(a) 57800000. To obtain: 5 .7 8 0 0 0 0 0
the decimal has been shifted to the left 7 positions.

= 5.78×10^7

(b) 0.00000001 To obtain: 0 0 0 0 0 0 0 0 1.
the decimal has been shifted to the right 8 positions.

= 1×10^{-8}

Self assessment

Convert the following numbers to scientific notation:

23400 9802.2 0.000283

Summary

* In general, scientific notation is written in the form: **N** x 10^x
  Where **N** = number between 1 and 10, while **x** = power (index) of10
* The reason for converting numbers into scientific notation is to make calculations with usually large or small numbers more concise
* The notation is based on powers (indices) of 10.
* For each shift of the decimal point one place to the left, the power (index) increases by 1.
* For each shift of the decimal point one place to the right, the power (index) decreases by 1.

Answers: 2.3400×10^4 ; 9.8022×10^3 ; 2.83×10^{-4}

Chemorganisers

Scientific Notation (Addition)

Problem

Express the following product in scientific notation: $(4.4 \times 10^2) + (3 \times 10^3)$

Before you start

- You cannot add numbers in scientific notation unless the power (index) of 10 is the same.
  - e.g. $(1.5 \times 10^2) + (2.4 \times 10^2) = (1.5 + 2.4) \times 10^2 = 3.9 \times 10^2$
  - but $(1.5 \times 10^3) + (2.4 \times 10^2)$ cannot be added until the powers (indices) of 10 are the same.
- In general $1^0 = 1$ and $10^0 = 1$
  $1^1 = 1$ and $10^1 = 10$
- To use your scientific calculator you need to find the **EXP** key, which is used to enter numbers in scientific notation.
  To enter the number 3.456×10^2, the key sequence is 3 . 4 5 6 EXP 2
  To enter the number 4.56×10^{-4}, the sequence will be 4 . 5 6 EXP +/- 4

Concepts

Scientific notation, power (index), decimal number, non-zero digit, add, subtract, divide, sign.

Strategy

The powers (indices) must be the same to add the above numbers. You must choose one power (index).

If you choose 10^2

(i) The power (index) in the second number decreases by 1 so you must shift the decimal point to the right one decimal place, therefore the number will be 30×10^2

(ii) Then add the numbers (4.4 + 30) and multiply them by the power (index) you choose (10^2)

But if you choose 10^3

(i) The power (index) in the first number increases by 1 so you must shift the decimal point to the left one decimal place, therefore the number will be 0.44×10^3

(ii) Then add the numbers (0.44 + 3) and multiply them by the power you choose (10^3)

Solution

For $(4.4 \times 10^2) + (3 \times 10^3)$.

If you choose power (index) **2,**

(i) (3×10^3) must be changed to (30×10^2).

Now the problem is:

(ii) $(4.4 \times 10^2) + (30 \times 10^2) = (4.4 + 30) \times 10^2 = 34.4 \times 10^2 = 3.44 \times 10^3$

But if you choose power (index) **3,**

(i) (4.4×10^2) must be changed to (0.44×10^3).

Now the problem is:

(ii) $(0.44 \times 10^3) + (3 \times 10^3) = (0.44 + 3) \times 10^3 = 3.44 \times 10^3$

Self assessment

Express the product in scientific notation:-

(a) $5 \times 10^6 - 2 \times 10^5 =$ (b) $3 \times 10^5 + 2 \times 10^4 =$

Summary

- To add or subtract, the power must be the same before the mathematical operation can be performed.
  Then add the numbers and multiply by the uniform power (index).
- For each shift of the decimal point one place to the left, the power (index) increases by 1.
- For each shift of the decimal point one place to the right, the power (index) decreases by 1.

Answers: (a) 4.8×10^6 (b) 3.2×10^5

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Chemorganisers

Scientific Notation (Multiply)

Problem

Express the product in scientific notation $(3 \times 10^5)(2 \times 10^3)$

Before you start

* $10^2 \times 10^3 = 100 \times 1000 = 100000 = 10^5$

The rule is: where multipling numbers expressed in powers (indices) of 10, just add the powers (indices).

e.g. $10^5 \times 10^7 = 10^{12}$

In general: $10^x \times 10^y = 10^{(x+y)}$

* Division means subtracting the powers (indices)

$10^x \div 10^y = 10^{(x-y)}$

Concepts

Scientific notation, power (index), decimal number, non-zero digit, add, subtract, divide.

Strategy

(1) Multiply the numbers

(2) Then add the powers (indices)

(3) The answer is the product from step1 multiply by the product from step 2

(4) If the number obtained does not lie between 1 and 10, adjust the power (index) of 10 to give correct scientific notation.

Solution

For $(3 \times 10^5)(2 \times 10^3)$

(1) Multiply the numbers: $3 \times 2 = 6$

(2) Then add the the powers (indices): $10^{(5+3)} = 10^8$

(3) The answer is: 6×10^8

Self assessment

Express the product in scientific notation:

(a) $(3 \times 10^2)(2 \times 10^0) =$

(b) $(9 \times 10^{-3}) \div (3 \times 10^3) =$

(c) $(3 \times 10^2)(2 \times 10^4) \div (2 \times 10^2) =$

Summary

* $10^0 = 1$
* $10^1 = 10$
* To multiply: $(N \times 10^x)(M \times 10^y) = (N \times M) \times 10^{(x+y)}$
* To divide: $(N \times 10^x) \div (M \times 10^y) = (N \div M) \times 10^{(x-y)}$

Answers: (a) 6×10^2 (b) 3×10^{-6} (c) 3×10^4

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Chemorganisers

Determination of Significant Figures

Problem

How many significant figures are there in the following

(a) 57800000 (b) 0.00000001

Before you start

* Measured quantities are generally reported in such a way that only the last digit is uncertain. All digits, including the uncertain one, are called: **significant figures**.

  For example: **14.586** ± 0.001 has **5** significant figures (numbers 1, 4, 5, and 8 are certain numbers while 6 is uncertain and could be 5 or 7).

* To determine the number of significant figures in a measured quantity, the following principles apply:

  ** A zero sandwiched between non zero digits is always counted as a significant figures. For example: 4205 has **4** significant figures.

  ** Zeros that set on the left are never counted as significant figures.
  For example: 0.0215 has **3** significant figures.

  ** Zeros that set on the right are counted as significant figures.
  For example: 4.20 has **3** significant figures.

  ** If a number ends in zeros but contains no decimal point, the zeros may or may not be significant. In this case it is better to use scientific notation.
  For example: 1200 may have 4, 3, or 2 significan figures.

  To avoid this, write the number in scientific notation as follows:

  1.2×10^3 (2 significant figures)

  1.20×10^3 (3 significant figures)

  1.200×10^3 (4 significant figures)

Concepts

Significant figures, non-zero digit, scientific notation, certain and uncertain numbers, decimal point.

Strategy

To solve any problem, apply the suitable rule from the above.

Solution

(a) **57800000** has **8** significant figures, but, if converted to scientific notation, the number will be **5.78** $\times 10^7$ then it has **3** significant figures

(b) 0.00000001 has 1 significant figure.

Self assessment

How many significant figures are in each of the following numbers:

(a) 0.1203 (b) 1300 (c) 1.02×10^4 (d) 23.456

Summary

* All digits, including the uncertain one, are called **significant figures**.
* To determine the number of significant figure in a measured quantity:
  Zeros sandwiched between non-zero digits are always counted as significant.
  Zeros that set on the left are never counted as significant figures.
  Zeros that set on the right are counted as significant figures.
* Use scientific notation if a number ends in zeros but contains no decimal point.

Answers: 4 4 3 5

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Rounding off

Problem

Round off 8.46610 to three significant figures.

Before you start

* Simply drop the digits that follow if the first of them is less than 5:
  For example, 9.8243 to **two** significant figures rounds off to **9.8**
* If the first digit to be dropped is greater than 5 or if it is 5 followed by non-zero digits, increase the preceding digit by 1.
  For example, 8.6271 to **three** significant figures rounds off to **8.63**
  6.2501 to **two** significant figures rounds off to **6.3**

Concepts

Significant figures, round off, digit, non-zero digit, greater than, less than, drop.

Strategy

You are given a number and asked to round it to the required number of significant figures

* Count from left to right → to the required significant figures (starting from the first non-zero digit)
* Look at its right digit then apply the suitable rule from the above.

Answers: yes, no, yes ; 7, 6.6 ; C,D,F&G ; F ; 1,5&1 ; A&H

Solution

8.46610 rounds to **three** significant figures to give **8.47**
(increase the preceding digit by 1 because the first digit to be dropped is greater than 5)

Self assessment

1 Which of the following is (are) correctly rounded off?
   (a) 53.25 to **two** significant figures equals 53
   (b) 4.652 to **two** significant figures equals 4.6
   (c) 0.80721 to **three** significant figures equals 0.807

2 Round off 6.650 to **one** and **two** significant figures.

3 Answer the questions below

A 0.001	**B** 11.200	**C** 3.001	**D** 5032
E 2.46	**F** 2.353	**G** 5.432×10^3	**H** 1×10^{-3}

(i) State which box (es) have 4 significant figures.................................
(ii) State which box (es) can be rounded off to 2.4 ....
(iii) The number of significant figures in box A is...., in B is...., and in H is......
(iv) State which boxes have the same values..

Summary

* Significant Figures are the number of digits known with complete certainty to be accurate plus one more.
* Drop the digits that follow if the first of them is **less than 5**.
* If the first digit to be dropped is **greater than 5** <u>**or**</u> **if it is 5 followed by non-zero digits, increase** the preceding digit by **1**.
* If the digit to be dropped is **5 or 5 followed by zeros, increase** the preceding digit by **1** if it is **odd** <u>and</u> to **leave** it unchanged if it is **even**.

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Chemorganisers

Rounding Off Calculated Numbers

Problem

(a) 5.374 + 1.0203 = ?   (b) 546.29 - 432.4567 = ?

Before you start

* In addition and subtraction the results are allowed **no** more decimal places than the number with **the fewest decimal places**

Concepts

Decimal places, significant figures, the fewest.

Strategy

You have addition and subtraction mathematical operations

The product will be the same number of decimal places as the number with the fewest decimal places

Solution

(a) 5.**374** + 1.0203 = 6.**394**   (5.**374** has the fewest decimal places **3)**

(b) 546.**29** - 432.4567 =113.**83**   (546.**29** has the fewest decimal places **2)**

Self assessment

Answer the questions below the following grid

A 0.0801	B 11.2 X 10^2	C 3.001	D 5432
E 24500	F 2.353	G 5.432 X 10^3	H 1 X 10^{-3}

(i) State which box(es) have 2 significant figures.................................

(ii) The scientific notation of box A is..

(iii) The number of significant figures in box A is...., in B is...., and in G is.....

(iv) The sum of box A + box C is...

Problem

(a) 0.7435 x 6.6 = ?   (b) 14.196 ÷ 7.18 = ?

Before you start

* In multiplication and division the results are allowed **no** more significant figures than the number with **the fewest significant figures**

Concepts

Decimal places, significant figures, the fewest

Strategy

You have a multiplication and division math operations

The product will be the same number of significant figures as the number with the fewest significant figures

Solution

(a) 0.7435 x **6.6** = **4.9**   (**6.6** has the fewest significant figures **2)**

(b) 14.196 ÷ **7.18** = **1.98**   (**7.18** has the fewest significant figures **3)**

Self assessment

Answer the questions below the following grid

A 0.0801	B 27.16 X 10^2	C 3.001	D 5032
E 24500	F 2.353	G 5.432 X 10^3	H 1.00 X 10^{-3}

(i) The scientific notation of box D is..

(ii) Box F can be rounded off to 2 significant figures to give ....

(iii) (Box **G**) x (box **H**) =.........................

Answers: none ; 8.01 x 10^{-2} ; 3, 3 & 4 ; 3.081 /// 5.032 x 10^3 ; 2.4 ; 5.43

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Common Logarithms

In your chemistry course you will deal with a variety of problems based on logarithms such as pH calculations.

Problem

Using your calculator determine the

(a) log 2150 (b) Antilog 2.4

Before you start

* As with scientific notation (exponential number), this is a way of working with very large and very small numbers.
* Log_{10} is the abbreviation for the term common logarithm (the 10 usually is omitted)
* The log value is the value of the power (index) of 10 to obtain your number.

  For example, log 100 = $\log 10^2$ = **2**

  log 10000 = $\log 10^4$ = **4**

  log 800 = $\log 10^{2.903}$ = **2.903**
* A positive log represents a number greater than one.

  For example, log (2345) = **3.3701**
* A negative log represents a number smaller than one.

  For example, log (0.005) = **- 2.301**
* Remember, you **can't** take the log of a **negative** value.

  For example, log (-160) = error
* Antilogs is the opposite of the logs. Sometimes you need to know what the original value was.

Concepts

Common logarithm, log, antilog.

Strategy

To determine the log

In your scientific calculator you will find a **log** key,

(1) Input the number 2150 by typing in the numbers on the keyboard
(2) Depress the **log** key
(3) Read the display
(Your calculator may be operate differently - check your manual)

To determine the antilog

In your scientific calculator you will find a $\mathbf{10^x}$ key,

(1) Input the number 2.4 by typing in the numbers on the keyboard
(2) Depress the **INV** or **SHIFT** key then depress the $\mathbf{10^x}$ key
(3) Read the display

Solution

(a) log 2150 = **3.3324**
(b) Antilog 2.4 = **251.19**

Self assessment

Answer with true or false?

(a) log (1.2×10^4) = 4.0792 (b) log 0.00823 = 2.0846
(c) antilog (- 0.5) = error (d) antilog 18.21 = 1.6218

Summary

* Log_{10} is the abbreviation for the term common logarithm (the 10 usually omitted)
* Antilogs is the opposite of the logs.

Answer: true false false false

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Chemorganisers

Common Logarithm Applications I

Problem

(a) log 120 + log 245 = ?   (b) log 4200 - log 1000 = ?

Before you start

* You can calculate with logs in the following manner

* To add logs **(log x) + (log y) = log (xy)**

For example, log 20 + log 50 = 1.3010 + 1.6990 = **3**
log (20 x 50) = log 1000 = **3**

* To subtract logs **(log x) - (log y) = log (x ÷ y)**

For example, log 750 - log 150 = 2.8751 - 2.1761 = **0.6990**
log (750 ÷ 150) = log 5 = **0.6990**

Concepts

Log, add, subtract, multiply, divide, scientific notation.

Strategy

(a) For adding logs **(log x) + (log y) = log (xy)**
just multiply the numbers and take the log for the product

or take log for each number then add the products

(b) For subtracting logs **(log x) - (log y) = log (x ÷ y)**
just divide the numbers and take the log for the product

or take log for each number then subtract the products

Solution

(a) log 120 + log 245 = ?
according to **(log x) + (log y) = log (xy)**
you can solve this problem by
log 120 + log 245 =
2.0792 + 2.3892 = **4.4684**
or, log (120 x 245) =
log (29400) = **4.4684** the same as the above.

(b) log 4200 - log 1000 = ?
according to **(log x) - (log y) = log (x ÷ y)**
you can solve this problem by
log 4200 + log 1000 =
3.6232 + 3 = **0.6232**
or, log (4200 ÷ 1000) =
log (4.2) = **0.6232** the same as the above

Self assessment

(a) (log 7.00 x 10^3) + (log 4.5 x 10^3) =
(b) log {(4.5 x 10^3) - (2.0 x 10^3)} + log (2.5 x 10^3) =
(c) 7.00 + log 3.50 =
(d) {(2.35 - log 2.00 x 10^3)} + (log 1.50 x 10^3) =

Summary

* Logarithms(logs) is a way of working with very large and very small numbers.
* To add logs log x + log y = log xy.
* To subtract logs log x - log y = log (x ÷ y).

Answer: (a) 7.5 (b) 6.8 (c) 7.54 (d) 2.23

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Common Logarithm Applications II

Problem

(a) log (33 x 45) = ?   (b) log (6028 ÷ 16) = ?

Before you start

* You can calculate with logs in the following manner
* **To multiply** log xy = log x + log y

For example,

log (10 x 100)	=	
log 1000	=	**3**
log 10 + log 100	=	
1 + 2	=	**3**

* **To divide** log (x ÷ y) = log x - log y

For example,

log (100 ÷ 10)	=	
log 10	=	**1**
log 100 - log 10	=	
2 - 1	=	**1**

Concepts

Log, add, subtract, multiply, divide, scientific notation.

Strategy

For multiplying logs **log xy = log x + log y**

* You have two options either to
  multiply the numbers and take the log for the product **log xy**

or, add the values of their logs **log x + log y**

For dividing logs **log (x ÷ y) = log x - log y**

* You have two options either to
  divide the numbers and take the log for the product **log (x ÷ y)**

or, subtract the values of their logs **log x - log y**

Solution

(a) log 33 x log 45 = ?
according to **(log xy = log x + log y)** you can solve this problem by
log 33 x log 45 = log 1485 = **3.1717**

or, log 33 = 1.5185
log 45 = 1.6532
log 33 + log 45 = 1.5185 + 1.6532 = **3.1717** the same as the above

(b) log 6028 ÷ log 16 = ?
according to **(log (x ÷ y) = log x - log y)** you can solve this problem by
log 6028 ÷ log 16 = log (6028 ÷ 16) = log 376.75 = **2.5761**

or, log 6028 = 3.7802
log 16 = 1.2041
log 33 - log 45 = 3.7802 - 1.2041 = **2.5761** the same as the above

Self assessment

(a) log (7.00 x 4.5) =
(b) 2.35 log $(2.0 \times 10^3 \div 1.6 \times 10^3)$ =
(c) 7.00 ÷ log 3. 50 =
(d) log $\{(4.50 \times 10^3)(2.00 \times 10^3) \div (3.00 \times 10^3)\}$ =

Summary

* Logarithms (logs) is a way of working with very large and very small numbers.
* To multiply log xy = (log x) + (log y)
* To divide log (x ÷ y) = (log x) - (log y)

Answer: (a) 1.50 (b) 0.23 (c) 12.9 (d) 3.477

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Chemorganisers

Natural Logarithms [ln]

In your chemistry course you will deal with a variety of problems based on natural logarithm (ln). You have used logs to the base 10 for calculations - especially in pH calculations. Natural logarithms use a strange number as the base [e = 2.71828] and this turns out to be a very important system of logaritms that occurs widely in calculations in the physical world around us.

Problem

Using your calculator determine the

(a) ln 2150 (b) Natural antilog 2.4

Before you start

* Logarithms based on the number **e** are called **natural logarithms** (ln)

* The natural logarithm of a **number** is the power (index) to which **e** (which has the value 2.71828) must be raised to equal the **number**.

 For example, ln 10 = **2.303** $e^{\mathbf{2.303}} = 2.71828^{\mathbf{2.303}} = 10$

* The relationship between ln and log is ln x = **2.303** log x

 For example, ln 10 = **2.303** log 10 = 2.303 x 1 = **2.303**

* The natural antilog of a number is **e** raised to a power (index) equal to that number.

 For example, natural antilog **2.303** = $e^{\mathbf{2.303}} = 2.71828^{\mathbf{2.303}} = 10$

Concepts

Natural logarithm, ln, natural antilog, e, power (index), log.

Strategy

To determine the ln

In your scientific calculator you will find a **ln** key,

(1) Input the number 2150 by typing in the numbers on the keyboard

(2) Depress the **ln** key

(3) Read the display

(Your calculator may be operate differently - check your manual)

To determine the antilog

In your scientific calculator you will find an $\mathbf{e^x}$ key.

(1) Input the number 2.4 by typing in the numbers on the keyboard

(2) Depress the **INV** or **SHIFT** key then depress the $\mathbf{e^x}$ key

(3) Read the display

(Your calculator may be operate differently - check your manual)

Solution

(a) ln 2150 = **7.6732**

(b) Natural antilog 2.4 = **11.0232**

Self assessment

Answer with true or false?

(a) natural antilog 12.3 = 2.5257 (b) ln 3.2×10^2 = 5.768

(c) natural antilog (-1.5) = 0.22 (d) ln 0.823 = 1.95×10^{-1}

Summary

* Logarithm based on the number **e** is called **natural logarithm** (ln)
 ln z = **x** $e^{\mathbf{x}} = 2.71828^{\mathbf{x}} = z$
* The natural antilog of a number is **e** raised to a power (index) equals to that number.
* Natural antilog **x** = $e^{\mathbf{x}} = 2.71828^{\mathbf{x}} = z$

Answer: false true true false

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Chemorganisers

% Purity Calculations from Simple Titration

Problem

0.500 g of impure sodium carbonate was dissolve in water and the solution titrated with 0.150 M hydrochloric acid. 15 mL were required to reach the end point. Calculate the % purity of the sodium carbonate?

Before you start

- % purity = mass of pure sample x $\frac{100\,\%}{\text{mass of impure sample}}$
- **M** means the molarity of the solution x $\frac{\text{mol standard}}{\text{L standard solution}}$
- Balanced equation(s) for the reaction(s) involved must be written

Concepts

Standard, unit cancellation, molarity, balanced equation, equivalence factors, % purity

Strategy

- Identify the standard and the unknown.
- Write balanced equation(s) for the reaction(s) involved
- Determine the relevant chemical equivalencies.
- Plan the calculation sequence
  volume of standard **to** moles of standard **to** moles of unknown **to** grams of unknown **to** % purity of unknown
- Set up equivalence factors
- Insert figures for each factor and complete the calculation.

Solution

Standard is HCl , unknown is Na_2CO_3

$2\,HCl + Na_2CO_3 = 2\,NaCl + H_2O + CO_2$

From the equation: 2 mole HCl equivalence to 1 mole Na_2CO_3

L HCl solution **to** mol HCl **to** mol Na_2CO_3 **to** g Na_2CO_3 **to** % purity of Na_2CO_3

$$\frac{\text{L HCl soln.}}{1000} \times \frac{\text{mol HCl}}{\text{L HCl soln.}} \times \frac{\text{mol } Na_2CO_3}{\text{mol HCl}} \times \frac{\text{g } Na_2CO_3}{\text{mol } Na_2CO_3} \times \frac{100\,\%}{\text{mass of impure sample}} = \%\ Na_2CO_3$$

$$\frac{\text{15 L HCl soln.}}{1000} \times \frac{\text{0.150 mol HCl}}{\text{1 L HCl soln.}} \times \frac{\text{1 mol } Na_2CO_3}{\text{2 mol HCl}} \times \frac{\text{106 g } Na_2CO_3}{\text{1 mol } Na_2CO_3} \times \frac{100\,\%}{\text{0.5 g of impure sample}}$$

= 23.9 % pure Na_2CO_3

Discussion

STANDARD — CHEMICAL EQUIVALENCE — UNKNOWN

$$\frac{\text{15 L HCl soln.}}{1000} \times \frac{\text{0.150 mol HCl}}{\text{1 L HCl soln.}} \times \frac{\text{1 mol } Na_2CO_3}{\text{2 mol HCl}} \times \frac{\text{106 g } Na_2CO_3}{\text{1 mol } Na_2CO_3} \times \frac{100\,\%}{\text{0.5 g of impure sample}} = 23.9\ \%\ \text{pure}$$

- mL HCl soln. to L HCl soln
- molarity of HCl
- from balanced equation
- Molecular weight
- % pure

Self assessment

(a) A sample of 0.760 g of an impure sample of $BaCl_2$ is dissolved in water and treated with an excess of Na_2SO_4. If the mass of $BaSO_4$ precipitate formed is 0.4105 g, what is the percent by mass of $BaCl_2$ in the original impure sample?

(b) 1.20 g of silver alloy were dissolved in nitric acid and excess sodium chloride solution is added to form o,950 g silver chloride. What is the mass of silver in this sample of alloy, and what is the percent by mass of silver in the alloy?

$Ag + HNO_3 \longrightarrow AgNO_3 + NO_2 + H_2O$

$AgNO_3 + NaCl \longrightarrow AgCl + NaNO_3$

Answers: (a) 48.2 % (b) 0.715 g, 59.6 %

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Writing Chemical Equations

It is of most importance to be able to write correctly chemical equations.

Problem

Write equations for the following reactions:

(a) Hydrogen chloride and calcium hydroxide

(b) Lithium oxide and water

Before you start

* A chemical equation is a way to describe what goes on in a chemical reaction. For example, the reaction between hydrogen and oxygen to form water is represented by the following equation:

$2\ H_2$	+	O_2	→	$2\ H_2O$
Reactant		Reactant		Product

* Chemical equations are written with the symbols of materials to include elements, ionic or covalent compounds, aqueous solutions, ions, or particles.

* There is an arrow pointing to the right that indicates the direction of the reaction.

* The materials to the left of the arrow are the reactants, or materials that are going to react. The materials to the right of the arrow are the products, or materials that have been produced by the reaction.

* It is useful to indicate whether the reactants or products are solids(s), liquids (l), gases (g), or dissolved materials in water (aq).

Concepts

Chemical reaction, equation, reactant, product, element, compound, ion, solid, liquid, gas, aqueous, arrow.

Strategy

In order to write a chemical equation:

(a) Write the formulae for the reactants and the products.

(b) The formulae must be written on the proper side of the arrow (reactants on the left and products on the right).

(c) Balance the chemical equation, don't change the formulae.

Solution

(a) The reactants formulae are: HCl for hydrogen chloride and $Ca(OH)_2$ for calcium hydroxide.

The equation is: $HCl + Ca(OH)_2 \rightarrow CaCl_2 + H_2O$

The balanced equation is: $2\ HCl + Ca(OH)_2 \rightarrow CaCl_2 + 2\ H_2O$

(b) The reactants formulae are: Li_2O for lithium oxide and H_2O for water.

The equation is: $Li_2O + H_2O \rightarrow LiOH$

The balanced equation is: $Li_2O + H_2O \rightarrow 2\ LiOH$

Self assessment

Write equations for the following reactions:

(a) Sodium chloride and silver nitrate

(b) Hydrochloric acid and ammonia

(c) Sulphuric acid and magnesium hydroxide

(d) Copper sulphate and zinc

Answer: (a) $NaCl + AgNO_3 = NaNO_3 + AgCl$ (b) $HCl + NH_3 = NH_4Cl$

(c) $H_2SO_4 + Mg(OH)_2 = MgSO_4 + 2\ H_2O$ (d) $CuSO_4 + Zn = Cu + ZnSO_4$

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Chemorganisers

Inorganic Compounds (Names and Formulae)

Problem

Write the formulae for each of the following compounds:

(a) Magnesium chloride (b) Aluminium sulphate (c) Titanium (IV) oxide

Before you start

To write correctly the formulae for compounds you need to know:

(1) Names, and symbols of the elements.
(2) Valencies of the elements.
(3) Names, formulae and valencies of groups (see reverse of this sheet).
(4) List of prefixes in common use.

Concepts

Formula, symbol, group, element, metal, compound, prefix, molecules.

Basic Rules

(1) If the compound has two elements only, the name is made up by taking the first element, followed the second element with its ending changed to **-IDE**.

eg.	sodium chloride	NaCl	
	iron (II) sulphide	FeS	[Note that iron has a valency of 2)

(2) If the compound has three or more elements present in it, almost always one of them is oxygen and this does not appear in the name for the compound. The compound is named using the other two elements (metal first), with the ending changed to **-ITE** or **-ATE**. (-ATE indicates more oxygen present than -ITE.)

eg	sodium sulphite	Na_2SO_3
	sodium sulphate	Na_2SO_4
	calcium nitrate	$Ca(NO_3)_2$
	potassium phosphate	K_3PO_4

Extra Rules

(a) An important exception: compounds containing hydrogen, oxygen and a metal are known as hydrox<u>ides</u> (NOT hydroxates): eg potassium hydroxide: KOH

(b) Two other important groups:

Ammonium is NH_4 (valency 1): e.g. ammonium chloride is NH_4Cl
Cyanide is CN (valency 1): e.g. sodium cyanide is NaCN

(c) Prefixes are sometimes used to avoid confusion (see reverse of this sheet).

e.g. SO_2 is sulphur dioxide [common name for sulphur (IV) oxide].

(d) Sometimes, the amount of oxygen in a series of compounds can vary and, in addition to **-ATE** and **-ITE**, we also use prefixes like **HYPO-** and **PER-** .

e.g.	sodium **hypo**chlor**ite**	NaClO [usually written: NaOCl]
	sodium chlor**ite**	$NaClO_2$
	sodium chlor**ate**	$NaClO_3$
	sodium **per**chlor**ate**	$NaClO_4$

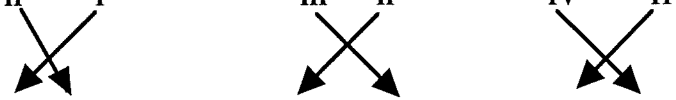
Solutions

(a) Write symbols with valencies written above in Roman numerals:

II I Mg Cl	III II Al SO_4	IV II Ti O

(b) Cross the valencies over:

II I	III II	IV II



Mg_1 Cl_2	Al_2 $(SO_4)_3$	Ti_2 O_4

(c) Re-write the formula:

$MgCl_2$	$Al_2(SO_4)_3$	TiO_2
[with "one" omitted]	[brackets as shown]	[divide by 2, omit 1]

Reverse of This Sheet

For tables of data and self-assessment.

Basic Data

(1) Every element has one or more than one valency number:

eg Na is always valency 1

Fe can be valency 2 or 3: can be shown as Fe(**II**) or Fe (**III**)

(2) Certain groups of atoms always seem to occur together and can be given a group valency. These groups only exist when linked together atoms and, most frequently, they exist as ions.

Here are the ten most common groups - you should memorise these:

Valency I		Valency II		Valency III	
Hydroxide	OH	Sulphate	SO_4	Phosphate	PO_4
Ammonium	NH_4	Sulphite	SO_3		
Nitrate	NO_3	Carbonate	CO_3		
Nitrite	NO_2				
Permanganate	MnO_4				
Acetate [ethanoate]	CH_3COO				

Some Common Acids

Hydrochloric acid	HCl	Carbonic acid	H_2CO_3
Nitric acid	HNO_3	Nitrous acid	HNO_2
Sulphuric acid	H_2SO_4	Sulphurous acid	H_2SO_3
Phosphoric acid	H_3PO_4		
Acetic acid	CH_3COOH	Oxalic acid	$(COOH)_2$

You should memorise these formulae

List of prefixes

Number of atoms	1	2	3	4	5	6	7	8	9	10
Prefix	mono	di	tri	tetra	penta	hexa	hepta	octa	nona	deca

Other Group Formulae

Here are some less frequently used group formulae

Valency I		Valency II		Valency III	
Cyanide	CN	Chromate	CrO_4	Arsenate	AsO_4
Perchlorate	ClO_4	Dichromate	Cr_2O_7		
Chlorate	ClO_3	Hydrogenphosphate	HPO_4		
Chlorite	ClO_2	Silicate	SiO_3		
Borate	BO_3	Selenate	SeO_4		
Hydrogen sulphite	HSO_3	Thiosulphate	S_2O_3		
Hydrogen carbonate	HCO_3				
Dihydrogenphosphate	H_2PO_4				

Self assessment

(1) Write the formulae for each of the following compounds:

(a) Potassium Bromide (b) Aluminium Oxide
(c) Sodium Nitrate (d) Magnesium Chloride
(e) Calcium Carbonate (f) Barium Oxide
(g) Aluminium Hydroxide (h) Sodium cyanide
(i) Copper (II) Phosphate (j) Cobalt (III) chloride
(k) Nitrogen dioxide (l) Barium hydrogen sulphite
(m) Cobalt (II) Oxide (n) Ammonium Sulphate

(2) Give the names for the following formulae:

(a) NaOH (b) ZnO
(c) As_2O_5 (d) $Ni(NO_3)_2$
(e) K_3PO_4 (f) $NaHSO_3$
(g) $Na_2S_2O_3$ (h) $(NH_4)_2HPO_4$

Answers: **(1)** (a) KBr (b) Al_2O_3 (c) $NaNO_3$ (d) $MgCl_2$ (e) $CaCO_3$ (f) BaO (g) $Al(OH)_3$
(h) NaCN (i) $Cu_3(PO_4)_2$ (j) $CoCl_3$ (k) NO_2 (l) $Ba(HSO_3)_2$ (m) CoO (n) $(NH_4)_2SO_4$
(2) (a) Sodium Hydroxide (b) Zinc Oxide (c) Arsenic Oxide (d) Nickel Nitrate
(e) Potassium Phosphate (f) Sodium Hydrogensulphite (g) Sodium Thiosulphate
(h) Ammonium Hydrogenphosphate

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Nomenclature of Inorganic Compounds

Problem

What is the name of the following:

(a) KBr (b) $FeSO_4$ (c) N_2O_4

Before you start

* Ionic compound consists of two parts

(1) The element that appears first in the formula .

(Which may have more than one oxidation state)

For example, **Na** has only one oxidation state, while **Fe** has two oxidation states

(2) The second part usually the anion, for binary ionic compounds end with **ide**

for ternary compounds end with **ate** or **ite**

Concepts

Ionic compound, molecular compound, element, metal, non-metal, symbol, binary ionic compound, ternary ionic compound, anion.

Strategy

Nomenclature of ionic compounds

(1) Identify the name of the first symbol.

(2) Determine the oxidation state for the atom. (It may have more than one state)

(3) Identify the name of the second symbol, drop the last letters and add **ide** for binary ionic compounds and **ate** or **ite** for ternary ionic compounds.

(4) Place the two names together.

Nomenclature of covalent compounds

(1) Identify the name of the first symbol.

(2) Identify the name of the second symbol, drop the last letters and add **ide**.

(3) Place the two names together.

(4) Use the following prefixes before each name:

Number of atoms	1	2	3	4	5	6	7	8	9	10
Prefix	mono	di	tri	tetra	penta	hexa	hepta	octa	nona	deca

Solution

(a) KBr

K is **Potassium**. (Oxidation state for all Group I elements are + 1)

Br is Bromine but change to **bromide**. (Binary ionic compounds)

The name is **Potassium Bromide**

(b) $FeSO_4$

Fe is **Iron**. (which may have more than one oxidation state)

SO_4 is the **Sulphate.**

Determination of the oxidation state for the Fe atom:

Let x = oxidation state of Fe atom (oxidation state for SO_4 = - 2)

1 (x) + 1 (- 2) = 0, therefore x = + 2 so Fe is in the + **2** state

so the name is: **Iron (II) Sulphate**

(c) N_2O_4

N is **Nitrogen** and you have 2 atoms therefore use **di**

O is Oxygen (change to **oxide)** and you have 4 atoms therefore use **tetra**

The name is **Dinitrogen Tetroxide.**

Self assessment

What are the names of the following:

(a) Na_2SO_4 (b) $Cu_3(PO_4)_2$

(c) CO_2 (d) Al_2O_3

(e) $BaCrO_4$ (f) CCl_4

Answers: Sodium Sulphate; Copper [II] Phosphate; Carbon Dioxide; Aluminium Oxide; Barium Chromate, Carbon Tetrachloride.

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Identifying a Compound As Ionic or Covalent (molecular)

Problem

Identify whether the following **compounds** are **ionic** or **covalent** (molecular):

(a) NaBr (b) N_2O_5

Before you start

* In naming compounds you have to decide whether you are looking at an **ionic** or a **covalent compound** (molecular compound).
* In general, **metals** combined to **non-metals** produce compounds that are **ionic**
  For example, Na_2SO_4 is an ionic compound because it has sodium which is a metal combined with the sulphate ion which is composed of non-metals.
* Combined **non-metals** produce compounds that are **covalent** (molecular).
  For example, SO_2 is a covalent compound because sulphur and oxygen are both non-metals.
* These "rules" do not necessarily apply to compounds in solution.

Concepts

Ionic compound, covalent compound (molecular), metal, non-metal, valency.

Strategy

Look at your compound

(a) If it composed of metal and non-metal, it is probably an ionic compound.

(b) If it composed of non-metals, it is a covalent compound (molecular).

Solution

(a) NaBr is an **ionic compound.**
Because it has sodium which is a **metal** combined with the bromide ion **non-metal.**

(b) N_2O_5 is a **covalent compound** (molecular compound).
Because nitrogen and oxygen are both **non-metals**.

Self assessment

Identify whether the following compounds are ionic or covalent (molecular):

(a) Na_2SO_4 (b) $Cu_3(PO_4)_2$
(c) CO_2 (d) Fe_2O_3
(e) $BaCrO_4$ (f) CCl_4
(g) $KMnO_4$ (h) H_2S
(i) H_2O_2 (j) $CaCO_3$

Summary

* Metals with valencies 1 & 2 form ionic compounds with non-metals.
* Metals with valency 3 are most frequently form ionic compounds with non-metals.
* Metals with valency 4 form covalent compounds (molecular compounds) with non-metals.
* Non-metals combined to non-metals produce covalent compounds (molecular).

Answers: ionic, ionic, covalent, ionic, ionic, covalent, ionic, covalent, covalent, ionic.

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Chemorganisers

Oxidation States (Numbers)

It is often useful to follow chemical reactions by looking at changes in the oxidation numbers of the atoms in each compound during the reaction. Oxidation numbers also play an important role in the systematic nomenclature of chemical compounds.

Problem

Determine the oxidation state of the underlined atoms in the following:

(a) <u>S</u>$_8$ (b) (<u>As</u>O_3)$^{-3}$ (c) K<u>Mn</u>O_4 (d) K_2<u>Cr</u>$_2O_7$

Before you start

- Oxidation numbers of an atom is the charge that atom would have if the compound was composed of ions.
- Valency is oxidation number with no sign.
- There are some guidelines in assigning oxidation states (numbers) to atoms in a compound or ionic species.

	Oxidation state	Examples	Exceptions
Group **IA** (Li, Na, K...)	+ 1	**Li**Cl, **Na**F	....
IIA (Be,Ca, Mg)	+ 2	**Be**Cl_2, **Ca**SO_4	....
IIIA (Al, B)	+ 3	**Al**Cl_3, **B**F_3	....
Oxygen	- 2	Na_2**O**, H_2**O**	peroxides H_2O_2
Hydrogen	+1	**H**$_2$S, **H**Cl	hydride Na**H**
All elements	zero per atom	Na has **0** (zero)	....
Mono-atomic ion	charge on the ion	Ca^{2+} = **+ 2**	....

The **sum** of the oxidation numbers in a <u>neutral compound</u> is <u>zero</u>.

e.g. H_2O: 2(+ 1) + (- 2) = **0**

The **sum** of the oxidation numbers in a <u>polyatomic ion</u> is equal to its <u>charge</u>.

e.g. $(SO_4)^{2-}$ (+ 6) + 4 (- 2) = **- 2**

Concepts

Oxidation state, group, mono-atomic ion, polyatomic ion, charge, valency, sum.

Strategy

(1) Look at each element find the appropriate rule
(2) Let x = the oxidation state of the unknown atom
(3) For a neutral compound the sum is of the oxidation states is equal to zero
(4) For a polyatomic ion the sum of the oxidation states is equal to the charge on the ion

Solution

a For S in S_8 the answer is 0.

b For As in (<u>As</u> O_3) $^{3-}$

(x) + 3(- 2) = - 3
x + (- 6) = - 3
x = + 3 the oxidation state of Arsenic (As) atom

c For Mn in K <u>Mn</u> O_4

1(+ 1) + 1(x) + 4(- 2) = 0
1 + x + (- 8) = 0
x = + 7 the oxidation state of Manganese (Mn) atom

d For Cr in Na_2 <u>Cr</u>$_2$ O_7

2(+ 1) + 2 (x) + 7 (- 2) = 0
2 + 2 x + (- 14) = 0
x = + 6 the oxidation state of Chromium(Cr) atom

Self assessment

Determine the oxidation state of the underlined atoms in the following:

(a) <u>**N**</u>$_2$O (b) H_2<u>**S**</u>O_4 (c) K<u>**Cl**</u>O_3 (d) <u>**S**</u>O_2
(e) Cu_3<u>**P**</u>$_2$ (f) Cu_3(<u>P</u>O_4)$_2$ (g) Ba<u>**Cr**</u>O_4 (h) <u>**Al**</u>$_2O_3$

Summary

- All Group I elements are + 1
- All Group II elements are + 2
- All Group VII (Halogens) elements are - 1 when ionic
- All compounds have a sum oxidation state of zero
- All elemental substances are zero

Answers: +1; +6; +5; +4; -3; +5; +6; +3.

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Chemorganisers

Balancing Chemical Equations

Chemical equations do not come already balanced. This must be done before the equation can be used in a chemically meaningful way (essential skill).

Problem

Copper nitrate reacts with sodium sulphide to give copper sulphide and sodium nitrate. Write a balanced equation for the reaction?

Before you start

* A balanced equation has equal numbers of each type of atom on each side of the equation.
* You will use two different numbers in the equation one before the formula and the other in the formula.
* In most equations one or more of the formulas is multiplied by some whole number in order to show the correct balance.

For example, the formation of ammonia NH_3 from nitrogen and hydrogen has the following equation

N_2 + $3\,H_2$ ⟶ $2\,NH_3$

2 atoms N   3x 2 atoms H   2 x 1 atoms N + 2 x 3 atoms H

2 atoms N + 6 atoms H   2 atoms N + 6 atoms H

Therefore, the equation is balanced.

* Once you use the right chemical formula in the equation you are not allowed to change any number after any symbol in the formula.

For example, changing O_2 to O_3 makes a change from the formula of oxygen to the formula of ozone, an entirely different substance.

* Any number in front of the formula makes it a multiplier for atoms in that formula.

For example, $2\,NH_3$ means 2 N + (2 x 3) H

Concepts

Balanced chemical equation, mass, atom, formula, reactant, product.

Strategy

(1) Set down all the correct formulas for reactants and products in the format of an equation (never change the formulas)

(2) Start for the most complicated compound **AND** treat groups as a unit.

(3) Start from left side of the equation and balance by inspection all **elements** on the reaction (remember leave O and H to the end)

Solution

(1) Set down all the correct formulas for reactants and products in the format of an equation (never change the formulas)

copper nitrate + sodium sulphide   copper sulphide + sodium nitrate

$Cu(NO_3)_2$ + Na_2S ⟶ CuS + $NaNO_3$

(2) Start for $Cu(NO_3)_2$ the most complicated compound and treat (NO_3) group as a unit. You have **2** (NO_3) groups in $Cu(NO_3)_2$ and only **1**(NO_3) group in $NaNO_3$. So multiply $NaNO_3$ by **2.**

$Cu(NO_3)_2$ + Na_2S ⟶ CuS + **2** $NaNO_3$

(3) If you look at the equation now, you will find that you have **1** Cu atom, **2** N atoms, **6** O atoms, **2** Na atoms, and **1** S atom in each side of the equation, therefore, the balanced equation is

$Cu(NO_3)_2$ + Na_2S ⟶ CuS + **2** $NaNO_3$

Self assessment

Balance the following reactions

(a) $Mg + P_4$ ⟶ Mg_3P_2

(b) $AgNO_3 + CaCl_2$ ⟶ $AgCl + Ca(NO_3)_2$

(c) $KOH + H_2SO_4$ ⟶ $H_2O + K_2SO_4$

(d) $Cu(NO_3)_2$ ⟶ $CuO + NO_2 + O_2$

Answers: **(a)** $3Mg + P_4 = 2\,Mg_3P_2$ **(b)** $2\,AgNO_3 + CaCl_2 = 2\,AgCl + Ca(NO_3)_2$
(c) $2\,KOH + H_2SO_4 = H_2O + K_2SO_4$ **(d)** $Cu(NO_3)_2 = CuO + 2\,NO_2 + (1/2)\,O_2$ **OR**
multiply each unit of the equation by **2** to get $2\,Cu(NO_3)_2 = 2\,CuO + 4\,NO_2 + O_2$

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Chemorganisers

Balancing Redox Equations (Method 1)

Chemical equations do not come already balanced. This must be done before the equation can be used in a chemically meaningful way

Problem

Balance the redox equation for the reaction between copper metal and nitric acid, HNO_3, to give Cu^{2+} and NO.

Before you start

- A balanced equation has equal numbers of each type of atom on each side of the equation.
- Oxidation- reduction reactions involved the transfer of electrons from one atom to another. (You can't have one without the other)

  Oxidation is electron loss (oxidation state of an atom becomes larger)

  Reduction is electron gain (oxidation state of an atom becomes smaller)

Concepts

Balanced equation, reduction, oxidation, redox, electron, atom, loss or gain electrons, half reaction.

Strategy

(1) Write the half equations:

(a) For the oxidation, electron loss (oxidation state of an atom becomes larger)

e.g. $Cu \longrightarrow Cu^{2+}$ oxidation state of Cu atom increased from 0 to 2+

(b) For the reduction, electron gain (oxidation state of an atom becomes smaller)

e.g. $NO_3^- \longrightarrow NO$ oxidation state of N atom decreased from 5+ to 2+

(2) Balance by inspection all elements (except O and H) on each half of the reaction

(3) Balance the oxygens by using H_2O.

(4) Balance the hydrogens by using H^+.

(5) Balance the charges by using electrons, e.

(6) Balance the number of electrons gained and lost by multiplying each species by the same factor to effect a balance.

(7) Add both half reactions together.

(8) In basic medium, for each H^+ add OH^- to both sides of the equation.

Solution

(1) Write the half equations

$Cu \longrightarrow Cu^{2+}$

$NO_3^- \longrightarrow NO$

(2) Balance by inspection all elements on each half of the reaction

$Cu \longrightarrow Cu^{2+}$

$NO_3^- \longrightarrow NO$

(3) Balance the oxygens by using H_2O.

$Cu \longrightarrow Cu^{2+}$

$NO_3^- \longrightarrow NO + 2\,H_2O$

(4) Balance the hydrogens by using H^+.

$Cu \longrightarrow Cu^{2+}$

$NO_3^- + 4\,H^+ \longrightarrow NO + 2\,H_2O$

(5) Balance the charges by using electrons, e.

$Cu \longrightarrow Cu^{2+} + 2\,e^-$

$NO_3^- + 4\,H^+ + 3\,e^- \longrightarrow NO + 2\,H_2O$

(6) Balance the number of electrons gained and lost by multiplying each species by the same factor to effect a balance (the first multiply by 3 and the second by 2 to end by 6 electrons on each half)

$3\,Cu \longrightarrow 3\,Cu^{2+} + 6\,e^-$

$2\,NO_3^- + 8\,H^+ + 6\,e^- \longrightarrow 2\,NO + 4\,H_2O$

(7) Add both half reactions together.

$3\,Cu + 2\,NO_3^- + 8\,H^+ \longrightarrow 3\,Cu^{2+} + 2\,NO + 4\,H_2O$

Self assessment

Write balanced equations for the following redox reactions:

(a) The reaction of permanganate ion (MnO_4^-) with bromide ion (Br^-) in acidic solution to form Mn^{2+} ion and bromine (Br_2).

(b) The oxidation of Cr^{3+} ions by hydrogen peroxide (H_2O_2) in alkaline solution to give chromate ions (CrO_4^{2-}). In this reaction the hydrogen peroxide is converted to water.

Note:

Try method 2 and choose the method that suite you.

Answers: (a) $2\,MnO_4^- + 10\,Br^- + 16\,H^+ \quad 2Mn^{2+} + 8\,H_2O + 5\,Br_2$

(b) $2\,Cr^{3+} + 3H_2O_2 + 10\,OH^- \quad 2\,CrO_4^{2-} + 8\,H_2O$

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Balancing Redox Equations (Method 2)

Chemical equations do not come already balanced. This must be done before the equation can be used in a chemically meaningful way.

Problem

Balance the redox equation for the reaction between copper metal and nitric acid, HNO_3, to give Cu^{2+} and NO.

Before you start

- A balanced equation has equal numbers of each type of atom on each side.
- Oxidation-reduction reactions involved the transfer of electrons from one atom to another (you can't have one without the other)

  Oxidation is electron loss (oxidation state of an atom becomes larger)

  Reduction is electron gain (oxidation state of an atom becomes smaller)

Concepts

Balanced equation, reduction, oxidation, redox, electron, atom, loss or gain electrons.

Strategy

(1) Write the half equations

(a) For the oxidation, electron loss (oxidation state of an atom becomes larger)

e.g. Cu $\quad Cu^{2+}$ oxidation state of Cu atom increased from 0 to 2+

(b) For the reduction, electron gain (oxidation state of an atom becomes smaller)

e.g. NO_3^- $\quad$ NO oxidation state of N atom decreased from 5+ to 2+

(2) Balance by inspection all elements (except O and H) on each half of the reaction

(3) Balance the number of electrons gained and lost by multiplying each species by the same factor to effect a balance.

(4) Add both half reactions together to make sure that all reactants in the two half reactions appear on the reactant side of the total and all products appear on the reactant side of the total.

(5) Balance the charge so the charge on the left is equal to the charge on the right. Use H+ for acidic solutions and OH^- for basic solutions.

Here how to balance charge: Firstly, determine the total chrge on each side, then determine how many H^+ or OH^- must be added and to what side to balance charge

(6) Balance the hydrogens and oxygens using H_2O.

Solution

(1) Determine the oxidation number of every atom in the reactants and products.

$Cu \rightarrow Cu^{2+}$ (Cu from 0 to + 2)

$NO_3^- \rightarrow NO$ (N from + 5 to + 2)

(2) Write the half equations

$Cu \rightarrow Cu^{2+}$

$NO_3^- \rightarrow NO$

(3) Balance by inspection all elements on each half of the reaction

$Cu \rightarrow Cu^{2+}$

$NO_3^- \rightarrow NO$

(4) Balance the number of electrons gained and lost by multiplying each species by the same factor to effect a balance.

$3\,Cu \rightarrow 3\,Cu^{2+} + 6e^-$

$2\,NO_3^- + 6\,e^- \rightarrow 2\,NO$

(5) Up the two half reactions together and simplify (cancel those species that appear on both sides).

$3\,Cu + 2\,NO_3^- \rightarrow 3\,Cu^{2+} + 2\,NO$

(6) Balance charges by using H^+ for acidic solutions and OH^- for basic solutions.

$3\,Cu + 2\,NO_3^- + 8\,H^+ \rightarrow 3\,Cu^{2+} + 2\,NO$

(7) Balance the hydrogens and oxygens using H_2O.

$3\,Cu + 2\,NO_3^- + 8\,H^+ \rightarrow 3\,Cu^{2+} + 2\,NO + 4\,H_2O$

Self assessment

Write balanced equations for the following redox reactions:

(a) The reaction of permanganate ion (MnO_4^-) with bromide ion (Br^-) in acidic solution to form Mn^{2+} ion and bromine (Br_2).

(b) The oxidation of Cr^{3+} ions by hydrogen peroxide (H_2O_2) in alkaline solution to give chromate ions $(CrO_4)^{2-}$. Hydrogen peroxide is converted to water.

Answers: (a) $2\,MnO_4^- + 10\,Br^- + 16\,H^+ \quad 2Mn^{2+} + 8\,H_2O + 5\,Br_2$

(b) $2\,Cr^{3+} + 3H_2O_2 + 10\,OH^- \quad 2\,CrO_4^{2-} + 8\,H_2O$

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Chemorganisers

The Ideal-Gas Equation: $PV = nRT$

In your chemistry course you will deal with a variety of problems based on the ideal-gas equation, $PV = nRT$, which involves four experimental quantities (P, V, n, and T) and one constant, R. You might need to solve for any of the four quantities.

Problem

A sample of 1.375 g of nitrogen (N_2) exerts a pressure of 0.9734 atm at a temperature of 12 °C. Calculate the **volume** of the gas, in litres, expressed to the correct number of significant figures.

Assume that nitrogen behaves as an ideal gas under these conditions. The ideal-gas constant, R = 0.08206 L atm $mole^{-1}$ K^{-1}, atomic mass of nitrogen is 14.0067 g, and 0 °C = 273.16 K.

Before you start

- PV = nRT is known as the ideal-gas equation.
- An ideal gas is a hypothetical gas whose behavior (pressure, volume, and temperature is described by the ideal-gas equation.
- The term R is called the gas constant.
- The value and units of R depend on the units of P, V, n, and T.
- Temperature **must** always be expressed in Kelvin: K = °C + 273
- The amount of gas (n) is normally expressed in moles.
- The units of volume and pressure are litres and atm respectively .
- The units of P, V, n, and T must agree with the units of R.

Concepts

Volume, litre, temperature, °C, K, pressure, torr., mass, gram, gas constant (R), atomic mass, significant figures (sig.fig.).

Strategy

You are given the mass (1.375 g), temperature (12 °C), and pressure (0.9734 atm) of sample of N_2 and asked to calculate the volume (in litres) for N_2.

(1) Tabulate the information given in the problem

(2) Find the amount of N_2 in moles by carrying out a little arithmetic,
From the gram formula weight of N_2 (2 x 14 = 28 g)

28 g of N_2	contain	1 mole N_2 molecules
1.375 g of N_2	contain	n moles N_2 molecules

(3) Calculate the volume of N_2 by rearrange PV = nRT to solve for **V**:

$$V = (nRT) \div P$$

Solution

(1) Tabulate the given information

P = 0.9734 atm		m = 0.375 g
R = 0.08206 $L.atm.mol^{-1}.K^{-1}$		T = 12 °C + 273 K = 285 K
V = Unknown (litres)		(Remember: must be Kelvins)

(2) Calculate number of moles of N_2 by carrying out a little arithmetic.
From the gram formula weight of N_2 (2 x 14 = 28 g)

28 g of N_2	contain	1 mole N_2 molecules
1.375 g of N_2	contain	1.375 x (1 ÷ 28) = 0.049 moles N_2 molecules

(3) Calculate the volume of N_2 by rearranging PV = nRT to solve for V

V = (nRT) ÷ P

= (0.04911 x 0.08206 x 285) ÷ 0.9734 = 1.18 litres N_2 (3 sig.fig.)

Self assessment

(a) A sample of oxygen at 24.0 °C and 745 torr was found to have a volume of 455 mL. How many grams of O_2 were in the sample?

(b) What volume (in L) does 28.0 g of N_2 occupy at 20.0 °C and 760 torr?

Answers: (a) 0.586 g (b) 24.0 L

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Chemorganisers

Problems based on the Ideal-Gas Equation: PV = nRT

In your chemistry course you will deal with a variety of problems based on the ideal-gas equation (PV = nRT). You may be faced with the situation in which P, V, and T all change for a fixed number of moles of gas or you may be asked to determine the density of a gas, its molar mass, and the volumes of gases involved in chemical reactions.

Problem

A closed vessel of volume 1000 litres is filled with carbon dioxide (CO_2) at 10 °C and 650 torr pressure.
(a) Calculate the mass (in grams) of carbon dioxide in the vessel?
(b) What will be the pressure if the temperature is raised to 35 °C?
(Relative atomic masses: C =12 and O =16. R = 62.36 $L.torr.mol^{-1}.K^{-1}$)

Before you start

* The value and units of the gas constant, R, depends on the units of P, V, n, and T.
* Temperature must always be expressed in Kelvin (K) = °C + 273 K.
* The amount of gas (n) is normally expressed in moles.

Concepts

Closed vessel, volume, litre, temperature, pressure, torr., relative atomic mass, gram, gas constan (R), significant figures (sig.fig.).

Strategy

You are given: volume (1000 litres), temperature (10 °C), and pressure (650 torr) of CO_2

(a) Calculate the mass (in grams) for CO_2
  (1) Tabulate the information given in the problem
  (2) Calculate the number of moles of CO_2 by rearranging PV = nRT to solve for **n**:
  n = (PV) ÷ (RT)
  (3) Carry out a little arithmetic:
  From the gram formula mass of CO_2 {12 + (2 x 16) = 44 g}
  1 mole of CO_2 molecules contain 44 g CO_2
  ? mole of CO_2 molecules contain ? x (44 ÷ 1) g CO_2

(b) Calculate the pressure
  (1) V, n, and R are held constant and T = 35 °C + 273 = 308 K
  (2) Rearrange PV = nRT to solve for **P**: P = (nRT) ÷ V

Solution

To calculate the mass (in grams) for CO_2

(1) Tabulate the given information
P = 650 torr V =1000 litres,
R = 62.36 $L.torr.mol^{-1}.K^{-1}$ T = 10 °C + 273 K = 283 K.

(2) Calculate the number of moles of CO_2 by rearrange PV = nRT to solve for **n**:
n = (PV) ÷ (RT)
= (650 x 1000) ÷ (62.36 x 283) = 36.8375 mole
= 36.8 mole (3 sig. fig.)

(3) Carry out a little arithmetic:
From the gram formula weight of CO_2 {12 + (2 x 16) = 44 g}
1 mole of CO_2 molecules contain 44 g CO_2
36.8 mole of CO_2 molecules contain 36.8 x (44 ÷ 1) g CO_2 = 1619.2 g CO_2
= 1.62 X 10^3 g CO_2 (3 sig. fig.)

To calculate the pressure

(1) V, n, and R are held constants and T = 35 °C + 273 = 308 K
(2) Rearrange PV = nRT to solve for **P**
P = (nRT) ÷ V
= (36.8 x 62.36 x 308) ÷ 1000 = 706.81torr = 707 torr (3 sig. fig.)

Self assessment

(a) A sample of 0.554 g of nitrogen (N_2), of volume 0.500 L, exerts a pressure of 0.9734 atm at 27 °C. If the gas pressure is decreased to be 0.525 atm and the temperature is increased to be 57 °C, calculate the gas **volume** under the new conditions? (R = 0.08206 L atm K^{-1} mol^{-1}, atomic mass of nitrogen is 14.0067 g mol^{-1}, and 0 ° C = 273.16 K)

(b) A sample of ammonia (NH_3) is found to occupy 250 mL under laboratory conditions of 27 °C and 740 torr. Find the **volume** at standard conditions of 0 °C and 760 torr. (All figures in the data are significant)

Summary

* PV = nRT is, in fact, a sum of several experimentally determined laws: Boyle's, Charle's, and Avogadro's.

Answers: (a) 1.02 L (b) 222 mL

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Introducing the Mole

Problem

Find the **mass**, in grams, of **3 moles** of sodium carbonate?

Before you start

* The **formula** is a group of chemical symbols which represent a molecule in a kind of chemical shorthand. They tell you which elements have combined to form a compound and their quantities.

  For example, the formula for ammonia is NH_3. This formula tells us that ammonia is made by the combination of the elements nitrogen and hydrogen. This formula is also one way of representing one molecule of ammonia and it shows that the molecule consist of 1 atom of nitrogen and 3 atoms of hydrogen.

* On the atomic mass scale, $^{12}C = 12$, the nitrogen atom has a mass of 17 atomic mass units (u) and hydrogen has 1 u. Therefore, the mass of ammonia (NH_3) molecule is (1 x 17) + (3 x 1) = 17 u. This is known as the **formula mass** (formula weight).

  For example, we say that the formula weight of ammonia (NH_3) is 17. When dealing with quantities measured in grams, then the **gram formula mass** of ammonia would be 17 g. This is often refered to as the **gram formula mass** as **molecular weight**.

* The **formula mass** of a substance (element or compound) is often used in chemistry and it contains a large number of particles. **The number is called a mole.** We can say that 17 g of ammonia contain a mole of ammonia molecule (where the mole represents a very large number).

* This can be applied widely: Chloroform has the formula $CHCl_3$.
  From the Periodic Table the atomic mass of carbon is 12 and of chlorine is 35.5.
  Therefore, the formula mass will be, C H Cl_3
  (1 x 12) + (1 x 1) + (3 x 35.5) = 119.5
  The **gram formula mass** of chloroform is 119.5 g which means 1 mole of chloroform molecules has a mass equals to 119.5 g.

Concepts

Formula mass (formula weight), atomic mass, atomic mass unit (u), atom, molecule, gram, element, compound, mole, formula, gram formula mass.

Strategy

You are given the number of moles of sodium carbonate and asked to calculate the mass of the sample in grams.

(1) Write the correct chemical formula for sodium carbonate
(2) From your Periodic Table find the atomic masses for sodium(Na), carbon(C), and oxygen(O) atoms.
(3) Calculate the formula mass (expressed in grams) of sodium carbonate (this is the mass of 1 mole)
(4) To calculate the mass of 3 moles just multiply the mass of 1 mole by 3

Solution

(1) The formula for sodium carbonate is Na_2CO_3
(2) From the Periodic Table atomic masses for Na = 23, C = 12, O = 16, so the formula mass for Na_2CO_3 = (2 x 23) + (1 x 12) + (3 x 16) = 106
(3) 1 mole of Na_2CO_3 = 106 g
3 moles of Na_2CO_3 = 3 x 106 = 318 g

Self assessment

How many moles are in the following:
(a) 11.7 g of sodium chloride (b) 27.0 g of water

Summary

* The **formula** is a group of chemical symbols which represent a molecule in a kind of chemical shorthand.
* The **formula mass** of a substance (element or compound) is often used in chemistry and contains a **mole** of particles of that substance.

Answers: (a) 0.2 moles (b) 1.5 moles

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Chemorganisers

Quantities That React Together

Problem

Magnesium and oxygen react together to form magnesium oxide.
What mass of oxygen is needed to react completely with 12 g of magnesium?

Before you start

* The balanced chemical equation gives all the vital information about the amounts of the reactants and products.

For example, look at: $H_2 + O_2 \longrightarrow 2H_2O$

This equation says that **2 molecules** of hydrogen react with **1 molecule** of oxygen to form **2 molecules** of water.

It equally says that 200 molecules of hydrogen react with 100 molecules of oxygen to form 200 molecules of water.

More usefully, it also says that **2 moles of hydrogen molecules** react with **1 mole of oxygen molecules** to form **2 moles of water molecules**.

Concepts

Balanced chemical equation, reactant, product, gram, mole, gram formula mass

Strategy

You are given the mass of one of the reactants (magnesium) and asked to calculate the needed mass of the other one (oxygen) to react completely with the given amount (in grams) of magnesium.

1 Write the balanced equation for the reaction
2 Interpret the equation
3 Translate the equation to grams
4 Carry out a little arithmetic to find grams of O_2 needed

Solution

1 Write the balanced equation for the reaction

$2Mg + O_2 \longrightarrow 2MgO$

2 Interpret the equation

2 moles of Mg react with 1 mole of O_2 to give 2 moles of MgO

3 Translate the equation to grams

$2 \times 24 = 48$ g $\quad 1 \times 32 = 32$ g $\quad 2 \times (24 + 16) = 80$ g

4 Carry out a little arithmetic to find grams of O_2 needed:

If 48 g of Mg react with 32 g of O_2

Then 12 g of Mg will react with $32 \times (12 \div 48) = 8.0$ g of O_2

Mass of oxygen need to react completely with 12 g Magnesium is 8.0 g

Self assessment

Aluminium reacts with hydrochloric acid to form aluminium chloride and hydrogen gas.
How many grams of aluminium needed to form 3.65 g of aluminium chloride?

Summary

* Always use balanced equation for the reaction.

Answer: 0.738 g

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The Mole and Solutions

Problem

How many mL of 2 M H_2SO_4 will be required to neutralise 25 mL of 1 M NaOH?

Before you start

* The millilitre (mL) is one thousandth of a litre: 1000mL = 1 litre

  If a solution contains 1 mole of dissolved material per litre it is said to be a **Molar** solution and the symbol used is **M**. Thus a 2 M solution contains 2 moles per litre.

* Neutralization is complete when all the H^+ (aq) of an acid have joined with exactly the same number of OH^- (aq) of an alkali:

  $$2\,H^+ (aq) + 2\,OH^- (aq) \longrightarrow 2\,H_2O\,(l)$$

* The reaction of a strong acid with strong alkali (base) gives new material called a **salt**:

H_2SO_4	+	2 NaOH	$\longrightarrow$	Na_2SO_4	+	$2\,H_2O$
acid		alkali (base)		a **salt**		water

Concepts

Strong acid, strong alkali (base), concentration, mole, neutralisation, salt, molar solution, molarity, neutralization point.

Strategy

(1) Imagine the alkali in a beaker: How many moles of OH^- in the beaker?
Number of moles OH^- = Volume in litres x Molarity x Number of OH^- in the formula

(2) Imagine the acid in a beaker: How many moles of H^+ in the beaker?
Number of moles H^+ = Volume in litres x Molarity x Number of H^+ in the formula

(3) When an acid neutralises an alkali. The number of H^+ = the number of OH^-

Solution

(1) Number of moles OH^- = Volume in litres x Molarity x Number of OH^- in the formula
= 25 ÷ 1000 L x 1 x 1 (i.e. 1 OH^- in NaOH)
= 0.025 moles OH^-

(2) Number of moles H^+ = Volume in litres x Molarity x Number of H^+ in the formula
Suppose that the volume of the acid is **V**
= (**V** ÷ 1000 L) x 2 x 2 (i.e. 2 H^+ in H_2SO_4)
= (0.004 **V**) Litres

(3) The number of H^+ = the number of OH^-
0.004 V = 0.025
V = 0.025 ÷ 0.004 = 0.00625 Litres = 6.25 mL
Thus: 6.25 mL volume of H_2SO_4 is needed.

Self assessment

(a) What is the molarity of $Ca(OH)_2$ when 100 mL of it can be exactly neutralised by 12.5 mL of 0.50 M HCl ?

(b) 100 mL of 0.20 M HCl are placed in a flask. How many millilitres of 0.40 M NaOH are required to bring the solution to the neutralisation point?

Summary

* Number of Moles OH^- = Volume (L) x Molarity ($mol.L^{-1}$) x Number of OH^-
* Number of Moles H^+ = Volume (L) x Molarity ($mol.L^{-1}$) x Number of H^+
* In our problem above:

At neutralisation point,
Number of moles OH^- (alkali) = Number of moles H^+ (acid)
Therefore, V x M x Number of OH^- = V x M x Number of H^+
Or, $\mathbf{V_1 \times M_1 \times P_1}$ **(alkali)** = $\mathbf{V_2 \times M_2 \times P_2}$ **(acid)**
[P stands for ***power*** (H^+ or OH^- per formula)]

Answers: 0.031 M 50 mL

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Limiting Reactants

Problem

Consider the following reaction:

$$4\,NH_3\,(g) + 5\,O_2\,(g) \longrightarrow 4\,NO\,(g) + 6\,H_2O\,(g)$$

How many **grams** of NO form when 1.50 g of NH_3 reacts with 1.85 g of O_2?

Before you start

* Any **chemical reaction** stops as soon as any **ONE** of the **reactants** is **totally used up.**
* The **reactant** that consumed completely in a reaction is called the **limiting reactant** or **limiting reagent** because it determines, or limits, the amount of product formed. The other **reactants** are sometimes called **excess reactants** or **excess reagents.**

For example,	Reactant	+	Reactant	→	Product
	$2H_2$		O_2		$2H_2O$
We predict:	2 x (2) = 4 g		1 x (32) = 32 g		2 x (18) = 36 g
If you have:	4 g		40 g		? g
After reaction:	totally consumed *(limiting reactant)*		8 g excess *(excess reactant)*		36 g formed

* The quantities of products formed in a reaction are always determined by the quantity of the limiting reactant.

Concepts

Chemical reaction, reactant, product, limiting reactant, excess reactant, consumed.

Strategy

You are given a chemical reaction and the quantities of the reactants [NH_3 and O_2], and you are asked to calculate the number of grams of NO, a product, that forms.

(1) Translate the equation to grams

(2) Calculate grams of NO formed from NH_3

(3) Calculate grams of NO formed from O_2

(4) Determine the limiting reactant (the reactant who give less grams of product NO), and the mass formed from the limiting reactant is the answer.

Solution

Because the amount of the two reactants are given, therefore this reaction is a limiting reactant problem.

(1) Translate the equation to grams

$4\,NH_3\,(g)$	+	$5\,O_2\,(g)$	→	$4\,NO\,(g)$	+	$6\,H_2O\,(g)$
4 x (17)		5 x (32)		4 x (30)		6 x (18)
68 g		160 g		120 g		108 g

(2) Calculate grams of NO formed from NH_3

	68 g NH_3	will produce	120 g NO
Thus:	1.50 g NH_3	will give	120 x (1.50 ÷ 68) = 2.647 g NO

Thus, 2.65 g of NO will be formed from 1.50 g of ammonia

(3) Calculate grams of NO formed from O_2

	160 g O_2	will produce	120 g NO
Thus:	1.85 g O_2	will give	120 X (1.85 ÷ 160) = 1.35 g NO

Thus, 1.35 g of NO will be formed from 1.85 g of oxygen

(4) Because O_2 gives less grams of product NO, it is the limiting reactant and the mass of NO formed is 1.35 g.

Self assessment

(a) 2.00 g of zinc metal is placed in an aqueous solution containing 2.50 g of silver nitrate, causing the following reaction to occur:

$$Zn\,(s) + 2AgNO_3(aq) \longrightarrow 2Ag\,(s) + Zn(NO_3)_2(aq)$$

How many grams of Ag will form?

(b) Consider the reaction: $2\,Al\,(s) + 3\,Cl_2\,(g) \longrightarrow 2AlCl_3\,(s)$

A mixture of 40.50 g of Al and 3.0 moles of Cl_2 are allowed to react. Which is the limiting reactant? How many grams of $AlCl_3$ are formed?

Summary

* A **limiting reactant** determines, or limits, the amount of product formed.

Answers: (a) 1.59g (b) Al, 200.25 g

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Simple Titration Calculations

Problem

50.0 mL of 0.20 M hydrochloric acid were required to neutralise a sample of sodium hydroxide solution. Calculate the mass of sodium hydroxide in the sample?

Before you start

* The standard is the known material
* M means the molarity of the solution = $\frac{\text{mol standard}}{\text{L standard solution}}$
* Balanced equation(s) for the reaction(s) involved must be written

Concepts

Standard, unit cancellation, molarity, balanced equation, equivalence factors

Strategy

* Identify the standard and the unknown.
* Write balanced equation(s) for the reaction(s) involved
* Determine the relevant chemical equivalencies.
* Plan the calculation sequence.(in most problems this will be weight of standard **to** moles of standard **to** moles of unknown
* Set up equivalence factors
* Insert figures for each factor and complete the calculation.

Solution

Standard is HCl, unknown is NaOH

$HCl + NaOH = NaCl + H_2O$

From the equation: 1 mole HCl equivalence to 1 mole NaOH

L HCl solution to mol HCl to mol NaOH to g NaOH

$$\frac{\text{L HCl soln.}}{1000} \times \frac{\text{mol HCl}}{\text{L HCl soln.}} \times \frac{\text{mol NaOH}}{\text{mol HCl}} \times \frac{\text{g NaOH}}{\text{mol NaOH}} = \text{g NaOH}$$

$$\frac{50.0 \text{ L HCl soln.}}{1000} \times \frac{0.20 \text{ mol HCl}}{1 \text{ L HCl soln.}} \times \frac{1 \text{ mol NaOH}}{1 \text{ mol HCl}} \times \frac{40.0 \text{ g NaOH}}{1 \text{ mol NaOH}} = 0.40 \text{ g NaOH}$$

Discussion

STANDARD | CHEMICAL EQUIVALENCE | UNKNOWN

$$\frac{50.0 \text{ L HCl soln.}}{1000} \times \frac{0.20 \text{ mol HCl}}{1 \text{ L HCl soln.}} \times \frac{1 \text{ mol NaOH}}{1 \text{ mol HCl}} \times \frac{40.0 \text{ g NaOH}}{1 \text{ mol NaOH}} = 0.40 \text{ g NaOH}$$

- mL HCl soln. to L HCl soln.
- molarity of HCl
- from balanced equation
- Molecular weight

Self assessment

(a) How many grams of sulfuric acid is needed to prepare 250 mL of 0.100 M H_2SO_4 ?

(b) How many grams of mercury(II) nitrate, $Hg(NO_3)_2$, is required to react with 16.82 mL of a 1.136 M solution of $CaCl_2$?
$Hg(NO_3)_2 (aq) + CaCl_2 (aq) = HgCl_2 (aq) + Ca(NO_3)_2 (aq)$

(c) How many grams of H_2O is formed when 25.0 mL of 0.100 M HNO_3 solution is completely neutralised by NaOH?

(d) What volume of 0.115 M $HClO_4$ solution is required to neutralise 50.0 mL of 0.0875 M NaOH?

(e) $14 KMnO_4 + 4C_3H_5(OH)_3 = 7 Mn_2O_3 + 7 K_2CO_3 + 5 CO_2 + 16 H_2O$
If the density of glycerol, $C_3H_5(OH)_3$, is 1.26 g/mL, what is the volume of glycerol would be required to react completely with 1.5 g $KMnO_4$?

Answers: (a) 2.45 g , (b) 6.202 g , (c) 0.045 g , (d) 38.0 mL , (e) 0.198 mL

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Activation Energy

Problem

In the decomposition of dinitrogen pentoxide, N_2O_5, the rate constants were $1.4 \times 10^{-4}\ s^{-1}$ at 35 °C and $5.0 \times 10^{-4}\ s^{-1}$ at 45 °C. What is the activation energy for this reaction? What is the rate constant at 55 °C?
[The gas constant, $R = 8.31\ J\ mol^{-1}\ K^{-1}$]

Before you start

* Arrhenius equation, $k = A\ e^{-E_a/RT}$, expresses the dependence of the rate constant, **k**, on the absolute temperature (Kelvin),**T**, while
  A is a constant which is called the frequency factor;
  e is the base of natural logarithms, 2.718...;
  $\mathbf{E_a}$ is the activation energy; and
  R is the gas constant 8.31 $J\ K^{-1}\ mol^{-1}$.
* Activation energy, $\mathbf{E_a}$, is the minimum energy required for two molecules to react after collision. The value of $\mathbf{E_a}$ depends on the particular reaction.
* It is possible to rearrange the Arrhenius equation at two temperatures to give:

$$\log \frac{k_2}{k_1} = \frac{E_a}{2.303\ R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right]$$

Concepts

Arrhenius equation, activation energy, natural logarithm, absolute temperature (in Kelvin), rate constant, gas constant.

Strategy

* **Given** the values of the rate constant at two different temperatures (in Kelvin)
* **Knowing** that Arrhenius equation for two different temperatures is:
  $\log (k_2 / k_1) = (E_a / 2.303\ R)(1/T_1 - 1/T_2)$, also, $R = 8.31\ J\ mol^{-1}\ K^{-1}$
* **To solve for the activation energy, $\mathbf{E_a}$:**
  Substitute the data given into the Arrhenius equation for two different temperatures.
* **To solve for the rate constant, $\mathbf{k_3}$, at a third temperature, $\mathbf{T_3}$:**
  Use Arrhenius equation as follows: $\log k_3 - \log k_1 = (E_a / 2.303\ R)(1/T_1 - 1/T_3)$.
  Then take the **antilog** for both sides.

Solution

* **To solve for the activation energy, $\mathbf{E_a}$:**
  Substitute the values in the Arrhenius equation for two different temperatures:

$$\log \frac{5.0 \times 10^{-4}}{1.4 \times 10^{-4}} = \frac{E_a}{2.303 \times 8.31}\left[\frac{1}{308} - \frac{1}{318}\right]$$

$$0.55 = \frac{E_a}{19.1}\left[3.25 \times 10^{-3} - 3.15 \times 10^{-3}\right]$$

$E_a = 1.05 \times 10^5\ J\ mol^{-1} = 1.05 \times 10^2\ kJ\ mol^{-1}$

* **To solve for the rate constant, $\mathbf{k_3}$, at a third temperature, $\mathbf{T_3}$:**
  Write the Arrhenius equation as follows:
  $\log k_3 - \log k_1 = (E_a / 2.303\ R)(1/T_1 - 1/T_3)$.
  Substitute the values:

$$\log k_3 - \log 1.4 \times 10^{-4} = \frac{1.05 \times 10^5}{2.303 \times 8.31}\left[\frac{1}{308} - \frac{1}{328}\right]$$

$$\log k_3 - (-3.85) = \frac{1.05 \times 10^5}{19.1}\left[3.25 \times 10^{-3} - 3.05 \times 10^{-3}\right]$$

$\log k_3 = -2.75$

Taking antilogarithms for both sides gives: $k_3 = 1.78 \times 10^{-3}\ s^{-1}$

Self assessment

(a) The rate constant for decomposition of acetaldehyde, CH_3CHO, when heated is 0.105 $mol\ L^{-1}\ s^{-1}$ at 759 K and 2.14 $mol\ L^{-1}\ s^{-1}$ at 836 K. What is the activation energy for this decomposition? What is the rate constant at 865 K?

(b) The activation energy for the formation of hydrogen iodide is $1.66 \times 10^5\ J\ mol^{-1}$, and the rate constant at 600 K was $2.7 \times 10^{-4}\ L\ mol^{-1}\ s^{-1}$.
At what temperature will the rate be $3.5 \times 10^{-3}\ L\ mol^{-1}\ s^{-1}$?

Reminder

* Use only absolute temperature (Kelvin),**T**.
* The gas constant, **R**, = 8.31 $J\ mol^{-1}\ K^{-1}$.

Answers: (a) $E_a = 2.1 \times 10^5\ J\ mol^{-1}$, $k = 5.80\ mol\ L^{-1}\ s^{-1}$ (b) 650 K

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Chemorganisers

Determining the Rate Law from Initial Rates

Problem

In a series of experiments to measure the rate of base hydrolysis of an ethyl ester:

ester + OH^- -------> alcohol + ethanoate

the following experimental data were obtained:

Exp.no.	Initial Concentrations (mol L^{-1})		Reaction Rate (mol L^{-1} s^{-1})
	[ester]	[OH^-]	
1	0.1	0.02	1.4×10^{-3}
2	0.1	0.04	2.8×10^{-3}
3	0.3	0.02	4.2×10^{-3}
4	0.2	0.04	**?**
5	**?**	0.02	2.8×10^{-3}

(a) Write down the rate expression for this reaction (Rate = ...)

(b) What is the value of the rate constant?

(c) What is the reaction rate in Exp. 4?

(d) What is the ester concentration in Exp. 5?

Before you start

* The rate law for a chemical reaction will have the concentration of all reactants raised to various powers. For example, for the reaction: A + B ------> C + D

  the rate law is: Rate = $k[A]^m[B]^n$

  It is important for you **to remember** that the reaction order with respect to each species in a rate law must be determined experimentally. They may or may not be related to the coefficients in the equation.

* By determining experimentally the values of the rate and the concentrations, it is possible to solve the rate equation to calculate the rate constant, k.

Concepts

Rate law, reaction rate, reaction order, rate constant, initial concentration.

Strategy

* Assume that the rate law has the following form: Rate = $k\,[OH^-]^m[ester]^n$

  then determine the reaction orders (powers **m** and **n**) by comparing two experiments in which the concentration of all reactants but one are held constant.

* To calculate the rate constant, substitute values from any experiment into the rate law.
* Use the rate law and the value of the rate constant to solve other parts of the problem.

Solution

(a) Look at experiments **1** and **2**, [ester] is unchanged, but when [OH^-] is doubled the rate is doubled , therefore, rate $[OH^-]^1$

Look at experiments **1** and **3**, [OH^-] is unchanged, but when [ester] is tripled the rate is tripled , therefore, rate $[ester]^1$

Thus, the rate law is: Rate = $k[OH^-]^1\,[ester]^1$

(b) Rearrange the rate law to solve for the rate constant, **k**, then substitute values from any of the experiments (1, 2, or 3) into:

$$k = \frac{Rate}{[OH^-]\,[ester]}$$

Using experiment **1**, you obtain:

$$k = \frac{1.4 \times 10^{-3}\ mol\ L^{-1}\ s^{-1}}{0.02\ mol\ L^{-1} \times 0.1\ mol\ L^{-1}} = 0.7\ L\ mol^{-1}\ s^{-1}$$

(c) Rate = $k\,[OH^-]\,[ester]$ = $0.7 \times 0.2 \times 0.04$ = 5.6×10^{-3} mol L^{-1} s^{-1}

(d) $$[ester] = \frac{2.8 \times 10^{-3}\ mol\ L^{-1}\ s^{-1}}{0.7\ L\ mol^{-1}\ s^{-1} \times 0.2\ mol\ L^{-1}} = 0.2\ mol\ L^{-1}$$

Self assessment

(a) The initial-rate method was applied to the decomposition of nitrogen dioxide,

$2\,NO_2\,(g)$ ---------> $2\,NO(g)$ + $O_2\,(g)$

It gave the following results:

Exp.no.	Initial [NO_2] (mol L^{-1})	Rate of formation of O_2 (mol L^{-1} s^{-1})
1	0.010	7×10^{-5}
2	0.020	28×10^{-5}

Find the rate law and the value of the rate constant with respect to O_2 formation?

(b) In a kinetic study of the reaction: $2\,NO\,(g)$ + $O_2\,(g)$ -----> $2\,NO_2\,(g)$

the following data were obtained for the initial rates of disappearance of NO:

Exp.no.	Initial Concentrations (mol L^{-1})		Rate of Reaction of NO (mol L^{-1} s^{-1})
	[NO]	[O_2]	
1	0.0125	0.0253	0.0281
2	0.0250	0.0253	0.1120
3	0.0125	0.0506	0.0561

Obtain the rate law. What is the value of the rate constant?

Answers: (a) Rate = $k[NO_2]^2$, k = 0.7 L mol^{-1} s^{-1} (b) Rate = $k[NO]^2[O_2]$, k = 7.1×10^{3} L^2 mol^{-2} s^{-1}

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Chemorganisers

Determining the Order of Reaction from the Rate Law

Problem

Nitric oxide, NO, reacts with hydrogen according to the equation:

$$2\,NO_{(g)} + 2\,H_{2(g)} \longrightarrow N_{2(g)} + 2\,H_2O_{(g)}$$

The experimentally determined rate law is: Rate = $k[NO]^2[H_2]$. What is the order of the reaction with respect to each reactant species? What is the overall order of reaction?

Before you start

* The quantitative measure of the rate at which a chemical process gives products is called its **rate of reaction**. You are familiar with the speed of travel and its most familiar unit: miles per hour. Thus, speed or rate is always expressed as a ratio.
  Speed of travel = rate of vehicle motion = change in position with time, e.g. miles / hour.
  Similarly, the rate of a chemical reaction is measured by the decrease in concentration of a reactant or the increase in concentration of a product in a unit of time.
  Rate of reaction = change in concentration of reactant or product with time expressed as moles per litre per second (mol L^{-1} s^{-1})
* The reaction order with respect to a given reactant species equals the exponent (power) of the concentration of that species in the rate law, as determined experimentally.
  Consider the reaction: $2\,NO_{(g)} + Cl_{2(g)} \longrightarrow 2\,NOCl_{(g)}$
  for which the rate equation is: Rate = $k\,[NO]^2\,[Cl_2]^1$.
  This means that the reaction is second order with respect to NO and the reaction is first order with respect to Cl_2 .
* The overall order of a reaction equals the sum of the orders of the reactant species in the rate law. In the above example, the overall order is 3 (= 2 + 1). The reaction is third order overall.

Concepts

Reaction order, exponent (power), concentration, rate law, overall order.

Strategy

Given an empirical rate law, obtain the orders with respect to each reactant (and catalyst , if any) and the overall order.

Solution

An order with respect to a species equals the exponent (the power) of its concentration.
The reaction is second order with respect to NO and first order with respect to H_2 .
The reaction is third order overall (= 2 + 1).

Self assessment

(a) The rate law for the reaction : $NO_{(g)} + O_{3(g)} \longrightarrow NO_{2(g)} + O_{2(g)}$
is: Rate = $k\,[NO]\,[O_3]$
What are the reaction orders with respect to each reactant, and the overall order of the reaction?

(b) If the order with respect to NO is 2, and the overall order of reaction is 3.
What is the rate law for the reaction: $2\,NO_{(g)} + Br_{2(g)} \longrightarrow 2\,NOBr_{(g)}$

(c) The experimentally determined rate law for the following reaction:
$CH_3Br_{(aq)} + OH^-_{(aq)} \longrightarrow CH_3OH_{(aq)} + Br^-_{(aq)}$
is: Rate = $k\,[CH_3Br]\,[OH^-]$
What is the order of reaction with respect to each reactant species?
What is the overall order of the reaction?

Summary

* The brackets, [ ], denote moles per litre concentration.
* The rate of a given reaction can be described by an experimentally determined rate equation of the form: Rate = $k\,[A]^m\,[B]^n$ in which A and B represent molar concentrations of reactants; **m** and **n** are usually, but not always, positive integers; and **k** is the rate constant.
* The exponents, **m** and **n**, describe the order of the reaction with respect to each specific reactant.
* The overall order of the reaction is the **sum** of the exponents.

Answers: (a) NO is **1**, O_3 is **1**, and overall is **2** (b) Rate = $k[NO]^2[Br_2]$
(c) CH_3Br is **1**, OH^- is **1**, and overall is **2**

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Chemorganisers

Half-Life Time of a Reaction

Problem

The rate constant for the first order decomposition of cyclobutane, C_4H_8, at 500 °C is 9.2×10^{-3} s^{-1}. What is the half-life time of C_4H_8 at this temperature?

Before you start

* Consider the decomposition of H_2O_2 :

$$H_2O_2 \text{ --------> } H_2O + 1/2\, O_2$$

As the reaction proceeds, the concentration of H_2O_2 decreases as it breaks up.

step:	start		1		2		3		4
concentration:	1.000		0.500		0.250		0.125		0.0625
time:	0 hr	↔ 6 hr	6 hr	↔ 6 hr	12 hr	↔ 6 hr	18 hr	↔ 6 hr	24 hr

During the first half-life time (from zero hours to 6 hours), the concentration decreases from 1.000 M to 0.500 M. During the second half-life time (from 6 hours to 12 hours), it decreases from 0.500 M to 0.250 M. During the third half-life time (from 12 hours to 18 hours), it decreases from 1.000 M to 0.500 M. The concentration decreases by half during each successive period of 6 hours.

* The half-life time, $t_{1/2}$, of a reaction is the time it takes for the reactant concentration to decrease to one-half of its initial value.
* The decomposition of hydrogen peroxide is a first order reaction, the half-life time of a first order reaction is independent of the concentration of the reactants. However, half-lives of higher order reactions depend on the concentrations of the reactants.
* It is possible to deduce mathematically for a first order reaction that:

$$\ln \frac{[A_o]}{[A]} = k\,t$$

where $[A_o]$ = initial concentration and $[A]$ = the concentration at any given time t.

When the concentration of A drops by half, then $[A] = 1/2\,[A_o]$

$$\ln \frac{[A_o]}{[A]} = \frac{[A_o]}{1/2\,[A_o]} = \ln 2 = 0.693 = k\,t_{1/2}$$

Therefore, $K\,t_{1/2} = 0.693$

$$t_{1/2} = \frac{0.693}{k}$$

Concepts

Half-life time , first order reaction, rate constant, concentration.

Strategy

* To calculate the half-life time just substitute the rate constant of the reaction in the following equation: $t_{1/2} = \frac{0.693}{k}$

Solution

The rate constant, K, is equal to 9.2×10^{-3} s^{-1}

Substitute into the equation:

$$t_{1/2} = \frac{0.693}{k} = \frac{0.693}{9.2 \times 10^{-3}\ s^{-1}} = 75.33\ s$$

Self assessment

(a) Sulfuryl chloride, SO_2Cl_2, decomposes in a first order reaction to sulfur dioxide and chlorine. At 320 °C, the rate constant is 2.20×10^{-5} s^{-1}.

(i) What is the half-life time of SO_2Cl_2 vapour at this temperature?

(ii) How long (in hours) would it take for 50.0 % of the SO_2Cl_2 to decompose?

(iii) How long it take for 75.0 % of the SO_2Cl_2 to decompose?

(b) Calculate the rate constant for the first order decomposition of hydrogen peroxide, H_2O_2, in water at 40 °C, using the data given in before you start section?

(c) For the following reaction: N_2O_5 --------> $2\,NO_2$ + $1/2\,O_2$

the rate constant is 4.80×10^{-4} s^{-1} at 45 °C. What is the half-life time of this reaction?

Summary

* The half-life time of a first order reaction is inversely proportional to the rate constant, K.

$$t_{1/2} = \frac{0.693}{k}$$

* A fast reaction has a large K and a short half-life.

Answers: (a) 3.15×10^4 s; 8.75 hr; 17.5 hr (b) 3.21×10^{-5} s^{-1} (c) 1.44×10^3 s = 24.0 min.

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Calculating ΔH° of a reaction

Problem

Calculate ΔH° for the reaction below at 298 K:

$3\,NO_2\,(g) + H_2O\,(l) \longrightarrow 2\,HNO_3\,(aq) + NO\,(g)$

The standard enthalpies of formation (ΔH°f) at 298 K in kJ mol^{-1} are:

NO_2 (g) = 33.2, H_2O (l) = - 285.8, HNO_3 (aq) = - 206.6, and NO (g) = 90.3

Before you start

* Consider the following reaction:

  $2\,Na\,(s) + 2\,H_2O\,(l) \longrightarrow 2\,NaOH\,(aq) + H_2\,(g) \quad \Delta H° = -281.9\ kJ$

  The standard enthalpy change for the reaction, ΔH°, indicates that 281.9 kJ of heat are given to the surroundings when 2 moles of sodium and 2 moles of liquid water react to give 2 moles of sodium hydroxide and 1 mole of hydrogen gas.
* The negative value of the standard enthalpy of the reaction, ΔH°, indicates an exothermic reaction (while a positive value would indicate an endothermic reaction).
* Enthalpy change, ΔH, is caused by bonds forming and breaking.
* Standard enthalpy of formation, ΔH°f, is the enthalpy change when 1 mole of the substance is formed from its elements in their normal states under standard conditions.
* A given amount of a substance has a definite enthalpy at a given temperature and pressure, because enthalpy is an extensive quantity (it depends on the amount of substance involved).

Concepts

Enthalpy (H), enthalpy change (ΔH), standard conditions, standard enthalpy of the reaction (ΔH°), standard enthalpy of formation (ΔH°f), extensive and intensive quantity, exothermic and endothermic reaction, surroundings.

Strategy

* Write the balanced equation with ΔH°f values recorded beneath it.
* Calculate ΔH°f for the reactants.
* Calculate ΔH°f for the products
* Subtracting the sum of ΔH°f values for reactants from values of products:

Reminder

** Remember to multiply the values of ΔH°f for the reactants and the products by the coefficients in the balanced equation.

** Be very careful of arithmetical signs.

** ΔH°f = 0 for element by definition.

** Pay particular attention to the state of each substance (solid, liquid, gas, and aqueous).

Solution

* The equation: $3\,NO_2\,(g) + H_2O\,(l) \longrightarrow 2\,HNO_3\,(aq) + NO\,(g)$

  ΔH°f:

Reactants	Products
3 x 33.2 + 1 x (- 285.8)	2 x (- 206.6) + 1 x 90.3
99.6 + (- 285.8)	- 413.2 + 90.3
99.6 - 285.8	- 413.2 + 90.3
- 186.2	- 322.9
ΔH°f (reactants)	ΔH°f (products)

* ΔH° for overall reaction = ΔH°f (products) - ΔH°f (reactants)

  ΔH° = - 322.9 - [(- 186.2)]

  = - 322.9 + 186.2 = - 136.7 kJ

Self assessment

(a) Calculate ΔH° at 298 K for the reaction:

$C_6H_6\,(l) + 15/2\,O_2\,(g) \longrightarrow 6\,CO_2\,(g) + 3\,H_2O(l)$

If ΔH°f in kJ mol^{-1} for C_6H_6 (l) = 49.0; O_2 (g) = 0; CO_2 (g) = - 393.5; and H_2O(l) = - 285.8

(b) In the following reaction: $2\,NH_3\,(g) + CO_2\,(g) \longrightarrow NH_2CONH_2\,(aq) + H_2O(l)$

How much heat is absorbed or evolved if ΔH°f in kJ mol^{-1} for NH_3 (g) = - 45.9

CO_2 (g) = - 393.5 NH_2CONH_2 (aq) = - 319.2 H_2O(l) = - 285.8

Useful thought

*** In this page, we have calculated the ΔH° of the reaction given the enthalpies of formation of all reactants and products. It is possible to calculate ΔH° of a reaction if all the enthalpies associated with bond forming and breaking are known.

Answers: (a) = - 3267 kJ (b) -119.7 kJ, heat is evolved (exothermic)

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Calculating ΔS° of a reaction

Problem

Calculate the change of entropy (ΔS°) for the reaction below at 298 K:

$C_6H_{12}O_6$ (s) ---------> 2 C_2H_5OH (l) + 2 CO_2 (g)

The standard entropies (S°) at 298 K in J mol^{-1} K^{-1} are:

$C_6H_{12}O_6$ (s) = 212 C_2H_5OH (l) = 161 CO_2 (g) = 214.

Before you start

- The randomness, or the amount of disorder, of a system can be determined quantitatively. It is described as the entropy, S, of the system.

	Ice	Water	Steam
S° (in J mol^{-1} K^{-1})	22	70	189
	Solid	Liquid	Gas

Increasing entropy →
Order → **Disorder**

- Consider the following reaction:

  2 SO_2 (g) + O_2 (g) -----> 2 SO_3 (g) ΔS° = - 188.0 J K^{-1}

  when 2 moles of SO_2 (g) and 1 mole of O_2 (g) react to give 2 moles of SO_3 (g). The entropy change for the reaction, ΔS°, run under standard state conditions, indicates a decrease in disorder (or an increase in order). This increase in order arises because 3 moles of gas are converted into 2 moles of gas, resulting in less disorder.

- Disorder reaches its minimum at zero Kelvin (a substance that is perfectly crystalline at zero Kelvin has an entropy of zero).

- The entropy usually increases in the following situations:

  ** A reaction in which a molecule is broken into two or more smaller molecules.
  For example, $C_6H_{12}O_6$ (s) -----> 2 C_2H_5OH(l) + 2 CO_2(g) ΔS° = 538 J mol^{-1}.K^{-1}

  ** A process in which a solid changes to a liquid or gas or a liquid changes to a gas.
  For example, H_2O (l) -----> H_2O (g) ΔS° = 119 J mol^{-1} K^{-1}

Concepts

Entropy (S), entropy change (ΔS), standard conditions

Strategy

- Write the balanced equation with S° values recorded beneath it.
- Calculate S° for the reactants.
- Calculate S° for the products
- Subtracting the sum of S° values for reactants from values of products:

Reminder

** Remember to multiply the values of S° for the reactants and the products by the coefficients in the balanced equation.

** Pay particular attention to the state of each substance (solid, liquid, gas, and aqueous)

Solution

- The equation: $C_6H_{12}O_6$ (s) ------> 2 C_2H_5OH (l) + 2 CO_2 (g)

  S° : 1 x 212 ; 2 x 161 + 2 x 214

  212 ; 322 + 428

  212 ; **750**

  S° (reactants) ; **S° (products)**

- ΔS° for overall reaction = S° (products) - S° (reactants)

  ΔS° = 750 - 212 = 538 J K^{-1}

Self assessment

(a) Calculate ΔS° at 298 K for the reaction: CO (g) + H_2O (g) ------> CO_2 (g) + H_2 (g)
If S° (in J mol^{-1} K^{-1}) for CO (g) = 198, H_2O (g) = 189, CO_2 (g) = 214, and H_2 (g) = 131.

(b) Calculate the entropy change for the reaction: H_2 (g) + 1/2 O_2 (g) ------> H_2O (l)
when the reactants and products are in their standard states at 25 °C. The standard entropies (S°) at 298 K (in J mol^{-1} K^{-1}) are: H_2 (g) = 131; O_2 (g) =205; H_2O (l) = 70.

Answers: (a) - 42 J mol^{-1} K^{-1} (b) - 163.5 J mol^{-1} K^{-1}

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Chemorganisers

Calculating $\Delta G°$ from $\Delta H°$ and $\Delta S°$

Problem

Calculate $\Delta G°$ for the reaction at 298 K:

	SO_2 (g)	+	1/2 O_2 (g)	------->	SO_3 (g)
if $\Delta H°_f$ in kJ mol^{-1} are:	- 297		0		- 395
and S° in J mol^{-1} K^{-1} are:	248		205		256

Before you start

* Reactions take place in the direction that allows overall entropy to increase (Second Law of Thermodynamics).

* If ΔH for a reaction is negative (an exothermic reaction), this provides heat energy to the surroundings, allowing the entropy of the surroundings to increase.
  If $\Delta S°$ for a reaction is positive, then the entropy of the reaction system increases.
  Combining these two ideas gives us the equation:

$\Delta G°$	=	$\Delta H°$	-	$T\Delta S°$
free energy change of the reaction		enthalpy change of the reaction		entropy change of the reaction

* If $\Delta G°$ of the reaction has:
  ** a negative value, this means that the products are favoured. It is said that the reaction is spontaneous (nothing to do with the speed of the reaction).
  ** a positive value means that the reactants are favoured. It is said that the reaction is not spontaneous.

Concepts

Free energy, enthalpy change, entropy change, spontaneous, non-spontaneous, exothermic reaction, products favoured, reactants favoured.

Strategy

* Calculate $\Delta H°$ and $\Delta S°$ for the reaction.
* Substitute the values into: $\Delta G° = \Delta H° - T\Delta S°$

Reminder

** $\Delta H°$ and $\Delta S°$ need to be expressed in the same unit of heat energy.
** The temperature should be in Kelvin scale.

Solution

* **To calculate $\Delta H°$:**

$\Delta H°_f$

SO_2 (g) + 1/2 O_2 (g) -------> SO_3 (g)

1 x (- 297)   1/2 x 0   1 x (- 395)
- 297   0   - 395
- 297   - 395

$\Delta H°_f$ (reactants)   **$\Delta H°_f$ (products)**

$\Delta H°$ for overall reaction = $\Delta H°_f$ (products) - $\Delta H°_f$ (reactants)

$\Delta H°$ = - 395 - [(- 297)] = - 395 + 297 = - 98 kJ = - 98000 J

* **To calculate $\Delta S°$:**

S°

SO_2 (g) + 1/2 O_2 (g) -----> SO_3 (g)

1 x 248   1/2 x 205   1 x 256
248   102.5   256
350.5   256

$\Delta S°_f$ (reactants)   **$\Delta S°_f$ (products)**

$\Delta S°$ for overall reaction = S° (products) - S° (reactants)

$\Delta S°$ = 256 - 350.5 = - 94.5 J K^{-1}

* **To calculate $\Delta G°$:**

$\Delta G°$	=	$\Delta H°$	-	$T\Delta S°$
	=	(- 98000) J	-	298 K x (- 94.5) J K^{-1}
	=	(- 98000) J	-	(- 28161) J K^{-1}
	=	- 69839 J	=	- 69.8 kJ

Self assessment

(a) For the reaction: O_3 (g) + O(g) -----> 2 O_2 (g)
$\Delta H°$ (reaction) = - 391.9 kJ and $\Delta S°$ (reaction)= 10.29 J K^{-1}. Calculate $\Delta G°$ (reaction) at 25 °C, and state whether the reaction is spontaneous or not?

Use the data given in the table below to solve the following questions.

(b) Calculate $\Delta G°$ at 298 K for the reaction : CH_4 (g) + 2 O_2 (g) ----> CO_2 (g) + 2 H_2O(g)

(c) Calculate $\Delta H°$, $\Delta S°$, and $\Delta G°$ for the following reaction at 298 K:
2 CH_3OH (l) + 2 O_2 (g) -----> CO_2 (g) + 4 H_2O(l)

	CH_4 (g)	O_2 (g)	CO_2 (g)	H_2O(g)	CH_3OH (l)	H_2O(l)
$\Delta H°_f$ (in kJ)	- 75	0	- 394	- 242	- 237	- 286
S° (in J mol^{-1} K^{-1})	186	205	214	189	127	70

Answers: (a) - 395.0 kJ, spontaneous (b) - 802 kJ (c) - 1064 kJ, - 170 J.K^{-1} , - 1013 kJ

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Chemorganisers

Calculating K from $\Delta G°$

Problem

Find the value of the equilibrium constant, **K**, at 25 °C (298 K) for the reaction:

$2 NH_3 (g) + CO_2 (g) \longrightarrow NH_2CONH_2 (aq) + H_2O(l)$

The standard free energy change, $\Delta G°$, at 25 °C is: - 13.6 kJ

Before you start

* The standard free energy change, $\Delta G°$, for a reaction determines the position of equilibrium for that reaction. Also the equilibrium constant defines the position of equilibrium, for example, in the reaction: $aA + bB \rightleftharpoons cC + dD$
  the equilibrium constant, K, is: $K = [C]^c [D]^d / [A]^a [B]^b$
* This allows us to express the position of an equilibrium in terms of a constant, K, the equilibrium constant. Clearly, if the equilibrium position favours the products, K will be large and positive. if the equilibrium position favours the reactants, K will be small and positive but greater than zero.
* It is now possible to relate this constant to the standard free energy change. We can do this by tabulating the values for both the standard free energy change and the equilibrium constant:

If reactants favoured	← when equilibrium is established →	If products favoured
$\Delta G° > 0$		$\Delta G° < 0$
$K < 1$ (but > 0)		$K > 1$

* Thus, both $\Delta G°$ and K can provide information about the equilibrium position in a reaction. It is important to know that, for a given reaction at a given temperature, K is constant. If we alter the temperature, we alter K.
* Mathematically, the relationship between $\Delta G°$ and K is:

$$\Delta G° = - RT \ln K$$

where R = the gas constant, and T = the temperature in Kelvin scale

* In gases, reaction concentrations are expressed in partial pressure (equilibrium constant is stated as K_p).
* In solutions, reaction concentrations are expressed in moles per litre (equilibrium constant is stated as K_c).

K-37

Concepts

Equilibrium constant, free-energy change.

Strategy

* Rearrange the equation: $\Delta G° = - RT \ln K$
  to give: $\ln K = \Delta G° \div (- RT)$
* Substitute the values into the equation.
* Use the **e^x** key or **inv** key then **ln** key of your calculator to obtain the K value.

Solution

$\Delta G° = - RT \ln K$

$\ln K = \Delta G° \div (- RT)$

$= - 13.6 \text{ kJ} \div (- 8.314 \text{ J mol}^{-1} \text{K}^{-1} \times 298 \text{ K})$

$= - 13600 \text{ J} \div (- 8.314 \text{ J mol}^{-1} \text{K}^{-1} \times 298 \text{ K})$

$= - 13600 \text{ J} \div \{(- 2478) \text{ J}\}$

$= 5.4883$

Use the **e^x** key or (**inv** key then **ln** key) of your calculator to obtain the K value.

$K = 2.42 \times 10^2$

Self assessment

(a) Find the equilibrium constant, **K**, at 25 °C (298 K) for the reaction:

$3 Fe_2O_3 (s) \longrightarrow 2 Fe_3O_4 (s) + 1/2 O_2 (g)$

if $\Delta G° = 195.9$ kJ

(b) What is the standard free energy, $\Delta G°$, at 298 K for the reaction:

$1/2 H_2 (g) + 1/2 Cl_2 (g) \longrightarrow HCl (g)$

What is the value of the equilibrium constant, **K**?

{ $\Delta G°_f$ for $H_2 (g) = 0 \text{ kJ mol}^{-1}$, $Cl_2 (g) = 0 \text{ kJ mol}^{-1}$, $HCl (g) = - 95.3 \text{ kJ mol}^{-1}$ }

Summary

* $\Delta G° = - RT \ln K$
* In gases, equilibrium constant is stated as K_p.
* In solutions, equilibrium constant is stated as K_c .

Answers: (a) 4.6×10^{-35} (b) $- 95.3 \text{ kJ mol}^{-1}$, 5.04×10^{16}

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Chemorganisers

Weak Acids and Weak Bases

Problem

Methanoic acid, HCOOH, is a weak acid with $K_a = 1.7 \times 10^{-4}$. For the methanoic acid:

(a) Write out the K_a expression.

(b) Calculate the $[H^+]$ and the pH of a 4.5×10^{-4} mol L^{-1} solution of the acid in water.

(c) Calculate the percent ionisation.

Before you start

* A weak acid (HA) is one which does not dissociate to any great extent.
  HA (aq) ==== H^+ (aq) + A^- (aq) (The position of equilibrium normally lies well to the left)
  Conveniently, it is true that acids and bases tend either to be weak as most organic acids in solution (less than 5% ionised) or strong (approaching100% ionised).
* Percent ionisation = (amount ionised in mol L^{-1} / initial concentration in mol L^{-1}) x 100
* For the equilibrium of a weak acid in aqueous solution, the equilibrium constant can be expressed as: $K_a = [H^+][A^-]/[HA]$
  The symbol K_a is used for the equilibrium constant which refers to the ionisation of an acid. The value of K_a gives a measure of the strength of the acid. (K_b is used for the ionisation of weak base).
* Consider the following example, a 0.10 mol L^{-1} solution of HCN, assume the concentration will be almost 0.10 mol L^{-1} with respect to undissociated molecules.
  The equilibrium is: HCN (aq) ==== H^+ (aq) + CN^- (aq) $K_a = 4.8 \times 10^{-10}$
  The expression for K_a will be: $K_a = [H^+][CN^-]/[HCN]$
  Each molecule of HCN that dissociates will give one hydrogen ion for each cyanide ion produced: $[CN^-] = [H^+]$
  Using this in the relationship for K_a: $K_a = [H^+]^2/[HCN]$
  Substituting the values gives: $K_a = 4.8 \times 10^{-10} = [H^+]^2 / 0.10$
  $[H^+] = 6.9 \times 10^{-6}$ mol L^{-1}
  The pH of the solution is therefore given by: pH = - log $[H^+]$ = 5.2
  Note: a 0.10 mol L^{-1} solution of a strong acid in water would give a pH of 1. HCN gives a pH of 5.2, arising from a concentration of hydrogen ions of 6.9×10^{-6} mol L^{-1}. This indicates that the extent of ionisation is around 1%.
* Similarly, the same considerations apply to weak bases.

Concepts

Weak acid, weak base, strong acid, strong base, equilibrium, pH, ionisation constant of weak acid (K_a) and for weak base (K_b), dissociation, percent ionisation.

Strategy

* Write the ionisation equilibrium for the weak acid.
* Write out the equilibrium constant expression
* Substitute the equilibrium concentration values into the equilibrium constan expression
* Find the concentration of the hydrogen ion
* Calculate the pH

Solution

* HCOOH (aq) === H^+ (aq)+ $HCOO^-$ (aq)
* $K_a = [H^+][HCOO^-]/[HCOOH]$
  Each molecule of HCOOH that dissociates will give one hydrogen ion for each methanoate ion produced: $[HCOO^-] = [H^+]$
  Using this in the relationship for K_a: $K_a = [H^+]^2 / [HCOOH]$
  Substitute values into the expression $1.7 \times 10^{-4} = [H^+]^2 / 4.5 \times 10^{-4}$
  Solve for $[H^+]$ $[H^+]^2 = 1.7 \times 10^{-4} \times 4.5 \times 10^{-4} = 7.7 \times 10^{-8}$
  $[H^+] = \sqrt{(7.7 \times 10^{-8})} = 2.77 \times 10^{-4}$ mol L^{-1}
* $[H^+] = 2.77 \times 10^{-4}$ mol L^{-1}
  therefore, pH = - log $[H^+]$ = - log (2.77×10^{-4}) = 3.56

Self assessment

(a) Methylamine, CH_3NH_2, is a weak base with $K_b = 4.4 \times 10^{-4}$. In water the following equilibrium is established: $CH_3NH_2 + H_2O$ === $CH_3NH_3^+ + OH^-$
Write out the expression for K_b for methylamine.
Calculate the $[H^+]$ and the pH of a 5×10^{-3} mol L^{-1} solution of methylamine in water.

(b) A 0.10 mol L^{-1} aqueous solution of acetic acid, $HC_2H_3O_2$, is 1.3 % ionised at 25 °C. What is the value of K_a for acetic acid at this temperature?

Reminder

** Do not confuse a weak acid with a dilute acid. A weak acid has a small K_a, and a dilute acid has a low concentration. It is possible to have a dilute, strong acid or a concentrated, weak acid.

** There are very few strong acids and bases. Common acids are HCl, HBr, HI, $HClO_4$, HNO_3, and the first ionisation of H_2SO_4 and H_3PO_4. Common bases are the hydroxides of metals like Li, Na, K, Mg,Ca, and Ba.

** Ion product for water, $K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$

Answers: (a) 6.76×10^{-12}, 11.17 (b) 1.7×10^{-5}

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Chemorganisers

pH Calculations

One of the most frequent uses for common logarithms in chemistry is in working pH problems.

Problem

(a) What is the pH of a solution whose hydrogen ion concentration is 0.015 M ?

(b) If the pH of a solution is - 3.80, what is its hydrogen ion concentration?

Before you start

* The pH is defined as - log [H+], where [H+] is the hydrogen ion concentration of a solution. H^+ concentration [H+] is measured in moles per litres.

Concepts

pH, solution, concentration, common logarithm, log, antilog, [H+] .

Strategy

(a) **To determine the pH**, use your scientific calculator : find the **log** key.

(1) Input the number 0.015 by typing in the numbers on the keyboard

(2) Depress the **log** key

(3) Read the display and take the negative value: pH = **-** log [H+]

(b) **To determine [H+]**, take the antilog of the pH value (3.80), sign changed.

In your scientific calculator you will find a $\mathbf{10^x}$ key.

(1) Input the number - 3.80 by typing in the numbers on the keyboard

(2) Depress the **shift** or **INV** key then depress the $\mathbf{10^x}$ key

(3) Read the display

Solution

(a) pH = - log [H+]
= - log 0.015
= - (-1.824) = 1.824

(b) pH = - log [H+] = 3.80

therefore log [H+] = - 3.80

[H+] = antilog (- 3.80)
= 1.59×10^{-4}

Self assessment

(a) What is the pH of the following solutions:

(i) 0.1 M HNO_3

(ii) 0.5 M HCl

(b) If the pH of a solution is 7, what is its hydrogen ion concentration?

Summary

* The pH is defined as - log [H+], where [H+] is the hydrogen ion concentration of a solution.
* **pH = - log [H+]**

Answer: (a i) 1 (a ii) 0.3 (b) 1×10^{-7}

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pH and pOH Calculations

Problem

(a) What is the pH of a solution whose hydrogen ion concentration is 0.015 mol L^{-1}?
(b) If the pH of a solution is 3.80, what is its hydrogen ion concentration?
(c) What are the pOH and pH of a 0.0125 mol L^{-1} solution of KOH?

Before you start

* Pure water ionises to form very small but equal amounts of hydrogen and hydroxide ions. $H_2O \longrightarrow H^+(aq) + OH^-(aq)$ $K_w = [H^+][OH^-] = 1.0 \times 10^{-14}$ (at 25 °C)
* Pure water is neutral, neither acidic nor basic, and at 25 °C, $[H^+] = [OH^-] = 1.0 \times 10^{-7}$.
* When an acid is added to pure water, $[H^+]$ becomes larger than 1.0×10^{-7} mol L^{-1}, and $[OH^-]$ becomes less than 1.0×10^{-7} mol L^{-1}, but not zero. Similarly, when a base is added to water, $[OH^-]$ becomes larger than 1.0×10^{-7} mol L^{-1}, and $[H^+]$ decreases but not to zero.
* $[H^+]$ tend to be very small numbers, e.g. 10^{-1} to 10^{-13}, rather than expressing $[H^+]$ as some very small number, it is often more convenient to describe it in term of pH. The pH of a solution is the negative logarithm of the hydrogen ion concentration, $[H^+]$, defined as: $pH = -\log[H^+]$
Where, p is a notation for the negative common logarithm.
[Common logarithm is used to the base 10, and $[H^+]$ is measured in mol L^{-1}]
* The pOH of a solution is the negative logarithm of the hydroxide ion concentration.
$pOH = -\log[OH^-]$
* $[H^+][OH^-] = K_w = 1.0 \times 10^{-14}$
It is possible to show that as: $pH + pOH = pK_w = 14.00$
it follows that: $pH + pOH = 14.00$

Concepts

pH, pOH, solution, concentration, common logarithm, log, antilog, $[H^+]$, $[OH^-]$.

Strategy

(a) **To determine the pH**, use your scientific calculator : find the **log** key.
(1) Input the number 0.015 by typing in the numbers on the keyboard
(2) Depress the **log** key
(3) Read the display and take the negative value: $pH = -\log[H^+]$

(b) **To determine $[H^+]$**, take the antilog of the pH value (3.80), sign changed.
In your scientific calculator you will find a **log** key.
(1) Input the number - 3.80 by typing in the numbers on the keyboard then ± key
(2) Depress the **shift** or **INV** key then depress the **log** key
(3) Read the display

(c) **To determine the pOH**, use the same method as in (a) above.
Then you can find pH from: $pH + pOH = 14.00$

Solution

(a) $pH = -\log[H^+] = -\log 0.015$
$= -(-1.824) = 1.824$

(b) $pH = -\log[H^+] = 3.80$
$\log[H^+] = -3.80$
taking antilog for both sides gives
$[H^+] = 1.59 \times 10^{-4}$

(c) $pOH = -\log[OH^-] = -\log 0.0125$
$= -(-1.90) = 1.90$
The pH can be found from the pOH.
$pH + pOH = 14.00$
$pH = 14.00 - pOH = 14.00 - 1.90 = 12.10$

Self assessment

(a) What is the pH of the following solutions:
(i) 0.50 mol L^{-1} HCl
(ii) 0.01 mol L^{-1} HI
(b) If the pH of a solution is 7, what is its hydrogen ion concentration?
(c) What is the concentration of hydroxide ions in an aqueous solution containing 0.042 mol L^{-1} KOH? What is the pOH of such a solution?
(d) What is the hydrogen ion concentration in the following aqueous solutions?
(i) 0.015 mol L^{-1} HNO_3
(ii) 0.01 mol L^{-1} NaOH
(e) What are the pH and pOH of a 0.0125 mol L^{-1} solution of HCl?

Summary

* In general:
$pH = -\log[H^+]$
$pOH = -\log[OH^-]$
$pH + pOH = 14.00$
* A neutral solution has a pH of 7.00 at 25 °C. While the pH of an acidic solution is less than 7, and for a basic solution pH is greater than 7

Answer: (a) 0.3 , 2 (b) 1×10^{-7} (c) 0.042, 1.38 (d) 0.015 , 1×10^{-12} (e) 1.90, 12.10

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Chemorganisers

Buffer Solutions

Problem

Calculate the pH of a buffer that is a mixture of 0.10 mol L^{-1} acetic acid and 0.10 mol L^{-1} sodium acetate. [K_a = 1.8 x 10^{-5}]

Before you start

* When the salt of a weak acid is dissolved in a solution of the weak acid, the resulting solution is observed to be resistant to pH change. For example, addition of small amounts of strong acids or alkalis to such a solution causes little alteration to its pH. Such a solution is known as a **buffer solution**, which have the unusual and valuable property that they can be diluted without appreciable change in pH.
* Equilibrium constants remain unchanged (at any given temperature). It is the concentrations of ions and molecules which adjust to maintain constant values of the equilibrium constants.
* Consider the buffer solution containing acetic acid and its salt, sodium acetate.
  The salt is, of course, fully ionised: CH_3COONa (s) ----> Na^+ (aq) + CH_3COO^- (aq)
  The acid is only slightly ionised: CH_3COOH (aq) ==== H^+ (aq) + CH_3COO^- (aq)
  The high concentration of acetate ions (from the salt) tends to drive the acid equilibrium to the left. Any addition of acid to the buffer has little effect on the pH. This is because the huge amount of acetate ions quickly converts the added hydrogen ions to unionised acetic acid molecules. The hydrogen ion concentration is maintained virtually unaltered. Small addition of alkali also have little effect on the pH. The huge amount of unionised acetic acid molecules can quickly ionise to produce sufficient hydrogen ions to react with the added hydroxide ions. Dilution has little effect in that both the hydrogen and hydroxide ions that are added can be effectively absorbed.
* This buffering action of such solutions is particularly important in biological systems where constancy of pH is essential to proper levels of enzyme activity. As an example, a pH close to 7.4 is essential human blood system is to transport oxygen efficiently.
* A similar argument can be applied to account for the buffering effect of a weak base in the presence of its salt.

Concepts

Buffer solution, weak acid, weak base, salt,strong acid, alkali, pH, concentration, ionised, slightly ionised, equilibrium, ion, molecule.

Strategy

* Write out the equilibrium constant expression
* [Acid] can be assumed to be the same because so little acid be ionised.
  [CH_3COO^-] comes almost entirely from the complete ionised salt.
  [H^+] is unknown and comes from the slightly ionisation of the acid.
* Substitute the values into the equilibrium constant expression.
* Find the concentration of the hydrogen ion then calculate the pH.

Solution

* The equilibrium expression is: K_a = [CH_3COO^-] [H^+] / [CH_3COOH]

  CH_3COOH (aq) ==== H^+ (aq) + CH_3COO^- (aq) (K_a = 1.8 x 10^{-5})
  CH_3COONa (s) ----> Na^+ (aq) + CH_3COO^- (aq) (completely ionised)

* [CH_3COOH] = 0.10 mol L^{-1} (so little be ionised)
  [CH_3COO^-] = 0.10 mol L^{-1} (comes almost entirely from the complete ionised salt)
  [H^+] = unknown (comes from the slightly ionisation of the acid)

* Substituting into K_a : K_a = [CH_3COO^-] [H^+] / [CH_3COOH]
  1.8 x 10^{-5} = (0.10) [H^+] / (0.10)
  [H^+] = 1.8 x 10^{-5} mol L^{-1}
* Find the pH pH = - log [H^+] = - log (1.8 x 10^{-5}) = 4.75

Self assessment

(a) Calculate the pH of a buffer solution composed of 0.12 mol L^{-1} benzoic acid and 0.20 mol L^{-1} sodium benzoate. [K_a = 6.5 x 10^{-5}]

(b) Assuming the total phenol / phenolate concentration is to be 0.10 mol L^{-1} . Calculate the concentrations of the buffer ions in a phenol / phenolate buffer whose pH is exactly 10.50. [K_a = 1.8 x 10^{-10}]

Summary

* Some common buffer pairs: CH_3COOH and CH_3COO^- ; NH_3 and NH_4^+;
  H_2CO_3 and HCO_3^- ; $H_2PO_4^-$ and HPO_4^-

Answers: (a) 4.41 (b) 0.085 mol L^{-1}, 0.015 mol L^{-1}

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Chemorganisers

Solubility Product, K_{sp}

Problem

The solubility product, K_{sp}, of silver iodide, AgI, is 1×10^{-16} at 25 °C. What is the solubility in $g\ L^{-1}$ of AgI at 25 °C in: (a) water

(b) 0.005 $mol\ L^{-1}$ potassium iodide, KI, solution?

[Relative atomic masses: Ag = 108 $g\ mol^{-1}$; I = 127 $g\ mol^{-1}$]

Before you start

* Consider the following example. When solid silver chloride, AgCl, is added to pure water, the equilibrium is described by the equation:

  AgCl (s) ===== Ag^+ (aq) + Cl^- (aq)

  The value of the equilibrium constant for an equilibrium involving the precipitation or dissolution of a slightly soluble electrolyte is called the **solubility product, K_{sp},** of the electrolyte. The concentration of the solid reactant does not appear in the solubility product expression: $K_{sp} = [Ag^+][Cl^-]$

  The product of the concentrations of Ag^+ and Cl^- must be equal to the solubility product when a saturated solution is in equilibrium with undissolved solute.
* Another example is when solid lead chloride, $PbCl_2$, is added to pure water, the equilibrium is described by the equation: $PbCl_2$ ===== Pb^{2+} (aq) + 2 Cl^- (aq)

  and the value of the equilibrium constant is: $K_{sp} = [Pb^{2+}][Cl^-]^2$
* This constant is the product of the concentration of the ions involved in the equilibrium, raised to the powers of their coefficients in the equilibrium equation.

Concepts

Solubility, solubility product, molar solubility, saturated solution, electrolyte, equilibrium, solute, slightly soluble, dissolution, precipitation.

Strategy

In water
- Write the balanced equation.
- Let **x** represent the moles of solid that dissolve.
- Determine the concentrations of aqueous ions stoichiometrically.
- Substitute these values into the K_{sp} expression and solve for **x**.
- Multiply the molar solubility by the molecular weight to convert the unit to $g\ L^{-1}$.

In solution
- [Acid] can be assumed to be the same because so little acid be ionised.
- $[I^-]$ comes almost entirely from the complete ionised KI.
- $[Ag^+]$ is unknown and comes from the slightly ionisation of AgI.
- Substitute the values into the K_{sp} expression and solve for $[Ag^+]$.
- Multiply the molar solubility by the molecular weight to convert the unit to $g\ L^{-1}$

Reminder

* In a solubility equilibrium such as: AgI (s) ======= Ag^+ (aq) + I^- (aq) adding either Ag^+ or I^- will shift the equilibrium to the left, reducing the solubility of AgI

Solution

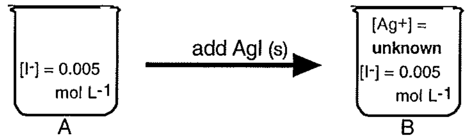
(a) **in water**

* If x moles of AgI is dissolved in 1 litre, at equilibrium $[Ag^+] = [I^-] = \mathbf{x}\ mol\ L^{-1}$.
* substituting into the K_{sp} expression gives $K_{sp} = [Ag^+][I^-] = [\mathbf{x}][\mathbf{x}] = 1 \times 10^{-16}$
* solving for **x** gives $\mathbf{x}^2 = 1 \times 10^{-16}$

  $\mathbf{x} = \sqrt{(1 \times 10^{-16})} = 1 \times 10^{-8}\ mol\ L^{-1}$
* to convert the molar solubility to grams to get the solubility in $g\ L^{-1}$

  $\mathbf{x} = 1 \times 10^{-8}\ mol\ L^{-1} \times 235\ g\ mol^{-1} = 2.35 \times 10^{-6}\ g\ L^{-1}$

(b) **in 0.005 $mol\ L^{-1}$ KI solution**



* In beaker A, because almost all the I^- in solution comes from the dissolved KI.

  $[I^-] = 0.005\ mol\ L^{-1}$
* In beaker B, after addition of AgI to KI solution,

  $[Ag^+]$ = unknown
* Substituting these values in the K_{sp} expression,

  $K_{sp} = [Ag^+][I^-] = [Ag^+][0.005] = 1 \times 10^{-16}$
* solving for $[Ag^+]$ gives

  $[Ag^+] = 1 \times 10^{-16} \div 0.005 = 2 \times 10^{-14}\ mol\ L^{-1}$
* to convert the molar solubility to grams to get the solubility in $g\ L^{-1}$.

  $[Ag^+] = 2 \times 10^{-14}\ mol\ L^{-1} \times 235\ g\ mol^{-1} = 4.7 \times 10^{-12}\ g\ L^{-1}$

Self assessment

(a) The equation for the dissolution of Hg_2Cl_2 is:

Hg_2Cl_2 (s) ======= $Hg_2^{\ 2+}$ (aq) + 2 Cl^- (aq)

Calculate the molar solubility of Hg_2Cl_2 if $K_{sp} = 1.1 \times 10^{-18}$? Remember $2[Hg_2^{\ 2+}] = [Cl^-]$

(b) The solubility product, K_{sp}, of silver chloride, AgCl, is 1.8×10^{-10} at 25 °C. What is the molar solubility of silver chloride.

Answers: (a) $6.5 \times 10^{-7}\ mol\ L^{-1}$ (b) $1.3 \times 10^{-5}\ mol\ L^{-1}$

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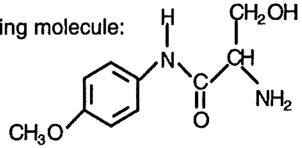
Chemorganisers

Functional Groups

Problem

Identify the four functional groups in the following molecule:



Before you start

* Organic compounds are organised into families of compounds which are known by **functional groups** (Atoms or groups of bonded atoms responsible for similar physical and chemical properties in the family of compounds)
* The study of organic compounds is organised into manageable groups of compounds whose reactivity is predictable.
* A functional group is the part of a molecule that effectively determines the compound's chemical properties (and many of its physical properties as well). For example, the functional group of an alkene is its carbon-carbon double bond.

** **For more detail turn over.**

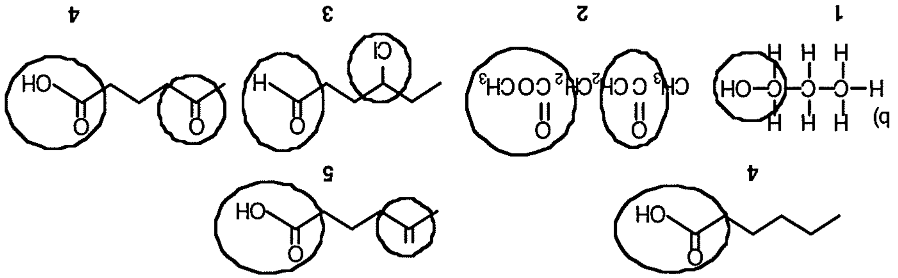
Concepts

Functional group, atom, physical property, chemical property, compound, reaction.

Strategy

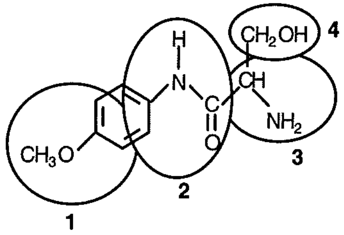
* Search for the different type of functional groups from one side to the other.
* Circle the functional groups

Answers: a) CH_3CH_2CCH 1 CH_3NHCH_3 2 CH_3CH_2COOH 3

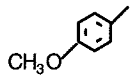


Solution

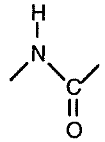
* Circle the functional groups



* The functional groups are:



1



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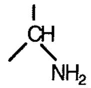

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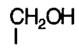
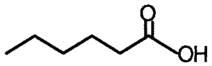


4

Self assessment

a) Identify the functional groups contained in each of the following structures:

CH_3CH_2CCH 1 CH_3NHCH_3 2 CH_3CH_2COOH 3



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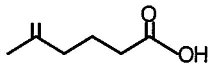

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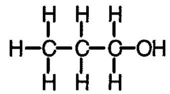
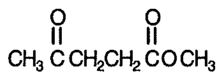
b) Identify the oxygen-containing functional groups in each of the following compounds:



1



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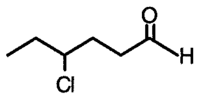

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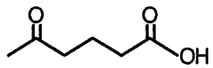

4

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Important Families Of Organic Compounds

Family	Example	IUPAC Name	General Formula	Functional Group
Alkanes	CH_3CH_3	Eth**ane**	R - H	C - H and C - C bonds
Alkenes	$CH_3CH=CH_2$	Prop**ene**	$RCH=CH_2$	$>C=C<$
	$CH_3CH=CHCH_3$	2-But**ene**	$RCH=CHR$	
	$(CH_3)_2C=CHCH_3$	2-Methyl-2-but**ene**	$R_2C=CHR$	
	$(CH_3)_2C=C(CH_3)_2$	2,3-Dimethyl-2-but**ene**	$R_2C=CR_2$	
Alkynes	$CH_3C\equiv CH$	Prop**yne**	$RC\equiv CH$	$-C\equiv C-$
	$CH_3C\equiv CCH_3$	2-But**yne**	$RC\equiv CR$	
Haloalkanes	CH_3CH_2Cl	**Chloro**ethane	R - X (X = F, Cl, Br, I)	$-\overset{\vert}{\underset{\vert}{C}}-X$
Aromatics		Benzene	Ar - H	Aromatic Ring
Alcohols	CH_3CH_2OH	Ethan**ol**	R - OH	$-\overset{\vert}{\underset{\vert}{C}}-OH$
Ethers	CH_3OCH_3	**Methoxy**methane	R - O - R	$-\overset{\vert}{\underset{\vert}{C}}-O-\overset{\vert}{\underset{\vert}{C}}-$
Aldehydes	CH_3CHO	Ethan**al**	$R-\overset{O}{\overset{\Vert}{C}}-H$	$-\overset{O}{\overset{\Vert}{C}}-H$
Ketones	CH_3COCH_3	Propan**one**	$R-\overset{O}{\overset{\Vert}{C}}-R$	$-\overset{\vert}{\underset{\vert}{C}}-\overset{O}{\overset{\Vert}{C}}-\overset{\vert}{\underset{\vert}{C}}-$
Carboxylic Acids	CH_3COOH	Ethan**oic Acid**	$R-\overset{O}{\overset{\Vert}{C}}-O-H$	$-\overset{O}{\overset{\Vert}{C}}-OH$
Esters	CH_3COOCH_3	Methyl ethan**oate**	$R-\overset{O}{\overset{\Vert}{C}}-O-R$	$-\overset{O}{\overset{\Vert}{C}}-O-\overset{\vert}{\underset{\vert}{C}}-$
Amides	CH_3CONH_2	Ethan**amide**	$R-\overset{O}{\overset{\Vert}{C}}-NH_2$	$-\overset{O}{\overset{\Vert}{C}}-\underset{\vert}{N}-$
	$CH_3CONHCH_3$		$R-\overset{O}{\overset{\Vert}{C}}-NHR$	
	CH_3CONH_2		$R-\overset{O}{\overset{\Vert}{C}}-NH_2$	
	$CH_3CONHCH_3$		$R-\overset{O}{\overset{\Vert}{C}}-NHR$	
Amines	CH_3NH_2	Methan**amine**	RNH_2	$-\overset{\vert}{\underset{\vert}{C}}-\underset{\vert}{N}-$
	$(CH_3)_2NH$	N-methylmethan**amine**	R_2NH	
	$(CH_3)_3N$	N,N-dimethylmethan**amine**	R_3N	

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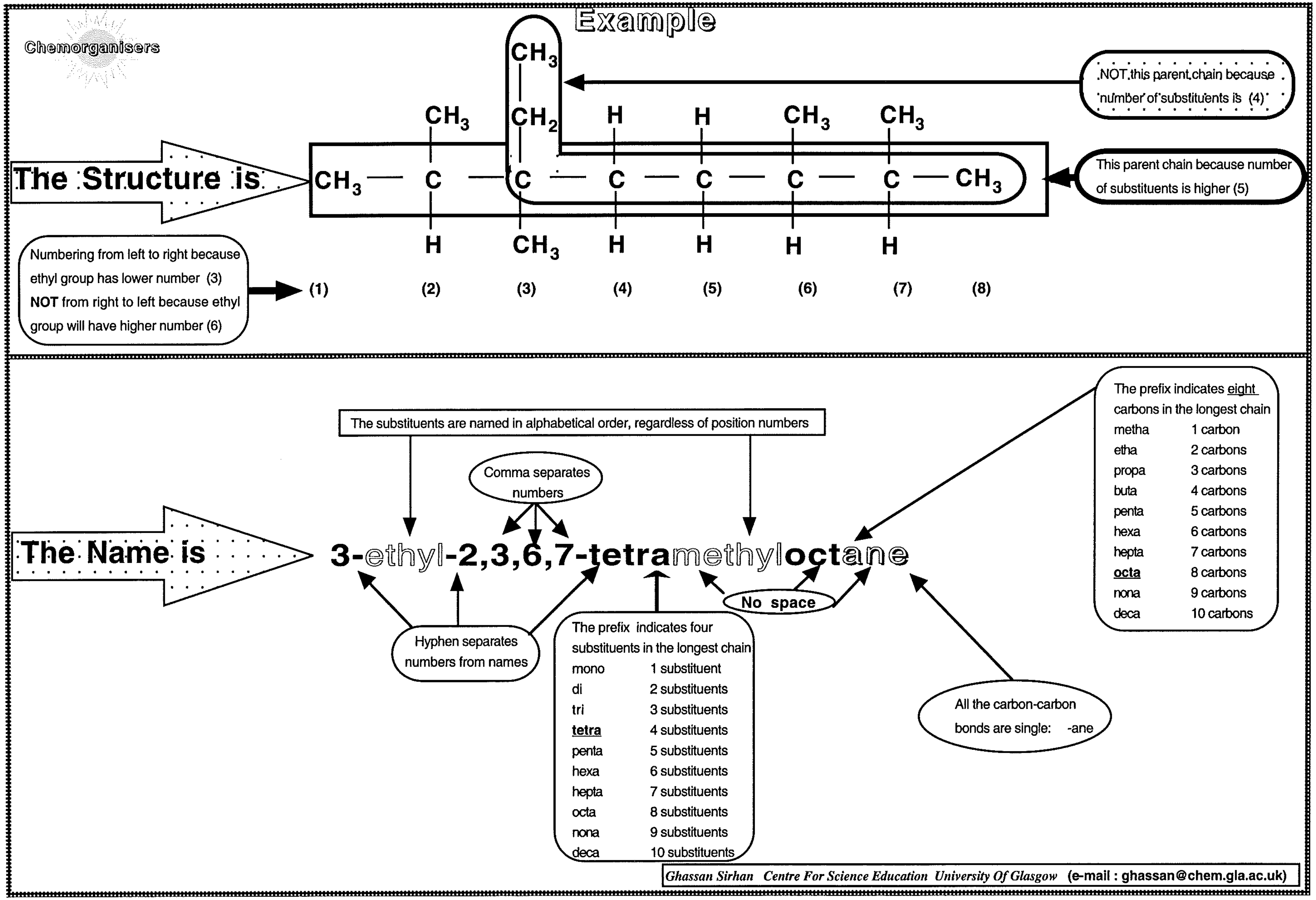
Example
Chemorganisers
The Structure is
NOT this parent chain because number of substituents is (4)
This parent chain because number of substituents is higher (5)
Numbering from left to right because ethyl group has lower number (3)
NOT from right to left because ethyl group will have higher number (6)
(1) (2) (3) (4) (5) (6) (7) (8)
The Name is
3-ethyl-2,3,6,7-tetramethyloctane
The substituents are named in alphabetical order, regardless of position numbers
Comma separates numbers
Hyphen separates numbers from names
No space
The prefix indicates four substituents in the longest chain
mono 1 substituent
di 2 substituents
tri 3 substituents
tetra 4 substituents
penta 5 substituents
hexa 6 substituents
hepta 7 substituents
octa 8 substituents
nona 9 substituents
deca 10 substituents
The prefix indicates eight carbons in the longest chain
metha 1 carbon
etha 2 carbons
propa 3 carbons
buta 4 carbons
penta 5 carbons
hexa 6 carbons
hepta 7 carbons
octa 8 carbons
nona 9 carbons
deca 10 carbons
All the carbon-carbon bonds are single: -ane
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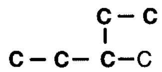
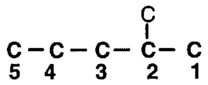
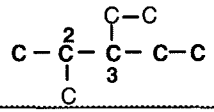
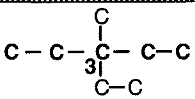
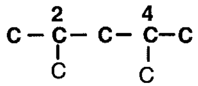
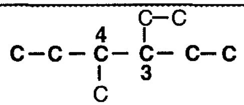
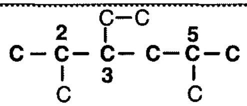
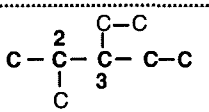
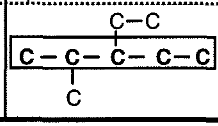
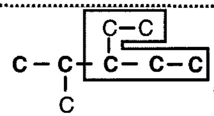
Chemorganisers

How You Name An Organic Compound ?

Example	Name	Rule	Explanation
	3-Methyl**pentane**	Locate the longest continuous chain of carbon . (parent chain)	The chain with 5 C atoms is the longest continuous chain, and the name is pentane. (**Pent** = 5 C, **-ane** is the ending for alkane)
	**2-Methyl**pentane	Number the longest chain beginning with the end of the chain nearer the substituent.	**2-Methyl**pentane NOT **4-Methyl**pentane because it should have the smallest number.
	3-Ethyl-**2**-methylpentane	When two or more substituents are present, give each a number corresponding to its location on the longest chain	**3**-Ethyl-**2**-methylpentane NOT **3**-Ethyl-**4**-methylpentane Number the longest chain beginning at the end nearest to the first branch point.
	3-Ethyl-**3**-methylpentane	When two substituents are present on the same carbon atom, use that number twice.	Each substituent is connected to carbon 3.
	**2,4-di**methylpentane	When two or more substituents are identical, indicate this by the use of the prefixes di-, tri-, tetra-, and so on.	The prefixes which used are: 1 = mono, 2 = di, 3 = tri, 4 = tetra, 5 = penta, 6 = hexa, 7 = hepta, 8 = octa, 9 = nona, 10 = deca.
	3-Ethyl-4-methylhexane	If there is no third branch, begin numbering nearest the substituent whose name has alphabetic priority	**E**thyl is before **m**ethyl in alphabetical order regardless of the position number.
	3-Ethyl-2,5-dimethylhexane	If the first branch occurs at an equal distant from each end of the longest chain, begin numbering nearest to a third branch.	3-Ethyl-2,5-dimethylhexane NOT 4-Ethyl-2,5-dimethylhexane For methyl groups its the same 2 and 5, but ethyl should have 3 not 4 (3 is the smallest number)
	3-Ethyl-2-methylpentane	If there are two equally long continuous chains, select the one with the most branches.	 Has ethyl and methyl groups  Has only isopropyl group

Notes:

1) Write out the name as one word

2)The parent name is placed last

3) Substituent should be listed alphabetically (i.e., ethyl before methyl).

4) In deciding on alphabetical order disregard multiplying prefixes such as “di” and “tri” .

5) Each and every substituent should has a number placed first.

6) Numbers are separated from words by a hyphen.

7) Commas are used to separate numbers from each other

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Chemorganisers

Functional Groups Nomenclature Summary

Family	Example	Name	Explanation
Alkyl Groups	CH_3 -	Methyl	Removal of hydrogen atom from methane CH_4
	CH_3CH_2 -	Ethyl	Removal of hydrogen atom from either end of ethane CH_3CH_3
	$CH_3CH_2CH_2$ -	Propyl	Removal of hydrogen atom from either end of propane $CH_3CH_2CH_3$
	$CH_3\overset{\mid}{C}HCH_3$	Isopropyl	Removal of hydrogen atom from middle C of propane $CH_3CH_2CH_3$
	$CH_3(CH_2)_2CH_2$ -	Butyl	Removal of hydrogen atom from either end of butane $CH_3(CH_2)_2CH_3$
	$CH_3CH_2\overset{\mid}{C}HCH_3$	*sec*-butyl	Removal of hydrogen atom from either of any interior C of butane $CH_3(CH_2)_2CH_3$
	$CH_3\overset{CH_3}{\overset{\mid}{C}}HCH_2$ -	Isobutyl	Removal of hydrogen atom from any CH_3 group of isobutane $CH_3\overset{CH_3}{\overset{\mid}{C}}HCH_3$
	$CH_3\underset{\mid}{\overset{CH_3}{\overset{\mid}{C}}}CH_3$	*tert*-butyl	Removal of hydrogen atom from middle C of isobutane $CH_3\overset{CH_3}{\overset{\mid}{C}}HCH_3$
Alcohols	$CH_3CH_2CH_2CH_2OH$	1-Butanol	Replacing the final **-e** of the name of the corresponding alkane with **-ol** [Give the C attached to -OH group the smallest number]
Aldehydes	$CH_3CH_2CH_2CHO$	Butanal	Replacing the final **-e** of the name of the corresponding alkane with **-al** [Start numbering from the C of the CHO group]
Ketones	$CH_3COCH_2CH_2CH_3$	2-Pentanone	Replacing the final **-e** of the name of the corresponding alkane with **-one** [Give the C of -CO group the smallest number]
Carboxylic Acids	$CH_3CH_2CH_2COOH$	Butanoic Acid	Replacing the final **-e** of the name of the alkane corresponding to the longest chain in the acid by **-oic acid**.
Esters	$CH_3COOCH_2CH_3$	Ethyl ethanoate	Replace the final **-ol** of the alcohol with **-yl** then replacing the final **-oic acid** of the corresponding acid by **-oate**.
Acid Chlorides	CH_3CH_2COCl	Propanoyl Chloride	Replacing the final **-oic acid** of the acid by **-yl chloride**.
Anhydrides	$CH_3COOCOCH_3$	Ethanoic anhydride	Replacing the word **acid** from the name of the carboxylic acid by the word **anhydride**.
Amides	$CH_3CH_2CONH_2$	Propanamide	Replacing the final **-oic acid** of the acid by **amide**.
Amines (Primary)	$CH_3CH_2NH_2$	Ethanamine	Replacing the final **-e** of the name of the corresponding alkane to which the -NH_2 group is attached by **amine**
(Secondary)	$CH_3CH_2NHCH_3$	N-methylethanamine	Adding N- and the name of the smallest alkyl group attached to the amino group before the name, as in primary amine above
(Tertiary)	$(CH_3CH_2)_3N$	N,N-diethylethanamine	Adding N,N-di and the name of alkyl groups attached to the amino group before the name, as in primary amine above.

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Chemorganisers

Formal Charge

Problem

Calculate the formal charge on the nitrogen atoms in the following:

a) $\ddot{N}H_3$ b) $CH_3\ddot{N}H_2$

Before you start

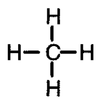
* When we write Lewis structures, it is often convenient to assign unit positive or negative charges, called **formal charges**, to certain atoms in the molecule or ion. This is nothing more than a bookkeeping method for electrical charges, because the arithmetic sum of all the formal charges equals the total charge on the molecule or ion.
* Consider methane CH_4 as an example. To calculate the formal charge at C atom you can use this equation: **Formal charge (F) = Z - S - U**

  [where **Z** is the group number on the periodic table (= the number of valence electrons in a neutral free atom).

  S is the number of shared electrons (= the number of bonds)

  U is the number of unshared electrons].

  To solve for the formal charge on C atom, write Lewis structure for methane

  and find the values of **Z** = 4, **S** = 4, and **U** = 0

  The **Formal charge (F) = Z - S - U = 4 - 4 - 0 = 0**

* There are often important chemical consequences when a neutral molecule contains centres whose formal charges are not zero. It is important that you be able to recognise these situations so you can understand the chemical reactivity of such molecules.

Concepts

Formal charge, Lewis structure, atom, molecule, ion, group number, valence electrons, shared electrons, unshared electrons.

Reminder

** Each bond consists of two electrons, one from each atom forming that bond. So in single bond 1 e from each, in double bond 2 e's from each, and in triple bond 3 e's from each.

** Unshared electron pairs represented as (:) or (-)

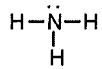
Strategy

* Draw Lewis structure
* Find for each individual atom:
  - its group number (Z) on the periodic table.
  - its number of shared electrons (S).
  - its number of unshared electrons (U).
* Calculate the formal charge by using the following formula:

  Formal charge (F) = Z - S - U

Solution

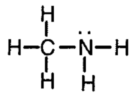
a) For $\ddot{N}H_3$ Lewis structure is



Z = 5 **S** = 3 **U** = 2

Formal charge (F) = Z - S - U = 5 - 3 - 2 = 0

b) For $CH_3\ddot{N}H_2$ Lewis structure is



Z = 5 **S** = 3 **U** = 2

Formal charge (F) = Z - S - U = 5 - 3 - 2 = 0

Self assessment

a) Assign the formal charges for O and N atoms in the following:

i) H - Ö - C ≡ N: ii) H - O - N ≡ C:

b) What is the formal charge of the nitrogen atoms in the following structures:

i) $[CH_3 NH_3]^+$ ii) CH_3 - N̈ = N = N̈:

Summary

* Molecules have no net electrical charge. They are neutral by definition. Therefore, the sum of the formal charges on each atom making up a molecule must be zero. For example, CH_4 and H_2O.
* The arithmetic sum of all the formal charges equals the total charge on the molecule or ion
* An alternative method for calculating formal charge is to use the equation:

Formal charge	= number of valence electrons in free atom	- number of valence electrons after bonding
	= number of electrons before bonding	- number of electrons after bonding

Answers: a) i) O = 0, N = 0 ii) O = +1, N = +1 b) i) N = +1 ii) from left N = 0, N = +1, N = -1

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Structure Representation

Chemorganisers

Problem

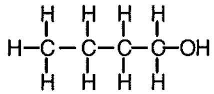
Represent 2-butanol in the following structural formulae:

a) a dash-line   b) condensed   c) a 'stick'   d) three-dimension

Before you start

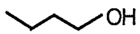
* To understand the chemistry of organic compounds, it is necessary to represent the structures of a molecule by a structural formula that shows the arrangement of atoms and bonds. For example, 1-butanol can be representing in different ways:

Dash structural formula (Expand)

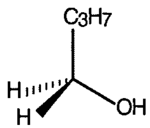


Condensed structural formula $CH_3CH_2CH_2CH_2OH$ or $CH_3(CH_2)_2CH_2OH$

'Stick' structural formula



Three-dimentional formula



Concepts

Representation, structural formula, dash-line, condensed, 'stick', three-dimention.

Strategy

(Examples are shown in before you start section)

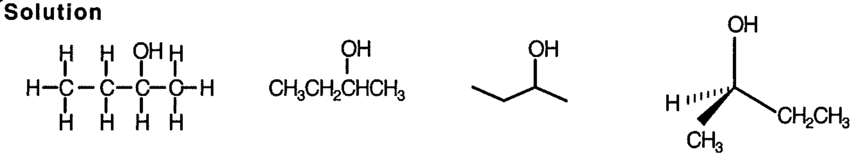
a) A dash-line structural formula
  * Write the longest carbon chain and number it.
  * Connect the substituents (groups) to the correct carbon atoms by a dash-line.
  * Provide each carbon atom with the proper number of hydrogen atoms to provide four bonds. (Note: the angles between the bonds are shown as 90°)

b) Condensed structural formula
  * The same as above but show only specific bonds (C-H bond need not be shown)
  * Represent repeated structural subunits which large structures may possess by grouping the subunits within parentheses.

c) A 'stick' structural formula
  * Arrange the carbon atoms in a zigzag manner (C and H atoms are not shown).
  * A carbon atom is assumed to be at the end of each line or at the intersection of lines.
  * Multiple bonds shown with multiple lines (atoms such as oxygen must be shown)

d) The three-dimensional shape of molecules on paper is shown by:
  * The wedge is viewed as a bond extending out of the plane of the page toward you.
  * The dot-line represents a bond directed behind the plane of the page.
  * The continuous line is a bond in the plane of the page.

Solution

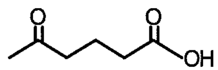


a) a dash-line   b) condensed   c) a 'stick'   d) three-dimension

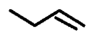
Self assessment

a) Represent 2-chlorobutane and hexanoic acid as
  i) a condensed structural formula   ii) a 'stick' formula

b) Write a more detailed structural formula for
  i) $CH_3(CH_2)_2CH_3$ ii)

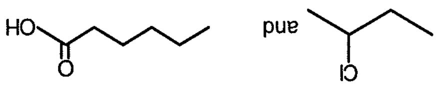


c) Name carefully the hydrocarbon represented by the 'stick' formula

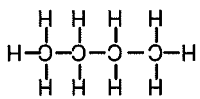


Answers: a) i) $CH_3CH_2CHClCH_3$ and $CH_3(CH_2)_4COOH$ or $CH_3CH_2CH_2CH_2CH_2COOH$

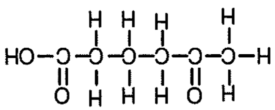
ii)



b) i)



ii)



c) 1-butene

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Chemorganisers

Structural Isomers

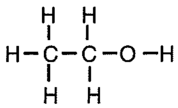
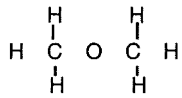
Problem

Write structural formulae of your choice for all of the structural isomers with the molecular formula C_4H_{10}

Before you start

* Different compounds that have **the same molecular formulae**, but differ in their **connectivity**, that is, in the sequence in which their atoms are bonded together, are called **isomers**.
* **Isomers** usually have **different physical properties** (e.g., melting point, boiling point, and density) and **different chemical properties**.

Let us consider the following example:

Different	Structure		
	Name	ethanol	dimethyl ether
	State at room temperature	liquid	gas
	M.p. (°C)	- 117.3	- 138.0
	B.p. (°C)	78.5	- 24.9
	Reaction with Na	reacts	does not react
Same	Number of bonds	8	8
	Molecular formula	C_2H_6O	C_2H_6O
	Formular weight	46	46

** The two compounds differ in their **connectivity**. The atoms of ethanol are connected in a way that is differnt from those of dimethyl ether .

** In ethanol there is a C-C-O- linkage, in dimethyl ether the linkage is -C-O-C-

** Ethanol has a hydrogen atom attached to oxygen, in dimethyl ether all hydrogen atoms are attached to carbon.

** It is the hydrogen atom covalently bonded to oxygen in ethanol that is displaced when this alcohol reacts with sodium.

Concepts

Structural isomers, molecular formula, connectivity, physical property,chemical property, gas, reaction, bond, ether, alcohol, reaction.

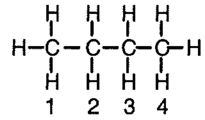
K-51

Strategy

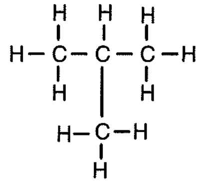
* Write the longest carbon chain and number it.
* Replace any hydrogen atom which connected to carbon number 2 in the longest chain by the CH_3 group from far end of the chain.
* Move this group if it gives you another isomer.
* If not take another CH_3 group from the other end and do the same.

Solution

* Write the longest carbon chain and number it.



* Replace any hydrogen atom which connected to carbon number 2 in the longest chain by the CH_3 group from far end of the chain (carbon 4).

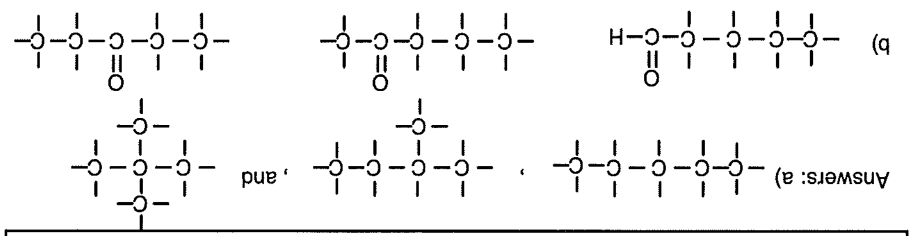


Self assessment

* Draw all possible molecules with the formula C_5H_{12}
* For the formula $C_5H_{10}O$, Draw all possible aldehyde and ketone molecules

Summary

* Structural isomers are different compounds that have the same molecular formula, but differ in their connectivity, that is, in the sequence in which their atoms are bonded together.



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Appendix K

Chemorganisers

Geometrical Isomers (Cis-Trans Isomers)

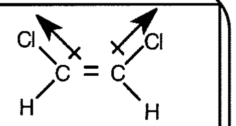
Problem

Which of the following alkenes can exist as cis-trans isomers? Write their structures?

(a) $CH_2 = CHCH_3$ (b) $CH_3CH = CHCH_3$ (c) $CHF = CHF$

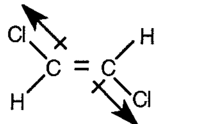
Before you start

* Restricted rotation of groups joined by a double bond causes a new type of isomerism that we illustrate with the two dichloroethenes written in the structers.
* The two planar compounds are different compounds, they are called **geometrical isomers (cis-trans isomers)**.
* They differ in the arrangement of their atoms in space. They have different physical properties (melting points, boiling points, polarities, etc.).



cis-1,2-dichloroethene

m.p.=- 80°C, b.p.= 60°C



trans-1,2-dichloroethene

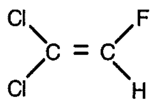
m.p.=- 50°C, b.p.= 48°C

Concepts

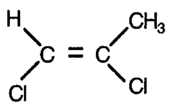
Cis-isomer, tran-isomer, alkene, rotation, group, double bond, isomerism, dash-line structural formula, polar, nonpolar.

Strategy

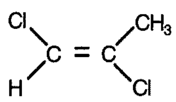
* Write the dash-line structural formula for the compound.
* Look at the carbons of the C = C
  ** No cis-trans isomers if one carbon has identical groups (or atoms).
  For example, $CCl_2 = CHF$



  ** Cis-trans isomers if each carbon has different groups (or atoms). Cis isomer if they are from the same side and trans isomer if they are from different side.
  For example, $CHCl = CClCH_3$



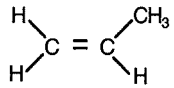
Cis-isomer



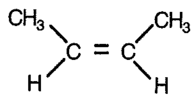
Trans-isomer

Solution

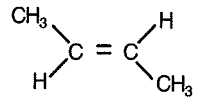
a) In $\mathbf{CH_2 = CHCH_3}$ cis-trans isomerism can not exist because one carbon atom of the C = C bears two hydrogen atoms.



b) In $\mathbf{CH_3CH = CHCH_3}$ cis-trans isomerism exists because each carbon atom of the C = C bears two different groups (or atoms) $\mathbf{CH_3}$ **group** and **H** atom.

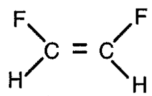


Cis-isomer

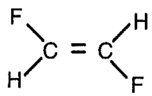


Trans-isomer

c) In **CHF = CHF** cis-trans isomerism exists because each carbon atom of the C = C bears two different atoms (**H** and **F**).



Cis-isomer



Trans-isomer

Self assessment

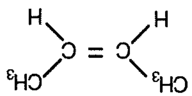
a) Write structural formulae for all of the alkenes with the formula $C_2Br_2Cl_2$

b) Which isomer of butene can exist as cis-trans isomers? Draw their structures? Decide which is polar and which is not?

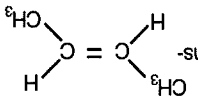
Summary

* Cis-trans isomerism is not possible if one carbon atom of the C = C bears two identical groups. For example, $CCl_2 = CHF$

b) $CH_3CH = CHCH_3$, cis-

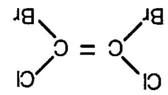


and trans-

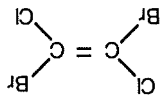


, cis is polar

Answers: a)



and



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Chemorganisers

Polarity

Problem

State which of the following are polar:

a) C-Cl b) C-C c) C-O d) CH_2Cl_2 e) CF_4

Before you start

* When two atoms of different electronegativities form a covalent bond, the electrons are not shared equally between them.
* The atom with greater electronegativity draws the electron pair closer to it, and a polar covalent bond results (Remember electronegativity is the ability of an element to attract electrons that it is sharing in a covalent bond)
* The direction of polarity of a polar bond is shown by an arrow with a cross at one end. The cross is near the end of the bond that is partially positive, and the arrow head is near the partially negative end of the bond.

  (partially positive end) +---> (partially negative end)
* Consider the hydrogen chloride molecule (HCl). Chlorine has a higher electronegativity than hydrogen, but the chlorine atom's attraction for electrons is not sufficient to remove an electron from hydrogen. Consequently, the bonding electrons in hydrogen chloride are shared unequally in a polar covalent bond. H +---> Cl

Polar	Nonpolar
When carbon forms single or multiple bonds to atoms other than carbon. { C-N, C-O, C=O }	Hydrocarbons of all types (saturated or not). { C-C, C=C }
Any diatomic molecule in which the two atoms are different. { HF, H_2O }	Any diatomic molecule in which the two atoms are the same. { Cl_2, H_2 }
If the molecule consist of more than two atoms, and has polar bonds but they do not cancel each other. { CH_3OH, CH_3Cl }	If the molecule consist of more than two atoms and has polar bonds but they cancel each other. { CO_2, CCl_4 }
When a carbon atom (or a hydrogen atom) is bonded to common nonmetal atoms. { C-N, C-O, C-F }	

K–53

Concepts

Polarity, polar bond, polar molecule, nonpolar bond, nonpolar molecule, nonmetal, electronegativity, covalent bond, single bond, multiple bond, atom, electron, molecule, diatomic molecule.

Strategy

* For the covalent bonds: See the **Reminder**
* For the molecules: - Draw Lewis structure
  - Indicate the polarity of each bond.
* From the shape of the molecule find if the polarity of the bonds cancels each other or not

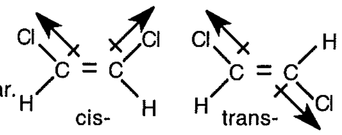
Solution

a) C-Cl polar bonds because the two atoms have different electronegativity.

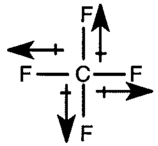
b) C-C nonpolar bond because the two atoms are similar.

c) C-O polar bond because the two atoms have different electronegativity.

d) CH_2Cl_2 the C- H bonds are nonpolar but C-Cl bonds are polar, cis-isomer is polar while trans-isomer is not polar.



e) CF_4 nonpolar molecule because the polar C- F bonds cancelled each other



Self assessment

a) Indicate bond polarity for the following compounds: CCl_4 and CH_3OH

b) Which isomer of 2-butene do you expect to have the higher boiling point?

Summary

* Large differences between the electronegativies of the bonded atoms increase the polarity of bonds.

Answers: a) C-Cl polar, C- H nonpolar, C-O polar, O-H polar b) cis-isomer

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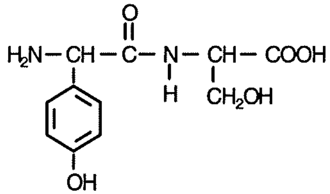
Hydrolysis

Chemorganisers

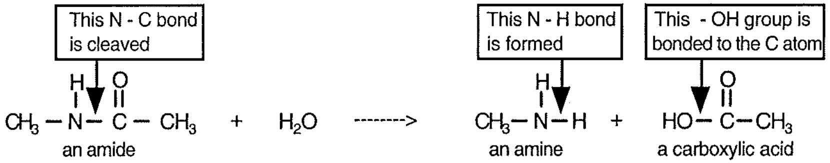
Problem

Hydrolysis of this compound in aqueous HCl gives two products. Draw these. remembering that the solution is acidic.

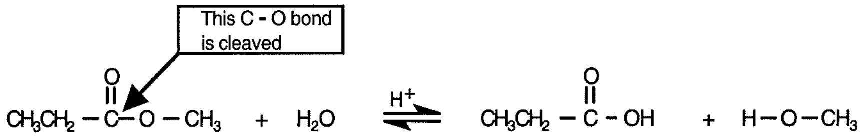


Before you start

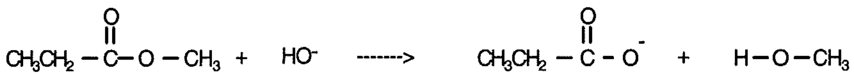
- In hydrolysis reactions water splits a large molecule into two smaller products molecules. The generalised reaction is: A - B + H_2O -----> A - H + HO - B
- Consider the hydrolysis of an amide to produce a carboxylic acid and an amine as an example of this process.



- One product molecule is bonded to a hydrogen atom derived from water. The other product is bonded to a hydroxyl group (-OH) derived from water.
- Another example is the hydrolysis of an ester to produce an acid and an alcohol



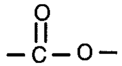
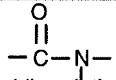
- The hydrolysis of an ester by a strong base is called **saponification**



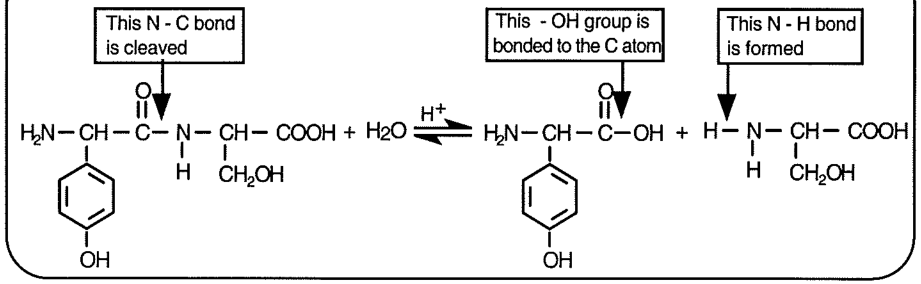
Concepts

Hydrolysis, reaction, reactant, product, molecule, atom, bond, amide, amine, carboxylic acid, hydroxyl group.

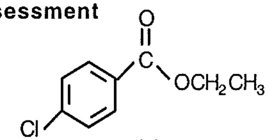
Strategy

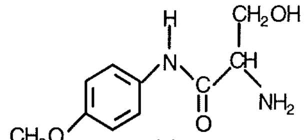
- Find the  or any other derivative linkage such as 
- Make OH bond to the carbonyl group to form carboxylic acid in acidic solution OR the salt in basic solution (saponification)

Solution



Self assessment

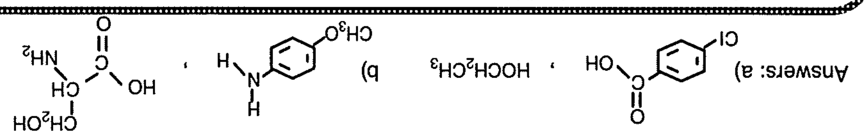

(1)


(2)

a) Draw the products from the acid-catalysed hydrolysis of (1).
b) Draw the products you expect on hydrolysis of (2) with aqueous NaOH.

Summary

	Hydrolysis	**Saponification**
Catalysed by	strong acid	strong base
Required	large excess of water	hydroxide, ester
Reaction mixture is	acidic	basic
Product is	carboxylic acid itself	carboxylate ion
Notes	the reverse of the esterification reaction	hydroxide is consumed equilibrium shift to the right(not reversible reaction),purpose to make soaps from ester



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Chemorganisers

Solubility

Problem

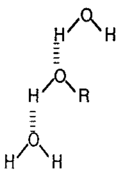
State which, in each pair, is more soluble in water:

a) CH_4 and NH_3 b) C_6H_5COOH and $C_6H_5COO^-$ Na^+ c) CH_3CH_2OH and CH_3-O-CH_3

Before you start

* A rule of thumb for predicting whether a solvent can dissolve some substance is called **like-dissolved-like** rule, where "like" refers to a likeness in polarity.

Polar solvents, such as water, are good for dissolving polar or ionic substances, like sugar or salt, because polar molecules or ions can attract water molecules around themselves.	Not polar solvents, like gasoline, do not dissolve sugar or salt, because not polar solvent molecules cannot be attracted to polar molecules or ions.



* In alcohols, the hydroxyl group (OH) is quite polar and it can both donate and accept hydrogen bonds.
* In carboxylic acids, the carboxyl group (COOH) has two oxygen atoms that can accept hydrogen bonds from water molecules. In addition the carboxyl group (COOH) has the hydroxyl group (OH) that can donate hydrogen bonds.
* The lower-formula-weight of alcohol, aldehyde, ketone, and carboxylic acid molecules form hydrogen bonds with water molecules. (This explains the water solubility)
* As the organic chain lengthens in, say alcohols and carboxylic acids they become relatively more hydrocarbon like, their water solubility decreases.
  For example, ethanol {CH_3CH_2OH} is more soluble than 1-hexanol {$CH_3(CH_2)_5OH$}
* Hydrogen bonds are weaker than ordinary covalent bonds.

Concepts

Solubility, solvent, soluble, molecule, substance, ion, polarity, alcohol, aldehyde, ketone, carboxylic acid, polar, not polar, covalent bond, hydroxyl group (OH), carboxyl group (COOH).

Strategy

Determine the polarity of the solvent

Determine the polarity of the compound

Apply the rule like-dissolves-like [polar compound dissolve in polar solvent and not polar compound dissolve in not polar solvent]

Solution

a) CH_4 is not polar compound, while NH_3 is a polar compound. Therefore, NH_3 is more soluble in water because water is a polar solvent.

b) $C_6H_5COO^-$ Na^+ is the more polar compound. Therefore, $C_6H_5COO^-$ Na^+ is more soluble in water because water is a polar solvent.

c) CH_3CH_2OH is the more polar compound. Therefore, CH_3CH_2OH is more soluble in water because water is a polar solvent.

Self assessment

Arrange the following molecules in order of increasing solubility in water:

i) methanol, 2-butanol, 2-methylpropene, butanoic acid

ii) CH_3OH, $CH_3CH_2CH_2OH$, CH_3CH_2OH

ii) 2-hexanone, hexane

iii) 1-pentanol, pentene

Summary

* Like-dissolved-like. (polar dissolved polar, not polar dissolved not polar)
* As the carbon content increases, the solubility in water decreases.

Answers: i) methanol, 2-butanol, butanoic acid, 2-methylpropene

ii) CH_3OH, CH_3CH_2OH, $CH_3CH_2CH_2OH$ iii) hexane, 2-hexanone iv) pentene, 1-pentanol

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