Making University Laboratory Work in Chemistry More Effective

by

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I dedicate this piece of work to:

my mother

who always struggled more and more to provide the facilities for a good life,

my father,

who is my ideal, and gave me help in my education at all times,

and finally,

to all my teachers who tried to show me the way to gain the knowledge.

Abstract

This study explores student perceptions of laboratory work in their first undergraduate year in a Scottish university and also asks them to reflect back on their school experiences. In a developed country like Scotland, secondary school laboratories are relatively well equipped and teaching staff are highly trained in working in the laboratory. The student perceptions about laboratory experiences in a developed country will offer a background against which laboratory instruction in a country like Pakistan can be developed. In Pakistan, laboratory work is not well organised and teaching staff are not trained. The overall aim is to enhance the laboratory learning in Pakistan, based on sound pedagogical evidence, particularly in the context of teacher training in an open learning situation. This study provides an overview of laboratory learning in chemistry in Scotland where such learning has been established for many years and an overview of laboratory learning in chemistry in Pakistan with the students in Allama Iqbal Open University.

The aims for school and university laboratory work are often ill-defined. It has been argued that laboratory work is essential in that chemistry is a practical subject but this view is inadequate. It is also possible that the student laboratory experience is of critical importance in the process of enhancing student cognitive understanding of science. Overall, laboratory work can be seen as a place which can make chemistry real for the learner but is also a place where the methods of chemistry can be illustrated, as understanding of the physical world is built up based on empirical evidence.

It is clear from the literature that, in the past, too little consideration has been given to where learning in the laboratory is effective and where it is weak. There is also a lack of evidence about functioning and effects although many have expressed disquiet over the laboratory experience. Considerable evidence has emerged that not all is well in laboratory instruction.

This study describes a survey which was conducted with 193 students and related particularly to their experience in a physical chemistry laboratory which did not involve pre-laboratory exercises. Pre-laboratory exercises were then developed for this laboratory and a second survey was conducted the following year, with a sample of 211. After the second survey, 60 students were also interviewed in groups in order to gain more information about their perceptions of the pre-laboratory exercises. A third survey was conducted with 229 first year chemistry students at the outset of their university chemistry course to explore their perceptions as they looked back on their school experience.

Surveys were then carried out in Pakistan with three different groups: first year BSc. students (229), second year BSc. students (150), and BEd. Trainee Secondary Teachers (118), all these groups being drawn from Allama Iqbal Open University, Islamabad. The aim was to explore students perception in a situation where laboratory work was not well established.

In the surveys of Scottish students' views about their school and university laboratory experiences, it is clear that, at both levels, the students have positive attitudes towards their experiences. At school level, this reflects the well organised laboratory work which is strongly integrated with other teaching. At university level, the long established place of laboratory work has led to a well organised system. The overall importance from the results of this survey was that students saw the importance of laboratory work and wished it to be a successful and satisfying experience.

In the Pakistan surveys, attitudes towards laboratory work are also positive. However, as there is little laboratory work at school, this can be seen as an indication that more is wanted while, at university, the laboratory work is much less well developed compared to Scotland and there is clear evidence that student views are becoming increasingly polarised with experience, a matter of some concern. Rigourous comparisons between Scotland and Pakistan were not considered appropriate in that the social, educational and professional structures are so very different.

In the study in Scotland, it was possible to look at a first year university laboratory over two years, before and after the introduction of pre-laboratory exercises. This revealed that it is *not* a good idea merely to 'add on' pre-laboratory exercises although students appeared to be strongly in favour of the exercises and could see their value. It also revealed how a change in learning must be undertaken with the full support of all staff involved if it is to have any chance of success.

Finally, in looking at the position of the training of secondary chemistry teachers in an open university, the evidence from work here and from the literature was used to develop the idea of paper laboratories. These were not designed to replace traditional laboratories. They were to be seen as a kind of pre-lab experience for traditional laboratories in general as well as a training for future secondary teachers in how to develop and use the laboratory experience for learning at school level. Four paper labs were devised and each involved pre-laboratory tasks, simulated laboratory tasks, and post-laboratory applications. They were tested in action in Pakistan and student perceptions of them were measured and found to be highly positive. It remains to be seen if they are effective in making the pupil experience of laboratory work in Pakistan schools more effective.

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Chapter One

Introduction

The laboratory is a place where a learner may experiment, applying skills and knowledge in seeking to gain understanding. On that basis, laboratory work is considered to be the characteristic features of science education and specially in chemistry education. It would be rare to find any sciencc course in an institution of higher education without a substantial component of laboratory work.

Laboratory work is regarded as an essential and integral part of undergraduate chemistry courses and the laboratory provides a setting for training not only in practical hand and instrument skills but also for many of the thinking, planning, recording, interpreting and group working skills that a degree course should include (Carnduff and Reid, 2003).

Of course, the question is to what extent these aims and skills are being achieved in laboratories today. Students can spend a considerable amount of time in the laboratory. It is obvious that anything that maximises what students gain from the time they are actually in the laboratory is worth doing. This might include changes in the strategy during the laboratory. It may require experiences to prepare the students in their own time before the actual experiment.

While the organisation and running of undergraduate laboratory courses can be complex and demanding of time and resources, developing meaningful laboratory experiences in an Open University context is even more daunting. In Pakistan, at Allama Iqbal Open University, science courses have introduced laboratory work on the higher level but there are science courses for Secondary School Science Teachers training (M.Ed. and B.Ed. Science Courses). The University faces a problem of laboratory teaching.

Therefore the purpose of this study is to develop some model which can offer guidance in developing laboratory work in a Distance Learning System. Allama Iqbal Open University is a Distance Learning or Open Learning University. The project will look at what is possible in school and university laboratories in order to establish the important features which allow university laboratories to be effective in reaching their goals.

1.1 Distance Education

Keegan, D. (1996) explained the educational philosophy of Open Learning emphasises giving learners choices about:

* medium or media, whether print, on-line, television or video;
* place of study, whether at home, in the work place, or any other;
* time for study, any time;
* support mechanisms, whether tutors on demand, audio conferences or computer-assisted learning; and
* entry and exit points.

According to Sparkes *et al.* (1983), the time continuum is a very important for a Distance Learning system. At one end, all learners and their tutors interact at the same time and same place, for example, face-to-face tutorials, seminars, workshops. At the other end, all learners and their tutors interact at different times and different place, for example, home study, computer conferencing, learners visit to learning resource centres at their leisure. Stewart, *et. al.* (1983) argues that the characteristics for Distance Learning Courses seen as a complete course or programme package should include all materials, tools, equipment and plans for delivery, learner support, learner evaluation and course evaluation.

Unfortunately the definition of 'distance education' is not entirely straightforward. One early definition of 'distance teaching' was put forward by Moore (1973):

> Distance teaching may be defined as the family of instructional methods in which the teaching behaviours are executed apart from the learning behaviours, including those that in a contiguous situation would be performed in the learner's presence, so that communication between the teacher and the learner must be facilitated by print, electronics, mechanical or other devices.

Moore (1980, 1983) used the term 'transactional distance', which he defined as a function of two variables, 'dialogue and structure':

> Dialogue describes the extent to which , in any educational programme, learner and educator are able to respond to each other. This is determined by the content or subject matter which is studied, by the educational philosophy of the educator, by the personalities of educator and learner, and by environmental factors, the most important of which is the medium of communication....

Keegan (1988, 1996) presented an elaborate definition. On this account, distance education is a form of education that is characterised by:

* the quasi-permanent separation of teacher and learner throughout the length of the learning process (this distinguishes it from conventional face-to-face education);
* the influence of an educational organisation both in the planning and preparation of learning materials and in the provision of student support services (this distinguishes it from private study and teach-yourself programmes);
* the use of technical media - print, audio, video or computer - to unite teacher and learner and carry the content of the course
* the provision of two-way communication so that the student may benefit from or even initiate dialogue (this distinguishes it from other uses of technology in education); and
* the quasi-permanent absence of the learning group throughout the length of the learning process so that people are usually taught as individual rather than in groups, with the possibility of occasional meetings, either face-to-face or by electronic means, for both didactic and socialisation purposes.

Bell and Tight (1993) proposed a more general definition of distance education:

> *Distance education refers to those forms of organised learning which are based on, and seek to overcome, the physical separation of learners and those (other than the learners themselves) involved in the organisation of their learning. This separation may apply to the whole learning process or only to certain stages or elements of it. Some face-to-face contact may occur, but its function will be to supplement or reinforce the predominately distance interaction...*

In fact, many institutions running programmes by distance education exploit different devices to try to narrow the transactional distance between the teachers and the students. These include tutorials or self-help groups arranged on a local basis, induction courses and residential schools, audio teleconferencing or computer conferencing, and other forms of personal support (Richardson, 2001).

1.2 Distance Education and the Role of Allama Iqbal Open University

Over the last three decades, distance education has become increasingly recognised as a significant form of education. Both developed and developing countries have seized upon its advantages to meet pressing educational and social needs. It is maturing rapidly from a field of study towards a discipline in its own right. More importantly, its effects are being felt and revealed, often quite strikingly, throughout the world and it has made its way deep into the educational, social and economic mainstreams of many societies.

The demand for education in the developing countries, through the formal system, has consistently run ahead of resources and the bulk of their population, therefore, remains educationally deprived. At the same time, social and economic pressures continue to increase.

Governments are aware that, due to the lack of basic education, they might have been wasting superior talents in this age of higher technology which has further stressed the need and importance of highly capable intellectual skills.

In Pakistan a distance learning model has been successfully used by Allama Iqbal Open University – a multimedia, multilevel, multimethod teaching institution. Within a short period of a decade, it has been able to offer courses from literacy to postgraduate level. It attracts large number of students – thanks to its distance teaching system, which takes the learning packages to the home or workplace of its students. As the concept of openness implies, courses are also made available to those who seek knowledge without enrolling for a degree, diploma or certificate programme. It provides a second chance to working adults who for some reason could not continue their education in the formal institutions and it seeks to improve their educational qualifications. It provides continuing education by affording in-service training to an increasing range of professionals, training which, until now, has been confined mainly to the teaching community. In addition, general education, technical, vocational and professional courses are also offered at various levels.

Allama Iqbal Open University employs all methods and techniques (print, broadcast and non-broadcast media, electronic and their combinations), appropriate to the level of the student and the requirements of the course, including face-to-face instruction where necessary.

With its system of reaching the student at his home or workplace and the concept of openness, which implies lifelong education, Allama Iqbal Open University is filling the gaps left by the conventional system and taking education to the area and groups unable to benefit from the formal system of education.

The Allama Iqbal Open University (AIOU) is primarily a distance teaching institution using multi-media techniques. The main components of its teaching system are:

(i) Correspondence packages, which include self learning printed texts and supplementary study material;
(ii) Radio and television broadcasts specially prepared for distance learners;
(iii) Tutorial instruction through correspondence and face to face at study centre,

where possible, and at workshops, where appropriate;

(iv) Course assignments as an instrument both of teaching and continuous assessment.

The University has had to face its gigantic task with few traditional academic norms to confirm and support it. Some foreign distance learning models did exist, but it was very soon discovered that the approaches (eg style of written materials, access to laboratories, access to computers) which held true in other societies, especially advanced western ones, were largely inapplicable here. It has to evolve a system which was at once economical, capable of administration within the context of the resources, services and technology available in the country, properly balanced against the needs and expectations of our people as well as being sufficiently flexible to accommodate the needs of changing circumstances.

1.3 Admission System

The AIOU divides the academic year into two semesters. Each semester normally lasts six months, from April to September and from October to March. All the courses are notified well in advance through special advertisements in national newspapers so that students may contact the Admissions Office or their nearest Regional Office and select the courses of their interest. There is always a deadline set for admission in each semester. Admission forms are received by the Admission Office which sends them to the Computer Centre for the preparation of enrolment lists and mailing labels.

1.4 Study System

After admission, instructional materials are sent to students at their home addresses or places of work. These printed units are supplemented by radio and TV programmes. Programme schedules are sent to students with the correspondence packages. In addition, assignments are set throughout the period of study. These assignments have a threefold function:

(i) They enable a student to have his performance and progress assessed regularly by expert tutors;

(ii) They enable a tutor to give instruction to his students through the comments and corrections made on the assignment;

(iii) They act as a pacing device for the student during his period of study.

Study centres are spread throughout the country and are managed by the respective Regional Offices. Tutor-student contact is therefore both by correspondence and at study centre meetings in the evenings or on weekly holidays. The tutor marked assignments are returned to the students with instructional notes. The marks obtained by students in these assignments are sent to the Controller of Examination for recording and the eventual preparation of results. Final examinations are held in the last week of each semester. The overall result is based on a combination of continuous assessment (40%) and final examination (60%). The minimum pass mark in each course is 33%, but the aggregate marks for the award of a complete of a certificate is 40%.

A student guide is provided to all students to help them plan their studies. The University has made considerable efforts to strike a balance between independent study and direct personal contact between students and academic staff. Instructional material, study guides, reading material, and audio video cassettes are designed and produced by course teams whose members are selected both from college of the formal system and teaching staff of the University.

The AIOU provides instruction mainly in Urdu, but English is also used as a medium of instruction in certain subjects.

1.5 The role of practical work in chemistry

Chemistry is an experimental science and its development and application demand a high standard of experimental work (Hanson *et al.,* 1993). This and many similar statements can be found littering chemical and science education literature. Dall'alba (1993) extends the idea and asserts that an important factor in higher education teaching is to initiate students into what it is to be a practitioner of their subject, but it is its extension to the learning of chemistry that can give rise to a divergence of views. Current thinking considers mass education where the majority of students in chemistry may have no intention of pursuing chemistry as a career. In these circumstances, it seems inappropriate to design a programme that is solely directed at training the professional chemist.

Laboratory work in chemistry is an expensive activity. Laboratories are costly to build and equip, and academic and technical staffing, instruments and consumables are a drain on resources. The perception is that it is becoming increasingly difficult to provide students with a high quality conventional practical experience. A Royal Society of Chemistry (Report, 1994) report states that 'the restrictions on resources and the time allocated to practical work are causing a decline in the extent of practical work and the standards achieved'. If the aim cannot solely be to train professional chemists, there are real questions about the nature and purpose of laboratory work: what outcomes are being sought?

It is time to think about the laboratory in terms of the quality of experiments rather than an assessment of skills. Time spent in the laboratory is not always well used. In a survey, Maskill and Meester (1993) found that, on average, a student in the first year of chemistry courses in English Universities performed over fifty titrations. Although these operations form part of a range of experiments, it cannot be a valuable learning experiences to carry out extensive repetition of this relatively simple manipulation.

Another problem relates to how to achieve participation in experiment design. Frequently, the material supplied to students reads like a recipe and it is often treated like a recipe by the student. Clearly, the development of recipe-following skills and the production of laboratory reports which reflect the production of 'correct' results (which may be found by consultation with other students) cannot justify the time and effort spent in laboratory provision. There is a need to specify the desirable outcomes and skills and to explore whether some of them cannot be developed in other, less expensive ways.

In 1998, Bennett listed some of the major skills which are ideally developed in a laboratory environment. These include:

manipulation;
data collection;
analysing data and observations
problem solving;
experiment design;
laboratory ambience

observation;
processing data;
interpretation;
team work;
communication and presentation;

A major problem is faced by the students in the progressive development of these skills as they move through an undergraduate course. Each laboratory experience may be valuable and worthy in its own right. However, the next session in the laboratory may not take into account the extent of skills developed in the earlier session. Even today the laboratory programme is not analysed according to the skills development context. To move in the direction of a skills driven programme is not only central to the quality of student progress but results in a more efficient use of the laboratory resources (Bennett, 1998).

Some undergraduate students have shown their negative attitude towards the long hours that are traditionally spent in the laboratory and that they often develop a negative attitude to the experience. The recipes style presentation of laboratory practical is a major contributor. Often the student reads through the notes line by line, mechanically carrying out the manipulations, with no real thought as to why certain actions are taken and how they fit into the overall outcome. Much of the intellectual effort should come before entering the laboratory: discussions, literature work, design of the experiment, sorting out quantities, conditions and equipment. This level of pre-laboratory activity is often denied the undergraduate and yet it forms a vital, essential and stimulating component (Bennett, 1998).

Johnstone's (1997) analysis of demand on working memory has had significant impact on the learning of chemistry but it is arguably in the laboratory where heed to these lessons is in greatest need. Many students, on entering the laboratory, are faced with a huge amount of information: anything from the location of chemicals and identification of the particular materials needed to begin the prescribed work, recognition of equipment and its handling, instrumentation, and safety requirements right across to the understanding of written instructions and verbal instructions. It should not be surprising that most students are unable to give much intellectual effort to the meaning of the laboratory activity. Indeed, the ability to work through a 'recipe experiment' line by line could be regarded as a major achievement in such circumstances.

1.6 Conclusions

It has to be recognised that the empirical is the fundamental way in which science enquiry works and, therefore, has an important place in undergraduate teaching in a subject like chemistry. However, laboratory teaching is expensive in time, manpower and resources. It is essential that the laboratory experiences are planned and prepared carefully in the light of educational principles so that students can gain the maximum from the time commitment. For this, aims must be specified clearly and assessment must reflect the aims. Doing this at a distance has its particular problems, especially in a country like Pakistan where laboratory work is not well developed. This will be the theme of this study.

The overall aim of the study is to establish some general principles, based on evidence, to bring about improvements in the laboratory provision in Pakistan at both school and university levels. The study will start by considering what is known from the literature relating to learning in a laboratory. The aim will be to gain an overview of the evidence already available.

Various surveys will be described. These will look at current practices in Scotland at both school and university levels as well as looking at the current situation in Pakistan. The aim is not to make detailed comparisons but to establish the general pattern of practice in a country where laboratory work is well developed and a country where laboratory work is still relatively undeveloped.

In the light of these, various developments will be described. The overall aim is to develop guidelines based on evidence which will enable learning in the laboratory to be more meaningful and more effective.

Chapter Two

Laboratories in Chemistry Education

2.1 Historical Perspective of Laboratory Work

It is approximately 160 years since laboratory work courses were first formally introduced by Liebig at Giessen (Morrell, 1972) and by Eton at the Rensselaer Polytechnic Institute (Menzie, 1970).

Before that, the only exposure of students to practical work was through the lecture-demonstration or through attendance at private classes which sprang up in university towns in the latter part of the eighteenth and early nineteenth century.

The development of laboratory classes within the university was inhibited for many years by the system of payment to professors. Their income was derived from the fee paid by students who attended their classes. The greater the number of students the greater the professor's income. The costs of equipment and consumables were borne by the professor out of this income (Morrell, 1969).

Thus the lecture-demonstration flourished since it could accommodate large numbers within a minimum amount of equipment and materials. Many professors went to great lengths to ensure that their demonstrations could be seen by their audiences and would provide vivid illustrations of the content of their lectures. Unfortunately for the lecture method, the lecture-demonstration is now almost a thing of the past.

Although individual practical work in Chemistry began to be established from 1824 in Germany and subsequently in the United States, Scotland and England. In 1847 William Thomson introduced teaching apparatus for lecture - demonstration to the teaching of natural philosophy at Glasgow College (Smith and Wise 1989). The practical Physics classes in England were proposed at Oxford in 1860, and started there at University College, London in 1866 (Shepherd, 1979) and King's College in 1868 (Phillips, 1981). This later development was partly due to the later emergence of specialisation in Physics.

The first institution to require laboratory work in Physics was the Massachusetts Institution of Technology in 1869. It was here that E.C. Pickering prepared the first Physics laboratory manual, published in 1873 (Phillips, 1981).

In Britain, laboratory teaching in Biology can be traced to the influence of T.H. Huxley at the Normal School of Science in South Kensington and his first summer course for science teachers in 1871 (Mittar, 1992).

Laboratory teaching became established in response to two pressures:

(i) Student demand for practical work was being met by teachers outside the university;
(ii) There was a need for training in research.

For example, when Chemistry developed into an enterprise, demanding research workers with sophisticated practical skills and the ability to undertake complex experimental procedures, there was an urgent call for adequate personnel. It might be thought that demand from industry would have been a contributory pressure but, as Cardwell (1972) points out, such a demand could only be made once suitable and recognised physicists or chemists existed. Although technological demand can be seen to have had very little influence on the emergence of laboratory teaching, it may have helped to establish the method. In physics, there were few jobs for students in industry for most of the nineteenth century except in the telegraph companies, and these were required mainly for routine testing (Moseley, 1971, cited by Shepherd, 1979). Apprenticeship training was no longer adequate, and formal practical instruction was established of a kind which could not be met by lectures.

This model has continued until today. There have been relatively few innovations during the intervening period and the laboratory manuals of the nineteenth century, with their emphasis on procedure and rule-following activity, would be quite recognisable by students today.

In 1886, Harvard University defined a set of forty experiments in physics, which students were expected to have completed before entry to the university. The 'Harvard Forty' would be familiar to almost all tertiary teachers today and represent the classic demonstration of phenomena and principles in physics, which have so dominated approaches to the introductory laboratory.

Perhaps the major change which is likely to be of enduring significance was the development since the Second World War of project work for all students, particularly in technological institutions. At one time projects were regarded as appropriate only for those who would pursue a research career and often not even for them. Today, it would be rare to find any science course without an element of project work (Bound, 1985).

In addition to the above historical perspective, the first teaching laboratory in Chemistry in Britain was established by Thomas Thomson in the University of Edinburgh in 1807. In 1819 he introduced this to the University of Glasgow, when he joined this University. In 1824, Liebig's established a Chemistry Laboratory at the University of Giessen. This was the most exciting period of the nineteenth century. It was the first institutional laboratory in which students were deliberately trained for membership of a highly effective research school by systematic research.

In Aberdeen, the practical classes in chemistry were started in 1829 under the supervision of Dr. French and Dr. Percival. A teaching laboratory was running in Dublin in the beginning of the nineteenth century. Later on, Cambridge and Oxford followed these Universities.

The lecture-demonstration course depends upon the availability of resources like apparatus and other necessary items. Until the 1830s, there were no formal courses of laboratory instruction despite the fact that occasional texts presented practical work. Later in 1835, David Boswell Reid and John Joseph Griffin initiated a purpose-built teaching laboratory to cater for individual practical experience in England. In spite of having an interest in bringing practical work into English schools, without laboratories suited to the purpose, there was little likelihood of launching laboratory based instruction in science. In 1854 there was a good display of ideas for classroom science (including apparatus for chemistry, meteorology, microscopy and astronomy) at the Educational Exhibition.

Laboratory classes then gradually developed over the next fifty years until eventually, in 1899, it came to be considered necessary that pupils be allowed to carry out experiments for themselves. By this time, however, most schools had already adopted this way and regarded practical work as an essential requirement for science teaching (Gee and Clackson, 1992).

However, credit goes to Edward Frankland for the growth of practical work in Britain, who throughout his life did much to encourage the introduction of laboratory instruction. He was a graduate of Liebig's laboratory. Largely by his efforts by 1876, there were one hundred and fifteen laboratories in operation in Britain, most being used for elementary school instruction.

Thus, practical training in chemistry sprang up in universities all over the Europe and North America. These were devoted to the teaching of skills directly used in industries and research (Letton, 1987, Johnstone and Letton, 1989, Khan, 1996).

It was at the turn of the nineteenth century that laboratory-based methods of teaching achieved its most rapid growth associated with the growth of research in school chemistry. At this time, individual practical work was accepted as an essential part of university chemistry course. Until then, laboratory instruction had been an isolated activity with little support: some of it private instead of instructional and outside the curriculum.

Practical work at this time played a vital role in confirming the theory which was already taught in the classroom. Some doubts also arose about the efficiency of teaching through practical work in chemistry. In 1910, the Progressive Education Movement had a major impact on the nature of science teaching in general and on the role of practical work in particular. In America John Dewey advocated an investigative approach and learning by doing in America (Hofstein & Lunetta, 1982).

In 1882, the Educational Department in England declared that, "the instruction of teaching given by the experts in science subjects shall be given mainly by experiments". Armstrong advocated the direct experimentation by the pupils rather than the demonstration experiments performed by the teacher. Hodson (1990) declared that too much time was wasted on repetitive individual practical work. Therefore, attention switched back once again to teacher demonstration. In 1932, the Education Board supported the same idea (pamphlet no. 89). This declared that there was "too much practical work of the wrong kind ...., too much remote from the natural interests and everyday experience of the children" (Hodson, 1990, 1993).

In 1935, Schlensenger studied the contribution of laboratory work to general education. He noticed that students who had previously exhibited "real interest in chemistry" developed the habit of doing their experiments mechanically to get the result expected rather than to observe what is actually going on in their test tubes" (Letton, 1987). Little seems to have changed since then.

Moreira 1980, stated that "in England and Wales the government sponsored the initiatives to increased the emphasis on the laboratory work in secondary schools". In this way, more resources were provided for practical work.

Towards the end of the twentieth century, more sophisticated alternatives had been introduced to facilitate effective learning in the laboratories. These included pre-lab experiences, films, video experiments, computer based pre-labs, and computer simulations.

Bennett & O' Neale (1998) proposed the following guidelines for the design of laboratory courses in chemistry:

(a) Design the laboratory course so that a range of skills are introduced in a logical sequence as a coherent package;

(b) Introduce the opportunity for real investigations very early in the course;

(c) Introduce pre and post laboratory sessions which actively engage the students.

These principles reflect the ideas of Denis Diderot, the French philosopher, who is quoted by Lester (1966), outlining three principal means of acquiring knowledge available to us: observation of nature; reflection; experimentation. Observation collects facts; reflection combines them; experimentation verifies the results of that combination.

2.2 Why have Laboratories ?

Laboratories are one of the characteristic features of education in the sciences at all levels. It would be rare to find any science course in any institution of education without a substantial component of laboratory activity. However, very little justification is normally given for their presence today. It is assumed to be necessary and important. It is taken for granted that experimental work is a fundamental part of any science course and this specially true for chemistry courses. Very frequently, it is asserted that chemistry is a practical subject and this is assumed to offer adequate justification for the presence of laboratory work. The development of practical skills among the students is often a suggested justification. Nonetheless, these arguments need to be questioned to justify the position or role of the laboratory in the field of chemistry education.

One of the main reasons to question the place of laboratory teaching is that laboratory programmes are very expensive in terms of materials but also in terms of staff time. Students' reactions to practical work are often negative and this may reflect a student perception that there is a lack of any clear purpose for the experiments: they go through the experiment without adequate stimulation.

It is important to think about goals, aims and objectives in the context of laboratory work. In the developed countries like UK, where a great deal of time and money is spent on doing practical work in schools and universities, there is a need for justifications for the presence of laboratory work which are based on sound empirical evidence. For developing countries, like Pakistan, the same justification is needed in order to set up and manage good laboratory experiences for chemistry students for all science courses.

Before exploring these issues and before focussing on specifies, it will be necessary to clarify the term, 'laboratory work'. Is this the same as practical work? Is it the same word used for teaching experimental science with different style? While in no way undermining the potential value of other practical activities, laboratory work here is used to describe the practical activities which student undertake using chemicals and equipment in a chemistry laboratory.

Boud *et. al.* (1986) stated that, when planning a course it is important to state clearly the course aims, goals and objectives: what to be taught, who is it to be taught to, by what means, and, most importantly, what are the intended outputs?

Gavin (1966), condemned laboratory work in which getting the so-called correct answer seemed to be more important than doing the experimental work itself. Gavin (1960), considered that much physics experimental work was set with too precise instructions and was, therefore, dull and uninspiring. His comments on physics might well apply also to chemistry.

Rose (1974) raised a fascinating question: could many important aims still be attained even if practical work were abolished. He suggested that this depends partly on our view of science which can be seen as established human knowledge, a problem solving activity, or concerned with the relation between theory and experiments.

It could be argued that practical work:

(1) Gives direct experience of basic material of the subjects and of complex apparatus to students;
(2) Offers important links between theory and observation.

Wills (1974) quoted results of a survey of students' opinions on the teaching of practical biochemistry as part of a medical course. He observed that half of the students showed little enthusiasm for laboratory work. He suggested a number of reasons. These can be summarised:

(1) The techniques used were not meaningful;
(2) The students were taught for relatively short periods of time;
(3) Only a small percentage of clinicians ever again undertake active lab work after qualification (perceived relevance is low);
(4) Theoretical understanding is gained relatively slowly through practical work;
(5) Students stressed the poor reward in knowledge gained for their future medical career.

Although these comments were written long ago and in a different context, many still apply in chemistry. In particular, it has to be noted that only a minority of those studying chemistry at university will go on to become bench chemists while the idea theoretical understanding only arises slowly by means of laboratory work has to be related to the idea that humans learn best by doing rather than by listening. These ideas will be explored later.

In thinking of laboratory work, there are some inevitable tensions. Students are not always best placed to see the relevance and importance of the elements of their course. On the other hand, there is a tendency for specialists to think in terms of presenting their subjects rather than of meeting the students' needs. Here again, the need for clearly formulated objectives, communicated effectively to students is seen to be important.

Tubbs (1968) worked with groups of eight students to help them to learn more about experimentation. A problem was outlined by the tutor, suggestions were invited from the students and these were discussed in some detail. The students then chose apparatus and spent three to four hours in making measurements, each in different ways. Finally, they discussed reasons for differences in their results and sources of experimental error. Tubs considered that first year students could profitably spend up to 20% of laboratory time in this way. He claimed that the method proved economical of staff time and, usually, of equipment. However, no evaluation was quoted.

Martin and Lewis (1968) attempted to clarify the purpose of experimental work for students by designing each experiment to achieve just one objective instead of the usual variety. They claimed that this resulted in considerable improvements in laboratory teaching but did not offer evidence.

Looking back over many decades, Vianna (1991) noted that, before the second world war, chemistry had been taught with a primary emphasis on knowledge objectives. This gradually shifted to a greater concern for process, attitude and interest and cultural awareness objectives in the war period and after the war.

2.3 Goals and Objectives

Objectives of practical work had been stressed from as far as the early nineteenth century and special attention had been given to practical work in the world war second by the teachers and researchers.

Several writers and researchers have discussed the rationale for practical work and have presented their aims and objectives for specific science courses as well as for practical work. Some of these are discussed below.

It does seem important that, for practical work to be effective, the goals, aims and objectives should be well defined. The issue is to find some agreement about what these aims and objectives might be. Such a question has been under investigation for decades, especially in UK, where much money and time has been spent on practical work in schools as well as in universities (Woolnough, 1983).

One way of looking at this was suggested by Johnstone and Wood (1977). In looking at school chemistry, they constructed and distributed the objectives in the following categories:

(1) Course objectives
(2) Experiment by experiment objectives
(3) Teacher objectives
(4) Pupil objectives.

Johnstone and Al-Shuaili (2001), formulated some possible aims for laboratory work:

(1) Manipulative skills;
(2) Observational skills;
(3) The ability to interpret experimental data;
(4) The ability to plan experiments.

To these, they added some affective aims:

(1) Interest in the subject;
(2) Enjoyment of the subject;
(3) A feeling of reality for chemical phenomena.

It is very difficult to organise the objectives of laboratory work because the stated objectives are either so detailed that they can only apply in specific laboratories in specific disciplines or are so general that they can include almost anything. The list of seven general aims suggested by Johnstone and Al-Shuaili is useful because it focusses potential objectives into meaningful categories.

Kirschiner and Meester (1988), suggested student centred objectives for practical work:

(1) To formulate hypotheses
(2) To solve problems
(3) To use knowledge and skills in unfamiliar situations

(4) To design simple experiments to test hypotheses
(5) To use laboratory skills in performing experiments
(6) To interpret experimental data
(7) To describe clearly the experiment
(8) To remember the critical idea of an experiment over a significantly long period of time.

From an historical perspective the amount of practical work in science courses has undoubtedly increased significantly over the last hundred years and has been accompanied by a shift in emphasis from the lecture-demonstration to the hands-on approaches. Nonetheless, in the UK in the past decade, time spent in laboratories has been reduced simply on grounds of cost as universities face declining budgets. What are the reasons that practical work is so important in science courses?

There are many reasons but the following may be the most important. Each scientific discipline has a range of specific techniques, skills, which are used by professional scientists of that discipline, and must be mastered by students before they can practise as experimentalists. Because These operations involve skills in the psychomotor domain, typically the manipulation of particular pieces of apparatus, together with skills in the cognitive domain, such as the ability to interpret, calculate and evaluate results from the measurements which were made.

Shymansky & Penick (1975) and Black & Ogorn (1979) grouped the aims of practical work into four classifications:

(1) The specific techniques or skills.
(2) The more abstract skills of experimental inquiry and the scientific method.
(3) The illustration of ideas of the subject.
(4) Aims in the affective domain.

Kerber (1988), expressed his views about the importance of practical work, that it should also be seen a medium for attitude development. Students are expected to develop an appreciation of the practical nature of science and its relevance and importance to industry and our environment. There is an expectation that students will grow to identify themselves as practical workers and will develop confidence in fulfilling the roles of the experimentalist.

Carnduff and Reid (2003) outlined the need of the laboratory work in chemistry in terms of three broad areas:

(1) "practical skills (including safety, hazards, rick assessment, procedures, instruments, observation of methods);
(2) transferable skills (including team working, organisation, time management, communication, presentation, information retrieval, data processing, numeracy, designing strategies, problem solving); and
(3) intellectual stimulation, connections with the 'real world', raising enthusiasm for chemistry".

Most of these will be and perhaps can be only be, achieved in laboratories or in laboratory related activities.

It could be argued that laboratories might illustrate scientific method, might build confidence and might improve understanding. They of course allow students to see reactions, substances and effects, and can encourage student-student and student-staff interactions (Pickering, 1987).

Carnduff and Reid (2003) provided a set of possible reasons for the inclusion of practical work in undergraduate courses in chemistry.

- Illustrating key concepts
- Seeing things for 'real'
- Introducing equipment
- Training in specific practical skills and safety
- Teaching experimental design
- Developing observational skills
- Developing deduction and interpretation skills
- Developing team working skills
- Showing how theory arises from experimentation
- Reporting, presenting, data analysis and discussion
- Developing time management skills
- Enhancing motivation and building confidence
- Developing problem solving skills

These are some of the tasks or objectives which more or less demand the presence of laboratory work in chemistry courses. Of course, this does not guarantee that such tasks and objectives can be achieved in the present situation. There may be a major need to change or improve the present situation to create more opportunity for the students to gain these objectives.

The development of powers of observation, measurement, prediction, interpretation, designing of experiments are dependent on laboratory work. However, laboratories at undergraduate level (perhaps also at other levels) did not seem play their role very well to gain these goals and objectives (Carnduff and Reid 2003).

2.4 Pressures on Laboratory Work

Some of the pressures on laboratory work have been discussed in the above section, in a general sense. In this section, specific pressures will be discussed.

According to Carnduff and Reid (2003) there is a tremendous pressure on higher education in the UK, with increasing numbers of students and falling unit resource levels especially over the past two decades. They further stated that, "The pressure of increasing numbers of students coupled with restriction on manpower, materials, equipment and contact hours have been significant". In the light of this, it is difficult to justify students spending many hours verifying results in the laboratory when they will never employ laboratory skills in their future professions.

Staff sometimes feel that students come to the laboratories without basic preparation. Students spend time in the laboratories without learning or learning very little. As learning environments, laboratories are very costly in terms of specialist accommodation, consumables, breakages and staff time. If laboratories are not being used for their potential strengths and the time is spent unproductively, they are a massive sink of scarce resources. On the other hand, students may find few connections between laboratories, lectures and assessments. The procedures of laboratories work are closed, where the outcome is already known. This whole exercise is boring according to the students point of view. The assessment encourages cheating or copying rather than thought or effort (Carnduff and Reid, 2003).

Conventional laboratories often fail to provide experience and training in developing the skills and understanding of the scientific process. Such practicals have little relevance to real life and to fail to promote in students a genuine interest and motivation for practical work.

Carnduff and Reid (2003) listed these pressures, related to practical work in undergraduate courses. They called them modern pressures.

- Cost of materials and equipment.
- Safety issues and disposal of chemicals.

- Staff and demonstrator costs.
- Lack of students preparation (due, partly, to outside remunerative work).
- School experiences are very different (and entry levels are more variable).
- Assessment: what are we rewarding?
- Is the credit given worth the effort?

2.5 Changing Strategies

Kirschner and Meester (1988) have reviewed the aims of practical work in the science curriculum and identified various criticism.

> There appears to be an overall agreement that laboratory work at present provides a poor return of knowledge in proportion to the amount of time and effort invested by the authority.
> All too often, the work done to a laboratory simply verifies something already known to the students.
> It is not at all uncommon to find a student who shows absolutely no understanding of the processes and techniques which he or she applied even a day earlier in the laboratory.
> Exercise are sometimes of a nature which tends to overwhelm the student, i.e. non-trivial experiments are not allowed enough time for assimilation and solution of the problem.
> Students almost never have the chance to spend time watching an expert do an experiment.
> The supervision of laboratory work is often inadequate.
> Practicals are often seen as isolated exercises, bearing little or no resemblance to earlier or future work".

Furthermore the apparently unsatisfactory nature of much practical work must be set in the context of increasing financial pressures.

The lack of a clear sense of purpose in the design of laboratory courses is another factor which emphasises the need to review and to change. Meester and Maskill (1995a) discovered from a study of first-year chemistry manuals, that the aims of the course were stated in only half of the manuals. While the learning objectives were mentioned only in seventeen cases. It might be more reasonable to conclude, however, that the main problem is the plurality of purposes.

At present, laboratory work might be employed to teach any one of a number of skills or processes. Difficulties arise when it is expected that several of these be taught at once without any previous knowledge. The undergraduate laboratory work is too often closed and predictable. Maskill (1995b) identified from a literature survey four classes of improvements to undergraduate laboratory work:

utilisation of electronic media;
methods for the explicit teaching of practical skills;
adaptations of laboratory manuals;
new approaches to laboratory work.

Maskill (1995b) reviewed briefly but usefully the range of developments in these areas before noting that little had been achieved in practice among the range of courses sampled. He suggested that :

> the reason little has changed in practical classes is probably that university teachers concentrate on the experiments to be performed by students and on the time available, rather than on the educationally best way to achieve their teaching aims ..., although all the evidence that they need to improve practical teaching is easily available.

This is quite an amazing statement. It pinpoints the root of the problem: too much emphasis on the experiments to be performed and not enough emphasis on what the students should be gaining. It asserts that 'all the evidence to improve practical teaching is easily available'. Perhaps the word 'all' is somewhat optimistic but, certainly, there is a wealth of evidence available which would enable university laboratory experiences to become much more effective in benefiting students.

This leads on the question about the students perceptions about the purposes of the practical work and how do they match the perceptions of the experts? Little work has been carried out on this comparison. Kirschner *et al.* (1993) studied the students' perceptions with those of experts' using a list of possible objectives. An interesting result was that most of the purposes were neither anticipated nor encountered by the students. The reasons were that students were not well prepared to perceive the purposes of the practical work and also the students have no or limited experience of this type of exercise. The authors pointed out that the value of the exercise must be severely limited by the students' unpreparedness, a conclusion which would apply to many practical exercises.

The conventional way of preparing students would be to encourage them to read their laboratory course manual but these typically overload them with information, whether in instantaneous fashion or cumulatively and so should be written with simplicity in mind if it be desired that students do not use them as cookbooks (Johnstone and Letton 1990). Experienced university lecturers know that only a minority of students do read the manuals before entering the laboratory unless specific tasks are allocated to them.

A second method of students preparation for laboratory work is the demonstration and data-interpretation exercise. Tan (1990) noted that students preparing for a practical exercise seem to benefit from a demonstration and data-interpretation exercise. Tan emphasised the importance of starting laboratory work and in particular not relying on students to use provided text for this purpose. The undergraduates in this study were found to integrate poorly their theoretical and practical knowledge and to learn in passive, superficial ways. The demonstration and data interpretation exercises probably work by forcing them to confront their partial comprehension and to grapple with it, instead of following the steady route of the laboratory recipe/protocol.

Hegarty-Hazel (1990) has provided a useful review. She concluded that 'tertiary science laboratory classes are like the curate's egg (things good and bad) - good in parts'. She identified a certain amount of successful innovation but lamented and puzzled over the 'astonishingly stable' nature of many practical exercises, especially those of the low-level, illustrative type, which may have persisted for up to a century. She further pointed out the reasons for lack of change may include:

little incentive to change them,
the innovative energies of teaching staff are often spent elsewhere, on lecturing/ tutoring ,
practicals are administered by graduate students, which have low status in order to change the practical work,
more senior staff, who might otherwise consider changes in the design of practical exercises, are distanced from the educational consequences of the status quo, they not be fully aware of the anachronistic nature of the exercises their course specifies.

Kyle *et al.* (1979) expressed the hope that the information gained from their analysis could be used immediately to improve the instruction given to the students for practical exercises. They pointed out that the teaching assistants were not usually trained and many of the problems which have been associated with undergraduate practical work might be removed by preparing better the supervisors for this work.

Moreia (1980) showed that students typically are not able to meet these more demanding assessment criteria, to the extent that it appears that they do not really know what it is they are being asked to do while carrying out some piece of practical work. Of course, this reflects on the particular instruction that the students received for the course, but it also draws attention to the traditions and conventions of science education which arguably do not emphasise the meaningful assimilation of the concepts involved in the performance of laboratory work. In other words, many students may have been brought up on recipe-type laboratory work, with little acknowledgement of the need to employ concepts intelligently.

Tamir (1977) has offered an alternative analysis. Laboratory exercises typically take place in long sessions, without scheduled breaks, and are dominated by the teachers. Although there is considerable variation among university laboratory exercises, they are typically not 'inquiry-oriented', have a long introductory phase and no concluding or evaluating phase. The explicit comparison in this study was again with high school laboratory work, which typically has a shorter introduction and a definite conclusion.

Laboratory work is expensive in terms of personnel, materials and accommodation and, with the doubts as to its efficacy, have come suggestions that new technologies be employed to achieve better learning at reduced cost. Fielden and Pearson (1978) reported a cost benefit analysis of the replacement of a traditional laboratory course by a video based approach, concluding that the innovation made significant savings of staff time, while being likely to break even financially.

2.6 Some conclusions

In this quick overview of laboratory work in university chemistry courses, a number of issues have become clear. Firstly, there seems much agreement that laboratory work has a rightful place in undergraduate courses. Secondly, there is much evidence which indicates that all is not well: an expensive learning experience is not bringing the benefits which justify the outlay. Thirdly, there is lack of clarity about the aims for laboratory work and students perceptions and experiences do not match aims.

Much of the problem lies in a confusion being 'doing' and 'learning'. Beasley (1985) has shown that a combination of thinking and doing works better leading to significant improvements in student's ability to perform psychomotor laboratory tasks. The danger is to stop; at the 'doing' and underemphasise the 'learning'.

It is possible to present the aims for laboratory work under four headings, although there is some overlap:

Skills relating to learning chemistry

There is opportunity to make chemistry real, to illustrate ideas and concepts, to expose theoretical ideas to empirical testing, to teach new chemistry.

Practical skills

There is opportunity to handle equipment and chemicals, to learn safety procedures, to master specific techniques, to measure accurately to observe carefully.

Scientific skills

There is opportunity to learn the skills of observation and the skills of deduction and interpretation. There is the opportunity to appreciate the place of the empirical as a source of evidence in enquiry and to be learn how to devise experiments which offer genuine insights into chemical phenomena.

General skills

There are numerous useful skills to be gained: team working, reporting, presenting and discussing, time management, developing ways to solve problems.

The important issue is that the university teacher needs to decide which skills are to be developed in a particular laboratory course, to set these out in clear, unambiguous terms for the students, and to seek that the whole design of the laboratory experience is consistent with the specified skills.

Chapter Three

Laboratory Work in Scotland and Pakistan

This chapter seeks to give a brief overview of the present provision of laboratory work in schools and universities in these two countries.

3.1 Practical Work in Scotland in Schools

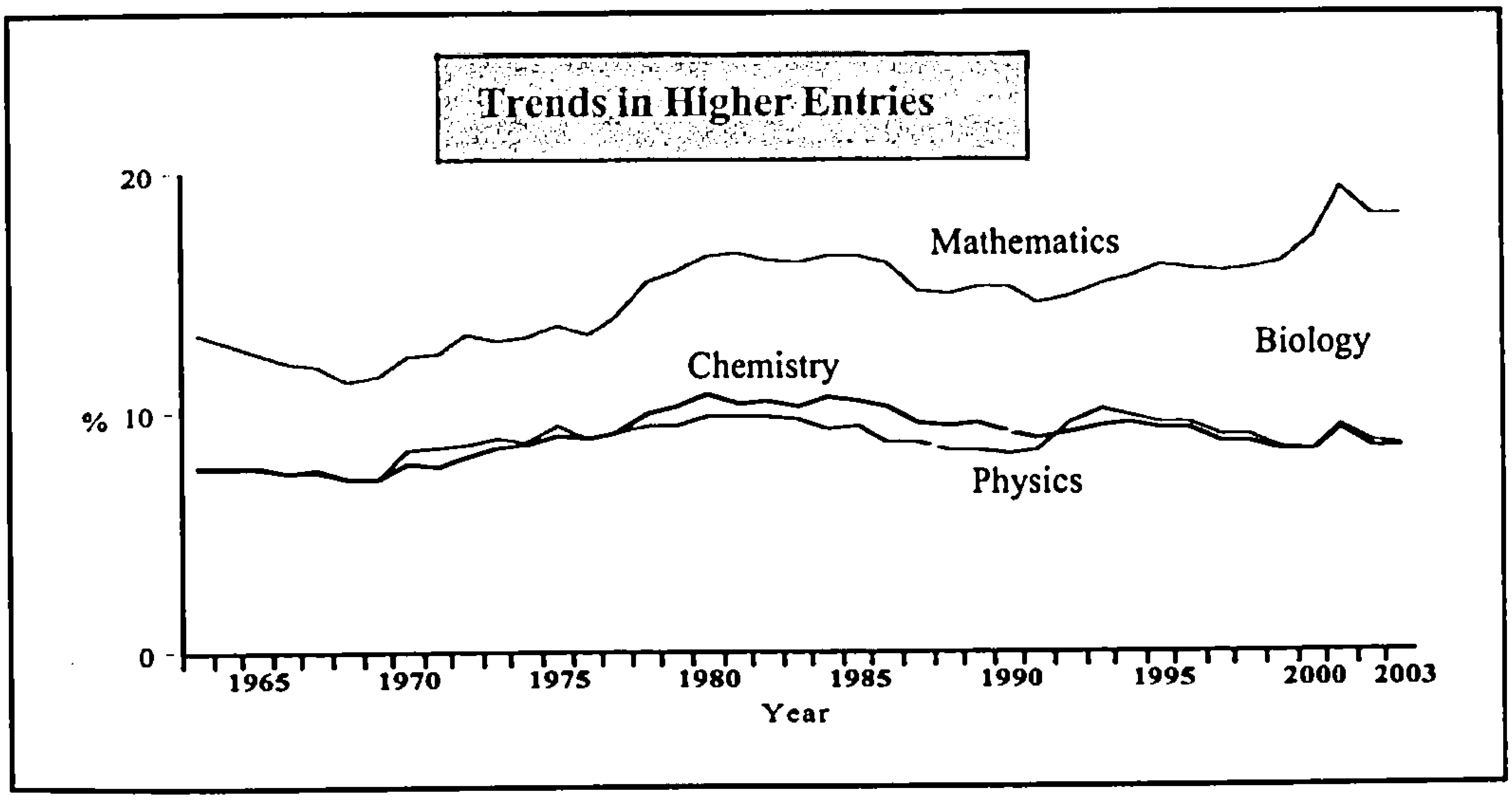
Laboratory work has for nearly a century a very strong place in all secondary school chemistry courses in Scotland. Indeed, chemistry is mainly taught in laboratory accommodation where teaching, discussion and practical activities are integrated and not seen as separate entities. In the earlier part of the twentieth century, some laboratory work was carried out by pairs of pupils. However, much was demonstration. This relied on a competent and trained chemistry teacher. Historically, chemistry was mainly taught by chemistry graduates and the quality of the graduates in teaching has always been high.

The main purpose of the laboratory work was to illustrate and make real the chemical ideas which were being taught. The syllabus hardly altered from the first world war to 1960 and much of the work was of a 'preparation and properties' nature, reflecting typical textbooks of the time. There was no formal assessment associated with national examinations at the Higher Grade.

In 1960, an 'Alternative Syllabus' in Chemistry for the Ordinary and Higher Grade was published (Chemistry at Ordinary and High Grades, 1969). The Ordinary Grade was a new examination to be sat at age 16, the Higher still being sat at age 17. The syllabus was seen as a five year course and was rapidly adopted, quickly replacing the old Higher Grade. The course has an enquiry aspect and early textbooks (Johnstone and Morrison, 1964 onwards) offered typical experiments which were designed to answer questions and offer evidence. This was not true discovery learning but more a kind of guided enquiry approach. The course was highly popular and numbers taking Chemistry at the Higher Grade rose in the late 1960s and throughout the 1970s. The graph below (figure 3.1) illustrates the pattern of uptake, related to the other sciences and mathematics.

In the late 1960s and throughout the 1970s, the first two years of the Alternative syllabus were steadily replaced by a new Integrated Science syllabus (Curriculum Paper 7, 1977) which contained little of the chemistry of the Alternative syllabus. The Alternative syllabus was modified as a result of this.

Figure 3.1 Trends at Scottish Higher Grade



The percentage scale in figure 3.1 is the proportion of entries of all Higher Grade entries
Source: Reid and Skryabina, 2002.

One of the features of the Alternative Syllabus was laboratory work carried out by pupils themselves. Demonstrations were only used where expense or safety demanded. Surveys of the place of laboratory work in Scottish schools showed consistent patterns of large amounts of pupil-based work being done (Johnstone & Wood, 1977).

During the 1980s, the development of a new syllabus called Standard Grade (Scottish Qualifications Authority, 1981, Chemistry, 1969) to replace the Ordinary Grade took place and by the end of the decade, most schools were following this syllabus. The Standard Grade took less time and was a shorter syllabus. Some of the more exciting chemistry was omitted and safety considerations began to influence what was possible. There was a strong move towards resource-based learning where chemistry learning took place in laboratories and pupils proceeded at their own pace (see, for example, Choice Chemistry, Frening, D. and Hadden, S., 1989). The Higher Grade was modified several times.

Laboratory work retained its high status in school chemistry but its nature changed steadily. It became less teacher directed and the exciting and dangerous experiments started to disappear. Assessment was introduced at Standard Grade and has not proved to be very successful, eventually requiring to be downgraded in importance in achieving examination success. The problem was that the assessment tested what could be tested easily and fairly. This tended to be routine laboratory skills and it is highly doubtful if such skills are important for most of the pupils. Teachers became adept at developing the right skills and it was difficult for a pupil to gain anything other than high marks.

Despite the problems, secondary school laboratory work in chemistry in Scotland is characterised by fairly well equipped laboratories (although many are old), a highly skilled teaching force (although dominated by older teachers) and an emphasis on experiments carried out by pupils themselves. Laboratory work is seen mainly as an illustration and confirmation of what is taught and up to Higher Grade there is little freedom for projects or open-ended enquiry. There have been post-Higher Grade school courses and these do involve project work but only a minority take such courses although Chemistry is a popular subject.

3.2 Practical Work in First Year Chemistry at Glasgow

There are two classes in first year Chemistry at Glasgow University. Both courses include laboratories in Physical, Inorganic and Organic Chemistry. The total number of students typically varies between 600 and 700.

At Glasgow University, according to the Course Handbook (2001 – 2002), the course has been designed to be both useful and interesting to all students and, at the same time, to provide a firm basis for later courses in Chemistry and other subjects. It is also mentioned that this is not an easy course. The whole course is divided into three main parts: lectures, laboratories, and problem sessions.

Each student will attend one three-hour laboratory class per week. The following objectives are listed:

To enable the student for preparations of laboratory work.
To enable the students to analyse and measure the experimental work.
To enable the students to report the practical outcome.
To enable the students to interpret the practical results.

This course also offers a chance to:

Undertake chemical reactions yourself,
Operate instruments and collect experimental data,
Think about experiment design,
Check students understanding of particular topics.

Laboratory work is marked (by demonstrators) and counts for 10% of the overall mark for the course. In the Physical Chemistry Laboratory Course (which will be considered in this study) there are five set experiments:

Experiment 1	pH Titrations.
Experiment 2	Conductometric Titrations.
Experiment 3	Solubility product.
Experiment 4	Heat of reaction.
Experiment 5	Activation energy.

Students work in pairs as far as possible and, in each 3 hour session, will complete one experiment, write the report in a report book, and present the report to demonstrators or staff members for marking. The reports should be concise and clearly presented. They should consist of a title, a brief statement of the processes studied (where possible this can be done by simply stating appropriate chemical equations), results of measurements, graphs and results of calculations, and the outcome of any other assignments for the experiments.

A major part of this study will look at student attitudes and perception relating to their laboratory experiences both at first year level and, looking backwards, at school. The other part of the study will look at practical work in Pakistan and the current situation is now outlined in more detail.

3.3 Practical work in Pakistan

This section traces the development of policy statements and relates these to the actual practicalities which occur today.

In many developing countries like Pakistan, science teaching in secondary schools is carried out with the precise objective of preparing students only for a particular university entrance examination, or simply to pass the examination to get admission in some professional university or college. This leads to a strong tendency for students and parents to want to achieve good grades rather than an understanding of science.

The style of teaching tends to be by lectures and laboratory work is heavily under-emphasised. Secondary and High Secondary and even the University teachers follow only the set courses and therefore, for them, teaching is telling and learning is listening in all too many Science classrooms. Assessment is based on recall and recognition rather than understanding. Clearly, such an approach to science teaching has little meaning for any level of science teaching.

Among other things, chemistry teaching in any school as well as in at university level requires some special arrangements:

* Trained and committed professionals
* Well designed laboratories
* Adequate funds to run the laboratories
* Well organised feedback system

In general, none of these arrangements operates in Pakistan. There are some laboratories in secondary schools but the equipment is inadequate and not comparable with that in developed countries. In some schools, the students can see this equipment lying in its cardboard boxes but they are not allowed to use it. There are many reasons and many constraints on the teacher: for example, there is no fund for breakages, there is no fund for the chemicals, and there is no fund for the other necessities used in laboratory work.

3.3.1 Aims for Laboratory Work

The following are quoted from the Higher Secondary School First Year Laboratory notebook/manual (1998).

1. A laboratory is a workshop, here the students and the research worker perform experiments, observe, analyse, formulate theories and test conclusions.
2. Understanding of the principles of Chemistry.
3. Laboratory work in chemistry subject is to make the subject more real and more lifelike.
4. Laboratory provides an opportunity to learn by doing.
5. The laboratory work is a sort of training in handling the apparatus, glassware and chemical reagents.

The Government of Pakistan Ministry of Education, in 1956, has summarised the aims and objectives of teaching science at different stages in the proceedings of the all-India seminar on the teaching of science in secondary schools.

At high and higher secondary level, the aims of teaching science should be;

1. To familiarise the pupils with the world in which they live and to make them understand the impact of science on society so as to enable them to adjust themselves to such environment.
2. To acquaint them with the "scientific method" and to enable them to develop the scientific attitude.
3. To give the pupil a historical perspective, so that they may understand the evolution of scientific development.

The report of the curriculum committee for secondary education (1961) gives the following two objectives of teaching of science:

1. To inculcate the scientific spirit and develop a scientific outlook among the students.
2. To provide such knowledge in science as may be applicable to every day problems of modern life and useful in dealing with them.

The same report also describes the essentials of the scientific outlook as;

1. A spirit of impartial inquiry.
2. A desire to understand things, as they are not as one would like them to be.
3. Reliance on observation of facts rather on preconceived notions.
4. Readiness to change one's opinion if new facts necessitate it.
5. Willingness to consider and accept the other man's point of view if it is supported by facts.

In a document released in 1973 by the Federal Board of Education, Islamabad, some of the more relevant aspects of these objectives are:

1. To acquire the knowledge about independent study techniques. Self directed investigations and activities to seek answers to the problems and acquire future knowledge.
2. To help the individual become more productive member of the society.
3. To give knowledge of national resources and of the skills and the techniques to utilise them most beneficently.
4. To inculcate an attitude of continuous inquiry and search in solving problems.

The specific objectives of laboratory curricula at this level in this document are:

1. To enable the students understand the principles governing chemical processes.
2. To enable the students make observations, study the facts and frame valid conclusions.
3. To enable the students acquire better understanding of the structure of matter and of the natural phenomena, obtaining in the universe.
4. To acquaint the students with laboratory as applied in every day life.
5. To prepare the students for professional careers.

It is clear that there have been many policy statements, all supporting the idea of a thriving and effective system of laboratory-based instruction in schools. Sadly, the means to achieve these aims is not in place. Resources are not present and teachers are not trained to use laboratory resources effectively.

3.3.2 Recent Developments in School Laboratory Learning

The National Science Teachers Association of Pakistan (1990) suggested these developments to improve the learning of sciences in the laboratory.

High School and College Level

All high school and college science must offer laboratory experiences for all students. Experiences must be provided for students who are unable to participate in specific laboratory activities.

A minimum of 40 percent of the science instruction time should be spent on laboratory related activities. This time includes pre-laboratory instruction in concepts relevant to the laboratory, hands-on activities by the students, and a post-lab period involving communication and analysis. Computer simulation and teacher demonstrations are valuable but should not be substitutions for laboratory activities.

Evaluation and assessment of student performance must reflect the laboratory experience. The full range of student experience in science should be measured by the testing program.

Laboratory activities in science need to be subjected to continual professional review. A need exists for ongoing research support for evaluating laboratory activities and their appropriate use at particular grade levels, for screening activities to ensure safety and for developing new laboratory activities. Special emphasis must be placed on disseminating the results of this research to teachers.

An adequate budget for facilities, equipment, supplies and proper waste management must be provided to support the laboratory experiences. Equipment and facilities must be maintained and updated on a regular basis. Unique instructional supplies must be provided in sufficient quantity that students have a direct, hands-on experience. For some activities, funds for field experiences must also be included in the budget.

Science should be taught in a space specifically dedicated to science classes with provisions for laboratory activities. A safe and well-equipped preparation and work space for students and teacher must be provided. Adequate storage space for equipment and supplies, including a separate storage area for potentially dangerous materials, must be provided. Special considerations should be given to ensure laboratory safety for the teacher and the students. Accommodation must also be made for computers and other electronic equipment in order to provide easy access for students to use these devices as laboratory tools.

A competent paraprofessional should be provided to assist with preparation for laboratory experiences, including set-up and clean up, maintaining community contacts, resources searching, and other supportive services.

Competent assistance should be provided to help with laboratory preparation and clean up, activities which represent an inefficient use of teacher time.

No more than two different preparations should be assigned to the teacher for any academic term. The development, implementation, and evaluation of effective laboratory activities require extensive time by the teacher.

The same teaching credit should be given to one hour of laboratory time as is given to one hour of lecture time. Teachers in the laboratory must constantly monitor students learning and anticipate, recognise, and respond to problem that arise.

The number of students assigned to each laboratory class should not exceed 24. The students must have immediate access to the teacher in order to provide a safe and effective learning.

Since the laboratory experience is of critical importance in the process of enhancing students' cognitive and effective understanding of science, therefore these recommendations will help to improve learning in the laboratory situation.

Such developments are welcomed but, unfortunately, it has not led to action and laboratory work in schools is either absent or very poorly conducted.

Chapter Four

The Nature of Learning I

4.1 What is Learning?

Learning encompasses many skills and experiences. This chapter seeks to look very broadly at learning, with special emphasis on the kind of learning which is possible in laboratory situations.

Learning can be defined in many ways. One of the simplest forms of learning is imitation. This means things produced as a copy of the real things. Such type of learning will be very useful in the laboratory situation. Imitating encourages one to grow and pretend freely without risk of being wrong or embarrassed.

Boud *et. al.* (1986) expressed the views that learning outcomes have the same relationship to aims and objectives as learning experiences have to the learning plans. Learning outcomes are what the students attain from the course. The learning outcomes of the laboratory course are closely related to its aims. Commonly in laboratory courses, the learning outcomes which are tested are those which are the easiest to measure by pencil-and-paper tests. Greater weight is placed upon students' ability to describe experimentation rather than upon their experimental skills, on the production of 'right' answers than on critical thinking, on correct conduct of experiments rather than experimental design and planning.

The research findings on laboratory learning are surprisingly disappointing. In general, at school level, the pupils' time in the laboratory does contribute positively to their enjoyment of the subject (Skryabina, 2003), so that increasing the laboratory component of a course should make it more interesting. The laboratory should be the place where new and useful skills are observed and where teachers assist the students towards the aims and objectives they have determined for the practical course. Laboratory work is a compulsory and integral part of undergraduate chemistry courses. The laboratory provides opportunities for training not only in practical hand and instrument skills but also for many of the thinking, planning, recording, interpreting and group working skills (Carnduff and Reid, 2003).

Gagne and White (1978), in an elegant series of research studies, developed a model which has two postulates. These postulates are very relevant to the problem of making laboratories more effective for learning. The first is called images, which is figural representations in memory of diagrams, pictures and scenes. These have a great potential for building up this type of memory, when the chemistry teacher demonstrates in the laboratory. The second is called episodes, which are the representations in memory of the past events in which the individual was personally involved. Both images and episodes are powerful aids to the recall of any knowledge associated with the students.

Two main concepts are involved in learning practical tasks, knowledge and skills. These two are distinguished and discussed by Seymour (1998). Knowledge involves memory for symbolic materials such as words, numbers or diagrams and is said to be learned when it is memorised and appropriately recalled. Skills involve non-symbolic information which must be acquired through motor and perceptual learning. In chemistry laboratories, this can be thought of in terms of the chemistry to be learned and the practical skills which should be mastered. This kind of analysis is of limited use in that it ignores attitudes, confidence, and important thinking skills like creativity and critical thinking.

Pazzani (1991) suggested that we have the ability to memorise the names of different components readily due to some prior knowledge of these components. However, if the names of these components are initially unfamiliar then learning will be poorer as compared to the first case. This suggests that, if the students have some ideas or some knowledge before the laboratory work, their understanding and performance will be good. In other words, their learning will be more distinguished as compared to the students have no pre-knowledge. This supports the notion of some kind of pre-laboratory activity.

Weick (1991) stated a traditional definition of learning as, " .... to become able to respond to task-demand or an environmental pressure in a different way as a result of earlier response to the same task/practice or as result of other intervening relevant experience. The sign of learning is not a shift of response or performance as a consequence of change in the stimulus-situation or in motivation, but rather a shift in performance when the stimulus-situation and the motivation are essentially the same. Such change in performance is said to require a hypothesising change in the responding organism". Such an attempt at a comprehensive description offers a fairly complex picture of the process.

Gagné's (1985) theory is based on the behaviourist view that skills should be learned one at a time in order to build on previous information. Kolb's (1984) learning theory implies that the concrete concepts must be mastered and then extended to the abstract level. Kolb (1981) explained that authentic learning enables the learner to "perform" at those levels where the "knowledge" is transferable to real world situations.

In discussing a definition of learning , the North Central Regional Educational Laboratory (NCREL) offered this

> The different curriculum standards reveal a common spirit. Over and over again, these professional organisations admonish traditional models of education for emphasising memorisation, and usefully to cover content at the expense of deep conceptual understanding. All emphasise in-depth learning; learning oriented to problem solving and decision making; learning embedded in real-life tasks and activities for thinking and communicating; and learning that builds on students' prior knowledge and experiences.

Alavi, Maryam (1994) called this theory of learning "a new theory of learning". He explained this theory as;

"Tell me and I will surely forget.
Show me and I might remember.
But make me do it, and I will certainly understand".

It is this kind of folklore which can hinder the sharing of educational research. Taken superficially, it might imply that the "doing' in a laboratory will, be definition, lead to better learning. The evidence from many is that this is simply not true. Consider the art of riding a bicycle. Clearly, telling the potential cyclist how to do it is not very helpful. Showing the person the skill is a little better but, in the end, the learner has to try it out for himself or herself. This is very different from the laboratory. If the aim is that a student will be able to carry out some specific skill (like handling a pipette), then the principle still works but the more fundamental aims for laboratories do not conform merely to such skill acquisition. Reading, listening, thinking, discussing will all be important elements to be taken along with the conduct of the experiment. Indeed, the actual conduct of the experiment may hinder the development of understanding.

It is difficult to summarise learning in a single phrase which will encompass all situations. Here, learning will be seen as an active, goal-directed construction of meaning. Learning involves experience that will change the behaviour. Learning needs goals and this is particularly important in laboratory learning where it is possible to have much activity without goal-directed learning.

4.2 Learning by Discovery

Johnstone and Shuaili (2001) suggested that the heuristic method taught by Armstrong early in the 20th century can be regarded as the origin of discovery laboratory teaching. In this, students were required to generate their own questions for investigation. No laboratory manual was used and the teacher provided minimal guidance. The student was placed in the role of discover.

They further emphasised that, similar to inquiry, the discovery approach is inductive but differs with respect to the outcome of the instruction and to the procedure followed. Whereas, in inquiry, the outcome is unknown to both the teacher and the learner, in the discovery learning, the teacher guides learners towards discovering a desired outcome.

Bruner's conception of discovery learning (1967) is not that students are to discover every bit of information by themselves but that they are to discover the inter-relatedness between ideas and concepts by using what they already know. Teachers should try to instil within their students a sense of confidence in the students ability to learn and to learn how to learn. Bruner (1967) thought that a significant difference could be made to a child's intellectual development by careful curriculum design and skillful teaching.

Bruner (1983) presented a course entitled, 'Man: A Course of Study' to 75 children, at the Underwood School in Newton, Massachusetts. The objective was to try out new ideas and materials on teaching that had been developed by working parties in the months leading up to the experiment. They worked with the students for a month. Later on, the individuals involved said that it had been one of the most stimulating experiences in their academic lives. However, it is not easy to see how this kind of approach can be adapted to university laboratories where, perhaps, hundreds of students have to be taught with minimum staff resources.

Bruner (1966) suggested that learning is an active process in which learners construct new ideas or concepts based on their current and/or past knowledge. The learner selects and transforms information, constructs hypotheses and makes decisions, relying on their cognitive structures. Cognitive structure (schema, mental models) provides meaning and organisation to experiences and allows the individual to go beyond the information given.

There are similarities between Bruner's approach and that of Piaget. Both believe that knowledge can be constructed by the students if they are presented with appropriate opportunities to learn. The constructivist perspective developed from such approaches. However, the constructivist approach has tended to focus on the problems arising from misconstructions rather than on the processes by which knowledge and understandings are constructed.

Bruner (1971), contended that students, starting at early primary school stages, should learn the structure of a body of knowledge instead of items of information which requires much memorisation. He also asserts that students should be taught and encouraged to discover information by themselves.

In order to learn about a body of knowledge, the curriculum should be designed in such a way that learning from stage to stage is carefully structured. As the child progresses in grade level, the body of knowledge being studied should progress in a way which he described as a spiralled curriculum. A spiralled curriculum is one in which each concept will spin into the next concept in line to produce an ever expanding learning spiral (Granger, 1992). For example, a logical step would be the development and utilisation of a taxonomic scheme involving familiar fauna or flora. The spiral then continues on to look at variations among plants, for example, angiosperms and gymnosperm which lead to flower structure and function (Granger, 1992).

Cognitive theories rest almost completely upon the notion that students have an internal desire to learn by wanting to accommodate and assimilate new information. Snelbecker (1974) said that discovery learning requires that the student participates in making many of the decisions about what, how, and when something is to be learned and even plays a major role in making such decisions. Instead of being "told" the content by the teacher, it is expected that the student will have to explore examples and for them "discover" the principles or concepts which are to be learned.

Many contend that the discovery learning versus expository debate continues a timeless debate as to how much a teacher should help a student and how much the student should help himself (Entwistle, 1981). Indeed, discovery learning presupposes a student desire to learn and that it is possible for the teacher to develop learning situations where students can construct their own understandings. In many areas, this may prove to be very difficult. It is unlikely that students can make discoveries in a few hours which took the best intellects many centuries to develop.

Bruner (1966) states that a theory of instruction should address four aspects:

(1) Predisposition towards learning;
(2) The ways in which a body of knowledge can be structured so that it can be most readily grasped by the learner;
(3) The most effective sequences in which to present material;
(4) The nature and pacing of rewards and punishments.

Each is now discussed briefly.

4.2.1 Curiosity and Uncertainty

Bruner (1967) felt that experiences should be designed which will help the students to be willing and able to learn. He called this the predisposition toward learning. Bruner believed that the desire to learn and to undertake problem solving could be activated by devising problem activities in which students would explore alternative solutions. The major condition for the exploration of alternatives was "the presence of some optimal level of uncertainty" (Bruner, 1967). This related directly to the student's curiosity to resolve uncertainty and ambiguity. According to this idea, the teacher would design discrepant event activities that would stimulates the student's curiosity. For example, the teacher might fill a glass with water and ask the students how many pennies they think can be put in the glass without any water spilling. Since most students think that only a few pennies can be put in the glass, their curiosity is aroused when the teacher is able to put between 25 - 50 pennies in before any water spills. This activity then leads to an exploration of displacement, surface tension, variables such as the size of the glass, how full the glass is, and so on. In this activity, the students would be encouraged to explore various alternatives to the solution of the problem by conducting their own experiment with glass of water and pennies (Bruner, 1967).

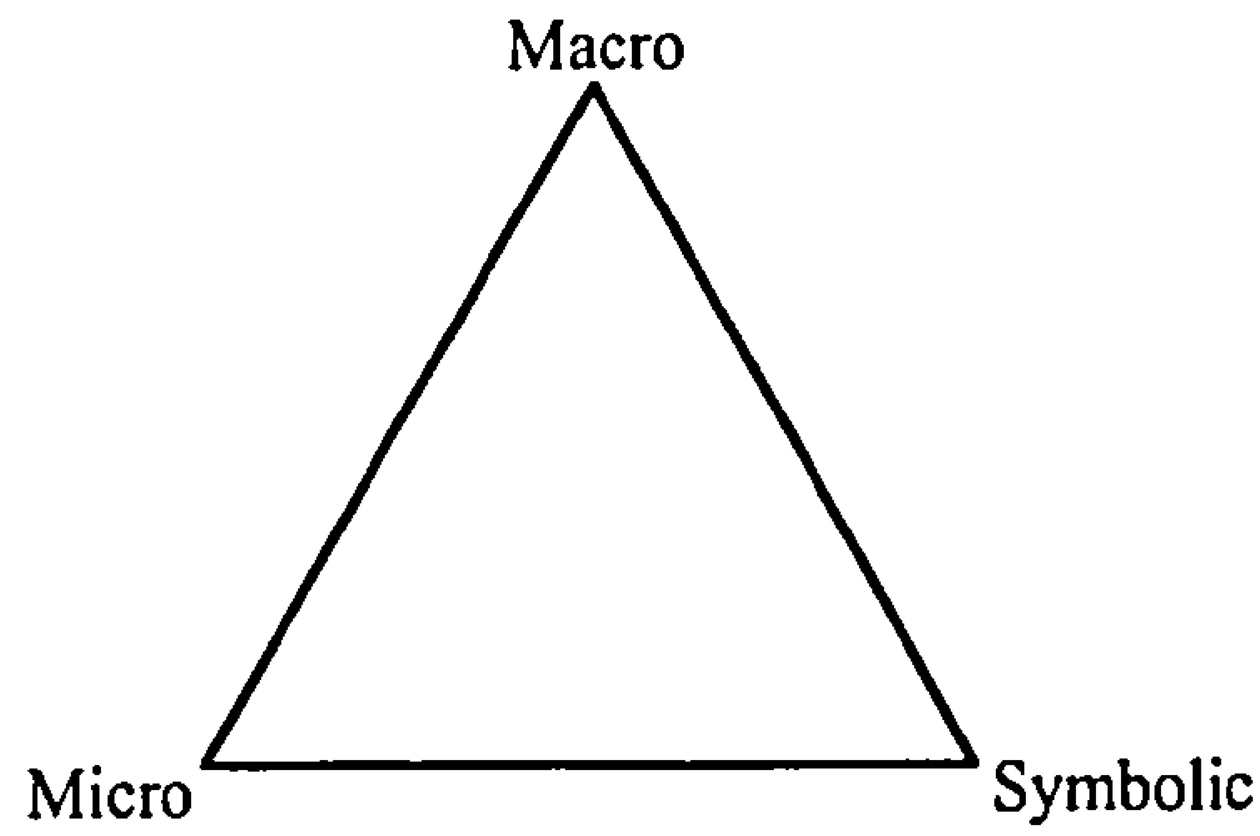
4.2.2 Structure of knowledge

The second component of Bruner's theory refers to the structure of knowledge. Bruner expressed it by saying that the curriculum specialist and teacher "must specify the ways in which a body of knowledge should be structured so that it can be most readily grasped by the learner" (Bruner, 1967). This idea became one of the important notions ascribed to Bruner. He explained it this way: "Any idea or problem or body of knowledge can be presented in a form simple enough so that any particular learner can understand it in a recognisable form." (Bruner, 1967).

According to Bruner, any domain of knowledge (Physics, Chemistry, Biology, Earth Science) or any problem or concept within that domain (law of gravitation, atomic structure, homeostasis, earthquake waves) can be represented in three ways or modes: by a set of actions (inactive representation), by a set of images or graphics that stand for the concept (iconic representation), and by a set of symbolic or logical statements (symbolic representation) (Bruner, 1967).

A very useful idea of multilevel thought has been proposed by Johnstone (1982). According to Johnstone, the science subjects can be seen as three levels or corners of a triangle.

Figure 4.1 Multi Level Thought (Johnstone, 1991)



The macro (descriptive and functional) level is described as the first level of multi-level thought where the student can see and handle materials and describe their properties. In other words, it is the tangible, edible and visible level: for example, water, sodium chloride in chemistry and plants, animals in biology, moving objects in physics and so on.

The micro level is really sub-micro level and is the second level of thought. In chemistry, this is the molecular and sub-molecular level in which an attempt is made to give mental pictures of substances which are described at the macro level. It involves atoms, electrons and bonds.

The symbolic (or representational) level is the third level of thought in which the learner tries to represent ideas and substances by formulae and their changes by equations. For example, the chemical equation of photosynthesis in plants,

$$6CO_2 + 6H_2O \longrightarrow C_6H_{12}O_6 + 6O_2$$

Johnstone (1991) has observed that much of the teaching occurs within the triangle where three levels of thought interact in varying degrees. The teacher, as an expert in his topic, can easily move from one corner to another or operate anywhere within the triangle but it is not the case for students. When the students are learning a new topic, the start may need to be at the macro level. When they have been put in the triangle, the teacher is not aware how much demand he is putting on the students in presenting the descriptive, representational and explanatory level at the same time. This simultaneous demand in three levels causes overloading of working memory space. This will be described in greater detail later. The main point to be noted here is that the teacher has enough knowledge and experience to know how to handle many ideas at once. In effect, the teacher can move from one corner of the triangle to an other or anywhere within the triangle. However, the student, as a beginner, does not have this skill and often finds it impossible to hold all the ideas simultaneously, becoming hopelessly confused (Johnstone, 1982).

4.2.3 Sequencing

The third principle was that the most effective sequences of instruction should be specified. According to Bruner, instruction should lead the learner through the content in order to increase the student's ability to "grasp, transform and transfer"(Bruner, 1966) what is learned. In general, sequencing should move from inactive (hands-on, concrete), to iconic (visual), to symbolic (descriptions in words or mathematical symbols). However this sequence will be dependent on the student's symbolic system and learning style.

One of the most important issues in the application of learning theory is sequencing of instruction. The order and organisation of learning activities affects the way information is processed and retained (Glynn & DiVesta, 1977; Lorch & Lorch, 1985; Van Patten, Chao & Reigeluth, 1986).

The idea of organising or sequencing learning activities has been studied by many. Some have based their ideas on a 'simple-to-complex' sequence (e.g., Bruner, 1973; Reigeluth, 1983; Scandura, 1973). Gagné stressed that the sequence is dictated by pre-required skills and the level of cognitive processing involved (Gagné, 1985). Mager (1975) allowed the learner the freedom to choose their own learning sequence based upon mastery of pre-requisite lessons while Merrill (1994) also proposed that the learner select their own learning sequence based upon the instructional components available.

Others have emphasised the goal-directed nature of behaviour. Thus, Tolman, (1932) and Newell and Simon (1972) specified that the sequence of instruction be based upon the goals/sub goals to be achieved.

Some of these ideas go right back to the more behavioural approach of Thorndike, and Skinner in supporting a linear sequence of instruction (Skinnner, 1968). From the behavioural perspective, learning amounts to stimulus-response pairings and mastery of a complex subject matter or task involves the development of a chain or repertoire of such connections. Indeed, a fundamental principle of Skinnerian programmed learning was the shaping of such stimulus-response chains.

4.2.4 Sequencing in the laboratory course

Woolnough (1994) suggested that the choice for the laboratory course planner is not, 'what is the best for my course?' but 'what combination of approaches dealing with material, will provide the most suitable experience for the students overall?' The skilful laboratory course designer needs to be able to take the desirable elements from each and balance them in a programme, which pursues all the major objectives that have been identified and provides a coherent experience for students.

One of the most important decisions to be made is how the course should be sequenced: how should the teaching plan be ordered to provide a coherent and educationally sound experience for students. Following this, what should be included in the laboratory manual, what students need to do before entering the laboratory and what they should do after each experiment.

If the laboratory is conceived as a discovery experience, the importance of knowing what the student knows at the outset and preparing the student mind for learning are extremely important. Johnstone and Vianna (1994) set up a very carefully designed experiment using five large groups of chemistry students following the same laboratory course. Among other things, they were exploring the effectiveness of pre-laboratory exercises and mini-projects on laboratory learning. They obtained clear evidence that pre-laboratory exercises and mini-projects *together* offered the best learning experience. Pre-laboratory exercises always brought about improvements but the effective use of mini-projects required the preparation brought about by pre-laboratory exercises. This emphasises that pre-laboratory preparation is a vital factor in maximising the educational value of laboratories.

In a parallel study in physics, Al-Zaman and Johnstone (1998) explored, in a skilfully constructed experiment in undergraduate physics, both learning gains and the development of attitudes when using pre-laboratory exercises. They found quite massive changes in student attitudes towards laboratories, attitudes becoming markedly more positive. They also found very large gains in what the students understood, evidenced by both demonstrator marking of laboratory reports and by the successful completion of post-laboratory exercises which tested understanding.

Sirhan *et al*, (1999) suggested that reducing the amount of the 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. Similarly, Garratt claims that there is some evidence for the proposition that covering less material results in more total learning (Garratt, 1997). Sirhan and Reid, (2001) concluded the importance of the idea of preparing the mind of the learner by applying the model of Johnstone and El-Banna (1986) and suggested that the pre-lecture can be used in any course in Higher Education. This brings benefits to those who are disadvantaged by their lack of previous experience of chemistry. In addition, the laboratory experience must be seen as a holistic experience:

student preparation before the laboratory, the actual laboratory investigation, what the student then does with the outcomes of the experiments.

Davies (1982) suggested these rules for sequencing:

Proceed from known to unknown;
Proceed from simple to complex;
Proceed from concrete to abstract;
Proceed from particular to general;
Proceed from observations to reasoning;
Proceed from whole to parts and back again to the whole.

These are the most simple rules. However. more recent studies enable us to go beyond this formulation and take into account the needs of the discipline, the needs of the learner and needs of the context for which the students are prepared. However, even this apparently simple set of rules are complex when applied by learners in unknown situations. Romiszowski (1981), suggested a much more comprehensive set of principles in relation to the above discussion but its complexity is a problem

4.3 Support for Discovery Learning

It can be argued that discovery learning matches cognitive development and some educators favour this type of learning because this approach is consistent with the ways that people learn and develop (Lawrence, 1998). For example, Bruner identified three stages of cognitive growth, similar to the stages identified by Piaget. Bruner believed that children move from an inactive stage to the iconic stage and finally to the symbolic stage. In the inactive stage, the child represents and understands the world through actions. To understand something is to be able to manipulate it, throw it or break it. At the iconic stage, the child represents the world in images: appearances dominate. This stage corresponds to Piaget's pre-operational thinking and its principle of conservation, in which the higher the water level, the more water there must be in the glass. At the final level, the child is able to use abstract ideas, symbols, language, and logic to understand and represent the world.

Discovery learning allows students to move through these three stages as they encounter new information. Firstly, it is suggested that the students manipulate and act on materials; then they form images as they note specific features and make observations; and finally, they abstract general ideas and principles from these experiences and observations. When students are motivated and participate in the discovery project, discovery learning leads to superior learning. However, it must be noted that Piaget is talking about biological maturation while Bruner is talking about a proposed sequence of experiences through which learners proceed.

4.4 Criticisms of discovery learning.

In theory, discovery learning seems ideal, but in practice there are problems. To be successful, discovery projects often require special materials and extensive preparations as well as a very considerable flexibility on the part of the teacher. This flexibility may be impossible to sustain, with large groups of students. To make matters worse, these preparations and concomitant flexibility do not always guarantee success. In order to benefit from a discovery situation, students must have basic knowledge about the problem and must know how to apply problem-solving strategies. Without this knowledge and skill, they will flounder and grow frustrated. Instead of learning from the materials, they may simply play with them. Critics believe that discovery learning is so inefficient and so difficult to organise successfully that other methods are preferable (Lawrence, 1998). This seems especially true for lower-ability students. Discovery methods may make too many demands on these students because they lack the background knowledge and problem-solving skills needed to benefit (Rowell & Dawson, 1988).

Hodson (1990, 1993), expressed the view that discovery instruction as not only philosophically unsound but also pedagogically unworkable. He asserted that the learner cannot discover something for which he/she is conceptually unprepared.

In the laboratory situation, it is not really reasonable to expect a group of students, in an afternoon laboratory session, to be able to discover what it took many decades for the best scientific brains in the world to discover. Indeed, the students may reach wrong conclusions in parallel ways to the mistakes, wrong deduction and cul-de-sacs which scientists have always experienced in their attempts to make sense of the world around them.

4.5 Summary

From his studies, Bruner found that the development of thinking was seen as a function of experience and was apparently independent of maturational factors. This observation stands in contradiction to the ideas of Piaget who emphasised development with age. Indeed, it does not match the findings of information processing where it is now know that the capacity to process information does increase with age up to the age of about 16 (Miller, 1956).

Bruner's key concept was 'representation'. This was the way that humans represent their knowledge: the inactive, iconic and symbolic. This can be thought of as knowing what actions to perform, knowing how to represent through internal visual imagery, knowing how to represent by means of a symbol system as in mathematics and language. For an individual to make progress, a concept would usually pass through each mode in turn. Knowledge and understanding was then increased by using all three modes together.

Discovery learning emphasises what Bruner (1960, 1966) calls a hypothetical mode (in the sense of developing hypotheses) of teaching and learning as opposed to a more didactic mode. Discovery learning encourages students to ask questions and formulate their own tentative answers, and to deduce general principal from practical examples or experience. Discovery learning takes place most notably in problem solving situations where the learner draws on his own experience and prior knowledge to discover the truths that are to be learned. It is a personal, internal, constructivist learning environment.

Discovery learning can be seen to have some similarities to the scientific model of enquiry. Students identify problems, generate hypotheses, test each hypotheses against collected data, and apply conclusions to new situations. The purpose of this type of instruction is to teach students thinking skills. In that sense, it is very difficult for any scientist to argue that discovery learning has no place in the teaching and learning process in the sciences.

Discovery learning encourages students actively to use their intuition, imagination, and creativity. Because the approach starts with the specific and moves to the general, the teacher presents examples and the students work with the examples until they discover the interrelationships. Bruner believes that classroom learning should take place through inductive reasoning, that is, by using specific examples to formulate a general principle.

4.6 Cognitive Load and Discovery Learning

Tuovinen (1997) suggested that discovery learning reduced the cognitive load by eliminating the extraneous working memory load caused by the use of some problem solving strategies during learning, or the elimination of split-attention and redundancy effects for material that imposes a high working memory load.

Cognitive load theory (Sweller, 1999, 1994) derives instructional design principles from aspects of what is described as our cognitive architecture. The theory assumes a very limited working memory (Miller, 1956), an effectively unlimited long-term memory (Simon and Gilmartin, 1982), the ability to hold large numbers of schemes (Chi, Glaser & Rees, 1985) that can vary in their degree of automaticity (Kotovsky, Hayes & Simon, 1985). This architecture interacts with instructional material in various ways.

Firstly, different learners will process the material in different ways. If the elements of material that require processing are incorporated in automated schema, working memory load (or cognitive load) will be low. Schemas allow many elements to be treated as a single element in working memory and automatic processing limits working memory demands compared to controlled, conscious processing (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977). However, if a learner does not possess the appropriate schemes, working memory overload is highly likely.

Secondly, the characteristics of the instructional material is important. Some material can be learned element by element without relating one element to another. Such material is low in element interactivity and low in intrinsic cognitive load. It imposes minimal demands on working memory. Alternatively, situations where a number of elements must be considered simultaneously for the successful execution of a task are called high element interactivity tasks.

Thirdly, the characteristics of the learner and the material to be learned interact. Material which imposes a heavy cognitive load for some people because they must deal with large numbers of interacting elements may impose less of a cognitive load for other people because they have acquired automated schemes that incorporate the individual elements.

It is argued that, in the process of dealing with information, working memory has only a limited processing capacity available to deal with distinct items at any given time, and that the capacity of working memory is often overloaded due to inappropriate presentation of material or inappropriate learner activities, leading to a reduction in learning and the capacity to solve problems. Thus, new material is learned most effectively and efficiently if the unnecessary cognitive load is reduced to a minimum. This obviously has high relevance in laboratory learning where the amount of information is frequently extremely high.

4.6.1 Practical application

Bruner's constructivist theory can be applied to instruction, as Kearsley (1994b) surmises, by applying the following principles:

(1) Instruction must be concerned with the experiences and contexts that make the student willing and able to learn (readiness).

(2) Instruction must be structured so that it can be easily grasped by the student (spiral organisation).

(3) Instruction should be designed to facilitate extrapolation and or fill in the gaps (going beyond the information given).

Bruner's constructivist theory asserts that learning is an active process in which learners construct new ideas based upon their current knowledge. Instruction can be made more efficient by providing a careful sequencing of materials to allow learners to build upon what they already know and go beyond the information they have been given to discover the key principles by themselves.

4.7 Learning by Sequencing Ideas in a Hierarchy

It would seem to be highly sensible, in designing a laboratory course, to start by defining aims and objectives. Then, various experiences can be arranged into a sequence that provides the right balance of concept development and skill development. Of course, attention must be paid to motivational aspects.

It is also important to consider how the various experiences can be presented to the students. When they come to a course, students are not aware of the thought behind the course and, consequently, some mechanisms need to be developed to inform the students about the reasons for inclusion of certain activities in the laboratory course, and what each activity is designed to achieve (Nelson, 1970).

Gagné first published his best known book "The Condition of Learning" in 1965. His early investigations into the psychological basis of effective teaching led him to believe that an instructional technology or theory must go beyond traditional learning theory. Gagné concluded that instructional theory should address the specific factors that contribute to the learning of complex skills. He described these factors in a 1968 article entitled "Learning Hierarchies" (Gagné, 1968). This article was originally presented by Gagné at the Annual Meeting of the American Psychology Association, San francisco, California.

Gagné suggested that learning tasks for intellectual skills can be organised in a hierarchy according to complexity:

stimulus recognition;
response generation;
procedure following;
use of terminology;
discriminations;
concept formation;
rule application;
problem solving.

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. It is important to recognise that Gagné presented it as an hierarchy, each stage being required for the success at the next stage.

In addition, the theory outline of nine instructional events and corresponding cognitive processes (Gagné, 1968):

(1) Gaining attention (reception)
(2) Informing learners of the objectives (expectancy)
(3) Stimulating recall of prior learning (retrieval)
(4) Presenting the stimulus (selective perception)
(5) Providing learning guidance (semantic encoding)
(6) Eliciting performance (responding)
(7) Providing feedback (reinforcement)
(8) Assessing performance (retrieval)
(9) Enhancing retention and transfer (generalisation).

These events should satisfy or provide the necessary conditions for learning and serve as the basis for designing instruction and selecting appropriate media (Gagné, Brings & Wager, 1992).

Gagné (1985) classified the types of learning outcomes. A good way to identify the types of learning is to ask how learning could be demonstrated:

motor skills	enable physical performance
attitudes	are demonstrated by preferring options
verbal information	is stated intellectual skills
concepts	are demonstrated by labelling or classifying things
rules are applied	principles are demonstrated
problem solving	allows generating solutions or procedures
cognitive strategies	are used for learning

Gagné suggests that, although different in detail, the same types of instructional activity are needed for all learning processes and learning outcomes. The importance behind the above system of classification is that each learning level requires "different internal and external conditions" (Kearsley 1994a) as described above. The primary significance of this hierarchy is to provide direction for instructors so that they can "identify prerequisites that should be completed to facilitate learning at each level" (Kearsley, 1994a). This learning hierarchy also provides a basis for sequencing instruction

4.8 Gagné and Laboratory Work

Bennett & O'Neale (1998) produced a list of complex skills. which may be traditionally developed in the traditional laboratory. The list includes:

(a) Manipulation skills;
(b) Observation skills;
(c) Data collection skills;
(d) Processing and analysis of data;
(e) Interpretation of observations skills;
(f) Problem solving skills;
(g) Team working skills;
(h) Experiment design skills;
(i) Communication and presentation skills;
(h) Laboratory know-how skills.

It is very clear that these are not a hierarchy. Manipulation skills, for example, are not necessarily related to observation skills. Thus, while Gagné's theoretical framework covers all aspects of learning, the focus of the theory is on intellectual skills. The theory has been applied to the design of instruction in all domains (Keller & Suzuki 1988). Gagné's nine instructional events and corresponding cognitive processes can serve as the basis for designing instruction and selecting appropriate media (Gagné, Brings & Wager, 1992, as cited in Kearsley, 1994a). Kearsley suggests the following principles to apply these instructional events.

(1) Learning hierarchies define a sequence of instruction.
(2) Learning hierarchies define what intellectual skills are to be learned.
(3) Different instruction is required for different learning outcomes.

However, there is considerable doubt if Gagné's ideas can be applied easily in the laboratory situation. Indeed, there is some doubt about other areas as well. In an early study, carried out by How & Johnstone (1971), it was found that the arrangement and writing of the statement of a question is important, so that it is caught and understood by the students. They also observed that students confused the subscripts of the chemical formulas with the coefficients of the equations, and they reached the conclusion that perhaps the mole in itself, is not something confusing, and that it could be the strategies used to arrive at it that might puzzle the students. Nonetheless, the idea of planning learning logically and building ideas up in sequences is certainly useful although the logical learning programmes as designed by teachers may not always match the actual learning approaches adopted by the learners.

Chapter Five

The Nature of Learning II

5.1 Learning by Building on Previous Knowledge

Two main aspects of learning may be present in laboratory learning: knowledge and skills. These two are distinguished and discussed by Bruner (1966) and Glasersfed (1989). In the context of chemistry, all kinds of chemical information, chemical concepts and chemical understandings might fall within the realm of knowledge while skills range from the practical skills of the bench chemist right across to team working skills, report writing, skills and hypothesis formation skills.

West and Fensham (1974) suggested that meaningful learning occurs when the learner's appropriate existing knowledge interacts with the new learning. Rote learning occurs when no such interaction takes place.

According to Ausubel and Robinson (1973), the following are thought to be the most likely circumstances which result in rote learning:

(1) The material to be learned lacks logical meaning;
(2) The learner lacks the relevant ideas in his own cognitive structure;
(3) The individual lacks a meaningful learning set (a disposition to link new concepts, propositions, and examples, to prior knowledge and experience).

Ausubel (1968) states that, "If I had to reduce all of educational psychology to one principle, I would say this: the most important single factor influencing learning is what the learner already known. Ascertain this and teach him accordingly". In making this statement, he was emphasising that, for meaningful learning to take place, it was essential to link new ideas on to ideas already held in long term memory. This would suggest that moving into completely new areas will be a difficult process.

5.2 Overview

Ausubel's (1978) theory is concerned with how individuals learn large amounts of meaningful material from verbal/textual presentations in a formal setting (in contrast to theories developed in the context of laboratory experiments). According to Ausubel, learning is based upon the kinds of superordinate, representational, and combinatorial processes that occur during the reception of information. A primary process in learning is subsumption in which new material is related to relevant ideas in the existing cognitive structure on a substantive, non-verbatim basis. Cognitive structures represent the residue of all learning experiences; forgetting occurs because certain details get integrated and lose their individual identity .

A major instructional mechanism proposed by Ausubel is the use of advance organisers:

> *"These organisers are introduced in advance of learning itself, and are also presented at a higher level of abstraction, generality, and inclusiveness; and since the substantive content of a given organiser or series of organisers is selected on the basis of its suitability for explaining, integrating, and interrelating the material they precede, this strategy simultaneously satisfies the substantive as well as the programming criteria for enhancing the organisation strength of cognitive structure."* (Ausubel, 1960).

Ausubel emphasises that advance organisers are different from overviews and summaries which simply emphasise key ideas and are presented at the same level of abstraction and generality as the rest of the material. Organisers act as a subsuming bridge between new learning material and existing related ideas.

Optimal learning generally occurs when there is a potential fit between the student's schemas and the material to be learned. To foster this association, Ausubel suggests that the lesson always begin with an advanced organiser - an introductory statement of a relationship of high-level concept, broad enough to encompass all the information that will follow. The function of the advanced organiser is to provide scaffolding or support for the new information. It is a conceptual bridge between new material and a student's current knowledge. Text books sometimes contain material which can act as an advanced organiser - the chapter overviews are examples if these outline the general principle on to which the new material can be linked. They serve three purposes:

(1) They direct attention to what is important in the coming material;
(2) They highlight relationships among ideas that will be presented;
(3) They remind the student of relevant information already in memory.

After presenting an advance organiser, the next step in an Ausubel lesson is to present content in terms of basic similarities and differences, using specific examples. To learn new material, students must comprehend the similarities between the material presented and what they already know. They must also see the differences so that confusion can be avoided. Along with the comparisons, specific examples must come into play. The best way to point out similarities and differences is with examples.

5.3 Importance of Prior Knowledge

According to Ausubel prior knowledge is the most important factor in learning. This means that learning depends substantially on what learners already know. He describes meaningful learning (as distinct from rote learning) as "nonarbitarary, substantive, nonverbatim incorporation of new knowledge into a cognitive structure" (Ausubel, 1968). He claims that meaningful learning occurs when the learner's appropriate existing knowledge interacts with the new learning. On the other hand, rote learning of new knowledge occurs when no such interaction takes place.

Depending on the nature of the learner's existing knowledge and how it interacts with the new knowledge, there will be varying degrees of meaningful learning. Ausubel calls those aspects of existing knowledge that can provide these interactions for meaningful learning, 'subsumers'. A subsumer is any concept, principle or generalising idea that the learner already knows which can provide association or anchorage for various components of the new knowledge (Ausubel, 1978).

Ausubel (1968) the emphasised that to learn meaningfully, individuals must relate new knowledge to relevant concepts and propositions they already know. In rote learning, on the other hand, new knowledge may be acquired by memorisation.

Both kinds of learning can happen simultaneously during an educational experience. This same situation arises when making the distinction between reception and discovery learning. By applying a variety of teaching approaches and materials, a combination of the above would probably be generated in a course or even one lesson. However, it might be a difficult task to define where and when each category, if any, took part during a teaching incident.

5.4 Scope and Practical Application

Ausubel clearly indicates that his theory applies only to reception (expository) learning in school settings. He distinguishes reception learning from rote and discovery learning; the former because it does not involve subsumption (i.e., meaningful materials) and the latter because the learner must discover information through problem solving. A large number of studies have been conducted on the effects of advance organisers in learning (Ausubel. 1968).

According to Ausubel, people acquire knowledge primarily through reception rather than through discovery. 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 stresses meaningful learning. Rote memory, for example, is not considered meaningful since memorisation omits the connection of new knowledge with existing knowledge. Ausubel also proposed his expository teaching model to encourage meaningful rather than rote reception learning. In his 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 believes that learning should progress deductively - from the general to the specific - and not inductively as Bruner recommended.

It is very clear that Ausubel takes a very different approach when compared to Bruner. In many traditional university laboratory situations, learning is almost absent (Johnstone & Wham, 1980). However, the very tightly defined structure, with closed experiments controlled by manuals which specify each stage precisely, offers virtually no room for any discovery of any kind. Equally, there is limited opportunity to link new material into ideas already grasped. The student is focussed on following instructions, obtaining results, and reaching a specified goal and there is little opportunity either for discovery or for meaningful learning.

5.5 Cognitive Learning Styles.

Cognitive styles refer to the preferred measures in which individuals process information. Unlike individual differences in abilities (eg,., Gardner, 1975, Guilford 1986, Sternberg, 1983, 85, 86) which describe peak performance, styles describe a person's typical mode of thinking, remembering or problem solving. Furthermore, styles are usually considered to be bipolar dimensions whereas abilities are unipolar (ranging from zero to a maximum value). Having more of an ability is usually considered beneficial while having a particular cognitive style simply denotes a tendency to behave in a certain manner. Cognitive style is usually described as a personality dimension which influences attitudes, values and social interaction.

Other cognitive styles that have been identified include:

(a) Scanning - differences in the extent and intensity of attention resulting in variations in the vividness of experience and the span of awareness
(b) Levelling versus sharpening - individual variations in remembering that pertain to the distinctiveness of memories and the tendency to merge similar event
(c) Reflection versus impulsivity - individual consistencies in the speed and adequacy with which alternative hypotheses are formed and responses made

(d) Conceptual differentiation - differences in the tendency to categorise perceived similarities among stimuli in terms of separate concepts or dimensions (Ausubel, 1966).

Learning styles specifically deal with characteristic styles of learning. Kolb (1984) proposes a theory of experiential learning that involves four principal stages:

(a) Concrete experiences (CE),
(b) Reflective observation (RO),
(c) Abstract conceptualisation (AC),
(d) Active experimentation (AE).

These four stages follow from each other. Concrete experience is followed by reflection on that experience on a personal basis. This may then be followed by the derivation of general rules describing the experience, or the application of known theories to it, this is the abstract conceptualisation, and hence to the construction of ways of modifying the next occurrence of the experience, this is active experimentation, leading once again to the next concrete experience. All this may happen in a flash, or over days, weeks or months, depending on the topic.

Theoretically, cognitive and learning styles could be used to predict what kind of instructional strategies or methods would be most effective for a given individual and learning task.

A number of cognitive styles have been identified and studied over the years. Field independence versus field dependence is probably the most well known style.

5.6 Field independence versus field dependence

According to Witkin *et al.*(1977), cognitive styles are the "characteristic, self-consistent modes of functioning which individuals show in their perceptual and intellectual activities". One aspect of cognitive style is perceptual style or the manner in which a person cognitively approaches a learning situation. In terms of perceptual style, a person can be classified as field independent or field dependent. Prior studies (Witkin *et al.*, 1977) have shown that field-independent and field-dependent students do not differ in learning ability but may respond differently to the content being presented as well as the learning environment. Students classified as field-independent tend to be highly analytical, are internally motivated, have self-defined goals and are more likely to solve problems without explicit instructions or guidance. Field-dependent learners have difficulty learning unstructured material, tend to need externally defined structure, goals and reinforcement and may need explicit instructions on how to solve a problem (Steele, 1989; Young & Fouts, 1993).

subsequent increase in field-independence that extends into adolescence. Since most children are identified for placement into gifted programs early in their academic careers, it is quite possible that the use of cognitive style as an identification tool with that age group could be discriminatory toward children who are cognitively delayed.

(b) Cognitive style has also been criticised due to gender differences. As Witkin *et al.* (1977) pointed out, males tend to be more field independent than females although these differences seem negligible before about age eight. Knowing this, many researchers might be hesitant to use cognitive style for fear of bias toward female students.

5.7 Information Processing

Piaget's theory of cognitive development has been a powerful influence for researchers in educational psychology. He saw cognitive development in terms of biological maturation and, according to him, intellectual development is the development of schema and the number and quality of schema varies with the age due to biological maturation. He totally ignored the effect of environment on intellectual development.

Vygotsky (1978), on the other hand, counted experiences to be important in cognitive development. According to him, every individual could go beyond his limited developmental capacity. He observed that humans have their zone of proximal development and can go beyond their limited capacity if they interact with a conducive environment or use the experiences of others. According to Vygotsky, a learner can do slightly better than what she has been designed to do. In 1974, Pascual-Leone (1974) argued that any cognitive task was considered to be a function of three parameters:

The mental strategy that was applied to the task (repertoire H);
The demand that the strategy placed on the mental capacity (M-demand);
The individuals own available mental capacity
(central computing space, M-space or M operator).

Pascual-Leone took Piaget's stages (or schema) as the qualitative indication of the subject's M-capacity or internal computing system. The M-capacity was thought to increase with age. In the light of his theory, it appeared that examination performance might be improved by involving the learner in specific experiences that provided mental strategies to apply in particular problem solving situations, thus making sense of Vygotsky's findings. From his own studies, Case (1980) believed that, although children could be taught sophisticated strategies for problem solving, their mental capacity (M-power) could not be increased through instruction.

Pascual-Leone made computing space (M-space) and repertoire responsible for the transformation and co-ordination of information held within the cognitive structure.

Functional capacity was described as the amount of M-space actually utilised in solving a problem. It was suggested that, when an individual interacts with a problem, he/she collects information and then that information has to be dealt with for the formation of new schema. This procedure is carried out by putting the information that represents the problem and the previously existing relevant information into one channel of the central processor M. As a result of this, new information that represents the solution to the problem is established within the individuals' repertoire. It was also argued that individuals continually applied and modified their repertoire of schema whilst interacting with the world in everyday life.

The maximum number of schemata that M could handle at a time was measured. Case showed that M capacity increases by one schema for every two years from childhood until maturity. Quite separately, Miller (1956) provided theoretical ideas which are fundamental to the information processing framework. He described 'chunking' and the capacity of short term memory. He used the term "chunk" to describe units of information which can be dealt by an individual. After various memory experiments, he suggested that the average capacity is about seven plus or minus two (7±2) separate chunks. This means that the average number of chunks of information which can be held at any time is seven.

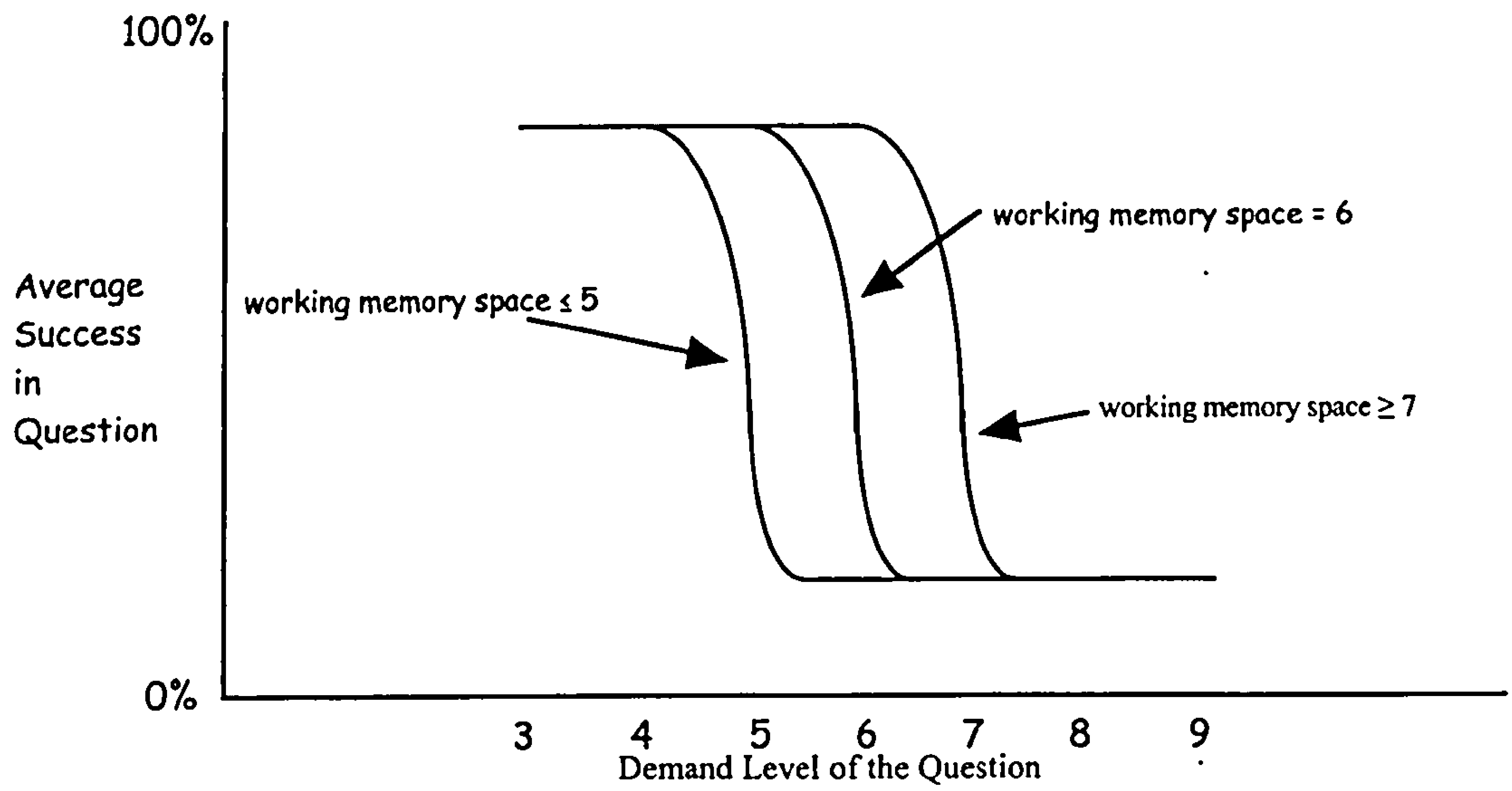
The classic example of chunks is the ability to remember long sequences of binary numbers because they can be coded into hexa decimal form. For example, the sequence 0010 1000 1001 1100 1101 1010 could easily be remembered as 2 8 9 C D A . Of course, this would only work for someone who can convert binary to hexadecimal numbers. In other words, the chunks must be meaningful.

Johnstone showed, after extensive empirical measurements, that when the students working memory capacity is exceeded, there is a sharp drop in performance. However, he also noticed that a minority of students continued to operate efficiently with problems which exceeded their capacity, and he deduced that they were probably employing chunking devices that enabled them to reduce the problem demand to less than their limit of capacity.

Johnstone and El-Banna (1989) tested student performance on a set of questions of varying working memory space demand. The demand was assessed by a team of experts and was defined as the minimum number of thought steps required for solution of the problem. The average success for each question was then plotted against "demand" and an S-shaped curve was obtained indicating a high and low plateau with rapid drop between them.

Here was "the hole in the middle" which had been observed before but could not be interpreted. The vertical part of the curve fell when the demand level was similar to the the measured working memory space of the students. This supported Miller's work about the working memory space of 7±2 and it also showed that whenever the demand (Z) exceeded the working memory capacity, the performance of students declined dramatically.

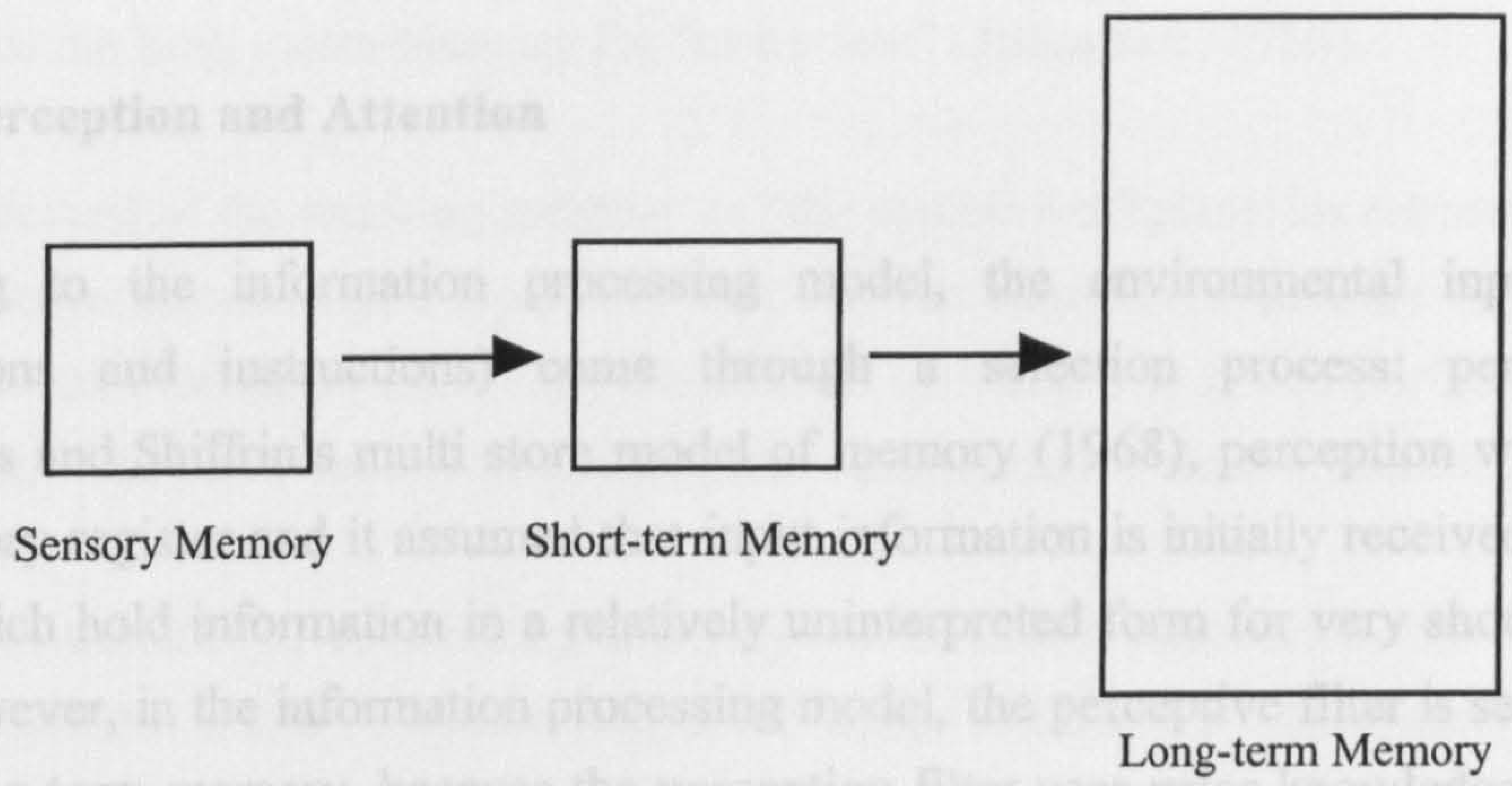
Figure 5.1 Demand level of the question



The first and most detailed information processing models of human memory put forward during the 1950s and 1960s were of the structural variety (Waugh and Norman, 1965). Traditionally, memory research has understood the usefulness of dividing memory into stages of acquisition, storage and retrieval. In 1950, cognitive scientists began creating models that acknowledged these stages. The models came to be known collectively as information processing models and their common features as the modal model. Although new memory models continue to evolve, the modal model provides a useful organiser for thinking about memory. The modal model divides memory into 3 major categories: sensory memory, short-term memory and long-term memory.

It is assumed that information is initially held in a specific sensory store but that information is initially rapidly lost through decay unless attention is paid to it. Attended items are passed on to a limited-capacity short term store (STS), where they are rehearsed or displaced by further items. Rehearsal is used both to maintain items in STS and to transfer information to a semi-permanent long term store (LTS). Waugh and Norman (1965) used the term "primary memory" to refer to STS and "secondary memory" to refer to LTS.

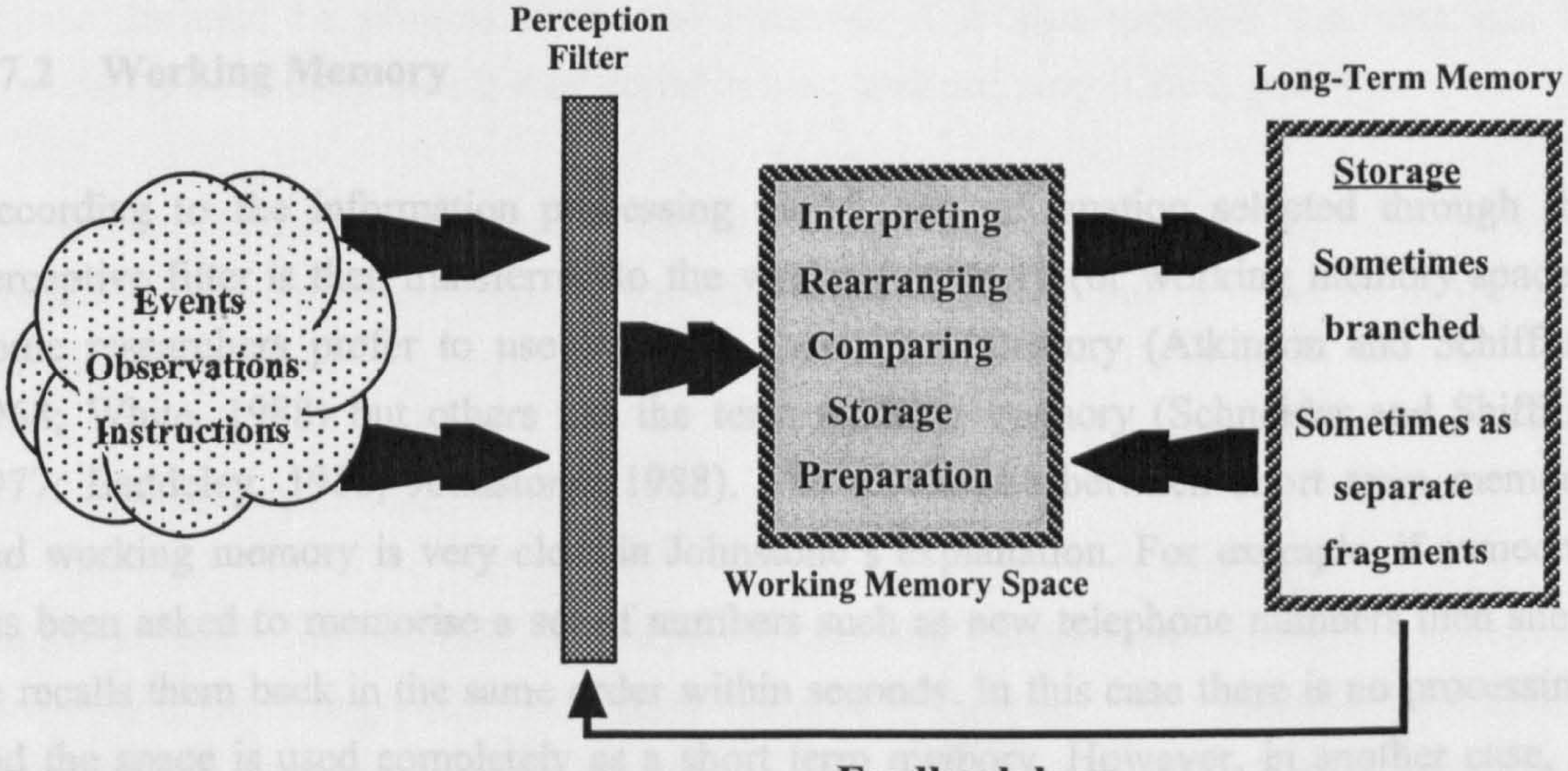
Figure 5.2 Modal Model of Memory



The diagram above identifies the stages most commonly included in information processing models based on a multi-stage model provided by Atkinson and Shiffrin (1978) and Baddeley (1994, 1986). This model depicts memory as entailing the flow of information between the three interrelated memory stores. There is also a control process that operates on the short-term memory and long-term memory stores (Bower, 1970; Schneider and Shiffrin, 1977).

Johnstone (1993) developed a model of information processing, (Fig. 5.3). It represents the flow of the information through the memory system and the processing of such information. Such a model makes predictions about how input information is dealt with in the human mind so that meaningful learning can take place. It also indicates where mislearning may take place.

Figure 5.3 Information Processing Model of Learning



This model has three parts: the perception filter, the working memory space, and the long term memory. Each will be now be discussed.

5.7.1 Perception and Attention

According to the information processing model, the environmental inputs (events, observations and instructions) come through a selection process: perception. In Atkinson's and Shiffrin's multi store model of memory (1968), perception was proposed as a sensory register and it assumed that input information is initially received by sensory stores which hold information in a relatively uninterpreted form for very short periods of time. However, in the information processing model, the perceptive filter is seen as driven by the long term memory, because the perception filter uses prior knowledge in the long term memory in order to select important information. According to Johnstone (1991), knowledge, concepts, beliefs and attitudes held in long term memory all can affect perception.

In White's idea (1988), the selection of events is vital in learning and what they select is affected by a learner's pre-knowledge, attitudes and abilities. Also, it depends upon:

(i) Attributes of events; properties like absolute intensity of a stimulus, motion and relative intensity of a stimulus;
(ii) Attributes of the observer; general level of alertness, range of cognitive strategies available to the observer;
(iii) Interaction between events and observer; selection is affected by whether the observer finds the events unusual, interesting or understandable, construction of patterns and seeing events as a collection of meaningful units. If it cannot be combined with a set of stimuli into a unit, it is not selected for attention (Bahar M. et al 1999).

5.7.2 Working Memory

According to the information processing model, the information selected through the perceptive filter is then transferred to the working memory (or working memory space). Some researchers prefer to use the term short term memory (Atkinson and Schiffrin, 1968; White, 1988) but others use the term working memory (Schneider and Shiffrin, 1977; Baddeley, 1986; Johnstone, 1988). The distinction between short term memory and working memory is very clear in Johnstone's explanation. For example, if someone has been asked to memorise a set of numbers such as new telephone numbers then she / he recalls them back in the same order within seconds. In this case there is no processing and the space is used completely as a short term memory. However, in another case, if someone is asked to receive input in the form of numbers and, if he is asked to sum the first the last and then multiply by the middle number, processing now begins to operate and the space is called working memory. Working memory can be defined as "that part of the brain where we hold information, work upon on it, organise it, and shape it, before storing it in the long - term memory for further use" (Johnstone, 1984).

Ashcroft described the working memory as "the mental workplace for retrieval and use of already known information". He points out that the short term memory implies a static short-lived store which is limited in the amount of work that it can perform. The more information to be held, the less processing can occur and vice versa (Ashcroft, 1994).

Information transferred to working memory (WM) can remain active 15 - 20 seconds without rehearsal. It can be remain longer if practice to do so. Working memory has limit of 7 ± 2 items. The capacity of working memory can be increased by chunking. Short term memory is equivalent to working memory, the different names reflecting the different uses of the space.

5.7.3 Long - term memory

The long term memory has an enormous capacity for storing information and is not prone to the same process of decay characteristic of the other two memory structures (Child 1986). Baddeley (1994), noted that there are theorists who believe that the material held in long term memory never decays but only becomes less accessible through time. Conversely, there are those who think that metabolic changes cause gradual decay until all memory traces disappear from the nervous system.

The transfer of information from short to working memory requires a considerable amount of concentration. Material is returned to the working memory in order to be utilised through the process known as retrieval. It is also assumed that data can be retrieved more quickly than it was stored in long term memory (Child, 1986).

Information for future reference is stored in long term memory (LTM). This LTM is thought to have unlimited capacity and duration. Most additions to LTM occur through deliberate efforts.

5.7.4 Chunking and Difficulty

Johnstone and Kellett (1980) acknowledged the interaction between conceptual knowledge, chunking and perceived subject difficulty. As students conceptual understanding increases they are able to create larger "chunks" of information and thus reduce the information load.

5.8 Working Memory and Laboratory Work

Laboratory work is a very important component of teaching and learning of science education. From an historical perspective, the amount of practical work in science courses has undoubtedly increased significantly over the last hundred years and has been accompanied by a shift in emphasis from the lecture / demonstration to the hands on approach.

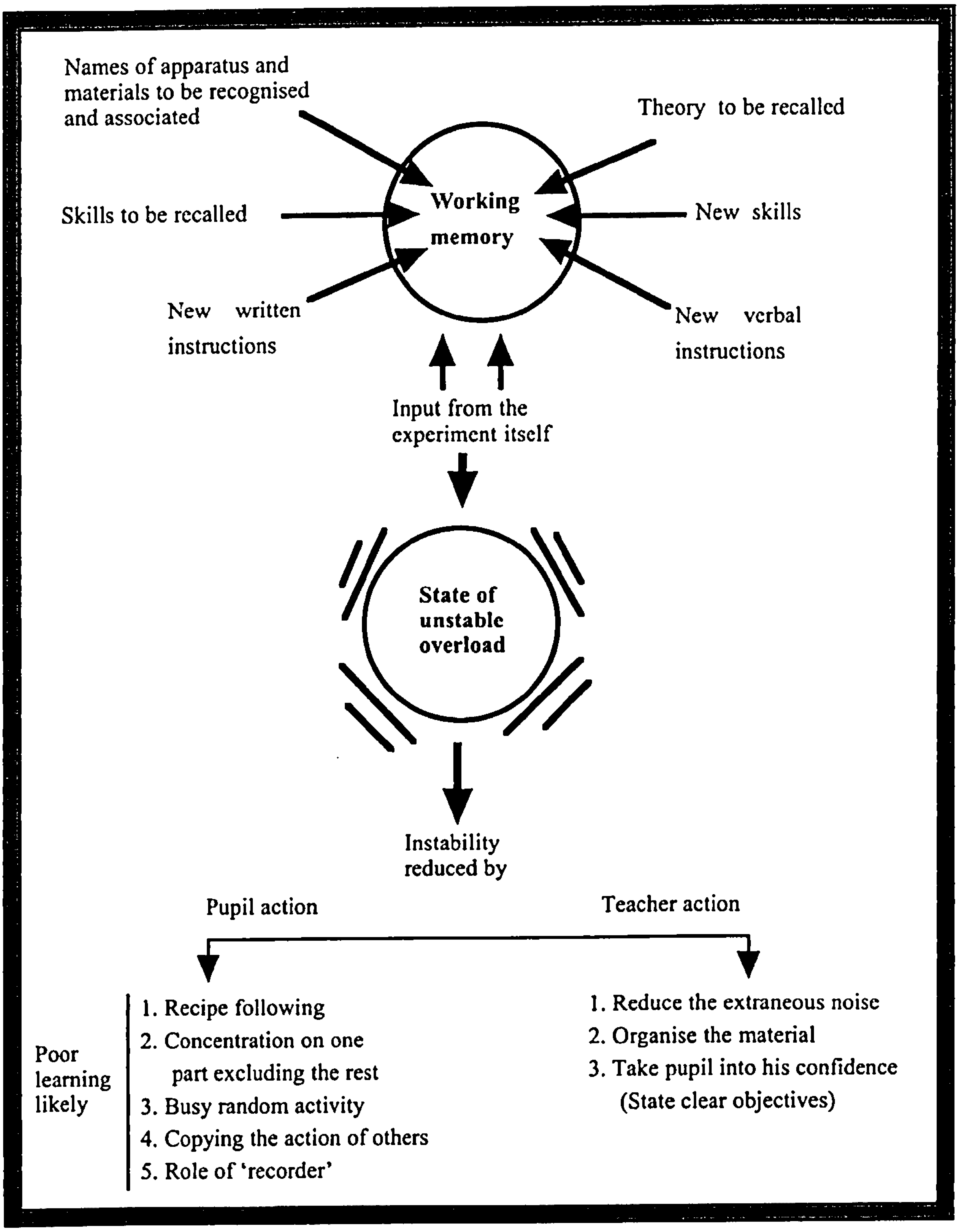
Speaking of schools, Solomon (1988, 1989), argues that the teaching of science should take place in a laboratory, because the exotic atmosphere of the laboratory stimulates the curiosity, creativity and discovery skills in students. However, in the laboratory situation, the student's working space can often become overloaded. In university laboratories, there may be information from a laboratory manual, from verbal instructions from demonstrators, from equipment, form the actual experiment being conducted as well as information which has to drawn from long term memory. The potential for overload is considerable. In addition, students mostly cannot differentiate between the noise (irrelevant information which is not important) and the signal (relevant information which is important).

Johnstone and Wham (1982) conducted extensive observations of the activities which were taking place in the laboratory and attempted to measure what learning was actually occurring. He suggested that practical work in laboratories did not produce effective learning when the individual's working memory was overloaded with new information .

During a laboratory experiment, the learner usually deals with a whole range of unfamiliar instructions, observations and deductions, and so on. Many facts and figures have to be collated and rearranged into some coherent form and hopefully understood by the end of the experiment. Sometimes students become completely overwhelmed with the sheer quantity of new material, before any real understanding of its purpose has taken place. When the amount of data exceeds the individual's working memory capacity, they may pursue some less demanding course of action, such as recipe following or copying from others. Although this, or similar tactics, may seem logical during the experiment, the exercise is generally ineffective as very little meaningful learning can occur under these conditions (Johnstone and Wham 1982).

Johnstone and Wham attempted to show that, when the quantity of information being presented to students in the laboratory was beyond their working memory capacity, then they eventually lost concentration and reached what was described as a 'state of unstable overload'. Therefore the limited capacity of the working space can be easily overloaded in practical work (Fig.5.4).

Fig.5.4 Overloading the working memory by practical work (adopted from Johnstone and Wham (1982).



Their model illustrates how the limited capacity of working space is overloaded, how the noise swamps the signal and lists the possible ways students act in order to reduce of overloading of working space. The Johnstone and Wham idea was that, "the signal ought to be enhanced by clarifying what is preliminary, peripheral and preparatory in order to suppress the irrelevant information (the noise). The experiment can be redesigned in order to avoid recipe following".

5.9 Conclusions

In this chapter the following were discussed:

Ausubel meaningful learning development;
Bruners' conception of discovery learning;
Gagnes' hierarchy of learning;
Cognitive style of learning;
Field independent and dependent learning; and
Information Processing Model.

All these different aspects of learning have complemented and overlapped each other in some areas. For example there are some generalisations with which Ausubel and Gagne seem to agree. They both agreed that prior knowledge can influence learning.

Ausubel interpreted learning as a continuous process of modification and amendment of the learners' cognitive structure. Learned materials, the knowledge in the cognitive structure and the learners' adaptation of meaningful learning may play a critical role in successful teaching and learning. Ausubel and Gagne have similar views in terms of learning hierarchies, the only difference being that Ausubel concentrated more on content knowledge rather than learning to think.

Cognitive styles of learning are independent of content of the subject matter. Cognitive styles are information processing habits, representing the learners' typical mode of perceiving, thinking, problem solving and remembering.

The information processing model give an indication of a limited space for an individual, within which one can deal with the teaching material and the problem solving task. In the laboratory situation, practical work is described as an area of educational difficulty, where the working memory can be easily overloaded and influenced due to a large number of variables.

Chapter Six

Attitudes in Science Education

6.1 Introduction

This chapter recognises the powerful effect of practical work in chemistry on attitudes of the learners, often influenced by the attitudes of the teachers. This chapter seeks to offer an overview of the literature relating to attitude to practical work.

6.2 What are attitudes?

The literature about attitudes, their nature and development is simply enormous (see Chaiken and Eagly, 1993) and it is not possible in the space here to do more than touch upon one or two important aspects. A person's attitudes are his/her consistent ways of anticipating, evaluating and responding to people, ideas, objects and situations.

Attitudes will affect behaviour, influencing what the learner selects from the environment, how they will react to teachers, the materials being used and the other students. This selection and the processing of the input of information which follow it are strongly influenced by the instructor's expectations, attitudes and concepts (Dunham, 1974).

Krech et. al. (1962) suggested a three-part structure of attitudes, consisting first of a cognitive component, that is, beliefs about an object, a person or a situation. Secondly, an attitude has an affective or feeling component and, thirdly, there is a response-potential or an action-tendency component.

All aspects of chemistry learning can contribute to attitudes towards chemistry and to the learning of chemistry. There will be the cognitive aspects: what the learner knows and experiences. There will be affective aspects: does the learner like experience of the learning, the subject itself and the instructor. There will also be the action component in the sense of what the learner actually does (and this will include practical work) and how the learner might use the chemistry learned.

Richardson, (1996) argued that attitudes are learned, and there are several perspectives in the study of learning, which are relevant to an understanding of attitude formation and development. The first perspective holds that consistent ways of perceiving, believing, feeling and behaving may be learned by becoming associated with experiences which are charged with emotions.

Secondly, attitudes are formed as a consequence of behaviour being 'reinforced'. Skinner (1968) used many practical applications of his 'operant conditioning' techniques in his teaching. These methods are also likely to be successful, he has argued, in the laboratory: 'In designing a laboratory course, if we keep an eye on the students' successes and the way in which they are spaced, we are more likely to produce a student, who not only knows how to conduct experiments but shows an uncontrollable desire to do so'.

A third perspective is concerned with the effects of role models. Young children use their parents as models and when they become teenagers they model themselves on the members of their peer-groups who have a high status in the group. Thinking of school levels, Mager (1968) has argued that, as some pupils use their teachers as models, this provides the latter with responsibilities and many opportunities for the development of favourable attitudes towards learning. Mager (1968) expressed it as "We must behave the way we want our students to behave".

The last perspective is related to the development of pupils' self-identity. Attitude learning tends to be self-consistent. Attitudes synchronise with each other so that within a pupil or a student (or teacher) there is a system of attitudes in which each one tends to be consistent with others. Attitudes towards the chemistry teacher are consistent with those held in relation to scientists: attitudes towards chemistry as a career agree to some extent with those towards the contribution which science has made to society. This was called by Katz (1960) the 'ego-defensive' function of attitude development.

Hargreaves (1972) argued that 'Education is concerned with the changing of attitude'. It almost seems as if he and other writers believe that, without changes in attitudes, there can be no education. Halloran (1967) indicated that attitude change depends upon several factors. Three of the most important of these are:

(a) the perception of the person presenting the information by those receiving it;
(b) the form in which the information is given;
(c) the characteristics of the people who are receiving the information.

One of the most significant factors appears to be the credibility of the communicator, - the chemistry teacher. At school level, the pupils' perception of the teacher may be influenced by factors outside the teachers' control. Two of the most important of these are: the pupils' previous experience of chemistry teachers and teaching. These may have encouraged the development of certain expectations towards the present 'role performer'. Secondly, the predominant attitude towards teachers and schools in the communities which are served by the school will be important.

Studies of the factors which attract students into the sciences show that the experience of the science subject and the teacher two dominant factors, corresponding to the first two of Halloran's factors (Skryabina, 2000). Three approaches for promoting the development of favourable attitudes towards chemistry may be examined.

The first approach is concerned with the satisfaction of needs (Maslow, 1954). Ausubel and Robinson (1969) stated that teaching and learning situations provide many opportunities for the satisfaction of the pupil's and teacher's needs. Learning experiences which bring, 'the thrill of discovery' a sense of greater knowledge, the warmth of a smile of recognition from a teacher, who appreciates the learner's attempted answer to a problem may have become important sources of personal satisfaction.

The second approach is based on learning theory. Mager (1968) has described it as 'teaching according to the principles of approach behaviour development and minimising the arousal of avoidance behaviour'. By this he means that, when a student is learning chemistry, he should do so in the presence of factors which will encourage a positive or 'approach' response rather than unpleasant or aversive factors which will lead to a negative response.

The third approach is based on 'the use of scientific inquiry as the methodology of learning' (Falk, 1971). She argues that the traditional methods of teaching have emphasised deductive rather than inductive thinking. This method will stimulate more positive approaches to learning because of their empirical and investigative characteristics. It was claimed that the learners will stimulate the development of curiosity, exploration and involvement. These approaches to learning chemistry are also believed to promote the development of values which are essential for the appreciation and practice of the skills used in scientific investigations. According to Falk (1971), these values, which encourage the development of scientific patterns of thinking, are primarily, 'the desire for knowledge and understanding and secondly, the belief in scepticism and open-mindedness'.

In all of this, there is a need for a level of security in learning for the development of positive attitudes. Dunham (1973, 1974), indicated that university students who have a strong need for direction and organisation perform best in structured and formal learning situations. Students need to know what is expected of them, that success is possible and that the effort is justified by the rewards. Students also need to feel that their learning is meaningful and making sense for them.

6.3 Attitudes of School Pupils and Teachers

It is widely observed that the laboratory is often one of the most popular parts of science courses at school level (Reid & Skryabina, 2002). Similarly, university students' views of practical work were much more positive than their views of lectures (Rollnick *et. al.*, 2000).

It has already been noted that, in Scotland, the amount of practical work conducted in school is very large, schools tend to be fairly well equipped and the practical activities are integrated well with the taught parts of the courses. However, practical work is not retained in Scottish schools because it is popular. It is seen by curriculum planners as having an important role. In the United Kingdom as a whole, H.E.Armstrong is often cited as being the prime evangelist in his advocacy of the introduction of more practical work into science education. He saw it as a powerful heuristic to aid the learning of science concepts (Brock, 1973). It was in the 1960s that the Nuffield Foundation provided money for curriculum development programmes in England and Wales in science education that attempted to disseminate Armstrong's ideas (Stevens, 1978; Jenkins, 1978; Waring, 1979). The programme was not entirely successful.

Hodson (1990, 1992, 1993a,b, 1996, 1986) has been a consistent critic of practical work that does not engage the pupil's thinking. Hodson argues that pupils need to have a clear conception of the purpose of an experiment in order to extract any benefit. Is the experiment to illustrate, to provoke questions, to suggest new ideas or simply to break up teaching? So it is not surprising that concern over the aims of practical work in science education has a history almost as long as that of compulsory education itself (Woolnough and Allsop, 1991, 1994; Lock 1988; Hofstein 1980).

Recent research into UK science teachers' attitudes to the aims of practical work in science education can usefully be traced back to the work of Kerr (1963). He used a 10 item inventory of aims. Since Kerr's work, others have modified or added to Kerr's original inventory. West (1974), Swain (1974), Gott & Mashiter (1994) and Gayford (1988) have all looked at aims for practical work in the UK. Lynch and Ndyetabura (1983), and Wilkinson and Ward (1997) surveyed teachers' attitudes to the aims for practical work in Australia.

Woolnough (1983) produced a set of 20 aims, which provided a suitable starting point for the study of Gilbert (1983). Their list is:

1 As a creative activity
2 • To make phenomena more real.
3 To help remember facts and principles.
4 • To practise seeing problems and seeking ways of solving them .
5 To indicate the industrial aspects of science.
6 • To promote a logical reasoning method of thought.
7 • To encourage accurate observation and description.
8 • For finding facts and arriving at new principles.
9 To be able to comprehend and carry out instructions.
10 • To elucidate theoretical work as an aid to comprehension.
11 To develop self-reliance.
12 • To arouse and maintain interest.
13 To develop an ability to communicate.
14 To develop an ability to co-operate.
15 To develop certain disciplined attitudes.
16 • To develop specific manipulative already taught.
17 • To verify facts and principles already taught.
18 To develop a critical attitude.
19 To give experience in standard techniques.
20 • To prepare students for the practical examinations.

Those marked • were used in the original Kerr (1963) study.

In his study, Gilbert (1983) looked at attitudes of Korean teachers and Egyptian teachers and compared these with their counterparts in England and Wales. Such comparisons are of limited value in that the conditions under which the teachers work differ so widely: different culture, different social and material background, different class situation. For example, Egyptian teachers are concerned with large classes, little apparatus and a restrictive curriculum, while Korean teachers work in conditions where the context is one of competition and striving for educational success, judged by the recall of factual knowledge.

The interesting thing is to look for those aspirations which are shared by all three groups. These are listed in order of overall priority.

7 To encourage accurate observation and description
4 To practise seeing problems and seeking ways to solve them
12 To arouse and maintain interest
2 To make phenomena more real
8 For finding facts and arriving at new principles

The teachers' attitudes are an expression of their pedagogic content knowledge (Shulman, 1986). Kyle, (1992) argues that any change to the science curriculum in culture must be sensitive to the needs of the people and their culture. Swain *et. al.* (1974) concluded that there are three broad issues which can affect opinions on the aims of practical work: national attitudes to education; perceptions on the nature of science, and the environment in which teachers find themselves. As Ushinsky commented when comparing science and science education,

> "Science is science precisely because it accepts only those conclusions which are consistent with the laws of general human thinking. Education takes the whole man as he is with all his national and individual characteristics – his body, soul and mind – and above all addresses itself to a man's character; and character is that very soil in which national characteristics are rooted".
>
> (cited in Holmes, 1986)

6.4 School Pupil Attitudes

Attitudes tend to be formed as a result of school experience and such attitudes will be brought to the university learning situation. In an important investigation which looked at the attitudes to science displayed by primary school pupils, prior to their transfer to secondary education, Hadden and Johnstone (1982) found very positive attitudes towards science among Scottish pupils. The study was carried out at a time before the introduction of formal primary science.

The findings reinforce the views of many secondary school science teachers that a very real initial advantage which they have in introducing incoming pupils to the world of science is the evident interest and enthusiasm for science which pupils bring with them. The causal factors which have initiated these favourable attitudes to science have been difficult to detect, but it appears that the influence of primary school activities, teachers, the mass media and science fiction are not prominent in the development of interest. The results were, in effect, an indication of the pupils' expectation of what secondary school science would hold in store for them (Hadden and Johnstone, 1982).

The literature on attitude research presents too many examples of confused, and sometimes conflicting, results which may emanate from a too liberal treatment of data which is, inevitably, less precise in nature than other forms of data. This view reflects a rejection of attitude scaling methodology, with its potential abuse of number and loss of detail. For a good discussion of the problems associated with attitude measurement, Johnstone's discussion offers a helpful overview (Johnstone, 1982).

In a follow-up paper, Hadden and Johnstone (1983) looked at the first two years of secondary schooling. They observed some erosion of initially highly polarised and favourable attitudes to science taking place. The evidence suggests that this erosion is more pronounced in science than it is in other subjects, but the evidence does not suggest that the erosion of interest has taken place to the extent that favourable attitudes to science (or to other subjects) have become unfavourable attitudes .

It should be noted at this stage that pupils' attitudes to the importance of arithmetic and mathematics have been enhanced rather than eroded by their exposure to the subjects at secondary school. They found no enhancement of attitudes to science in any aspect they explored. The results reported by Alison (1986) confirm that most children's attitudes to science decline between the ages of 11 and 13 or 14.

They presented evidence that the erosion of interest in science has been due more to the erosion of girls' attitudes to science than boys'. It is worthy of note that differences between girls' and boys' attitudes to science detected at this stage were not apparent before exposure to secondary school science in that the differences found were concerned with the nature of science only and not interest in science. This provoked a search for possible causes of these differences and one area which was explored was that of the content of the science syllabus

It was found, however, that of a fairly wide selection of syllabus topics examined attitudes to them from girls differed in only five cases to those of boys and three of these were concerned with the concept of energy. It cannot be claimed, therefore, that differences which have emerged between girls' and boys' attitudes can be fully accounted for by their preferences for certain syllabus topics, although this may well be a minor factor. Clearly, other factors are present.

The effects of the attitudes of science teachers were also taken into account but no evidence emerged that teachers who claimed to be very confident in their pupils' ability to attain course objectives produced pupils whose attitudes to science were better than those of other pupils who made no such claims (or, indeed , were pessimistic about their pupils' ability in this regard) . It may well be that this provides corroboration of views held elsewhere (Brown, 1991) that teachers rarely teach intentionally towards stated course objectives, rather than providing any indication that attitudes of teachers are not transferred to their pupils. A further possibility is that pupils' attitudes to science, at this early stage, although eroding somewhat, are still sufficiently positive to withstand pessimistic views of the attainability of course objectives held by their teacher. A most interesting indicator was that very favourable attitudes to science which appeared to be held by the vast majority of pupils at the primary school stage had eroded at significantly different rates according to the secondary attended by the pupils. This suggests that a factor causing attitude erosion lay within specific schools.

Students at the school level are very interested in practical work. They like working in the laboratory, so they show more positive attitude towards sciences courses. Students are also attracted by science topics at the university level. Work with university students has shown very clearly that students of both sexes are attracted by topics which can be described as 'modern' (Letton, et. al. 1998; Skryabina, 2000). It appears that topics that are perceived to have high relevance to the lifestyle of the learners are attractive. This has also been confirmed with school pupils (Reid and Skryabina, 2002).

This almost certainly explains the enormous success of the Scottish Standard Grade syllabus in Physics, which was deliberately designed to be applications-led in nature. In the applications-led course, the applications are introduced and define the course, the underpinning course being developed to make sense of the application. This type of approach is discussed by Reid (1999, 2001). This is a clear message to curriculum designers, that syllabi are highly attractive in Physics, when designed in applications-led form (Reid and Skryabina, 2003). The analysis showed clearly that large number of pupils were being retained in Physics.

Following the introduction of the National Literacy Strategy (DfEE1998a) and the Numeracy Strategy (DfEE 1999), measurements were made of pupil attitudes towards science experiments (among many other things) with English and Welsh pupils, aged 5-11. The findings showed that the pupils liked co-operative practical work and choosing equipment and finding out what happens but they are not so keen on working out how to set up the investigation or finding out why the results occur. They also much preferred the teacher telling them answers.

These findings accord with Parkinson *et al.* (1994) who, working with 11– 14 year old children, found the most common feature that attracted them to science was the amount of practical work and the opportunity to work with others. Piburn and Baker (1993) interviewed 83 elementary pupils in the USA and concluded that younger pupils rate experiments in science more highly than do secondary pupils because, in the USA, the curriculum is less assessment-oriented at this stage and the pupils welcome the open–ended enquiries that this allows. In this study, the attitudes of the girls as science investigators are significantly more positive than those of the boys. Girls' positive attitude to writing science may reflect their higher attainment, boys may be more positive about use of equipment because, as Bateson *et al*,. (1990) and Johnson and Murphy

(1986) found, they perform at a higher level on practical items using science equipment. Tobin (1988, 1986) noted that secondary boys monopolise science equipment in activities they were interested in, with the effect that girls' participation declined.

The development of favourable attitudes towards science is increasingly being recognised as an important aspect of science education. Young people's attitudes to science may well prove more lasting when they leave school than the pieces of scientific knowledge they have acquired. Tomorrow's adults will live in a rapidly changing technological environment, and their attitude to that change will influence their ability to cope with it in emotional as well as material ways. An important element in generating positive attitudes will be pupil attitudes towards laboratory work.

6.5 University Science Laboratories

Fraser and Wilkinson (1993) describe the development of a new instrument for assessing student perceptions of psycho social environment in science laboratory classrooms in their paper on British schools and universities. They presented the background that, although laboratory teaching is one of the hallmarks of education in the sciences (Hegarty, 1990; Tobin, 1990), there are serious questions about whether the great expense of maintaining and staffing laboratories is really justified (Giddings & Hofstein, 1980; Hofstein & Lunetta, 1980; Lunetta et al., 1981; Walberg, 1991), and whether or not many of the aims of laboratory teaching could be pursued more effectively and at less cost in non-laboratory settings (Pickering, 1987). Furthermore, university students' reactions to practical work often confirm the views of critics in that students find that laboratory classes are boring and that they go through the motions of experimentation without stimulation and often without any clear purpose.

At school level, Gallagher (1987) concluded that "Laboratory work is an accepted part of science instruction but we know very little about its functioning and effects" while Layton (1989) claims that many teachers lack the understanding of scientific inquiry or the skill to teach it. Tobin (1986) found that most laboratory activities are insufficiently well implemented to facilitate genuine inquiry. Similarly, at the university level, the content did not allowed students to recognise problems, design experiments, or to select their methods and materials (Hegarty, 1990).

6.6 Conclusions

The dilemma is a familiar one: how to ensure that students learn efficiently as much as possible of what is desired, given that intensive individual coaching will rarely be available. Given also that time and finance are in limited supply, and that students learning by this means is in no way guaranteed, what should be the place of student laboratory work in an undergraduate chemistry course ?

Where chemistry is concerned, of course, laboratory based work has long been a principal tool of the educator, at least since Liebig began training chemists at Giessen in the early nineteenth century. As Kirschner and Meester (1988) put it, "laboratory work is simply part of the science game and yet there is so much that can be done to improve laboratory classes, by way of making full use of the older teaching methods and introducing new ones", that one wonders why any laboratories retain the dull traditional pattern so disliked by staff and students alike (Read, 1969). How many would disagree with this statement even today? Other sceptical voices often make themselves heard (Johnstone and Wham 1980, Stone 1972).

In general, there has been a shift towards students as the focus of the educational process and often, the science laboratory work has been the means chosen to achieve this end. This implies that theoretical aspects of the course must be related to the laboratory experience. An aim is to develop on the part of the student a critical attitude towards measurement and data-taking which leads him to give searching consideration to the methods by which data are obtained and analysed and to study the reliability and meaning of his results in the widest sense. Then, having understood the basic ideas, the student should be encouraged to apply these techniques in tackling experiments and solving problems himself (Court *et al.* 1976).

According to Dall' Alba (1993), one of the keys to teaching in higher science education is the initiation of the students into the 'practice' of their subject, e.g. what it is like to be a physicist or a chemist. The argument has long been put forward that students of science should be able to *do science* and that this should be taught by example in teaching laboratories. Also, one of the ways of learning scientific concepts was to do science. To a certain extent, the debate has always been polarised with some educators emphasising the doing of science over the learning of concepts, others placing the emphasis on the concepts themselves (Layton, 1973). It may be doubted whether these dimensions of science education could be explored simultaneously. In general, there has been a consensus that some laboratory work in science is necessary in any course of science instruction, although it is not always questioned or agreed as to what exactly are its purposes.

Millen (1970) suggested, in the wake of Robbins[1], that practical work should promote the general powers of the mind: by this, he meant concept manipulation. The point was made that automation and other technological improvements had made measurement an activity less dependant on human skills. Thus, the argument for practical work derived from the acquisition of skills should not be stressed overmuch. Others have argued that laboratory work at least at the introductory stage should be concerned with the exemplification of material presented in abstract form by means of text or lecture (Shymansky and Penick, 1979).

It is hard to imagine learning to do science, or learning about science, without doing laboratory work. Experimentation underlies all scientific knowledge and understanding. Despite the importance of experimentation in science, the introductory laboratory fails to convey the excitement of discovery to the majority of our students (Johnstone and Wham, 1979). They generally give introductory science laboratory low marks, often describing them as boring or a waste of time. The question is, why is it so? It is clear that many introductory laboratory programmes are suffering from neglect. Typically, students work their way through a list of step-by-step instructions, trying to reproduce expected results and wondering how to get the right answer. While this approach has little do with science, it is common practice because it is efficient. Laboratories are costly and time consuming, and predictable, "cookbook" laboratories allow departments to offer their laboratory courses to large numbers of students.

Improving undergraduate laboratory instruction has become a priority in many institutions, driven, in part, by cost and time considerations. Some laboratories encourage critical and quantitative thinking, some emphasise demonstration of principles or development of laboratory techniques, and some help students deepen their understanding of fundamental concepts (Hake, 1992).

Developing an effective laboratory requires appropriate space, equipment and the most creative teachers. Still, those who have invested in innovative introductory laboratory programmes report very encouraging results: better understanding of the material, much more positive student attitudes toward the lab, and more teaching staff participation in the laboratory (Wilson, 1994).

[1] Robbins reported on the expansion of Higher Education in the UK., 1963

Chapter Seven

Background to Empirical Observation

7.1 Overview

This study is seeking to explore chemistry laboratory experiences with students. The particular longer term aim is to see how laboratory work in an Open University in Pakistan which trains secondary school chemistry teachers can develop its programmes so that teachers are equipped to use laboratories effectively and efficiently.

The starting point was to look at first year chemistry undergraduates at Glasgow to see how they have perceived their school experiences in practical chemistry and their university experiences in practical chemistry. In particular, the study will focus on the place, nature and effectiveness of pre-laboratory exercises on student perceptions, previous work having shown clearly the power of pre-laboratory exercises on increased learning in physics (Al-Zaman and Johnstone, 1998), inorganic chemistry (Johnstone, Sleet and Vianna, 1994 and 1999), and in developing positive attitudes towards laboratory work in physics (Al-Zaman and Johnstone, 1998).

In the physical chemistry laboratory course, there were no pre-laboratory exercises up to session 2000-1. It was possible to survey these students and to compare them to those of the following session (2001-2) after pre-laboratory exercises were introduced. These exercises were merely added, without altering the laboratory manual. Later, the laboratory manual was re-written, with the pre-laboratory exercises integrated into it.

In a separate experiment, it was possible to survey student perceptions of laboratory work at the beginning of their university course, thus giving a good picture of how they saw laboratory work at school.

Similar surveys were carried out in Pakistan with three groups of students: first year BSc students, second year BSc students, and students who already had a degree in chemistry and were preparing for a career in secondary teaching in chemistry (BEd students). In making these parallel surveys, no attempt was made to make quantitative comparisons in that the educational structures of the two countries are so different that comparison would be of limited value.

Summary of Surveys

(1) First Year Chemistry students at Glasgow, with no prelaboratory experience in their physical chemistry laboratory (March 2001)
(2) First Year Chemistry students at Glasgow, with a prelaboratory experience (as an 'add-on') in their physical chemistry laboratory (March 2002) - followed up by interviews
(3) First Year Chemistry students at Glasgow on entry (October 2001).
(4) First Year Chemistry students at Pakistan towards the beginning of their course (summer 2002).
(5) Second Year Chemistry students at Pakistan towards the end of their course (summer 2002).
(6) BEd Chemistry students at Islamabad Open University, towards the end of their course (summer 2002)

The purpose of the surveys was to offer an overview of student self perceptions of laboratory work in a setting where laboratory work was well established as well as gaining an overview of student perceptions of laboratory work in a setting where school laboratory work is not well established and in a university setting where laboratory work is intrinsically difficult.

The real problem is how to make laboratory experiences real for students in an open university and how to use these experiences as an effective preparation so that these new teachers would be able to operate school laboratories effectively and efficiently in terms of student attitudes and learning. To this end, the needs of the Pakistan students were analysed and their backgrounds in chemistry noted. A set of what are called here 'paper labs' were developed and tested with these students. The aim of each paper lab was to incorporate pre-laboratory exercises, simulated experimental data, and post-laboratory applications, to make the laboratory experiences more meaningful.

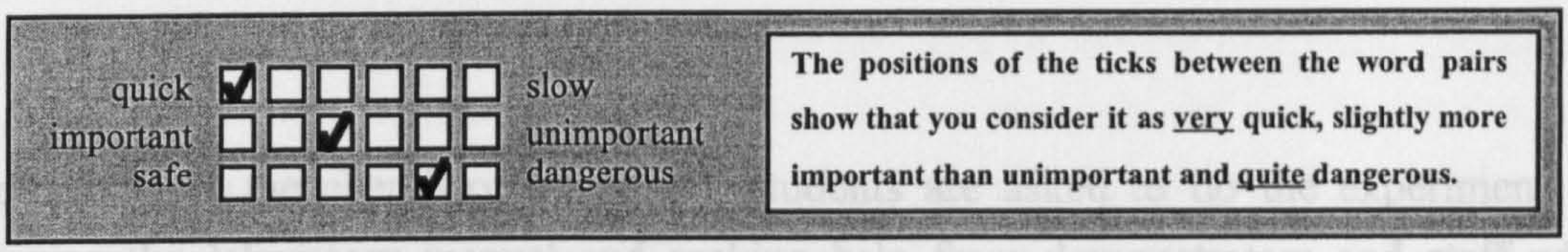
The procedures used will now be described.

7.2 The Surveys

The survey questionnaires developed contained questions in a variety of styles. The main three are described here. Following work by Thurstone (1929), Likert (1932) suggested a way to measure attitudes using a five point scale. Students respond using 'strongly disagree', 'disagree', neutral', 'agree', strongly agree' to various statements related to the issue being explored. For reasons discussed elsewhere (Reid, 2003), Likert's scaling approach was not adopted but responses to each question were analysed separately.

In 1947, Osgood *et al.* developed a useful approach by placing adjectives or adjectival phrases at opposite ends of a set of boxes, students being asked to tick the box which best reflected their view. This is illustrated by the instructions used in the questionnaires here:

Here is a way to describe a racing car:



Another approach to attitude measurement is to ask students to make selections from a list of statements or to place statements or items in an order of importance according to some criterion. This type of approach was used with a question where students were asked to select the most important three reasons for including laboratory work.

7.3 Pre-laboratory exercises

Students often come unprepared or ill-prepared to begin laboratory work. They may have forgotten underlying ideas which are essential to make sense of the experiment. The procedures may be unfamiliar. Students often have difficulty in completing the necessary calculations relevant to the experiment and to the laboratory report. This lack of preparation may make the laboratory experience less than ideal and may lead to the development of negative attitudes.

The pre-laboratory experience is a way of addressing some of these problems. Pre-laboratory exercises can be used to remind students of ideas which have been forgotten or to develop ideas which have yet to be taught. They may also seek to make the link between the underlying chemistry and the practicalities of the actual experimental observations.

In developing the set of five pre-laboratory exercises used here, the first step was to look at the experimental in detail and to define the key underlying ideas which would be necessary to make sense of the work. The specific pre-laboratory tasks were then designed to ensure that these key ideas were understood. The set of pre-laboratory exercises were given to several experienced staff members for comment and adaptations were incorporated.

One difficulty was that the manual already existed and the pre-laboratory was devised as an 'add-on'. Carnduff and Reid (2003) emphasised the importance of seeing the laboratory experience as a whole, from pre-laboratory to post-laboratory exercises. The impact of the pre-laboratory exercises was assessed by means of questionnaire and interviews.

7.4 Re-writing the Laboratory Manual

Traditionally in the chemistry laboratory, students are asked to do the experiments by following the laboratory manual and seeking help from demonstrators and staff when necessary.

The literature contains many reports of information processing research which has direct implications for the design of instructional written materials. For example, Johnstone and Letton (1991) report that the experimental instruction and observational load encountered by students in the laboratory results in recipe learning. The students follow the manual without any understanding. The authors advocate the following actions to change the instructional written materials.

(1) Reduce noise in the instruction manual.
(2) To create confidence in students working in the laboratory, introduce skills-oriented laboratory work.
(3) Use pre-laboratory exercises.
(4) Use post-laboratory exercises.

Johnstone, Sleet and Vianna, (1994), using an information processing model of learning, suggested some changes to a first year undergraduate chemistry laboratory. Changes included rewriting of instructions manuals, reorganisation of the laboratory, the use of pre-laboratory exercises, training in laboratory skills and the introduction of mini-projects. They pointed out that "much of the student behaviour in laboratories is that of recipe following. They gain hand skills but it is all too possible to follow mindlessly the instructions in a manual".

The importance of the laboratory manual is very great, and the opportunity arose to re-cast the manual in the light of previous research. The pre-laboratory exercises were incorporated as an integral part of the process. The first aim was to reduce the amount of information. Much of this was achieved by layout and the use of dialogue boxes. Students could grasp the flow of the ideas and then return to look at a particular dialogue box to master some idea or see how some calculation might be carried out. Language was kept simple and consistent with the way they had been taught previously. Unnecessary information was removed and clear aims were specified. The re-cast laboratory manual is shown in full in **appendix A.** Unfortunately, it was not possible to test the re-written laboratory manual with students.

The need for clear aims is consistent with Moreira (1980) who found that, in many cases, students perform an experiment without clear ideas about what they are doing or what lies behind the experiment. Many of them are not able to identify the basic concepts or phenomena of the experiment. In each case, if the students do not know the basic concepts or phenomena of the practical work, then the experimental instructions are unlikely to contribute towards their understanding of the experiment.

7.5 The Paper Labs

Before the paper labs were developed, an analysis of the likely experience of the Pakistan students was carried out in terms of what experiments they had carried out in their degrees (where there is limited practical work) and the kind of perceptions of laboratories they were likely to hold.

Four themes were then selected, to give experiments which were sufficiently intellectually challenging but were also relevant to the kind of training and experience they needed in order to become effective chemistry teachers. These paper labs were refined and edited many times before sending them to Pakistan to be used by students. The students also completed a report on how they found them.

7.6 Research questions

While the project had a very practical aspect in developing solutions to apparently intractable problems in Pakistan, there were also fundamental educational issues being addressed.

(1) Do pre-laboratory exercises as an 'add-on' have any effect on student attitudes compared to the lack of pre-laboratory exercises?

(2) What are the attitudes of the students who have used pre-laboratory exercises towards their studies in chemistry?

(3) What do the students like most and least about using the pre-laboratory exercises?

(4) What are the students perspectives regarding the use of pre-laboratory exercises in helping with their success in laboratory work ?

(5) How are prelabs seen when introduced as an 'add-on' and as an integral part of the manual?

(6) What is the potential for the 'paper lab' experience in terms of preparing secondary teachers in an open-university context?

7.7 Semi-structured Interviews

Interviews took place during the laboratory sessions when pre-laboratory exercises were in use. The total number of the students interviewed was 60. The students were interviewed informally in groups, according to their practical group. The time of the interview was 15 minutes for each group. Although informal, the following key themes were explored:

Understanding of theory,
Preparation for experiment,
Learn new practical techniques,
Theory and practical linked,
Motivation and interest,
Organisation of experiments,
Working on your own,
Daily application,
Reporting of the experimental results,
Pre-laboratory exercises.

Careful notes were kept of all interviews and these were summarised to give a semi-quantitative impression of the views of the students. The interviews were designed to complement the use of questionnaires and to offer evidence on the validity of the questionnaires.

7.8 Samples and Statistical Treatment of the Data

In all the Glasgow surveys, samples of around 200 were sought, drawn from the first year chemistry class, while 60 of the group who had experienced pre-laboratory exercises as an 'add-on' were interviewed. In Pakistan, for each year group samples of around 200 were also gained. When looking for student reaction to the paper labs, a sample of 100 students was sought.

Where comparisons between data were involved, the statistic chi-square (χ^2) was used. Chi-square is a statistic which can be used to see whether two sets of frequencies are the same or are, in probability terms, different. The statistic makes no assumptions about distributions of responses (it is non-parametric) but there are two areas where care must be taken in using this method. The first relates to how the control group is defined.

If two frequency distributions are compared and one is clearly a control group, the research question then asks if the second group differs from the control. This is known as the 'goodness of fit' use of chi-square. If neither group can be thought of as a control group (as in gender comparisons, for example), the best measure of the control group is the combination of both groups. The calculation must allow for this. This is known as the use of chi-square as a 'contingency test'. This was used in this study . A full discussion of these applications can be found in Reid, 1978.

The other area where caution is needed is when any category is low. It is very easy in such circumstances for a spurious statistical significance to be found simply because a change in small numbers is a large percentage change but might only involve a handful of respondents showing some viewpoint. Typically, each category should not be less than 10 or 5%, whichever is smaller.

7.9 Assumptions and limitations

Samples were generally high and this gives confidence in relation to reliability. Some questions (those which looked back at school experiences) were unaffected by the introduction of pre-laboratory exercises and consistency of responses offered further evidence of reliability. In addition, the questionnaires were developed using well-tested formats whose reliability was known to be good. Validity was checked by asking the opinions of 'experts'.

Samples were essentially what was available. They were not selected in any way and the researcher had no influence on the sampling. It is also assumed that students respond honestly to the questions on survey and in the interview. Previous work suggest this is a reasonable assumption.

In the following chapter, the data obtained form the surveys in Glasgow and the development of the pre-labooratory exercises. In chapter 8, there is parallel discussion abut the surveys from Pakistan, with the following chapter describing the paper labs and their use.

Chapter Eight

Results and Discussion

8.1 Introduction

The purpose of this project was to gain insights into the place of laboratory work in university courses and to explore how laboratory work might be enhanced, particularly in the context of the needs in Pakistan where teachers are unsure about how to use school laboratories and university laboratory work tends to be very restricted and formal.

The project started by looking at what was happening with first year chemistry students at Glasgow University. They were asked to look back at their school experience and also to reflect on their university experience. Glasgow has two chemistry classes (General Chemistry and Chemistry I) and all first year laboratories have integral pre-laboratory exercises, with the exception of the Physical Chemistry laboratory in the Chemistry I course. It was planned to introduce such pre-laboratory exercises into this course and it was, therefore, useful to look at student perceptions before and after these pre-laboratory exercises were introduced. The aim was explore student perceptions in a situation where laboratory work was well established at both school and university levels. This could be used as a backcloth when looking at the situation in Pakistan.

8.2 First Survey at Glasgow

The first step was to gain a picture of what was happening. This involved applying a questionnaire to the Chemistry-I class in the year (2001) when the Physical Laboratory did not involve pre-laboratory exercises.

The questionnaire aimed to gain insights into student opinions about:

Their school laboratory experiences in chemistry,
Their preferred style of working in a school chemistry laboratory,
Their preferred style of working in a university chemistry laboratory,
Their overall university chemistry laboratory experiences,
The physical chemistry laboratory at university level.

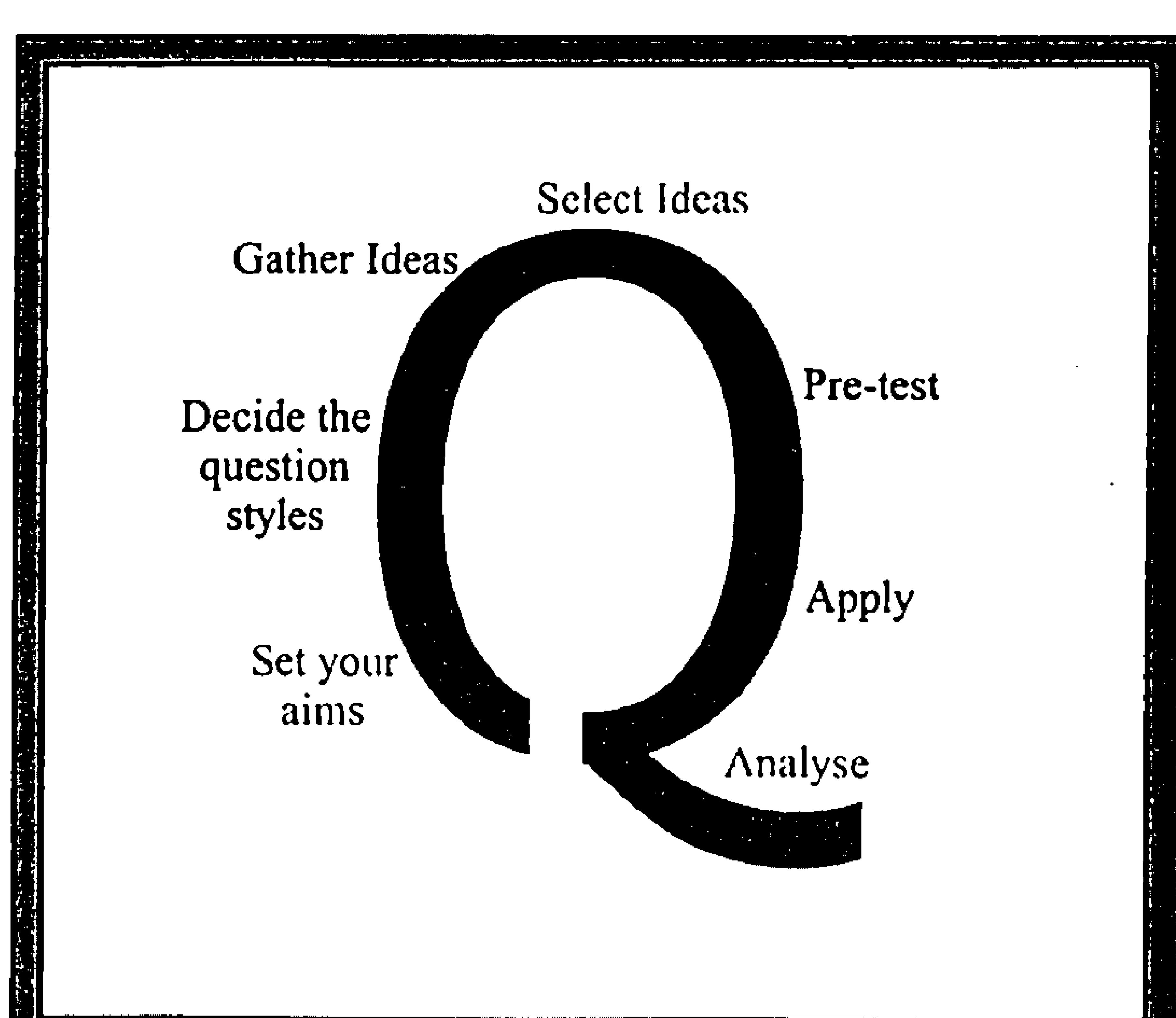
There are no strict rules for the construction of a questionnaire but there are established guidelines (eg.. Reid, 2003). Denscombe (1998) proposed the development of a list of written questions, selecting such questions which closely relate to the aims of the study. It is useful to consult experts (those familiar with the situation) to offer advice on the final question selection. It is important that ambiguities are avoided and that the students who read the questions gain the meaning intended by the designer. This allows for consistency and precision in terms of the wording of the questions, and makes the processing of the answers easier. This consistency and precision will encourage reliability and validity in the questionnaire.

Reid (2003) offers a set of guidelines:

"(a) *Write down as precisely as possible what you are trying to find out;*
(b) *Decide what types of questions would be helpful;*
(c) *Be creative and write down as many ideas for questions as you can;*
(d) *Select what seem the most appropriate from your list - keep more than you need;*
(e) *Keep the English simple and straightforward, avoid double negatives, keep negatives to a reasonable number, look for ambiguities, watch for double questions;*
(e) *Find a critical friend to comment on your suggested questions;*
(f) *Pick the best, most appropriate and relevant questions, thinking of time available;*
(g) *Layout is everything!!*
(h) *Try your questionnaire out on a small sample of students (eg.. a tutorial group) - ask for comments, criticisms. Check time required.*
(i) *Make modifications and only then apply to larger group;*
(j) *Analyse each question on its own."*

He summarised these in a simple diagram (figure 8.1, below)

Figure 8.1 Summary of instructions for the development of questionnaire



It is important that any questionnaire designed to measure attitudes should be both reliable (be able to reproduce the results after a certain period of time) and valid (actually measure what is aimed to measure) (Oppenheim, 1992).

There is much in the literature about reliability (Ravid, 2000) but most describe measures of internal consistency, using correlation techniques. However, if the questions are designed to measure numerous different features, then internal consistency is not necessarily important and traditional methods are inappropriate. If questions are designed carefully, the questionnaire being of a reasonable length and care taken in its use, then reliability will not be a major issue. However, with the questionnaires used here, it was possible to look at reliability by considering responses to certain questions in repeated use of the questionnaire. This will be discussed when the results are considered.

The validity of a measuring instrument refers to the extent to which the instrument measures what is expected to measure: whether the data or values obtained from the measurement really indicate people's attitude toward the object. There are two useful opportunities to check validity. One of which is an expert approval of the methods designed for attitude measurement: this was used in this study to check the validity of the data collected. The other is to interview some of the sample to see whether their expressed views correspond to those observed in the questionnaires. This was used in one place in this study.

The questionnaire was applied in March, 2001 and 193 completed questionnaires were returned, being a return rate of about 48%. The questionnaire is shown in full (with all questions polarised one way for clarity) with the response data shown as percentages. The questionnaire in the exact form it was applied is shown in **appendix B.**

(1) What are your opinions about your <u>school</u> laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	15	32	23	15	8	6	Useless
Helpful	15	28	29	12	9	5	Not helpful
Meaningful	11	26	28	17	12	3	Meaningless
Understandable	24	33	24	9	5	3	Not understandable
Satisfying	9	23	31	18	8	9	Not satisfying
Interesting	15	28	30	13	6	4	Not interesting
Well organised	17	28	25	14	8	5	Not well organised

(2) In your <u>school</u> *chemistry laboratory* which did you prefer ? (*Tick ONE box*)

Working individually	15
Working in pairs or small groups	78
Watching a class demonstration	8

(3) In your *university chemistry laboratories* which do you prefer ? (*Tick ONE box*)

Working individually	6
Working in pairs or small groups	89
Watching a lecture demonstration	2

(4) What are your opinions about your *overall university chemistry laboratory experiences* (all chemistry laboratories) ? *Tick ONE box on each line.*

Helpful	22	45	21	6	2	0	Not helpful
Useless	3	10	11	17	34	19	Useful
Meaningless	2	7	17	20	32	18	Meaningful
Understandable	13	41	24	10	7	0	Not understandable
Satisfying	13	33	31	11	8	0	Not satisfying
Interesting	16	32	29	11	5	2	Not interesting
Well organised	24	36	24	5	5	0	Not well organised

(5) Think about your *laboratory in Physical Chemistry* (which you have completed in January).

What are your opinions about the following statements?
Tick ONE box on each line.

(a)	I find writing lab reports largely a waste of time................................	0	13	37	42	5
(b)	The experimental procedure was clearly explained in the manual........	11	73	9	3	0
(c)	It was easy to see the relationship between the experiments and the lecture course..	4	38	28	21	4
(d)	I felt confident in carrying out the experiments................................	7	46	27	15	0
(e)	These labs made me more interested in chemistry................................	6	38	28	24	0
(f)	The experiments encouraged me to think about the chemistry which was involved..	8	42	26	17	0
(g)	I found the lab report difficult to write..	0	17	29	40	10
(h)	I prefer working on my own..	4	5	18	42	26
(i)	I am often confused by the lab manual..	0	9	28	48	7
(j)	I feel confidant when I enter the chemistry laboratory.........................	4	31	38	19	4
(k)	The purpose of the experiment was clear to me....................................	0	37	36	17	4
(l)	I should like to do open-ended project work as part of my chemistry laboratories..	3	9	36	31	10
(m)	I was so confused in the laboratory that I ended up following the manual without understanding what I was doing..........................	0	17	29	37	8
(n)	I only understood the experiment when I started to write the report at the end of the experiment..	0	25	31	34	4

(6) No responses were obtained.

8.2.1 The Results

The students involved had completed much of their first year laboratory course including the Physical Laboratory. However, this particular laboratory did not not involve pre-laboratory exercises. The results from each question are now discussed in turn.

(1) What are your opinions about your School Laboratory experiences in chemistry?
(For clarity the data are shown again, - as % of sample of 193)

Useful	15	32	23	15	8	6	Useless
Helpful	15	28	29	12	9	5	Not helpful
Meaningful	11	26	28	17	12	3	Meaningless
Understandable	24	33	24	9	5	3	Not understandable
Satisfying	9	23	31	18	8	9	Not satisfying
Interesting	15	28	30	13	6	4	Not interesting
Well organised	17	28	25	14	8	5	Not well organised

The aim of this question was to find out how students feel towards their laboratory experiences at school. It is clear that, overall, the students tended to be positive about their laboratory work at school level. However, there is slightly less assurance that they found their school laboratory experience meaningful or satisfying when compared to the other aspects. In Scottish schools, laboratory work is integrated tightly to the taught course and it tends to be well organised. This is reflected in the data obtained.

Questions 2 and 3 explore students working preferences. The data are summarised here for clarity *(as % of the sample of 193)*

In your *chemistry laboratory* which did you prefer ? (*Tick ONE box*)

	school	*university*
Working individually	15	6
Working in pairs or small groups	78	89
Watching a class demonstration	8	2

It can be seen that they strongly prefer to work in groups and demonstrations are not highly favoured.

The structure of question 4 is the same as question 1 but it seeks to look at their overall experience of laboratories at university in chemistry. For clarity, the results are shown again (as % of the sample of 193)

(4) What are your opinions about your *overall university chemistry laboratory experiences* (all chemistry laboratories) ? *Tick ONE box on each line.*

Helpful	22	45	21	6	2	0	Not helpful
Useful	19	34	17	11	10	3	Useless
Meaningful	18	32	20	17	7	2	Meaningless
Understandable	13	41	24	10	7	0	Not understandable
Satisfying	13	33	31	11	8	0	Not satisfying
Interesting	16	32	29	11	5	2	Not interesting
Well organised	24	36	24	5	5	0	Not well organised

Looking at question 4, overall, student perceptions are positive, with the majority in every question taking a positive or neutral line. However, it is clear that the pattern of results is very different from question 1 in some areas and this is discussed later.

The aim of question 5 was to find out the attitude of the students towards Physical Laboratory at University level. This had been completed recently. The results show (shown below for clarity as % of the sample of 193) that the students tend to have fairly neutral attitudes towards the Physical Chemistry laboratory.

Table 8.1 Results in percentages about Physical Lab. at University level.

		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
a	I find writing lab reports largely a waste of time	0	13	37	42	5
b	The experimental procedure was clearly explained in the manual	11	73	9	3	0
c	It was easy to see the relationship between the experiments and the lecture course	4	38	28	21	4
d	I felt confident in carrying out the experiments.	7	46	27	15	0
e	These labs made me more interested in chemistry	6	38	28	24	0
f	The experiments encourage me to think about the chemistry which was involved.	8	42	26	17	0
g	I found the lab report difficult to write.	0	17	29	40	10
h	I prefer working on my own.	4	5	18	42	26
i	I am often confused by the lab manual.	0	9	28	48	7
j	I feel confidant when I enter chemistry lab.	4	31	38	19	4
k	The purpose of the experiment was clear to me.	0	37	36	17	4
l	I should like to do open-ended project work as part of my chemistry laboratories.	3	9	36	31	10
m	I was so confused in the laboratory that I ended up following the manual without understanding what I was doing	0	17	29	37	8
n	I only understood the experiment when I started to write the report at the end of the experiment.	0	25	31	34	4

However, it is possible to see the preference for group working although a minority wish to work on their own while some reservations over project work (which is not used in the university course) seem to be present. The laboratory manual was comprehensive and this is reflected in the responses while the tight organisation of the laboratory probably influences students towards more positive attitudes overall.

8.2.2 Statistical Comparisons

Questions 1 and 4 seek the same information about school laboratories and university laboratories respectively. It is possible to compare the overall pattern of responses in these two questions. This was achieved using the statistic chi-square which was discussed in the previous chapter.

Chi-square was calculated using sets of six frequencies but some frequencies were grouped where sample sizes fell below the limits of 10 or 5%. As no control group is specified, chi-square as a contingency test was used (see appendix C).

In table 8.2 frequencies of responses of questions 1 and 4 are compared. For each word pair, the top line of percentages is for question 1 (school) and the lower line is for question 4 (university). Chi-square values, with degrees of freedom and significance levels are shown. The sample size is 193.

Table 8.2 Comparison of School and University Laboratories

Useful	15	32	23	15	8	6	Useless	$\chi^2 = 4.36$(df4)
	19	34	17	11	10	3		n.s.
Helpful	15	28	29	12	9	5	Not helpful	$\chi^2 = 33.16$ (df3)
	22	45	21	6	2	0		$p < 0.01$
Meaningful	11	26	29	17	12	3	Meaningless	$\chi^2 = 9.54$ (df4)
	18	32	20	17	7	3		n.s.
Understandable	24	33	25	9	5	3	Not understandable	$\chi^2 = 8.35$ (df4)
	13	41	24	10	7	0		n.s.
Satisfying	9	23	31	18	8	9	Not satisfying	$\chi^2 = 14.17$ (df4)
	13	33	31	12	6	2		$p < 0.01$
Interesting	15	28	30	13	6	4	Not interesting	$\chi^2 = 1.54$ (df4)
	16	32	29	12	4	2		n.s.
Well-organised	17	28	25	14	8	5	Not well-organised	$\chi^2 = 20.37$(df4)
	24	36	24	5	4	2		$p < 0.01$

Although school laboratories are run very differently form those at university, the views of the students on four of the dimensions in table 8.2 are similar. However, in three dimensions, there are differences between their views of school and university chemistry laboratories. In each case, the views of university laboratories are more positive. Students indicate that they find university laboratories more helpful, satisfying and well-organised.

This might reflect the fact that university laboratories are more recent in their experience or that the students are becoming more committed to chemistry. Undoubtedly, university chemistry laboratories tend to be very well organised.

Questions 2 and 3 looked at their preferred ways of working at school and university: working individually, working in pairs or small groups, and watching a class demonstration. The data are presented in table 8.3 as percentages,

Table 8.3 Comparison of Preferred Style of Working

N = 193	Working individually	Working in pairs or groups	Watching a demonstration
School	15	78	8
University	6	89	2

It is clear that, in general, working in pairs and small groups is preferred, especially at university level. This may reflect a certain lack of confidence, with group work offering some kind of shared responsibility. It is certainly consistent with the general popularity for group work (Wood 1993). It is not possible to use chi-square with the entire data in that the percentage electing for 'watching a demonstration' is too low. However, looking at the first two columns only, a chi-square value of 7.2 is obtained ($p < 0.01$, df1), suggesting that the preference for individually working has declined since school.

8.3 Pre-laboratory Exercises.

Expecting students to engage in laboratory activities without some form of prior consideration or tuition may leave them feeling insecure, and result in a rather poor understanding of what is happening. It is therefore usual to engage them in some form of pre-laboratory activity, highlighting the essential ideas of the work, introducing new principles and concepts, and pointing out potential pitfalls.

The necessity for some kind of pre-laboratory preparation is patently obvious. It applies as much to conventional laboratories as it does to more open-ended and investigative laboratories. A student entering a laboratory without some preparation is likely to spend considerable time with minimal learning (Johnstone and Wham, 1979). Laboratories are very costly in terms of specialist accommodation, consumables, breakages and staff time. If they are not being used for their potential strengths and the time is spent unproductively, they are a massive waste of scarce resources.

Pre-laboratory activity may be conducted in the first portion of the laboratory time, or carried out prior to the scheduled laboratory period. The former method has immediacy as a major advantage, since the main activity follows on directly. There is, however, little opportunity for students to reflect on what has happened, and to check up on any aspects of information that they are unsure about. For these reasons, it can be argued that pre-laboratory activities should be carried out before students enter the laboratory, unless there are unavoidable constraints (David, 2001).

Pre-laboratory preparation is not just reading the manual before entering the laboratory. Many students ignore this because they know that they can survive the laboratory quite comfortably without doing it. The conventional laboratory may not be engaging the mind, merely exercising the ability to read and follow instructions. The kind of pre-laboratory work which is being recommended must be as carefully prepared as the laboratory manual itself. It can take many forms, but it must prepare the students to be an active participant in the laboratory (Johnstone and Shuaili, 2001).

The pre-laboratory exercises may be in the form of a lecture or in the form of assignment. The majority of the pre-laboratory instruction in the past has been in the form of a pre-laboratory lecture by the supervisor. Morcerino (1997) argues that this system has two main disadvantages.

(1) Students are not required to do anything in preparation for laboratory work. As a result, they are likely to come to the pre-laboratory lecture without having so much as read the laboratory manual to find out what they are going to be doing in the laboratory. This means the pre-laboratory lecture needs to be very through.

(2) There is very little time for students to think over the information given during the pre-laboratory lecture before actually carrying out the procedure in the laboratory.

Sirhan and Reid (2001) described a pre-lecture as an "activity carried out before a block of lectures, designed to ensure that the essential background knowledge is established and is accessible so that new learning can be built up on a sound foundation". They went on to explain the need of pre-lecture as, "students will come to lectures with a wide variety of background knowledge. In some cases, previous learning in chemistry mat have led to an incomplete or incorrect grasp of concepts. 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 is not only present but stored in such a way that it is accessible and understood correctly". The importance of the idea of preparing the mind of the learner was first laid down by Ausubel (1968).

It is reasonable that the same kind of arguments might apply to learning in the laboratory. One of the simplest ways to prepare the mind before a laboratory session is to require questions on the activity to be an answered by them in a written assignment before they enter the laboratory. The purposes of the questions are:

(1) To ensure that the students know, in general terms, what will happen in the next laboratory session.
(2) To assist students to understand the steps involved in the analytical procedure by focusing attention on the chemical processes involved.
(3) To direct students' attention to key aspects of the procedure.

Some of the answers to the questions can be derived from information provided in the manual, but the use of text books may also be required. Students are expected to arrive at the laboratory session with written answers, which are inspected and checked by staff (David, 2001).

It is not expected that assigning pre-laboratory questions will necessarily eliminate the need for the pre-laboratory talk. However it is hoped that, having answered the pre-laboratory questions, students will come to the pre-laboratory lecture with a greater understanding not only about the procedures they are about to carry out, but also the theoretical basis for the experiment. It is also hoped that the pre-laboratory questions will be effective in getting students to think about what they are going to be doing in the laboratory and why. This will make the laboratory sessions more useful in consolidating the concepts taught in the lectures.

Another method for the exposure of students to laboratory activities both prior to and during the laboratory session is through the use of media such as videotapes and tape-slide programmes. These are popular because the products are cheap to prepare compared with films, and they can be easily changed or edited to suit any particular teacher or class. The use of media has several advantages in terms of making the experiment real for the students. Media are mostly used for both pre- and in-laboratory instruction relating to manipulative skills.

Pantaleo (1975) used videotapes to teach students basic skills of weighing and titration, with evidence of marked improvement in performance. Gagen (1978) has described the use of videotapes for teaching infrared spectroscopy, and Fine *et al.* (1977) the use of lap-dissolve projection systems for chemistry techniques.

Pickering (1987) introduced an idea of pre-laboratory in which students were required to write out their own procedure, in any form they chose from the given instructions. Students were not permitted to take the provided instructions into the laboratory but completed the laboratory work by referring only to their own notes. These notes were collected at the end of the laboratory class and graded by the supervisor. (Pickering, 1987). This is an ingenious idea which may make the laboratory a much more rigorous and demanding learning experience. However, if introduced without great care, student reaction might be negative while the demand on high quality of supervision may increase.

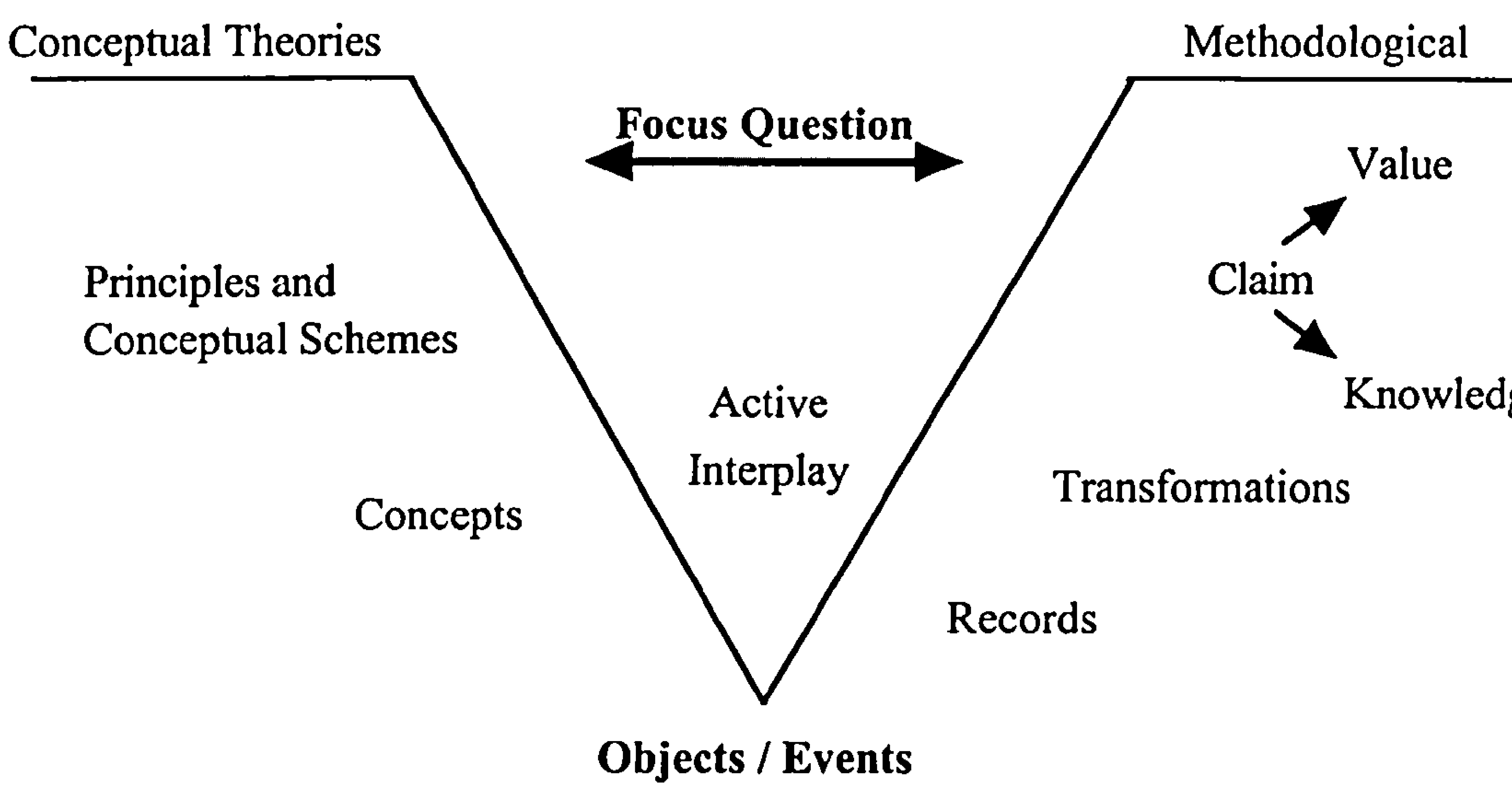
Computer assisted learning (CAL) is increasingly used in a pre-laboratory role, as a means of guiding the student through the theory associated with an experiment, and examining the experimental design. Beasley (1979, 1978) argued that all these different experiences can give the student mental or physical practice for the coming experiment, and maximise the efficient use of laboratory time.

Wilson (1980), provided computer assisted learning (CAL) in the pre-laboratory mode for physics laboratory students. The students completed a CAL activity prior to the actual experiment; the student then selected the independent variables and assigned values to them. The simulation provided data on the dependent variables just as would be provided in the laboratory. This may help the students to perform the actual experiment but may encourage them from guessing there answers through simulation without understanding. Moor, Smith and Avner (1980), involved a simulation of the determination of the percentage of oxygen in a sample of $KClO_3$ by thermal decomposition in the presence of MnO_2. If the students knew to set up the apparatus for the actual experiment, then the simulation may be helpful. Also, to complete the simulation the student must weigh the sample, heat to constant weight, cool, weigh the residue and do the calculations.

Wiegers and Smith (1980) reported ten pre-laboratory lessons for an organic laboratory course, and claimed that in nine of them the use of the programs resulted in a reduction in time for completion of laboratory work compared with the time taken by a control group with no CAL exposure. Gilbert *et al.* (1982) described how students were able to optimise instrumental parameters to yield accurate absorption spectra by investigating the effects of spectral band width, wavelength scan speed and pen period on the spectra. The students then carried out laboratory work involving these functions on a real spectrophotometer.

One of the criticisms of laboratory work is that the emphasis is usually on the methodological aspects of the exercise. Thus, even if the exercise is well designed, and the student produces a set of results or observations, these are not readily related back in a meaningful way to the conceptual framework that underpins the experimental work. The experimental results are isolated from theory, and the experiment can appear to be trivial and out of a scientific context. In a series of publications, Novak (Novak, 1979, 1980, 1984; Novak and Gowin 1984; Novak, Gowin and Johansen 1984) developed an instructional device to link concepts and methods to help overcome this problem. They called this called V mapping, as shown in the diagram 8.2.

Figure 8.2 Diagram of a V map, showing the main elements (from Novak 1979)



The essential features of the map are displayed in Figure 8.2. At the base of the V are the events, or results, that occur as an outcome of some experimental activity. On the left hand side are the theoretical aspects of the work, increasing in generality from the bottom of the V, where specific concepts are sited, to general theoretical schemes at the top. The right hand side is concerned with the methods used to generate knowledge, again arranged in hierarchical order from records taken of the events to generalised knowledge claims.

The major purpose of the V is to help students understand the function of laboratory work in science: it is claimed to be particularly useful if constructed as a pre-laboratory activity. The teacher might, for example, construct a V map in a tutorial session, building up the connections between theory and method by starting with a discussion of the event being observed. This leads to a discussion of what records might be taken and what concepts were used to guide observation of these particular events, or take those particular records. An alternative approach is to provide some aspects of the V and then expect students to complete the map as an individual exercise. V maps can also be included in laboratory manuals.

8.4 Second Survey at Glasgow

In the second phase of the study, pre-laboratory exercises were developed for the Chemistry-I Physical Chemistry Laboratory. These were used with the first year class in 2001-02. There are five experiments in this laboratory and five sets of exercises were developed and given to the students in advance of each laboratory. The pre-laboratory exercises were marked by the laboratory demonstrators. Straightforward paper-based exercises were used for simplicity. These are shown overleaf. The pre-laboratory exercises are shown with student instructions and demonstrator marking briefs in appendix D. For clarity the actual pre-laboratory exercises are shown in full.

EXPERIMENT 1 pH Titrations

Reminder: A solution is said to be one Molar if it contains 1 mole of solute per litre of solution. Thus, a 0.3M solution of NaOH contains 0.3 moles of sodium hydroxide per litre of solution.

(1) Write down the number of moles of solute in:

(a) 1 litre of 0.1M sulphuric acid

(b) 0.5 l of 2M potassium hydroxide

(c) 250 ml of 0.4 M nitric acid

(2) What volume of 1.00 M sodium hydroxide solution is required exactly to neutralise 100 ml of 0.05M acetic (ethanoic) acid ?

Reminder: The units of concentration are moles per litre. When we talk of the ***strength*** *of an acid or base we are* ***NOT*** *describing the concentration. We are describing the extent of ionisation. A strong acid or base is one which is close to 100% ionised in aqueous solution while a weak acid or base has a low degree of ionisation (usually 5% or less). Sulphuric, nitric and hydrochloric are three strong acids while organic acids (like acetic) are weak. The hydroxides of metals in columns I and II of the periodic table are strong while most other bases are weak.*

When acids and bases are mixed, salts are formed. However, even if enough acid has been added to neutralise the alkali exactly, the pH will not necessarily be 7. The salts formed can react with the water (they are said to be 'hydrolysed'). Here is an example of such an equilibrium reaction – sodium ethanoate (acetate) reacting with water :–

$$CH_3COONa + H_2O \rightleftharpoons CH_3COOH + Na^+ + OH^-$$

(3) Because acetic (ethanoic) acid is weak, the equilibrium in the above equation lies well to the right. Explain why this will result in a solution of sodium acetate in water being alkaline.

(4) Suggest a likely pH (above 7, about 7, or below 7) for solutions of each of the following salts in water:

Sodium chloride; Ammonium chloride; Potassium acetate (ethanoate); Calcium nitrate

(5) If we know the approximate pH (above 7, about 7, or below 7) of the salt formed at the equivalence point of an acid / base titration , we can select an indicator which will change colour over the appropriate pH range. Given the following table of indicators, select the indicator you would choose for each of the following titrations:

(a) sodium hydroxide and sulphuric acid

(b) potassium hydroxide and acetic (ethanoic) acid

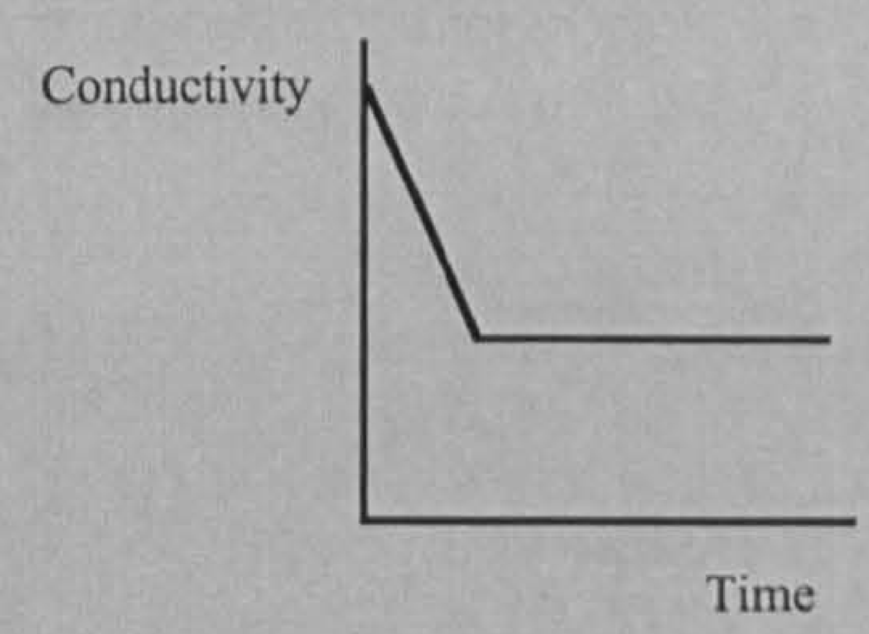
(c) ammonium hydroxide and hydrochloric acid

Indicators	Colour change	pH interval
Methyl orange	Orange- Yellow	2.1- 4.4
Methyl red	Red - Yellow	4.2 - 6.3
Bromthymol blue	Yellow - Blue	6.0 - 7.6
Phenolphthalein	Colourless - Red	8.3 - 10.0

EXPERIMENT 2 Conductometric Titrations

Dilute sulphuric acid conducts electricity extremely well. The conductivity of the solution is due to the motion of hydrogen ions and sulphate ions. When some magnesium powder is added to very dilute sulphuric acid, the conductivity of the solution falls rapidly. The magnesium forms magnesium ions while the hydrogen ions are removed as hydrogen gas. The magnesium ions are less mobile than hydrogen ions. The graph alongside illustrates what is observed.

(1) Refer to the graph and
- (a) Explain why the conductivity falls sharply to begin with.
- (b) Explain why the conductivity levels off after a short while.

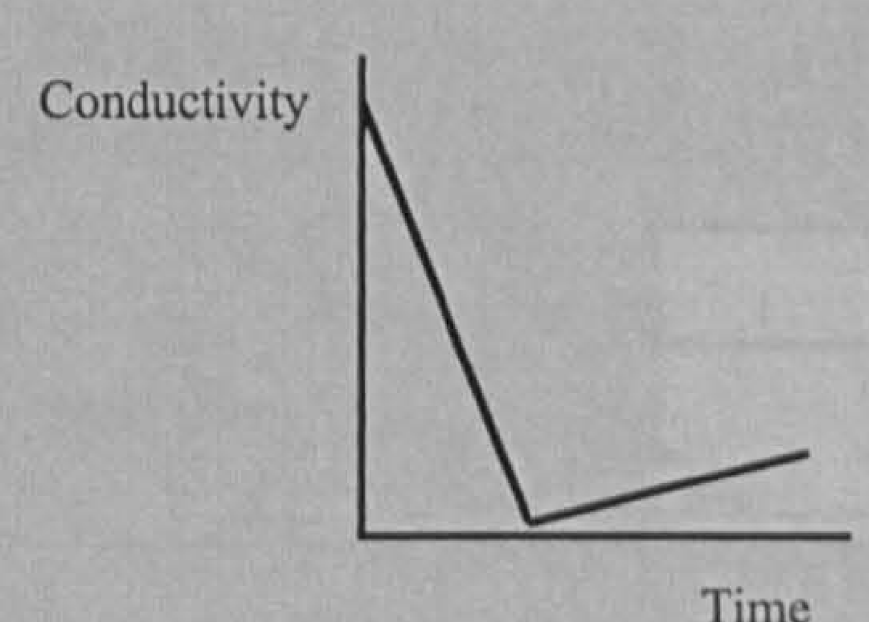


(2) Suppose the same experiment was repeated using very dilute sulphuric acid and copper oxide. A very similar graph is produced. Explain clearly why the graph has the same shape.

Reminder: Hydrogen ions are the most mobile and are about twice as mobile as hydroxide ions. Other ions vary in mobility but tend to about half as mobile as hydroxide ions.

(3) Next, the experiment is repeated using very dilute sulphuric acid and very dilute sodium hydroxide is gradually added. Draw the graph you would expect to obtain, explaining its shape.

(4) In a final experiment, very dilute barium hydroxide solution is added slowly to very dilute sulphuric acid and the graph alongside is obtained. What does the graph tell you about barium sulphate ?



EXPERIMENT 3 Solubility Product, K_{sp}

Reminder: *When a substance like silver iodide (which has a low solubility in water) is placed in water, an equilibrium is set up This can be represented by the equation, shown below and the solubility product (K_{sp}) is 1×10^{-16} at 25˚C.*

$$AgI(s) \rightleftharpoons Ag^+(aq) + I^-(aq) \qquad K_{sp} = [Ag^+][I^-] = 1 \times 10^{-16}$$

Suppose we dissolve enough silver iodide in water at 25˚C to make a saturated solution and we find that there are x moles of AgI dissolved in 1 litre of water at equilibrium.

- Thus: $[Ag^+] = [I^-] = x$ mol l^{-1}.
- Substituting into the expression for K_{sp} gives: $K_{sp} = [Ag^+][I^-] = [x][x] = 1 \times 10^{-16}$
- Solving for x gives: $[x]^2 = 1 \times 10^{-16}$ and, $x = 1 \times 10^{-8}$ mol l^{-1}
- The solubility of silver iodide in water is, therefore: $= 1 \times 10^{-8}$ moles per litre
- To convert the solubility in moles per litre to grams per litre, we multiply by the formula mass of the solid
- Thus: solubility of AgI in water at 25 ˚C $= [(1 \times 10^{-8}) \times 235]$ g per litre $= 2.35 \times 10^{-6}$ g l^{-1}

(1) The solubility product, K_{sp}, of silver chloride, AgCl, is 1.8×10^{-10} at 25˚C. What is the solubility of silver chloride in moles per litre at the same temperature.

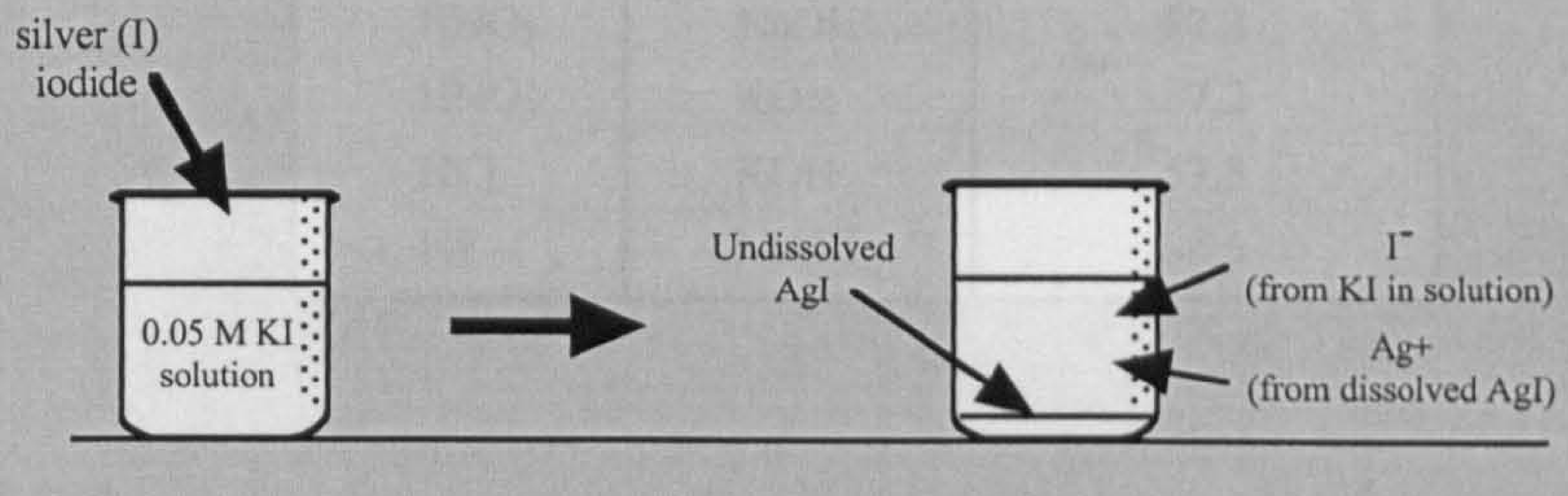
(2) What is the effect of changing the temperature on the value of a solubility product ?

Reminder : In the above discussion, we have looked at a single solute. However, the solubility of the original solute can change if a second solute is added. For example, suppose that silver iodide is dissolved in water which already contains potassium iodide (0.05 moles per litre). In the final solution, almost all of the iodide ion in solution comes from the dissolved potassium iodide, which is highly soluble, while the silver ions in solution come from the silver iodide sparingly soluble. The value of K_{sp} at the same temperature does not alter.

Thus: $K_{sp} = 1 \times 10^{-16} = [Ag^+][I^-] = [Ag^+] \times (0.05)$

Giving: $[Ag^+] = (1 \times 10^{-16}) \div 0.05 = 2 \times 10^{-14}$ mol l^{-1}

The amount of silver iodide which has dissolved is, therefore: $[(2 \times 10^{-14}) \times 235]$ g l^{-1}



(3) Calculate the solubility in moles per litre at 18˚C of lead sulphate, $PbSO_4$, in:

(a) pure water

(b) 0.10 M $Pb(NO_3)_2$

K_{sp} of lead sulphate at 18˚C is: 1.06×10^{-8}

EXPERIMENT 4 Heat of Reaction

Reminder: *When thermal energy is added continuously to water, the temperature will rise until the water reaches its boiling point. The amount of heat energy required to raise the temperature of the water to bowling point will depend on the initial temperature of the water, the amount of water present, and the heat capacity of water. The heat capacity of water is the amount of heat required to produce a one Centigrade degree rise in the temperature. The heat capacity of water is 4.18 Joule ml^{-1} $°C^{-1}$ (or 4.18 Joule g^{-1} $°C^{-1}$)*

(1) Calculate:

(a) The temperature rise if 100 ml of water is heated with 1200 J of energy.

(b) The final temperature if 50g of water at 21°C is heated with 1000 J of energy.

(2) When solutions of acids and bases are mixed, energy is released (i.e. the reaction is exothermic). This energy raises the temperature of the water. What else might also be heated up ?

(3) If 100ml of 1M HCl is mixed quickly with 100ml of 1M NaOH, a temperature rise of 6.2°C is observed. Predict the temperature rise if, under the same conditions, 10ml of 1M HCl is mixed quickly with 10ml of 1M NaOH.

(4) When acids and bases are mixed, thermal energy is released. Here are some data.

(a) Explain why several of the values are almost the same.

(b) Suggest an explanation why one value (the value for HCN) is much higher (less exothermic).

(c) Suggest an explanation why one value (the value for for HF) is much lower (more exothermic).

Acid	**Base**	**ΔH ($kJmol^{-1}$)**
HCl	NaOH	-57.1
HCl	KOH	-57.2
HCN	KOH	-11.7
HNO_3	NaOH	-57.3
HNO_3	KOH	-57.2
HCl	KOH	-57.3
HF	NaOH	-68.6

EXPERIMENT 5 Activation Energy.

(1) What is meant by activation energy ?

(2) In what way does absolute temperature relate to temperature on the Centigrade (Celsius) scale ?

(3) Explain clearly what you understand by first order reactions and second order reactions.

Reminder: *The logarithm of a number to the base ten is the power to which ten must be raised to give that number.*

Thus:

$$\log_{10}(17.4) = 1.24 \qquad \text{because:} \quad 10^{1.24} = 17.4$$

Logarithms can be expressed to any base with respect to any number. A useful, if unexpected, base is e which has a value of 2.718. Logarithms to the base e are known as natural logarithms and are symbolised by ln .

Thus:

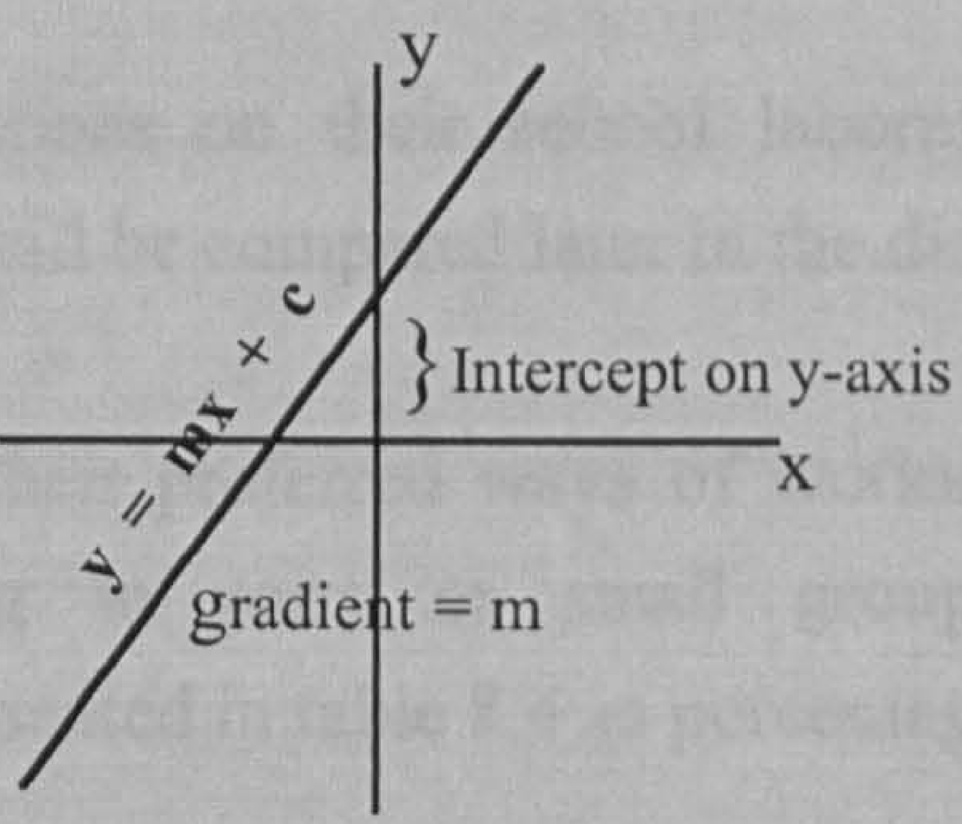
$$\ln(17.4) = 2.86 \qquad \text{because:} \quad e^{2.86} = 17.4$$

A useful connection between natural logarithms and logarithms to the base 10 is:

$$(2.303)\log_{10}(x) = \ln(x)$$

(4) The equation of a straight line is: $y = mx + c$

A graph of this function shows that the intercept on the y-axis has a value of c and that the gradient of the straight line is m.



When looking at the speed of chemical reactions, it can be shown that a relationship which is very like

$y = mx + c$ is obtained:

$$\ln(t) = E_a/RT + \text{constant}$$

where:

E_a = the activation energy for the reaction
t = time for reaction to reach a certain point
R = gas constant
T = temperature of reaction in degrees Kelvin

Using the y-axis for ln (t) and the x-axis for 1/T, sketch a graph similar to the graph for $y = mx + c$ shown above. Describe how you would calculate a value for the activation energy from such a graph.

8.4.1 The Results

The laboratory work was completed by the students in January 2002 and the questionnaire was then applied about a month later in early March 2002. The questionnaire was identical except that one extra question was added which related specifically to the pre-laboratory exercises. The number of returned questionnaires was, 211, being about 53% of the class group. The questionnaire results are shown below (polarised the same way for clarity), with the data as %. The original form of the questionnaire is shown in appendix E. The questionnaire data were considered in a way similar to the discussion of the previous year's data. Later, comparisons will be made between the data in the two questionnaires (those with no pre-laboratory in the Physical laboratory and those with pre-laboratory exercises.

(1) What are your opinions about your _school_ laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	15	40	27	9	7	3	Useless
Helpful	11	35	31	13	4	3	Not helpful
Meaningful	8	29	32	19	8	3	Meaningless
Understandable	17	36	27	10	6	2	Not understandable
Satisfying	10	21	30	31	13	5	Not satisfying
Interesting	15	27	28	15	9	4	Not interesting
Well organised	11	26	29	15	7	8	Not well organised

As before, the students reflections on their school laboratory experience was largely positive. The two years results will be compared later in the discussion.

Questions 2 and 3 looked at their preferred ways of working at school and university: working individually, working in pairs or small groups, and watching a class demonstration. The data are presented in table 8.4 as percentages

Table 8.4 Preferred Working Style

N = 211	Working individually	Working in pairs or groups	Watching a demonstration
School	15	75	8
University	16	81	2

It is clear that, in general, working in pairs and small groups is preferred, especially at university level. Again, this may reflect a certain lack of confidence, with group work offering some kind of shared responsibility. There are no statistically significant differences between their views of school and university laboratory work.

Questions 1 and 4 were identical, looking at school laboratories and university laboratories respectively. A comparison of attitudes towards school laboratory and overall university chemistry laboratory was carried out by looking the students' opinions using χ^2 as a contingency test (Table 8.5). The upper line shows views of school laboratories.

Table 8.5 Comparison of school and university laboratories

Useful	15	40	27	9	7	3	Useless	$\chi^2 = 16.6$ (df4) $p < 0.001$
	15	24	26	19	11	3		
Helpful	11	35	31	13	4	3	Not helpful	$\chi^2 = 5.7$ (df4) n.s.
	16	29	32	9	1	3		
Meaningful	8	35	32	19	8	3	Meaningless	$\chi^2 = 1.3$ (df4) n.s.
	9	28	28	17	11	1		
Understandable	17	36	27	10	6	2	Not understandable	$\chi^2 = 10.6$ (df4) $p < 0.05$
	9	30	36	13	10	1		
Satisfying	10	21	30	17	13	5	Not satisfying	$\chi^2 = 6.4$ (df4) n.s.
	11	24	37	16	7	3		
Interesting	15	27	28	15	9	4	Not interesting	$\chi^2 = 1.0$ (df4) n.s.
	11	26	29	14	7	4		
Well-organised	11	26	29	15	7	8	Not well-organised	$\chi^2 = 33.7$ (df4) $p < 0.001$
	27	29	27	6	2	2		

As before, many of the dimensions show little difference in perspective between school and university laboratories. However, where there are differences, the university laboratories are seen as less positive in two areas: useful and understandable. As before, university laboratories are seen as better organised than school laboratories. It is very difficult to see any reason why there are differences between this group and the group of the previous Question 5 aimed to gather information about students' attitudes towards their laboratory in physical chemistry at university level which they had completed recently. All the responses (frequencies) are on a five point scale. For clarity, the first and second choice, and the fourth and fifth were summed. This gives three categories: agree, neutral, disagree. The picture which emerged for each statement is shown in table 8.6 below as percentages, the sample being 211.

Table 8.6 Perceptions of the Physical Laboratory

		Strongly agree	Agree	Neutral	Disagree	Strongly disagree
a	I find writing lab reports largely a waste of time	4	14	24	51	4
b	The experimental procedure was clearly explained in the manual	12	64	13	6	2
c	It was easy to see the relationship between the experiments and the lecture course	2	24	28	35	8
d	I felt confident in carrying out the experiments.	4	45	22	21	4
e	These labs made me more interested in chemistry	6	28	36	22	6
f	The experiments encourage me to think about the chemistry which was involved.	9	41	27	19	2
g	I found the lab report difficult to write.	3	27	32	33	2
h	I prefer working on my own.	4	9	20	38	26
i	I am often confused by the lab manual.	0	11	26	54	4
j	I feel confident when I enter chemistry lab.	3	31	35	20	7
k	The purpose of the experiment was clear to me.	4	35	26	25	7
l	I should like to do open-ended project work as part of my chemistry laboratories.	4	9	39	27	15
m	I was so confused in the laboratory that I ended up following the manual without understanding what I was doing	5	17	29	39	6
n	I only understood the experiment when I started to write the report at the end of the experiment.	4	22	35	32	3
o	I found the pre-laboratory exercises a waste of time.	4	12	28	44	9

This is the overall perception of the students about physical laboratory. Encouragingly, students have positive attitude towards the physical laboratory, experiments work and manual. Students also understood the manual and the laboratory exercises were also clear to them. As might be expected, many students found no relationship between the experiments and the lecture course while one third of the students claimed to have no idea about the purpose of laboratory work.

Quite a number of the students were not in a position to understand the experiment when they started to write the report at the end of the experimental work while several expressed a lack of confidence when they enter the chemistry laboratory.

In amy ways, the picture is much as might be expected. Perhaps the matter of most concern is the proportion who failed to see the interrelationship between lecture and laboratory, an issue not easy to resolve. For organisational reasons, it is not possible for all experiments to follow the relevant lecture material. In addition, the fact that only about a third found the laboratory made them more interested in chemistry. This observation certainly needs to be addressed by these planning laboratories.

Question 6 was an open-ended question. In the first questionnaire not a single student made any comments. However, in this questionnaire (with pre-laboratory exercises) 120 students recorded comments. It is not obvious why so many commented when none had done so before. However, evidence which will discussed later indicated that the use of the pre-laboratory exercises had not been completely helpful and students may have taken this opportunity to register some kind of protest.

The comments are summarised again here for clarity:

Practicals are not related to theory.	19	students	16%
Practicals are not interesting.	16	students	13%
Preferring small groups (maximum 4)	13	students	11%
Calculations were difficult.	23	students	19%
Practical procedure was not clear.	15	students	13%
Demonstrator was not helpful.	13	students	11%
Demonstrator should be rotated.	6	students	5%
Marking system was not good.	15	students	12%

Many of these comments are typical of the kinds of criticisms that have been levelled against university chemistry laboratory experiences in general.

8.5 Comparison of Two Surveys

There are is no reason to suppose that the two year groups were different in any particular way, other than the latter group had completed pre-laboratory exercises. Indeed, in the questions which could not be influenced by the pre-laboratory experience in the physical chemistry laboratory, the results of the two year groups were extremely consistent, supporting the expected similarity of the two groups and offering confidence in reliability of the measurements.

This can be seen when comparing the data from question 1 for the groups with (N=211) and without (N=193) pre-laboratory exercises in the Physical Laboratory (Table 8.7 shows the 'with' group on the upper line). Question 1 looked back at school chemistry laboratory experiences.

Table 8.7 Comparison of question 1 with and without pre-laboratory exercises.

Useful	15	40	27	9	7	3	Useless	$\chi^2 = 7.6$ (df4) n.s.
	15	32	23	15	8	6		
Helpful	11	35	31	13	4	3	Not helpful	$\chi^2 = 7.2$ (df4) n.s.
	15	28	29	12	9	5		
Meaningful	8	35	32	19	8	3	Meaningless	$\chi^2 = 2.9$ (df4) n.s.
	11	26	28	17	12	3		
Understandable	17	36	27	10	6	2	Not understandable	$\chi^2 = 3.5$ (df4) n.s.
	24	33	24	9	5	3		
Satisfying	10	21	30	17	13	5	Not satisfying	$\chi^2 = 5.9$ (df5) n.s.
	9	23	31	18	8	9		
Interesting	15	27	28	15	9	4	Not interesting	$\chi^2 = 1.4$ (df4) n.s.
	15	28	30	13	6	4		
Well-organised	11	26	29	15	7	8	Not well-organised	$\chi^2 = 4.1$ (df5) n.s.
	17	28	25	14	8	5		

As might be expected, there are no significant differences between the two groups. This is evidence supporting the reliability of the survey.

However, it is interesting to note the difference between the two groups in their view of chemistry laboratories at university. The upper line shows the group who had experienced the Physical pre-laboratory exercises (N=211), the lower line showing the group who had not experienced the Physical pre-laboratory exercises (N=193).

Table 8.8 Comparison of Q. 4 with and Q. 4 without pre-laboratory exercise

Useful	16	29	32	9	1	3	Useless	$\chi^2 = 37.6$ (df2) $p < 0.001$
	22	45	21	6	2	1		
Helpful	15	24	26	16	11	3	Not helpful	$\chi^2 = 25.64$ (df4) $p < 0.001$
	19	34	17	11	10	3		
Meaningful	9	28	28	17	11	1	Meaningless	$\chi^2 = 19.0$ (df4) $p < 0.001$
	18	32	20	17	7	2		
Understandable	9	30	36	13	10	1	Not understandable	$\chi^2 = 25.16$ (df3) $p < 0.001$
	13	41	24	10	6	1		
Satisfying	11	24	37	16	7	3	Not satisfying	$\chi^2 = 11.92$ (df3) $p < 0.05$
	13	33	31	11	6	2		
Interesting	11	26	29	14	7	4	Not interesting	$\chi^2 = 10.2$ (df4) $p < 0.05$
	16	32	29	11	5	2		
Well-organised	27	29	27	6	2	2	Not well-organised	$\chi^2 = 2.55$ (df2) n.s.
	24	36	24	5	4	2		

Question 4 looked at their experiences of university laboratories in general. Each student would undertake three laboratories (physical, inorganic and organic) and, by the time of the questionnaire, they would have completed two laboratories and have partially completed the third. It has to be remembered that the other two laboratories had pre-laboratory exercises is use.

In every dimension except one, the group who had experienced the pre-laboratory exercises in the Physical Laboratory are less positive and more neutral in their views. The one exception is the laboratory organisation where there is no difference between the groups. It is surprising that the introduction of the pre-laboratory exercises in one of the three laboratories has created such differences although the questionnaire was administered only a few weeks after the completion of the physical laboratory

In their survey of the use of pre-laboratory exercises across many universities, Carnduff and Reid (2003) emphasised that the length of the pre-laboratory exercises is very important. Long pre-laboratory exercises have to be worthwhile but not so long that student resistance is generated. They also noted that management and assessment were also important for the effective use of pre-laboratory exercises. The pre-laboratory exercises were long and quite demanding. Informal feedback from demonstrators indicated that the length was too great. In addition, the students may have seen them as an extra task in that they were not integrated in any way into the laboratory manual.

Question 5 aimed to gather information about students' attitudes towards their laboratory in physical chemistry at university level which they had completed recently and, by comparing the two year groups, this question offers evidence about the impact of the pre-laboratory exercises.

This question consisted of fourteen statements. All the responses (frequencies) are on a five point scale. For clarity, the first and second choice, and the fourth and fifth were summed. This gives three categories: agree, neutral, disagree. The picture which emerged for each statement for each year group is shown in table 8.10 below as percentages, the samples being 193 and 211.

Table 8.9 Perceptions of the Physical Laboratory

a	I find writing lab reports largely a waste of time	No pre-lab	13	37	47	$\chi^2 = 17.4$, df3 $p < 0.01$
		Pre-lab	18	24	55	
b	The experimental procedure was clearly explained in the manual	No pre-lab	84	9	3	$\chi^2 = 21.44$ df2 $p < 0.01$
		Pre-lab	76	13	8	
c	It was easy to see the relationship between the experiments and the lecture course	No pre-lab	42	28	25	$\chi^2 = 28.14$ df2 $p < 0.01$
		Pre-lab	26	28	43	
d	I felt confident in carrying out the experiments.	No pre-lab	53	27	15	$\chi^2 = 18.68$ df2 $p < 0.01$
		Pre-lab	49	22	25	
e	These labs made me more interested in chemistry	No pre-lab	44	28	24	$\chi^2 = 11.16$, df2 $p < 0.01$
		Pre-lab	34	36	28	
f	The experiments encourage me to think about the chemistry which was involved.	No pre-lab	50	26	17	$\chi^2 = 2.00$, df2 n.s.
		Pre-lab	50	27	21	
g	I found the lab report difficult to write.	No pre-lab	17	29	50	$\chi^2 = 32.59$ df2 $P < 0.01$
		Pre-lab	30	22	35	
h	I prefer working on my own.	No pre-lab	9	18	68	$\chi^2 = 8.18$ df3 $P < 0.05$
		Pre-lab	13	20	64	
i	I am often confused by the lab manual.	No pre-lab	9	28	55	$\chi^2 = 5.05$df3 n.s.
		Pre-lab	11	26	58	
j	I feel confident when I enter chemistry lab.	No pre-lab	35	38	23	$\chi^2 = 7.66$ df3 n.s.
		Pre-lab	34	35	27	
k	The purpose of the experiment was clear to me.	No pre-lab	37	36	21	$\chi^2 = 17.38$ df3 $P < 0.01$
		Pre-lab	39	26	32	
l	I should like to do open-ended project work as part of my chemistry laboratories.	No pre-lab	12	36	41	$\chi^2 = 5.02$ df3 n.s.
		Pre-lab	13	39	42	
m	I was so confused in the laboratory that I ended up following the manual without understanding what I was doing	No pre-lab	17	29	45	$\chi^2 = 76.75$ df3 $P < 0.01$
		Pre-lab	22	29	45	
n	I only understood the experiment when I started to write the report at the end of the experiment.	No pre-lab	25	31	38	$\chi^2 = 0.45$df2 n.s.
		Pre-lab	26	35	35	

It is clear from the above table, that majority of the students understood the manual, more than half of the students have the confidence to carry out the experimental work in the laboratory. This made them chemistry more interesting . Students considered practical work supported with quite adequate written instructions. The laboratory work appeared to be regarded as more worth while. Quarter of the students are not in favour of working in their own but they are preferring to work in groups. On the other side about half of the students view was that experiments encourage them to think about the chemistry course, however, one third was no confidence, when they enter chemistry laboratory. One third of the students have the idea that the purpose of the experiments were not clear to them.

These are some mixed views of the students about the manual, about the experiments and about the understanding of the practical work. Overall the students were quite favourable towards the perceptive of physical laboratory and they have positive attitude towards physical laboratory.

8.6 Semi-structured Interviews

In order to gain further insights into the way the pre-laboratory exercises were operating and other aspects of the physical laboratory, it was possible to interview informally some of the students during their laboratory time. The total number of the students interviewed was sixty. The students were interviewed in groups according to their practical group. The time of the interview was about 15 minutes for each group. This was done during one complete week of laboratories when laboratories were running each day.

The structure of the interview explored the following themes. Under each theme, a summary of the responses of the students is given. Of course, in looking at the responses, it has to be remembered that such interviews give students opportunities to express views which may be based on their inadequate work or commitment rather than shortcomings in the laboratory experience.

(1) *Understanding of theory and concepts of physical chemistry.*

90% of the students indicated that they did not understand the theory involved in their practical work. If laboratory course is to be successful (from the students' point of view) then the basic theory and concepts of chemistry involved in the practical should be clear to the students. They also indicated that they had difficulty with symbols and notations leading to some confusion in completing calculations.

(2) *Preparation for experiments.*

70% indicated they did not feel prepared for the laboratories, with only 10% feeling that they were prepared. Inevitably, poor preparation will reduce student understanding. 25% indicated that pre-lab revising the material before starting would be their way of preparation. Here, the pre-laboratory exercise has a clear role.

(3) *Working on your own.*

60% students like small group (2 – 3 students group). This confirms the popularity of group work.

(4) *Attitude of the students towards the laboratory course.*

About 80% students stated that they did not like physical chemistry laboratory course giving the following reasons:

(a) They found it confusing, with the demonstrators sometimes increasing the confusion;
(b) The course is not related with the daily life. This confirms previous work in other areas of science learning at university level: students wish their science studies to be related to life (see Skryabina, 2000).
(c) The practicals are not linked with the text book (theory) or, in other words, with the chemistry concepts.
(d) They liked biology practical course because, to them, the practical are directly related to the theory, concepts etc.
(e) In the chemistry laboratory (practical) we cannot observed the results directly but in the biology practical we can. This is a strange comment and perhaps needs further exploration.

(5) *Motivation and interest.*

Approximately 75% students offered suggestions for the creation of motivation and interest:

(a) Demonstrations should be organised.
(b) The theory, concepts, equations, should be clear.
(c) The materials in pre-labs integrated with the manual.

(7) *Looking at the manual, their opinions tended to be negative.*

(a) Difficult to understand (55%);
(b) Not fully explained (64%);
(c) Difficult to understand the equations (70%);
(d) The experimental procedure was not clear (73%);
(e) Difficult to follow the calculations (80%).

(8) *Learning new practical techniques.*

When asked about whether they had learned any new techniques, all the students stated that they had learned no new techniques. The students also claimed that there was no difference in the techniques of the experiments in school and in university. Looking at the experiments in the laboratory, most of the techniques are probably covered in the Higher Grade course, with the remainder in the Advanced Higher. Nonetheless, the use of the techniques is different in some cases and the demand levels were greater.

(9) *Daily application of chemistry.*

More than 80% students suggested that they were not aware about the application of the laboratory work chemistry in daily life. If this is a true reflection of the student groups as a whole, this is a matter of concern, given the evidence about the importance of this aspect of science learning.

(10) *Demonstrator's role after the introducing of pre-lab exercises.*

60% of the students indicated that they were not happy with the role of the demonstrators in the laboratory. They recognised that a useful aspect of the demonstrator's role is to issue and mark the pre-laboratory exercises, thus quickly identifying the poor students needing help and bringing help to where it was most needed.

(11) *Students view about the pre-lab exercises.*

The following is a summary of the student views:

(a) 35% of the students did not clearly distinguish the pre-laboratory exercises from the actual experiments.
(b) The pre-laboratory exercises were easy to understand but difficult to apply (60% of the students).
(c) 70% felt that the pre-laboratory helped to understand the actual practical.
(d) 70% students stated that their understanding was improved by the pre-lab exercises.
(e) 50% students stated that the language of the pre-lab was easy but the calculations were difficult.

(f) Some 60% students were in favour of examples of calculations to be included in the pre-laboratory exercises.
(g) 40% students were happy with the format of the pre-lab.
(h) 60% students stated that the pre-labs are approximately related to the chemistry theory course.

8.7 Interview Results and Questionnaire Results.

It is fascinating that the impressions left by the data derived from the interviews are so very different from the questionnaire data. From the questionnaires, it would appear that the introduction of the pre-laboratory exercises had produced a negative effect on the student group. This could have arisen for many reasons.

Firstly, the pre-laboratory exercises were an 'add-on' and appeared to be extra work. They were almost certainly too long. Information from the laboratories showed that the demonstrators were not sympathetic in that, with little warning, they were faced with extra work, marking these pre-laboratory exercises. This reaction is quite understandable but there may have been a negative 'message coming from the demonstrators. It also became apparent that, very quickly, there arose a 'black market' of correct answers, thus defeating the purpose of the exercise. This probably happened because of the excessive time demand of the pre-laboratory exercises. Although every attempt was made to make the pre-laboratory exercises consistent with the manual, this was not easy.

The questionnaires indicated that the introduction of the pre-laboratory exercises had not been a great success. Despite this evidence, the evidence from the interviews suggested something rather different. Apparently, students could see the point of the exercises and thought they were valuable.

Of course, it is possible that the students were merely being polite to the interviewer. On the other hand, it could be argued that the questionnaire was not testing the same thing. It looked at the reaction to the laboratory overall. It is perfectly possible that the extra work for both demonstrators and students (and technicians, as labs overran at times) set up a negative atmosphere which influenced general views.

Whatever are the reasons, several lessons can be derived. Firstly, 'add on' pre-laboratory exercises are not the right way. Secondly, the laboratory experience must be viewed holistically - pre-laboratory exercises, experimental and post-laboratory experiences. Thirdly, it is important that demonstrators are comfortable with changes.

8.8 School Experiences

The work discussed so far has focussed mainly on the experiences of students during their first university year in chemistry laboratories and, in particular, on the impact of pre-laboratory exercises. In that the work in Pakistan related to those who were training to be secondary school chemistry teachers, it was decided to explore the perceptions of first year students at the outset of their course, looking back on their school experiences

A questionnaire was developed to explore what students, soon after entering the university, thought of their experiences of laboratory work. The questionnaire aimed to measure:

Opinions about school laboratory experiences in chemistry;
Preferred working in school chemistry laboratory;
Preferred working in university chemistry laboratory;
Students past experiences in chemistry laboratory work;
Why laboratory work is part of most chemistry courses.

The questionnaire was administered at the Glasgow University, first year chemistry students in 2002, near the start of the first term. 229 completed questionnaires were returned, being a return rate of about 57%. The responses are shown below, as percentages.

(1) What are your opinions about your school laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	28	33	27	6	4	2	Useless
Not helpful	0	6	13	21	37	22	Helpful
Understandable	19	38	23	10	5	0	Not understandable
Satisfying	14	26	33	16	6	3	Not satisfying
Boring	0	9	15	32	28	14	Interesting
Well organised	16	29	24	14	12	5	Not well organised
The best part of chemistry	19	28	23	19	5	4	The worst part of chemistry
Not enjoyable	2	3	11	28	35	20	Enjoyable

(2) In your school chemistry laboratory, which do you prefer ? (*Tick ONE box*)

Working individually	7
Working in small groups	85
Watching a demonstration	8

(3) In your college chemistry laboratories, which do you prefer ? (*Tick ONE box*)

Working individually	10
Working in small groups	83
Watching a demonstration	7

(4) Think about your past experiences in chemistry laboratory work.
Tick the box which best reflects your opinion.

(a) I believe that the laboratory is a vital part in learning chemistry........	38	46	5	0	0
(b) I prefer to have written instructions for experiments........................	35	44	8	4	0
(c) All the chemicals and equipment that I needed were easily located....	18	47	17	8	0
(d) I was unsure about what was expected of me in writing up my experiment...	6	34	17	28	0
(e) Laboratory work helps my understanding of chemistry topics..........	16	53	12	5	0
(f) Discussions in the laboratory enhance my understanding................	25	45	15	3	0
(g) I only understood the experiment when I started to write about it afterwards...	3	17	37	27	4
(h) I had few opportunities to plan my experiments...........................	6	28	25	31	0
(i) I felt confident in carrying out the experiments in chemistry............	7	31	26	20	3
(j) I found writing up about experiments pointless............................	2	7	18	51	12
(k) The experimental procedure was clearly explained in the instructions given...	13	43	21	8	0
(l) I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing..................	0	21	24	37	6
(m) I feel that examinations should take account of laboratory experiments I have completed...	13	41	21	9	4

(5) Here are several reasons why laboratory work is part of most chemistry courses.
Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses. **[The data shown here are raw data]**

Experimental work makes chemistry more enjoyable for me.	65
Experiments illustrate theory for me.	100
Laboratory work allows me to test out ideas.	38
Experiments allow me to find out about how materials behave.	51
Experiments teach me chemistry.	40
Experimental skills can be gained in the laboratory.	96
Experiments assist me to plan and organise.	21
Experimental work allows me to think about chemistry.	71

The responses to each question are now discussed in turn.

It is natural to seek some type of award after finishing any type of work and 54% reflected this viewpoint. There is a real danger, however, that assessing laboratory work focusses on those areas where assessment is easier and neglects those areas which may be more important. Work from many years ago pinpointed clearly the problems and dangers in assessing practical work (Gunning, & Johnstone, 1976).

(1) What are your opinions about your school laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	28	33	27	6	4	2	Useless
Not helpful	0	6	13	21	37	22	Helpful
Understandable	19	38	23	10	5	0	Not understandable
Satisfying	14	26	33	16	6	3	Not satisfying
Boring	0	9	15	32	28	14	Interesting
Well organised	16	29	24	14	12	5	Not well organised
The best part of chemistry	19	28	23	19	5	4	The worst part of chemistry
Not enjoyable	2	3	11	28	35	20	Enjoyable

The responses tend to be fairly positive indicating that their school experience of chemistry laboratory work has been positive. This confirms the general findings that laboratory work at school level tends to be highly popular and, in Scottish schools, the work is tightly integrated with other teaching. Teachers tend to use laboratory work to illustrate ideas and, in the eyes of pupils, this may be powerful in making the chemistry more real for them.

Question 4 explored this in more detail and the responses of each part are now discussed. The data (as %) are show again, for clarity, with the response of *strongly agree* being first and *strongly disagree* being last.

(a) I believe that the laboratory is a vital part in learning chemistry *38 46 5 0 0*

Encouragingly, the majority of the students recognise the importance of the laboratory work in learning chemistry.

(b) I prefer to have written instructions for experiments *35 44 8 4 0*

Most students like the laboratory / experimental instructions in written form. It may be to help them to run their laboratory work more efficiently or it simply may reflect the insecurity that they may feel when they are not sure what they are to do.

(c) All the chemicals and equipment that I needed were easily located *18 47 17 8 0*

One of the frustrations of laboratory work can be not being able to locate key materials or equipment. It appears that this is not a major problem in their school experience.

(d) *I was unsure about what was expected of me in writing up my experiment* 6 34 17 28 0

40% of the students felt that they were unsure about what had to be written at the end of the experiment. This may reflect the uncertain way in which school laboratory work is reported. Such work is often used to illustrate what is being taught and any write up is incidental while other work is used to gain results which have to be recorded and discussed.

(e) *Laboratory work helps my understanding of chemistry topics* 16 53 12 5 0

The majority of the students agree that laboratory work help them to understand the chemistry topics. They draw some relationship between the laboratory work and their course of chemistry. Again, this reflects the strong tradition in Scottish schools where practical work and taught components are closely integrated.

(f) *Discussions in the laboratory enhance my understanding* 25 45 15 3 0

The students were agreed that through discussion in the laboratory their understanding about laboratory work is enhanced. This may merely reflect their liking for group work (shown in questions 2 and 3) or it may be a recognition that discussion actually aids learning. The evidence shows that group work has this benefit (Yang, 2000)

(g) *I only understood the experiment when I started to write about it afterwards* 3 17 37 27 4

While 20% agreed with the statement, 31% disagreed, with a large number undecided. This is one major issue relating to practical work. It can illustrate ideas well or it can end up confusing because there is so much to take in that thinking about its significance is not easy.

(h) *I had few opportunities to plan my experiments* 6 28 25 31 0

Again, there is a spread of experiences. At school level, there is limited opportunity for planning their own laboratory work unless they have studied at Advanced Higher Grade.

(i) *I felt confident in carrying out the experiments in chemistry* 7 31 26 20 3

While 38% expressed confidence, 23% were not confidant. It is important to recognise that, for some students, the situation in the laboratory is unfamiliar and they can lack confidence in facing new experiments.

(j) *I found writing up about experiments pointless* 2 7 18 51 12

It is interesting to note that 63% disagreed with this statement, with only 9% agreeing. It is encouraging that their school experience has developed such a positive attitude.

(k) *The experimental procedure was clearly explained in the instructions given* 13 43 21 8 0

The positive attitude of the students in general probably reflects the way experimental work at school level is so tightly related to class teaching. The teacher plays a central role and it is clear that few students had found a lack of clarity in their previous experience.

(l) *I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing* — *0 21 24 37 6*

21% agreed with the statement and this suggests that they knew what to do but were uncertain of the meaning or significance. However, encouragingly, 43% disagree with the statement.

(m) *I feel that examinations should take account of laboratory experiments I have completed* — *13 41 21 9 4*

While most teachers appear to use practical work in Scottish schools to illustrate ideas taught in class, it was felt important to see how these students saw the purpose of laboratory work. In question 5, students were asked to tick three reasons. The student's reasons are summarised again for clarity, showing the actual number of ticks:

(5) Here are several reasons why laboratory work is part of most chemistry courses.
Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

Experimental work makes chemistry more enjoyable for me.	65
Experiments illustrate theory for me.	100
Laboratory work allows me to test out ideas.	38
Experiments allow me to find out about how materials behave.	51
Experiments teach me chemistry.	40
Experimental skills can be gained in the laboratory.	96
Experiments assist me to plan and organise.	21
Experimental work allows me to think about chemistry.	71

Students pinpoint two reasons well ahead of the others. In terms of chemistry teaching, experimental work can make the taught part of the course more real and illustrate ideas which have been presented. The gaining of experimental skills was also rated highly. In fact, such skills may be less important than indicated here in that most graduates in chemistry do not become bench chemists while the vast majority of those who take chemistry at school will never use specific laboratory skills. However, it does reflect the way practical work is assessed at Standard Grade.

8.9 Summary

Laboratory work in Scottish schools and universities is well established and well organised. This is reflected in the data obtained. It is easy for students to be critical of certain aspects and this may sometimes reflect a lack of commitment. Certainly, the student groups seemed to be aware of some key purposes for laboratory work and see it is a relevant part of their education in chemistry. The overall impression from the questionnaires was that students saw the importance of laboratory work and wished it to be a successful and satisfying experience.

Nonetheless, the difficulty in relating laboratory work to the lecture course at university level was apparent and the place of the pre-laboratory exercise in helping to bridge this gap was appreciated. The interviews, if a true reflection of student reaction to the pre-laboratory exercises, suggested a mature and responsible attitude and an appreciation of what was being attempted.

However, the introduction of the pre-laboratory exercises was not entirely successful. The importance of integrating the exercises with the manual and ensuring that demonstrators are aware of their purpose may be important lessons. The laboratory manual was completely re-cast and shortened, with the pre-laboratory exercises integrated into it. Unfortunately, it was not possible to test this revised manual out with students. The revised manual is shown in full in the appendix A and the original manual is shown in appendix F.

Chapter Nine

Data From Pakistan Surveys

9.1 Surveys in Pakistan

Having looked at the situation in Scottish schools and one university department in Scotland where the importance of laboratory work is well established, it was now appropriate to explore the situation in Pakistan where laboratory work is not so well established and to the particular difficulties with an open university which trains secondary teachers. The first stage was to use in Pakistan the same questionnaire which was used with the students at Glasgow at the start of their course. It was applied to three groups, all drawn from Allama Iqbal Open university:

BSc first year chemistry students
BSc second year chemistry students
BEd students preparing to be secondary chemistry teachers
(they had already completed their BSc in chemistry)

The aims of the questionnaire was explore student perceptions in a situation where laboratory work was not so well established at both school and university levels. Quantitative comparisons with the data obtained in Scotland are note made. There are so many differences between the educational experiences of students in the two countries that straightforward comparisons are impossible.

The aim was to establish an overview of the perceptions of students in Pakistan to laboratory work in order to identify areas where support is needed. The full data obtained are now listed without comment. The data are then discussed by looking at the year groups in pairs. Finally, some overall comparisons are made between the three groups and some qualitative observations are noted in the context of the data obtained form Glasgow.

The samples sizes are:

First year BSc students	229 completed questionnaires	return rate 76%.
Second year BSc students	150 completed questionnaires	return rate 60%.
BEd Trainee teachers	118 completed questionnaire	return rate 47%.

The data are presented as percentages unless otherwise stated.

9.2 First year BSc Students

(1) What are your opinions about your school laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	51	25	11	4	3	4	Useless
Not helpful	4	6	7	8	15	55	Helpful
Understandable	45	16	17	6	4	4	Not understandable
Satisfying	40	24	14	10	5	4	Not satisfying
Boring	14	7	8	7	17	48	Interesting
Well organised	25	24	17	9	4	13	Not well organised
The best part of chemistry	42	22	13	7	4	4	The worst part of chemistry
Not enjoyable	10	5	9	8	20	43	Enjoyable

(2) In your school chemistry laboratory, which do you prefer ? (*Tick ONE box*)

Working individually	22
Working in small groups	69
Watching a demonstration	5

(3) In your college chemistry laboratories, which do you prefer ? (*Tick ONE box*)

Working individually	27
Working in small groups	68
Watching a demonstration	3

(4) Think about your past experiences in chemistry laboratory work.
Tick the box which best reflects your opinion.

(a)	I believe that the laboratory is a vital part in learning chemistry....	58	35	5	2	0
(b)	I prefer to have written instructions for experiments..................	31	48	13	7	0
(c)	All the chemicals and equipment that I needed were easily located	24	33	16	20	5
(d)	I was unsure about what was expected of me in writing up my experiment..	15	29	31	11	7
(e)	Laboratory work helps my understanding of chemistry topics.......	44	39	10	2	3
(f)	Discussions in the laboratory enhance my understanding.............	39	41	8	7	2
(g)	I only understood the experiment when I started to write about it afterwards..	21	32	18	22	5
(h)	I had few opportunities to plan my experiments.........................	17	40	16	18	7
(i)	I felt confident in carrying out the experiments in chemistry..........	38	41	11	6	3
(j)	I found writing up about experiments pointless..........................	15	25	21	25	12
(k)	The experimental procedure was clearly explained in the instructions given..	28	38	17	8	3
(l)	I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing................	7	25	14	28	22
(m)	I feel that examinations should take account of laboratory experiments I have completed...	39	36	14	4	4

(5) Here are several reasons why laboratory work is part of most chemistry courses.
Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

Experimental work makes chemistry more enjoyable for me.	45
Experiments illustrate theory for me.	35
Laboratory work allows me to test out ideas.	31
Experiments allow me to find out about how materials behave.	42
Experiments teach me chemistry.	37
Experimental skills can be gained in the laboratory.	26
Experiments assist me to plan and organise.	12
Experimental work allows me to think about chemistry.	30

9.3 Second Year BSc Students.

(1) What are your opinions about your school laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	53	17	14	4	2	9	Useless
Not helpful	11	13	6	13	17	39	Helpful
Understandable	42	23	16	5	4	9	Not understandable
Satisfying	32	30	8	15	0	14	Not satisfying
Boring	17	5	5	7	28	37	Interesting
Well organised	30	27	7	7	6	23	Not well organised
The best part of chemistry	41	21	17	9	0	11	The worst part of chemistry
Not enjoyable	11	7	9	7	22	44	Enjoyable

(2) In your school chemistry laboratory, which do you prefer ? (*Tick ONE box*)

Working individually	25
Working in small groups	65
Watching a demonstration	10

(3) In your college chemistry laboratories, which do you prefer ? (*Tick ONE box*)

Working individually	26
Working in small groups	65
Watching a demonstration	9

(4) Think about your past experiences in chemistry laboratory work.
Tick the box which best reflects your opinion.

(a) I believe that the laboratory is a vital part in learning chemistry......	67	19	5	0	8
(b) I prefer to have written instructions for experiments......................	25	51	9	5	8
(c) All the chemicals and equipment that I needed were easily located.	26	29	17	17	10
(d) I was unsure about what was expected of me in writing up my experiment..	19	22	19	24	9
(e) Laboratory work helps my understanding of chemistry topics.........	39	36	12	5	7
(f) Discussions in the laboratory enhance my understanding...............	33	43	14	4	5
(g) I only understood the experiment when I started to write about it afterwards..	17	37	13	19	12
(h) I had few opportunities to plan my experiments..........................	21	35	19	13	8
(i) I felt confident in carrying out the experiments in chemistry...........	22	39	21	11	7
(j) I found writing up about experiments pointless...........................	15	27	23	25	7
(k) The experimental procedure was clearly explained in the instructions given..	23	42	16	14	4
(l) I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing..............	9	23	18	35	13
(m) I feel that examinations should take account of laboratory experiments I have completed...	39	40	13	4	5

(5) Here are several reasons why laboratory work is part of most chemistry courses.
Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

Experimental work makes chemistry more enjoyable for me.	43
Experiments illustrate theory for me.	39
Laboratory work allows me to test out ideas.	37
Experiments allow me to find out about how materials behave.	31
Experiments teach me chemistry.	26
Experimental skills can be gained in the laboratory.	27
Experiments assist me to plan and organise.	14
Experimental work allows me to think about chemistry.	45

9.4 BEd Trainee Teachers

(1) What are your opinions about your school laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	55	15	11	4	0	6	Useless
Not helpful	13	0	6	6	17	49	Helpful
Understandable	52	17	9	0	7	8	Not understandable
Satisfying	42	18	10	6	3	12	Not satisfying
Boring	13	6	3	8	14	46	Interesting
Well organised	31	9	15	3	8	24	Not well organised
The best part of chemistry	52	14	9	4	3	3	The worst part of chemistry
Not enjoyable	12	8	5	8	14	46	Enjoyable

(2) In your school chemistry laboratory, which do you prefer ? (*Tick ONE box*)

Working individually	15
Working in small groups	75
Watching a demonstration	6

(3) In your college chemistry laboratories, which do you prefer ? (*Tick ONE box*)

Working individually	31
Working in small groups	64
Watching a demonstration	3

(4) Think about your past experiences in chemistry laboratory work.
Tick the box which best reflects your opinion.

(a) I believe that the laboratory is a vital part in learning chemistry......	65	30	4	1	0
(b) I prefer to have written instructions for experiments.....................	34	47	8	6	0
(c) All the chemicals and equipment that I needed were easily located...	24	19	23	21	8
(d) I was unsure about what was expected of me in writing up my experiment..	15	41	18	13	5
(e) Laboratory work helps my understanding of chemistry topics.........	47	35	9	5	0
(f) Discussions in the laboratory enhance my understanding..............	37	38	9	10	0
(g) I only understood the experiment when I started to write about it afterwards..	14	35	11	25	8
(h) I had few opportunities to plan my experiments..........................	15	35	20	17	5
(i) I felt confident in carrying out the experiments in chemistry...........	31	42	6	14	0
(j) I found writing up about experiments pointless..........................	11	23	20	25	8
(k) The experimental procedure was clearly explained in the instructions given..	20	48	13	10	5
(l) I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing....................	11	24	13	30	18
(m) I feel that examinations should take account of laboratory experiments I have completed..	31	53	6	4	0

(5) Here are several reasons why laboratory work is part of most chemistry courses.
Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

Experimental work makes chemistry more enjoyable for me.	36
Experiments illustrate theory for me.	36
Laboratory work allows me to test out ideas.	28
Experiments allow me to find out about how materials behave.	24
Experiments teach me chemistry.	23
Experimental skills can be gained in the laboratory.	42
Experiments assist me to plan and organise	11
Experimental work allows me to think about chemistry.	33

9.5 Comparison of First Year and Second Year Data.

The first year students were those who were at the start of their BSc course in Chemistry and their views will largely reflect school experience. The second year students had completed their first year at university and were near the start of their second year course. The degree lasts for two years for an ordinary degree and three for a honours degree. This comparison will offer insights into the way student perceptions have changed with time: in other words, do the two groups differ from each other? It will also consider the general pattern of perceptions from students in this university in Pakistan.

For each question, the data are presented in table form as percentages. The first row shows the first year students responses and the second row shows the secondary year students responses. In order to see if the two groups differed in their responses, chi-square was applied to the raw data as a test of continuity. The chi-square values are shown, with the degrees of freedom shown in brackets. Data grouping is carried out where necessary to fulfil the requirements for chi-square. The significance of results is also shown. For clarity, all the questions are presented polarised the same way, with the more positive end at the left. The use of chi-square is discussed in Appendix C. Each question is now discussed in turn.

(1) What are your opinions about your school laboratory experiences in chemistry?

Table 9.1 Comparison of First Year and Second Year Data ($N_1 = 229$, $N_2 = 150$)

Useful	51	25	11	4	3	4	Useless	$\chi^2 = 5.4$(df3)
	53	17	14	4	2	9		n.s.
Helpful	55	15	8	7	6	4	Not helpful	$\chi^2 = 14.3$(df3)
	39	17	13	6	13	11		$p<0.01$
Understandable	45	16	17	6	4	4	Not understandable	$\chi^2 = 3.4$ (df3)
	42	23	16	5	4	9		n.s.
Satisfying	40	24	14	10	5	4	Not satisfying	$\chi^2 = 8.5$ (df4)
	32	30	8	15	0	14		n.s.
Interesting	48	17	7	8	7	14	Boring	$\chi^2 = 8.0$ (df3)
	37	28	7	5	5	17		$p<0.05$
Well organised	25	24	17	9	4	13	Not well organised	$\chi^2 = 13.1$ (df4)
	30	27	7	7	6	23		$p<0.05$
The best part of chemistry	42	22	13	7	4	4	The worst part of chemistry	$\chi^2 = 2.2$(df4)
	41	21	17	9	0	11		n.s.
Enjoyable	43	20	8	9	5	10	Not enjoyable	$\chi^2 = 0.8$(df5)
	44	22	7	9	7	11		n.s.

It might be expected that there would few differences between the first year and second year students when asked to look back at their school laboratory experiences in chemistry. Indeed, the use of chi-square shows few significant differences (three different, five not significantly different) and this supports the reliability of the measurements. However, looking at most of the questions, there is slight tendency for views to be polarised, with the second year showing a greater degree of polarisation at the negative end. However, in only three questions is this significant, with second year being more negative in their view about the helpfulness of laboratories, their view of interest and their view of laboratory organisation. It is difficult to explain this difference although it may that their views are being coloured by a longer experience of university laboratory work.

Overall, many of the attitudes are fairly positive although polarisation is evident, especially with second year. Usually, laboratory work at school level is popular (eg.. Skryabina, 2000). However, it does appear that the university experience of laboratory work may be reducing the positive attitudes somewhat. It is important to remember that positive attitudes are important. Thus, Keller (1983) noted that interest for learning activities learn is very important. If some activity is boring then the learner may lose the interest to learn.

The views of the students in Pakistan seem much more positive towards laboratory work at school level, despite the fact that Pakistani pupils appear to do very much less practical work. Are their positive views an expression of a higher appreciation of what little they have done with a desire to have more?

(2) In your school chemistry laboratory, which do you prefer ?

Table 9.2 Comparison of the data of School Chemistry Laboratory working.

	Working individually	Working in pairs or groups	Watching a demonstration
First Year (229)	22	69	5
Second Year (150)	25	65	10

As might be expected, the two groups are very similar in their responses. This may simply reflect their school experience where group work is the normal style.

(3) In your college chemistry laboratories, which do you prefer ?

Table 9.3 Comparison of College Chemistry Laboratory working.

	Working individually	Working in pairs or groups	Watching a demonstration
First Year (229)	27	68	3
Second Year (150)	26	65	9

In question 2 and 3, the majority of the students preferred to work in groups. Nonetheless, there is a minority (around one quarter) who still prefer working individually. Compared to the Glasgow data, working individually is given a higher rating.

In question 4, the responses of each part are now discussed. The data are show for clarity, with the response of *strongly agree* being first and *strongly disagree* being last. FY stands for first year and SY for second year in the following description.

(4) Think about your past experiences in chemistry laboratory work.
(First Year: $N_1 = 229$, Second Year: $N_2 = 150$)

(a) I believe that the laboratory is a vital part in learning chemistry

FY	*58*	*35*	*5*	*2*	*0*	
SY	*67*	*19*	*5*	*0*	*8*	χ^2 (df2) = 12.9 $p < 0.01$

Encouragingly, the majority of the students at both levels recognise the importance of the laboratory work in learning chemistry. However, the second year students are more positive in their views, with slight signs of some polarisation. Perhaps their greater study of chemistry has produce a greater awareness of the importance of the laboratory, at least for most of them.

(b) I prefer to have written instructions for experiments

FY	*31*	*48*	*13*	*7*	*0*	
SY	*25*	*51*	*9*	*5*	*8*	χ^2 (df3) = 7.43 n.s.

Most students like the laboratory / experimental instructions in written form. It may be to help them to run their laboratory work more efficiently or it simply may reflect the insecurity that they may feel when they are not sure what they are to do.

(c) All the chemicals and equipment that I needed were easily located

FY.	*24*	*33*	*16*	*20*	*5*	
SY.	*26*	*29*	*17*	*17*	*10*	χ^2 (df4) = 4.00 n.s.

One of the frustrations of laboratory work can be not being able to locate key materials or equipment. The two two year groups do not differ in their experiences, suggesting that there are some problems at both school and university. However, it does not appear to be a serious issue.

(d) I was unsure about what was expected of me in writing up my experiment

FY	*15*	*29*	*31*	*11*	*7*	
SY	*19*	*22*	*19*	*24*	*9*	χ^2 (df4) = 16.2 $p < 0.01$

44% of the first year students and 41% of the second year felt that they were unsure about what had to be written at the end of the experiment. This may reflect the uncertain way in which school laboratory work is reported. Such work is often used to illustrate what is being taught and any write up is incidental while other work is used to gain results which have to be recorded and discussed. However, the differences between the groups suggests a slightly more positive attitude with the older group.

(e) Laboratory work helps my understanding of chemistry topics

FY	*44*	*39*	*10*	*2*	*3*	
SY.	*39*	*36*	*12*	*5*	*7*	χ^2 (df3) = 7.3 n.s.

The majority of the students at both levels agree that laboratory work help them to understand the chemistry topics. They draw some relationship between the laboratory work and their course of chemistry. Again, this reflects the strong tradition in schools at Pakistan where practical work and taught components are closely integrated.

(f) Discussions in the laboratory enhance my understanding

FY	*39*	*41*	*8*	*7*	*2*	
SY	*33*	*43*	*14*	*4*	*5*	χ^2 (df3) = 4.4 n.s.

The students were agreed that through discussion in the laboratory their understanding about laboratory work is enhanced. This may merely reflect their liking for group work (shown in questions 2 and 3) or it may be a recognition that discussion actually aids learning. The evidence shows that group work has this benefit (Heller and Mark, 1992).

(g) I only understood the experiment when I started to write about it afterwards

FY	*21*	*32*	*18*	*22*	*5*	
SY.	*17*	*37*	*13*	*19*	*12*	χ^2 (df4) = 8.2 n.s.

Over 50% agreed with this statement at both levels suggesting that this is one major issue relating to practical work. It can illustrate ideas well or it can end up confusing because there is so much to take in that thinking about its meaning is not easy. This is a case where doing does not necessarily lead to greater understanding.

(h) *I had few opportunities to plan my experiments*

FY	*17*	*40*	*16*	*18*	*7*	
SY.	*21*	*35*	*19*	*13*	*8*	χ^2 (df4) = 3.4 n.s.

This is a sad feature of much laboratory work at both school and university. At both levels, there is limited opportunity for planning their own laboratory work. So much is so tightly prescribed that there are few opportunities to carry out the very procedures which make experimental work so vital in any science.

(i) *I felt confident in carrying out the experiments in chemistry*

FY	*38*	*41*	*11*	*6*	*3*	
SY	*22*	*39*	*21*	*11*	*7*	χ^2 (df3) = 19.8 $p < 0.01$

The majority of the students at both levels seem confident on the laboratory situation. It is important to recognise that, for some students, the situation in the laboratory is unfamiliar and they can lack confidence in facing new experiments.

(j) *I found writing up about experiments pointless*

FY	*15*	*25*	*21*	*25*	*12*	
SY	*15*	*27*	*23*	*25*	*7*	χ^2 (df4) = 0.3 n.s.

It is interesting to note that around 40% agreed with this statement in each year although views are spread widely. Of course, writing up could be resented because it is demanding of time and energy. Nonetheless, the data do suggest that the nature of the writing-up is unsatisfactory.

(k) *The experimental procedure was clearly explained in the instructions given.*

FY	*28*	*38*	*17*	*8*	*3*	
SY	*23*	*42*	*16*	*14*	*4*	χ^2 (df3) = 4.7 n.s.

The positive attitude of the students in general probably reflects the way experimental work at school and university level is so tightly prescribed. The teacher plays a central role and it is clear that few students had found a lack of clarity in their previous experience at both levels.

(l) *I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing.*

FY	*7*	*25*	*14*	*28*	*22*	
SY	*9*	*23*	*18*	*35*	*13*	χ^2 (df4) = 6.5 n.s.

Despite the clarity of the instructions, about one third in each year group expressed the view that they were following instructions without understanding. This is a worrying result in that it suggests that, for these students, their practical work will be largely ineffective as a means of learning.

(m) I feel that examinations should take account of laboratory experiments I have completed.

FY	*39*	*36*	*14*	*4*	*4*		
SY	*39*	*40*	*13*	*4*	*5*	χ^2 (df3) = 0.8	n.s.

It is natural to seek some type of award after finishing any type of work, 75% reflected this viewpoint at first year and 79% at second year. There is a real danger, however, that assessing laboratory work focusses on those areas where assessment is easier and neglects those areas which may be more important.

(5) Here are several reasons why laboratory work is part of most chemistry courses.

Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

	First year	*Second year*
Experimental work makes chemistry more enjoyable for me.	45	43
Experiments illustrate theory for me.	35	39
Laboratory work allows me to test out ideas.	31	37
Experiments allow me to find out about how materials behave.	42	31
Experiments teach me chemistry.	37	26
Experimental skills can be gained in the laboratory.	26	27
Experiments assist me to plan and organise.	12	14
Experimental work allows me to think about chemistry.	30	45

While laboratory work is part of most chemistry courses, the reasons for its presence are often not explicit. The aim of the question was to find out the thoughts of the students for laboratory work as a part of most chemistry courses.

It is clear that enjoyment is rated highly by both year groups. This is a pattern which has been found in other studies where laboratory work is often seen as enjoyable. This is important in that enjoyment and motivation are both important aspects of effective learning. Both year groups consider that experimental work illustrates theory which probably reflects the way laboratory work is used at school level.

In two areas, the first year year students see practical work as revealing how materials behave and as a means by which teaching has taken place while the second year students rate these aspects less highly. In another two areas (testing ideas and thinking), the second year students have higher ratings than the first year. These changes must reflect the experience of laboratory work during the first year university course.

9.6 Comparison of First Year and Trainee Teacher Data

A similar comparison is now made between the first year students and the trainee teachers. The latter group have already been through a chemistry degree and are, in general, a little older as well as being more experienced. The sample of first year students was 229 (as before) while the sample of trainee teachers was much smaller at 118.

(1) What are your opinion about your school laboratory experiences in chemistry?

In Table 9.4 , the first row shows the first year students responses and the second row shows the trainee teacher responses.

Table 9.4 Comparison of First Year and Trainee Teacher Data (N_1 = 229, N_2 = 118)

Useful	51	25	11	4	3	4	Useless	χ^2 = 3.7(df2) n.s.
	55	15	11	4	0	6		
Helpful	55	15	8	7	6	4	Not helpful	χ^2 = 1.6(df2) n.s.
	49	17	6	6	0	13		
Understandable	45	16	17	6	4	4	Not understandable	χ^2 = 3.8 (df3) n.s.
	52	17	9	0	7	8		
Satisfying	40	24	14	10	5	4	Not satisfying	χ^2 = 2.4 (df3) n.s.
	42	18	10	6	3	12		
Interesting	48	17	7	8	7	14	Boring	χ^2 = 0.4 (df2) n.s.
	46	14	8	3	6	13		
Well organised	25	24	17	9	4	13	Not well organised	χ^2 = 12.7 (df3) p<0.01
	31	9	15	3	8	24		
The best part of chemistry	42	22	13	7	4	4	The worst part of chemistry	χ^2 = 5.7(df3) n.s.
	52	14	9	4	3	3		
Enjoyable	43	20	8	9	5	10	Not enjoyable	χ^2 = 2.2(df2) n.s.
	46	14	8	5	8	12		

As both groups are looking back to their school experiences, it might be expected that similar patterns of responses would be likely. However, the trainee teachers have completed their BSc in chemistry and they are also a different population in that they have elected to take the BEd with the aim of entering secondary teaching. In the question where there is a significant difference, the trainee teachers are less favourable in their responses. In many cases, there is tendency for views to be more polarised. This may reflect the fact that their university laboratory experiences have not been too good or it may simply be that they wish to create better experiences when they become teachers and feel more strongly that what they experienced was not as good as it might have been.

(2) In your school chemistry laboratory, which do you prefer ?

Table 9.5 Comparison of data at School Chemistry laboratory working

	Working individually	Working in pairs or groups	Watching a demonstration
First year (229)	22	69	5
Trainee teacher (118)	15	75	6

Like the previous group data, in this group the majority of students at both levels preferred to work in small groups.

(3) In your college chemistry laboratories, which do you prefer ?

Table 9.6 Comparison of the data at College Chemistry laboratory working

	Working individually	Working in pairs or groups	Watching a demonstration
First year (229)	27	68	3
Trainee Teacher (118)	31	64	3

As it is clear from the above Table 9.6 that the students has preferred to do work in small groups. What the reason may be?

(4) Think about your past experiences in chemistry laboratory work
(First Year: $N_1 = 229$, Trainee Teachers: $N_2 = 118$)

In question 4, the responses of each part are now discussed. The data are shown as percentages for clarity, with the response of *strongly agree* being first and *strongly disagree* being last. The FY stands for first year and TT for trainee teacher in the following description.

(a) I believe that the laboratory is a vital part in learning chemistry

FY	*58*	*35*	*5*	*2*	*0*	
TT	*65*	*30*	*4*	*1*	*0*	χ^2 (df1) = 1.9 n.s.

Encouragingly, the majority of the students at both levels recognise the importance of the laboratory work in learning chemistry. In relation to school science, Hodson (1990) quotes a statement from 1882 which makes the assertion that "the instruction of scholars in science subjects.... shall be given mainly by experiments". It appears that many of the above groups think similarly.

(b) *I prefer to have written instructions for experiments*

FY	*31*	*48*	*13*	*7*	*0*	
TT	*34*	*47*	*8*	*6*	*0*	χ^2 (df1) = 1.5 n.s

Most students like the laboratory / experimental instructions in written form. It may be to help them to run their laboratory work more efficiently or it simply may reflect the insecurity that they may feel when they are not sure what they are to do. Millar (1987) states that students must understand the how and why of science. Therefore, there have some type of instructions to know or understand the how and why of the science.

(c) *All the chemicals and equipment that I needed were easily located*

FY	*24*	*33*	*16*	*20*	*5*	
TT	*24*	*19*	*23*	*21*	*8*	χ^2 (df3) = 7.8 n.s

The two groups express a similar pattern of responses.

(d) *I was unsure about what was expected of me in writing up my experiment*

FY	*15*	*29*	*31*	*11*	*7*	
TT	*15*	*41*	*18*	*13*	*5*	χ^2 (df3) = 8.5 $p < 0.05$

There is an interesting difference between the two groups, with the trainee teachers being more unsure in the context of writing up. This may reflect longer experience as a result of having completed their BSc or it may be a level of uncertainty when they are now being asked to plan experiments for school pupils.

(e) *Laboratory work helps my understanding of chemistry topics*

FY	*44*	*39*	*10*	*2*	*3*	
TT.	*47*	*35*	*9*	*5*	*0*	χ^2 (df1) = 0.00 n.s.

The majority of the students at both levels agree that laboratory work helps them to understand the chemistry topics. They draw some relationship between the laboratory work and their course of chemistry. Again, this reflects the strong tradition in schools at Pakistan where practical work and taught components are closely integrated.

(f) *Discussions in the laboratory enhance my understanding*

FY	*39*	*41*	*8*	*7*	*2*	
TT	*37*	*38*	*9*	*10*	*0*	χ^2 (df3) = 0.3 n.s.

The students were agreed that through discussion in the laboratory their understanding about laboratory work is enhanced. This may merely reflect their liking for group work (shown in questions 2 and 3) or it may be a recognition that discussion actually aids learning. The evidence shows that group work has this benefit (Heller and Mark, 1992).

(g) I only understood the experiment when I started to write about it afterwards

FY	*21*	*32*	*18*	*22*	*5*	
TT	*14*	*35*	*11*	*25*	*8*	χ^2 (df4) = 6.1 n.s.

The data reveal a range of views, with the majority tending to agree. Inevitably, this is a reflection of the way laboratories are run. Hodson (1990) blames the teachers for this kind of situation and he asserts that teachers use practical work because they are brainwashed into thinking it is effective and useful while they making it ineffective.

(h) I had few opportunities to plan my experiments

FY	*17*	*40*	*16*	*18*	*7*	
TT	*15*	*35*	*20*	*17*	*5*	χ^2 (df3) = 1.1 n.s.

At first year 57% agreed, and 25% disagreed, on the other hand at Trainee teacher level 50% agreed and 22% disagreed. Again, there is a spread of experiences. At school level, there is limited opportunity for planning their own laboratory work.

(i) I felt confident in carrying out the experiments in chemistry

FY	*38*	*41*	*11*	*6*	*3*	
TT	*31*	*42*	*6*	*14*	*0*	χ^2 (df2) = 3.7 n.s.

The majority of the students at both levels express confidence in a laboratory situation. This is encouraging. However, it does not follow that they are doing experiments well or are understanding what they are doing.

(j) I found writing up about experiments pointless

FY	*15*	*25*	*21*	*25*	*12*	
TT	*11*	*23*	*20*	*25*	*8*	χ^2 (df3) = 0.4 n.s

Quite a number in both groups agree with this statement and this clearly is an issue needing addressed.

(k) The experimental procedure was clearly explained in the instructions given.

FY	*28*	*38*	*17*	*8*	*3*	
TT	*20*	*48*	*13*	*10*	*5*	χ^2 (df3) = 6.3 n.s

The positive attitude of the students in general probably reflects the way experimental work at school and university level are so tightly related to class teaching. The teacher plays a central role and it is clear that few students had found a lack of clarity in their previous experience at both level. According to Tamir (1989), teachers are the key factor to realising the potential of any and all science activities.

(l) I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing

FY	*7*	*25*	*14*	*28*	*22*	
TT	*11*	*24*	*13*	*30*	*18*	χ^2 (df4) = 2.4 n.s.

Although nearly one half disagree, it is a matter of concern that around a third do agree with this statement. If their responses do reflect their actual experience, this is an area where improvement is very much needed.

(m) I feel that examinations should take account of laboratory experiments I have complete

FY	*39*	*36*	*14*	*4*	*4*	
TT	*31*	*53*	*6*	*4*	*0*	χ^2 (df1) = 6.3 $p < 0.05$

It is natural to seek some type of award after finishing any type of work although assessing laboratory work may focus on those areas where assessment is easier and neglects those areas which may be more important.

While laboratory work is part of most chemistry courses, the reasons for its presence are often not explicit. The aim of question 5 was to find out the thoughts of the students for laboratory work as a part of most chemistry courses. Students were asked to tick three reasons. The student's reasons are summarised again for clarity, showing the percentages values for both levels.

(5) Here are several reasons why laboratory work is part of most chemistry courses.
Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

	First Year	*Trainee Teacher*
Experimental work makes chemistry more enjoyable for me.	45	36
Experiments illustrate theory for me.	35	36
Laboratory work allows me to test out ideas.	31	28
Experiments allow me to find out about how materials behave.	42	24
Experiments teach me chemistry.	37	23
Experimental skills can be gained in the laboratory.	26	42
Experiments assist me to plan and organise.	12	11
Experimental work allows me to think about chemistry.	30	33

In many of the questions, similar patterns of responses occur but, in three of the questions, the rating from the trainee teachers has dropped. Their perception of enjoyment has fallen, perhaps reflecting experiences over their BSc degree. The rating of trainee teachers that experiments allow them to find out about the behaviour of materials and their rating that chemistry is taught through experiments have both fallen markedly.

Is this because, with experience, their views have changed as they have become more aware that experiments have not done this for them or is it that, faced with secondary teaching, their perceptions are having to be modified? Perhaps the rise in the rating for trainee teachers in their view that experimental skills can be gained suggests that their views have been altered during their first degree. It is possible that the emphasis in their BSc laboratories has raised the status of skills and downplayed the status of learning. It is possible that this relates to a manual-driven laboratory experience where little learning actually occurred.

9.7 Comparison of Second year and Trainee Teacher Data

The BEd students (trainee teachers) have already gained their BSc and have taken a step of commitment towards a teaching career. How do these different perspectives affect their attitudes towards laboratory work? The second year sample was 150 and the Trainee teacher students sample was 118.

(1) What are your opinions about your school laboratory experiences in chemistry?

In Table 9.7, the first row shows the second year students responses and the second row shows the Trainee teacher responses.

Table 9.7 Comparison of Second year and Trainee Teacher Data ($N_1 = 150, N_2 = 118$)

Useful	53	17	14	4	2	9	Useless	$\chi^2 = 1.66$(df2)
	55	15	11	4	0	6		n.s.
Helpful	39	17	13	6	13	11	Not helpful	$\chi^2 = 7.77$(df2)
	49	17	6	6	0	13		n.s.
Understandable	42	23	16	5	4	9	Not understandable	$\chi^2 = 4.80$(df2)
	52	17	9	0	7	8		n.s.
Satisfying	32	30	8	15	0	14	Not satisfying	$\chi^2 = 7.47$ (df2)
	42	18	10	6	3	12		n.s.
Interesting	37	28	7	5	5	17	Boring	$\chi^2 = 0.08$ (df2)
	46	14	8	3	6	13		n.s.
Well organised	30	27	7	7	6	23	Not well organised	$\chi^2 = 14.05$ (df2)
	31	9	15	3	8	24		$p<0.01$
The best part of chemistry	41	21	17	9	0	11	The worst part of chemistry	$\chi^2 = 8.72$(df2)
	52	14	9	4	3	3		n.s
Enjoyable	44	2	7	9	7	11	Not enjoyable	$\chi^2 = 2.29$(df2)
	46	14	8	5	8	12		n.s.

As might be expected, the perceptions of both groups about their school experiences are similar. Both groups have been away from school for some time and have studied chemistry at university (including laboratory experiences). The one question where a significant difference occurs relates to the laboratory organisation but the significant difference mainly arises from a move from positive to a more neutral perception on the part of trainee teachers.

Of greater interest is that the amount of polarisation of views. Groups of students seem to hold very positive or very negative views, with no distribution really conforming to a normal distribution. The more polarised group appears to be the trainee teacher group although the differences are not significant. This is a matter of concern in that a significant minority of trainee teachers appear to hold very negative perceptions relating to several aspects of laboratory work at school level and this may influence the way they use laboratories in their own teaching.

(2) In your school chemistry laboratory, which do you prefer?

Table 9.8 Comparison of the School Chemistry Laboratory working

	Working individually	Working in pairs or groups	Watching a demonstration
Second year (150)	25	65	10
Trainee teacher (118)	15	75	6

(3) In your college chemistry laboratories, which do you prefer ?

Table 9.9 Comparison of the College Chemistry Laboratory working

	Working individually	Working in pairs or groups	Watching a demonstration
Second year (150)	26	65	9
Trainee Teacher (118)	31	64	3

In this case also, the majority of the students preferred to work in small groups.

(4) Think about your past experiences in chemistry laboratory work

(Second year: $N_1 = 150$, Trainee teachers: $N_2 = 118$)

In question 4, the responses of each part are now discussed. The data are show for clarity, with the response of *strongly agree* being first and *strongly disagree* being last. The SY stands for first year and TT for trainee teacher in the following description.

(a) I believe that the laboratory is a vital part in learning chemistry

SY	*67*	*19*	*5*	*0*	*8*		
TT	*65*	*30*	*4*	*1*	*0*	χ^2 (df1) = *5.1*	*n.s.*

Encouragingly, the majority of the students at both level recognise the importance of the laboratory work in learning chemistry.

(b) I prefer to have written instructions for experiments

SY	*25*	*51*	*9*	*5*	*8*		
TT	*34*	*47*	*8*	*6*	*0*	χ^2 (df1) = 2.7	n.s.

Again, written instructions are preferred for both groups.

(c) *All the chemicals and equipment that I needed were easily located*

S Y	*26*	*29*	*17*	*17*	*10*		
TT	*24*	*19*	*23*	*21*	*8*	χ^2 (df3) = 4.2	n.s

The majority were happy about this organisational aspect.

(d) *I was unsure about what was expected of me in writing up my experiment*

SY	*19*	*22*	*19*	*24*	*9*		
TT	*15*	*41*	*18*	*13*	*5*	χ^2 (df3) = 14.2	$p < 0.01$

44% of the first year students and 41 % of the second year felt that they were unsure about what had to be written at the end of the experiment. This may reflect the uncertain way in which school laboratory work is reported. Such work is often used to illustrate what is being taught and any write-up is incidental while other work is used to gain results which have to be recorded and discussed.

(e) *Laboratory work helps my understanding of chemistry topics*

SY	*39*	*36*	*12*	*5*	*7*		
TT	*47*	*35*	*9*	*5*	*0*	χ^2 (df1) = 3.4	n.s.

The majority of the students at both levels agree that laboratory work help them to understand the chemistry topics.

(f) *Discussions in the laboratory enhance my understanding*

SY	*33*	*43*	*14*	*4*	*5*		
TT	*37*	*38*	*9*	*10*	*0*	χ^2 (df2) = 1.2	n.s

The students were agreed that through discussion in the laboratory their understanding about laboratory work is enhanced. This may merely reflect their liking for group work (shown in questions 2 and 3) or it may be a recognition that discussion actually aids learning.

(g) *I only understood the experiment when I started to write about it afterwards*

SY	*17*	*37*	*13*	*19*	*12*		
TT	*14*	*35*	*11*	*25*	*8*	χ^2 (df4) = 2.2	n.s.

As before, the responses to this question are a matter of concern. Both groups have considerable experience of university laboratories and their perception must reflect their university experience.

(h) *I had few opportunities to plan my experiments*

SY	*21*	*35*	*19*	*13*	*8*		
TT.	*15*	*35*	*20*	*17*	*5*	χ^2 (df3) = 1.3	n.s.

There is a wide range of views, but the responses reflect the limited opportunities for planning their own laboratory work.

(i) I felt confident in carrying out the experiments in chemistry

SY	*22*	*39*	*21*	*11*	*7*	
TT	*31*	*42*	*6*	*14*	*0*	χ^2 (df1) = 8.80 $p<0.01$

The majority of the students at both level have the confident on the laboratory situation. However, the trainee teachers indicate a much higher level of confidence. This could simply arise because they now posses their BSc degree.

(j) I found writing up about experiments pointless

SY	*15*	*27*	*23*	*25*	*7*	
TT	*11*	*23*	*20*	*25*	*8*	χ^2 (df3) = 0.2 n.s.

Responses here confirm that the writing up procedures which they have experienced have not been entirely satisfactory in their view.

(k) The experimental procedure was clearly explained in the instructions given.

SY	*23*	*42*	*16*	*14*	*4*	
TT	*20*	*48*	*13*	*10*	*5*	χ^2 (df3) = 1.6 n.s.

The tightly prescribed manual-driven laboratory experience influences this range of views.

(l) I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing

SY	*9*	*23*	*18*	*35*	*13*	
TT	*11*	*24*	*13*	*30*	*18*	χ^2 (df4) = 2.6 n.s.

Student views are widely spread.

(m) I feel that examinations should take account of laboratory experiments I have completed

SY	*39*	*40*	*13*	*4*	*5*	
TT	*31*	*53*	*6*	*4*	*0*	χ^2 (df1) = 5.00 n.s.

As before, they want credit for work done.

While laboratory work is part of most chemistry courses, the reasons for its presence are often not explicit. The aim of the question was to find out the thoughts of the students for laboratory work as a part of most chemistry courses. Students were asked to tick three reasons. The student's reasons are summarised again for clarity, showing the percentages values for both levels.

(5) *Here are several reasons why laboratory work is part of most chemistry* courses.

Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

	Second Year	*Trainee Teacher*
Experimental work makes chemistry more enjoyable for me.	43	36
Experiments illustrate theory for me.	36	36
Laboratory work allows me to test out ideas.	37	28
Experiments allow me to find out about how materials behave.	31	24
Experiments teach me chemistry.	26	23
Experimental skills can be gained in the laboratory.	27	42
Experiments assist me to plan and organise.	14	11
Experimental work allows me to think about chemistry.	45	33

When discussing the comparison between first year students and trainee teachers, it was noted that there was a decline in ratings in three areas, with one increase. The results here are similar. It is worth looking at all three years together, the questions being numbered to aid discussion:

		First Year	*Second Year*	*Trainee Teacher*
(1)	Experimental work makes chemistry more enjoyable for me.	45	43	36
(2)	Experiments illustrate theory for me.	35	36	36
(3)	Laboratory work allows me to test out ideas.	31	37	28
(4)	Experiments allow me to find out about how materials behave.	42	31	24
(5)	Experiments teach me chemistry.	37	26	23
(6)	Experimental skills can be gained in the laboratory.	26	27	42
(7)	Experiments assist me to plan and organise.	12	14	11
(8)	Experimental work allows me to think about chemistry.	30	45	33

Because of the nature of this kind of rating data, it is difficult to check statistically for significance. However, the following general observations are made. In two questions (2 and 7), ratings have not changed while, in 3 questions (1,4 and 5), ratings have fallen. The decline in question (1) has been noted as a matter of concern while the the decline in (4) and (5) may reflect increased realism. The rise in question (6) occurs between the second year and the trainee year and may either indicate an emphasis which they have experienced or a commitment to a purpose for their own teaching. In two questions (3 and (8), the highest rating occurs for the second year and at almost certainly reflects the style of laboratory work in the second year.

The pattern of responses is very different when compared to figures form Scottish students, almost certainly reflecting the vast differences between the two education systems and the place of laboratory work in chemistry courses.

9.8 Comparisons across the three groups

In most of the questions, there were few significant results which showed any kind of trend across the three year groups. However, three parts of question 4 were interesting.

(a) I believe that the laboratory is a vital part in learning chemistry

FY	*58*	*35*	*5*	*2*	*0*	FY/SY	χ^2 (df2) = 12.9	$p < 0.01$
SY	*67*	*19*	*5*	*0*	*8*	FY/TT	χ^2 (df1) = 1.9	n.s.
TT	*65*	*30*	*4*	*1*	*0*	SY/TT	χ^2 (df1) = 5.1	n.s.

The significant change occurs between first and second year and then remains statistically the same.

(d) I was unsure about what was expected of me in writing up my experiment

FY	*15*	*29*	*31*	*11*	*7*	FY/SY	χ^2 (df4) = 16.2	$p < 0.01$
SY	*19*	*22*	*19*	*24*	*9*	FY/TT	χ^2 (df3) = 8.5	$p < 0.05$
TT	*15*	*41*	*18*	*13*	*5*	SY/TT	χ^2 (df3) = 14.2	$p < 0.01$

This reveals a move from unsure to disagree from first to second year and then the positive attitude is restored to an even stronger position for trainees.

(i) I felt confident in carrying out the experiments in chemistry

FY	*38*	*41*	*11*	*6*	*3*	FY/SY	χ^2 (df3) = 19.8	$p < 0.01$
SY	*22*	*39*	*21*	*11*	*7*	FY/TT	χ^2 (df2) = 3.7 n.s.	
TT	*31*	*42*	*6*	*14*	*0*	SY/TT	χ^2 (df1) = 8.8	$p < 0.01$

There is a deterioration from first to second year and then a partial restoration.

9.9 Summary

The direct comparisons of both data are not possible due to difference in curriculum and other physical facilties. The Scottish students have more laboratory experiences than Pakistani students. Both groups have positive attitude towards laboratory work, despite the fact that Pakistani students appear to do very much less practical work.

The expectations are that Pakistani students have more desire towards the laboratory work. They have more ambitions towards laboratory work.

The more ideal data is the Teacher Trainee, which is more polarised as compared to the First and Second years students. This is very significant, when the Teacher Trainee will use the laboratory in their own teaching.

Chapter Ten

The Idee of Paper Laboratories

10.1 Introduction

In the teaching and learning of chemistry, a sound understanding of both the theoretical and practical aspects of the discipline is essential. It is contended that if students are better prepared for a laboratory exercise, then they will understand more fully the rationale behind the processes both at a practical level and in terms of the chemistry involved.

Historically, chemistry laboratory work was introduced some 160 years ago and is now a standard feature of all applied science at all levels. There are different types of teaching which can be applied in laboratory teaching learning situations and these have been discussed in detail in chapter four. However, it must be stressed that the sole purpose of laboratory teaching is to facilitate learning.

This study has offered on overview of the place of laboratory learning in chemistry in a setting where it has been established for many years (Scotland). It has also offered an overview of laboratory learning in chemistry with students in Allama Iqbal Open University in Pakistan. The next stage is to explore how laboratory learning in chemistry might be enhanced in an open learning context, using the principles which have emerged from educational evidence. This led to the concept of paper laboratories and these are now described.

10.2 Effectiveness of laboratory work

In the context of teacher education, laboratory work requires specific goals. If it can be assumed that the first degree (BSc) has offered laboratory work in such a way that students can see the place of the empirical in illustrating ideas, checking ideas and developing new insights, as well as giving students confidence in key practical skills, then laboratory work in teacher education has to build on these. The 'if' is important.

Secondary chemistry teachers need to gain insights into how to make laboratory work an effective learning situation for school pupils. This goes beyond skills acquisition. It goes beyond the empirical verification of known facts. It must involve the development of meaningful practical situations which illustrate, challenge and provoke enquiry. It must make chemistry real to the young learner and it must illustrate the way the experimental is the key method of enquiry in a science subject.

Czerniak and Lumpe (1996) notes that many teachers receive science instruction in educational settings that separate laboratory work time from lecture time. Information was given but not necessarily integrated with experiments. Usually the teaching came first and the laboratory experiences came later (Czerniak, 1996).

Looking specifically at university courses, Johnstone and Letton (1990) noted that, with all resources given to practical work, many of the aims set by the designers are not being achieved very well. However, in studies where pre-laboratory activities have been employed (Johnstone, *et al.*, 1994) and (Johnstone, *et al.*, 1998), there is clear evidence that learning has increased and motivation has been enhanced.

Designers of university laboratory courses might, on reflection, agree that their students experience a continuum of learning experiences. These might include: previous school work, chemistry lectures, courses in parallel subjects, reading, the internet, workshops, pre-laboratory activities, laboratory experiments, recording, interpreting, reporting, extending, interactive questioning, assessment and feedback. revision and examinations. In considering pre-laboratory exercises, as well as any other material, it is important to design material and methods to take account of this continuum and the requirements for effective learning.

At school level, if the goals of laboratory work are to be met, then the teachers will be the leaders with curiosity, confidence and enthusiasm for science teaching (Horton & Hutchinson, 1997).

10.3 Aims of paper laboratories

In an open university setting for training chemistry teachers, it is important to set clear goals. There will be very limited time for 'hands on' laboratory experience in such courses but it is possible that some outcomes can be achieved through paper-based exercises. These paper-based laboratories must take into account the previous experience of the students (through their BSc programmes) and the needs of the students as they enter secondary teaching.

For undergraduate chemistry laboratory work, papers laboratory aims may or may not be similar to the actual laboratory work. These aims can be grouped into the following broad overlapping themes. The students (trainee teachers) may be able:

(a) To see something of the way science operates as it seeks to gain answers from the physical world;
(b) To think about practical problem solving;
(c) To understand theoretical models and their application in the real world;
(d) To illustrate chemical ideas.
(e) To understand / explore the procedure of experimental work.
(f) To find the applications of chemistry knowledge.

10.4 Development of Paper laboratories

A set of four paper laboratories was developed. Together, they were designed as a set with the following features:

(1) They were based on chemistry which would be relevant for school courses at secondary level but the demand level of thinking was designed to be appropriate for BSc graduates in Pakistan.
(2) They were set in several parts, each with exercises and questions to be returned to a tutor by post who would then send the next part (for practical reasons, in the trial, they were used as a single package).
(3) They tried to offer to the students insights into ways by which experimental work could be used in secondary teaching.
(4) They used accessible layout, diagrams and illustrations, to offer a model for teachers to use in schools.
(5) They incorporated the features of pre-laboratory experiences, the gaining and interpreting of experimental evidence, the application of findings in real life.
(6) The tried to make chemistry real and relate it strongly to applications.

In designing the paper labs, numerous chemistry texts were scrutinised. In particular, the set of textbooks entitled "Chemistry Takes Shape", now long out of print, was found to be helpful (Johnstone and Morrison, 1964, 1965, 1966, 1967)

The four paper labs have the following themes:

(1) Making simple Inorganic Compounds
(2) Corrosion and Electrolysis
(3) Carbonated Rocks
(4) Fats and Oils

The four paper labs were revised in the light of comments from experienced chemistry teachers in Scotland. These paper labs were sent to Pakistan and distributed to a sample of chemistry students who were training to be teachers. Written instructions were provided for the administering these paper labs see appendix H.

It was impossible to gain information about the effectiveness of such paper labs in enabling student teachers to become better equipped to operate laboratory experiences for school pupils. This would have required several years of work. What was possible was to allow a sample of student teachers to try them out, and to look at their opinions of the paper labs. This was conducted in May 2003 in two districts in Pakistan, with 150 students. 75 evaluation sheets were returned by post, a return rate of 50%.

Paper Lab 1 is shown below to illustrate the idea while the remaining three are in the Appendix G.

Paper Lab 1

Making Simple Inorganic Compounds

Aim: To establish the simple rules for inorganic inter conversions so that you can work out reasonable reaction routes.
To enable you to understand, plan and operate a laboratory experience at school level based on simple inorganic inter-conversions.

Part 1 Solubility and insolubility

Many inorganic compounds are ionic, especially those involving metals. Some of these compounds have low solubility in water (we call them insoluble) while others dissolve well (we call them soluble). Many rocks are inorganic ionic compounds. As it rains, the more soluble rocks dissolve and are washed into the sea. Look at the sea. There are numerous different ions dissolved in sea water. Alongside, there is a list of the more common ions in the sea.

Look at the table alongside.

(a) The amount of bromide ion in the sea seems very low but it is still worth extracting from the sea. Suppose you have 1 tonne (1000 Kg) of sea water. Calculate the mass of bromine which you could obtain from this.

Mass of bromine obtainable from 1 tonne sea water = ... g

(b) Think of 1 cubic kilometre of sea water. Estimate the mass of bromine in this volume of sea water?

Mass of bromine in 1 cubic kilometre of sea-water = ... tonnes

(c) Almost all carbonates are insoluble in water. Suggest why there is so much carbonate ion in sea water by thinking from where it might have come.

....

Now turn over for the answers

Answers to the questions

(a) 70g

(b) 7×10^4 tons

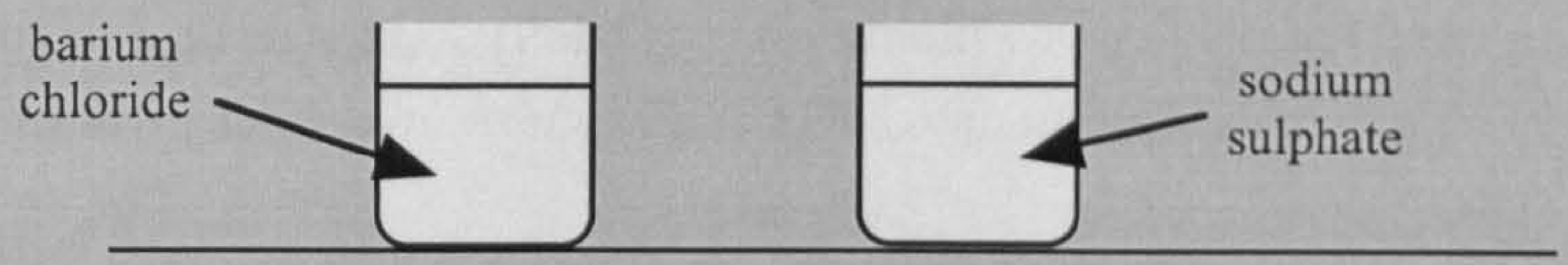
(c) Did you think of the atmosphere?

Carbon dioxide dissolves slowly in sea water to give carbonate ions.

****

In solution in water, ions move around but they will form solids when the solid is insoluble in water.

Here are two solutions in two separate beakers:



In one beaker, there is a solution of barium chloride. Being soluble in water, the barium and chloride ions are free in the water. In the other beaker, sodium and sulphate ions are present in the water.

If the two solutions are mixed, the barium ions and the sulphate ions link together to form insoluble barium sulphate which, in a few minutes, settles to the bottom of the beaker as a precipitate, leaving the sodium and chloride ions free in the water above.

This gives us a very neat way to obtain barium sulphate, separated from the sodium chloride. All we have to do is to filter off the solid barium sulphate, wash it in clean water and we have obtained barium sulphate.

Here is another example. We wish to make copper (II) carbonate (which is insoluble) from copper (II) sulphate (which is soluble). We have to add a compound which contains carbonate ions but which is also soluble in water. Sodium carbonate is water soluble.

If we add sodium carbonate solution to copper sulphate solution, the copper ions form insoluble copper (II) carbonate with the carbonate ions. We can summarise the reaction:

$$\underset{\text{(soluble)}}{CuSO_4} + \underset{\text{(soluble)}}{Na_2CO_3} \longrightarrow \underset{\text{(insoluble)}}{CuCO_3} + \underset{\text{(soluble)}}{Na_2SO_4}$$

If we know the solubilities of compounds, we can work out simple ways to make compounds from each other.

Remember:	**In solutions containing ionic compounds, the ions are free.**
	If two ions form an insoluble compound, this allows us to separate this compound from the other ions in the solution.

Please Turn Over

Here is a summary of the solubilities of some compounds:

(1) Compounds contained column I metals (eg. sodium and potassium) are soluble in water;
(2) All nitrates are soluble in water;
(3) Most sulphates (except barium sulphate and lead sulphate) are soluble in water;
(4) Most chlorides (except silver chloride and lead chloride) are soluble in water;
(5) Most carbonates (except column I metal carbonates) are insoluble in water;
(6) Most oxides and hydroxides (except column I and II metals) are insoluble in water.

Now try the following:

(a) Given a solution of lead (II) nitrate [$PbNO_3$], how would you make lead (II) sulphate [$PbSO_4$] ?
(Write the equation for the reaction, showing which compounds are soluble and insoluble.)

....

(b) Given some crystals of calcium chloride, how would you obtain some crystals of calcium carbonate ?
***(Describe** what you would do clearly in words.)*

....

....

....

(c) Describe how would you convert nickel (II) sulphate into nickel (II) nitrate.

....

....

....

....

Your answers will be given in Part 2

Part 2 Inorganic Compound Interconversion

Here are the answers

(a) $PbNO_3$ (*soluble*) + Na_2SO_4 (*soluble*) $\longrightarrow$ $PbSO_4$ (*insoluble*) + $NaNO_3$ (*soluble*)

(b) Firstly, dissolve the calcium chloride crystals in some water. Add a solution of sodium carbonate. Calcium carbonate will form as tiny crystals. Filter off the calcium carbonate and wash the solid with some clean water. Leave to dry to obtain calcium carbonate crystals. [A useful trick is to heat the mixture before filtering. The heat energy allows the crystals to grow larger and it makes filtering quicker.]

(c) *In this case, both the nickel (II) sulphate and the nickel (II) nitrate are water soluble. Therefore, we must* ***remove*** *the sulphate ions as an insoluble sulphate (either lead sulphate or barium sulphate). Here we describe the method using barium sulphate.*

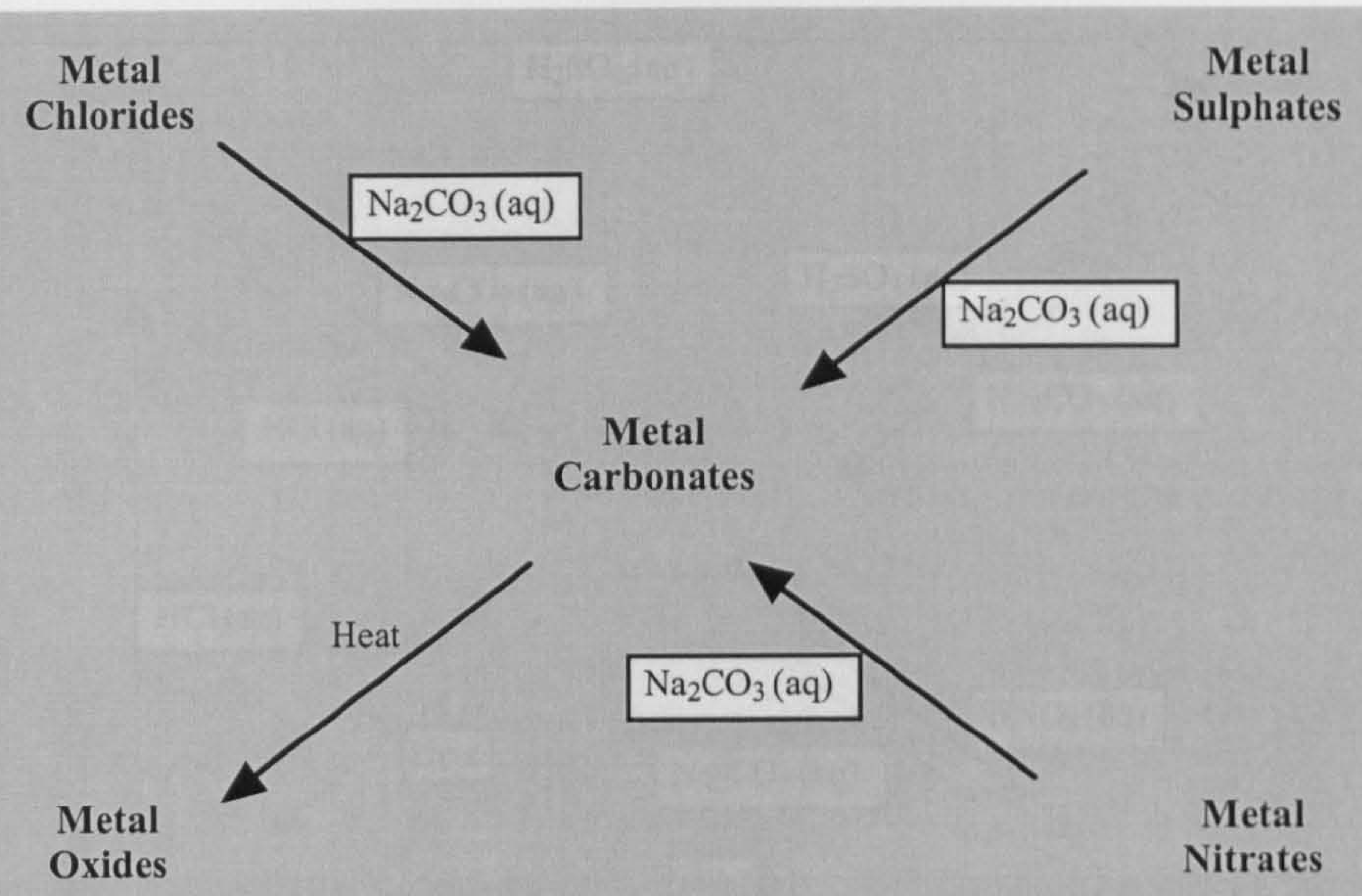
Dissolve the nickel (II) sulphate in water and add barium nitrate solution. Filter off the insoluble barium sulphate and collect the green solution of nickel (II) nitrate. Evaporate off half the water and then leave the solution to form green crystals of nickel (II) nitrate. [If we evaporate off all the water, the nickel (II) nitrate may decompose with the heat].

ion	% by mass in the sea
Chloride	1.935
Sodium	1.077
Magnesium	0.129
Sulphate	0.090
Calcium	0.041
Potassium	0.041
Bromide	0.007
Carbonate	0.003

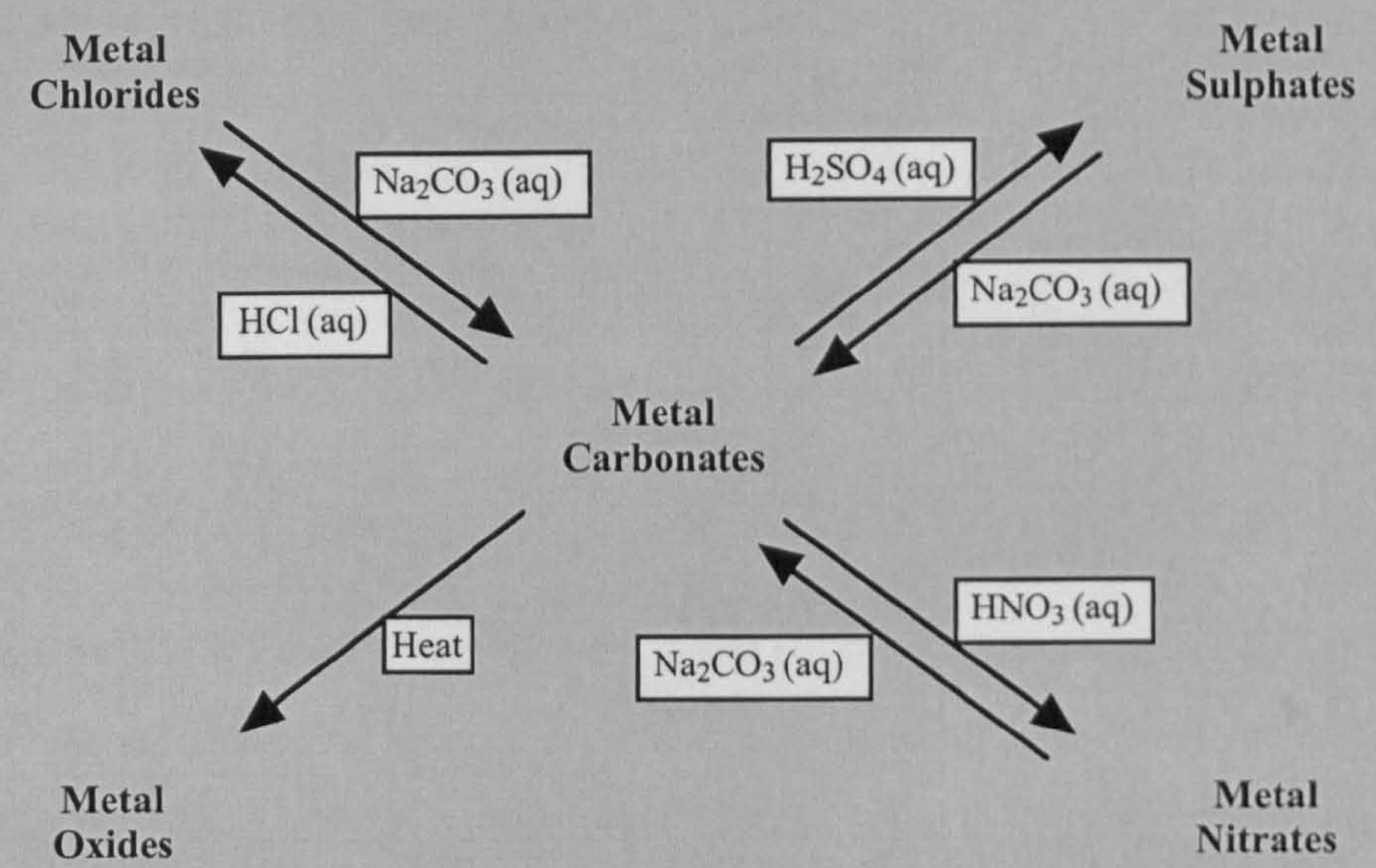
****

Making Inorganic Compounds

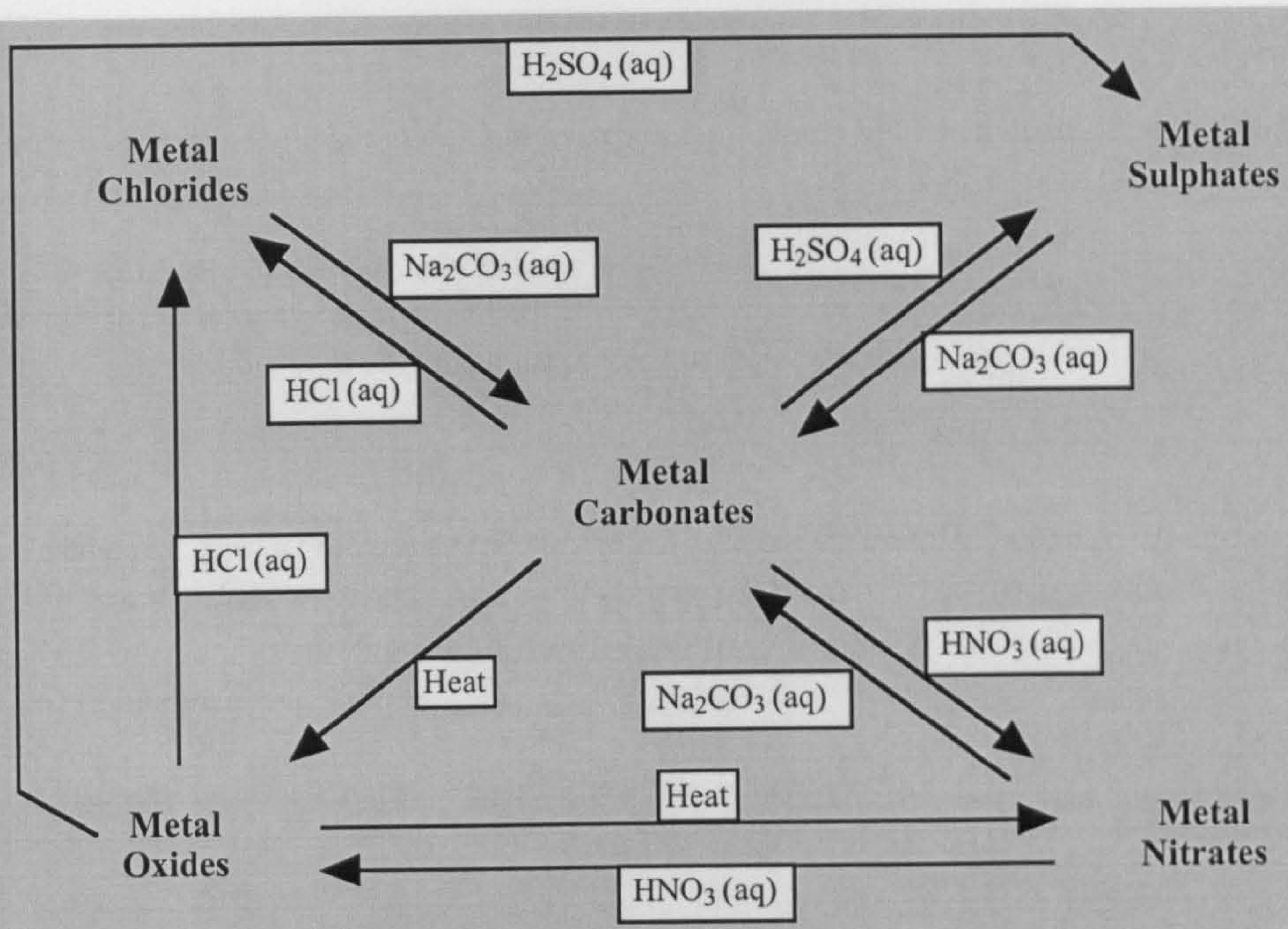
If we treat solutions of metal chlorides, nitrates or sulphates with sodium carbonate (a soluble carbonate), we obtain the insoluble metal carbonate which can be filtered off, washed and dried:



However, carbonates react with acids to forms salts, carbon dioxide and water. This gives us an easy way to make chlorides, nitrates and sulphates from metal carbonates. We can add this to our diagram:



Finally, you will remember that metal oxides react with acids to form salts and water. Also metal nitrates decompose with heat to give metal oxides. This allows us to complete the diagram.



H2SO4 (aq)
Metal Chlorides
Metal Sulphates
Na2CO3 (aq)
H2SO4 (aq)
HCl (aq)
Na2CO3 (aq)
Metal Carbonates
HCl (aq)
HNO3 (aq)
Heat
Na2CO3 (aq)
Heat
Metal Oxides
Metal Nitrates
HNO3 (aq)

Your Task

Imagine you are to write the instructions for an experiment which your school students will carry out in the laboratory. Your instructions must:

(a) Be in the correct order;
(b) Be simple and clear;
(c) Show your school students what to expect at each stage.

The experiment is:

Given some crystals of copper (II) sulphate, make some crystals of copper (II) carbonate and then convert these to give a solution of copper (II) nitrate. You are given beakers, a funnel, filter paper and a stirring rod, a Bunsen and tripod stand, some sodium carbonate solution and some nitric acid solution.

Write your instructions, as a series of steps, in the space below:

(a) ....

(b) ....

(c) ....

(d) ....

(e) ....

(f) ....

(g) ....

(h) ....

(i) ....

(j) ....

Your answer will be given in Part 3

Part 3 Applying the ideas

Here is the set of instructions for your school students.

(a) Dissolve some blue copper (II) sulphate crystals in a little water, stirring as necessary.
(b) Add sodium carbonate slowly to the copper sulphate solution until not more pale green copper (II) carbonate is seen to form.
(c) Heat the mixture very gently for a few minutes using the Bunsen, sitting the beaker on a tripod stand.
(d) Allow the mixture to cool for a few minutes and the pour carefully through the filter paper in the filter funnel.
(e) Wash the pale green solid with a little clean water.
(f) Scrape the green solid into another beaker.
(g) Add nitric acid very slowly until the green solid almost all dissolves.
(h) Filter the dark green solution to remove the last traces oil the pale green solid
(i) Heat the dark green solution and boil off half the water
(j) Leave the dark green solution for a few days until the water evaporates and you will obtain attractive needle like green crystals of $NiNO_3$

Magnesium from the Sea

Although magnesium occurs widely in rocks, it is easier to obtain magnesium compounds from the sea. The important compound we want is magnesium oxide. This has a wide range of uses including agriculture, glass manufacture, pigments, plastics and electrical insulation.

We have to find some compound of magnesium which will be sufficiently insoluble in water to be able to filter from the sea water as a solid. However, whatever we add to the sea water to form this compound must not also cause insoluble compounds of other metal ions to form.

Here are some data for solubilities at 25°C.

Magnesium Compound	Solubility (gl-1)	Calcium Compound	Solubility (gl-1)	Sodium Compound	Solubility (gl-1)	Potassium Compound	Solubility (gl-1)
$MgCO_3$	0.100	$CaCO_3$	0.015	Na_2CO_3	180	K_2CO_3	1120
$Mg(OH)_2$	0.009	$Ca(OH)_2$	1.56	NaOH	1090	KOH	1120
MgF_2	0.08	CaF_2	0.016	NaF	40	KF	950

(a) Work out which magnesium compound to form from the magnesium ions in the sea water. *remember, it must be insoluble and not likely to be contaminated by other insoluble compounds.*

Your choice: ....

(b) Work out what you might add to the sea water to obtain this magnesium compound.

Your choice: ....

(c) Having obtained this magnesium compound as a precipitate form the sea, how will you convert it into magnesium oxide:

Your reaction: ....

Your answer will be given in Part 3

Part 4 Final Thoughts

(a) $Mg(OH)_2$ It cannot be the fluoride because solid CaF_2 will also appear

It cannot be the carbonate because solid $CaCO_3$ will also appear.

(a) $Ca(OH)_2$ In fact, you could use NaOH or KOH but $Ca(OH)_2$ is less expensive

(c) $Mg(OH)_2$ decomposes with heat to give the oxide and water:

$$Mg(OH)_2 \longrightarrow MgO + H_2O$$

Some Interesting Extras

(a) Most rocks are silicates. Silicates, like carbonates, are highly insoluble in water and do not wash into the sea.

(b) Iodides, like chlorides and bromides are usually water soluble and wash into the sea. However, an analysis of sea water shows that there is almost no iodide ions in the sea. Certain types of sea weed have absorbed all the iodide ions and, in some countries, there is an industry to extract the iodine form the sea weed.

(c) All nitrates are water soluble and you would never expect to find nitrate rocks. However, in parts of Chile, it never rains and there are nitrate deposits. In the past, these were mined and explored as the basis of fertilisers.

(d) We have based everything in this paper lab on solubility. However, this is not quite correct. Strictly speaking, we have to talk about solubility product.

Consider an insoluble salt like magnesium hydroxide. Even insoluble compounds dissolve to some extent.

The solubility product for $MgOH)_2$ is: $k_{sp} = [Mg^{2+}] [(OH^-]^2 = 1.2 \times 10^{-11}$

We want to remove the maximum amount of the magnesium ions from sea water and this is achieved by adding an excess amount of hydroxide ions (as calcium hydroxide). Because the solubility product is a constant at a given temperature, increasing the concentration of hydroxide ions means that the concentration of magnesium ions in solution falls.

10.5 Presentation and Analysis of Data

The data collected through the use of the four paper labs in this study are presented below. The survey used is shown, with the responses (N = 75) in percentages. The evaluation sheet is shown in its original form in appendix H.

		SA	*A*	*N*	*D*	*SD*
(1)	The organisation of the paper labs was excellent.	35	60	4	0	0
(2)	The presentation of the material in these paper labs was clear	42	53	3	1	0
(3)	The paper labs were too long	0	15	31	46	5
(4)	I did not like the style of the paper labs	0	1	6	76	15
(5)	The knowledge required to use the paper labs was reasonable.	24	56	16	0	0
(6)	The paper labs involved too much practical detail.	9	36	23	25	5
(7)	I found the paper lab useful to prepare labs in future	41	41	8	10	0
(8)	The paper labs did not add to my understanding of chemistry.	1	5	11	48	32
(9)	The paper labs have altered my views of practical work.	11	63	20	4	1
(10)	I found paper labs to be little more than a cookbook.	4	11	35	36	11
(11)	Overall, I found useful information to help me as a teacher.	43	45	6	1	0
(12)	The style of the paper labs was different from my usual practical book.	33	49	5	3	0
(13)	I am even more confused about making simple inorganic compounds.	0	11	12	53	23
(14)	I never really understood corrosion and electrolysis until I completed the paper lab.	16	21	11	31	19
(15)	I understand about soaps and detergents much better now.	25	55	11	5	1
(16)	The paper lab on chalk gave me many ideas for my future school pupils.	28	48	17	6	1

(17) Please make any comments you wish about the paper labs.

The students comments were collated under the following headings:

		Total	Percentages
(1)	Style was interesting and new	18	24
(2)	Useful for teachers	14	19
(3)	Needs to be polished	12	16
(4)	No comments	12	16
(5)	Useful for students	10	13
(6)	Informative	11	15
(7)	Well organised	8	11
(8)	Thought provoking 7	9	
(9)	Improved my knowledge about labs	7	9
(10)	Will change the teaching	7	9

From the student responses, clearly they appreciate the paper labs and see their usefulness. The students have positive attitude towards these paper labs from all aspects. Of the specific topics covered by the paper labs, the responses suggest that, in three of them they have been particularly successful. However, there is some reservation of the students about the understanding of corrosion and electrolysis.

Their views about mechanical issues are positive: issues like organisation, presentation and length of the paper laboratories. The comments about the knowledge, which was presented in these paper labs and the understanding of these paper labs are both positive. Clearly the paper labs are regarded as useful and the style was certainly appeared to be new and interesting. It was not possible to interview students to gain further insights on the questionnaire results.

10.6 Conclusions

Time did not permit a long term study of the effectiveness of the paper labs on trainee teachers or, more importantly, on the quality of learning achieved by school pupils. That is an experiment for the future. However, this study has shown that they are workable in the context of the situation in Pakistan where laboratory work at school and first degree level is not too well established.

This group of trainee teachers found the paper labs helpful in future and the signs are that they do offer a kind of template for good practice which will benefit pupils of the future. It is to be hoped that scientific attitudes and skills can be developed in science trainee teachers by a purposeful preparation of teaching unit (paper lab) and by putting the students in activities, involving them in discussion and designing the experiments.

The effectiveness of the paper labs as a preparation for the actual laboratory experiences of the trainee teachers could not be assessed in the time. An important question is whether the paper labs will bring benefit to the pupils. However, with so little practical work currently in most schools, the paper labs offer a template illustrating how to run experimental work and what it can do. This may be particularly important with trainee teachers who themselves have no model from their own school days of how laboratories should operate.

In a distance learning system, it is important to use a wide variety of different types of media. Paper laboratories to be used in the distance learning system offer one more medium of instruction. Although the reactions of the trainee teachers was very positive, further adjustments may have to be made to the timing of such paper labs.

In the distance learning system that operates at Allama Iqbal Open University, assignments are used for two purposes: or internal assessment and to prepare the students for final examination, (external assessment). In the same way paper labs could be used as for the above two purposes.

Of course, paper laboratories are not the same was 'wet' laboratories. They cannot give the students the 'feel' for the use of equipment and chemicals. There are no smells, no colour changes, direct observations from real equipment or reactions. They cannot train students for the practical skills in using equipment and handling chemicals safely.

The paper labs seek to prepare students so that they can make more of their limited time in 'wet' laboratories. They seek to prepare students by linking experimental to theoretical ideas. They seek to provoke thought and encourage the kind of thinking in which the experimental is seen as the source of evidence from which conclusions can be drawn.

Chapter Eleven

Conclusions

At the outset, it was stated that the laboratory is a place where a learner may experiment, applying skills and knowledge in seeking to gain understanding. The university laboratory must be seen as a place where understanding of chemistry is enhanced.

This study has aimed at exploring underlying ideas which can offer guidance in developing laboratory work in a distance learning system. To that end, the project has looked at what is possible in traditional school and university laboratories in Scotland, in order to establish the important features which allow university laboratories to be effective in reaching their goals. The project then looked at the situation in Pakistan and described the development of paper labs as one way potentially to increase the effectiveness of laboratory teaching, based on evidence from expressed views of students.

11.1 Summary

The project looked at a university chemistry laboratory (Physical Chemistry) where pre-laboratory exercises had not been introduced. Pre-laboratory exercises were developed and the effects of these considered using short surveys.

Students in this laboratory were generally favourably disposed to their previous school experiences in the laboratory and found university laboratories to be well organised and the supporting written instructions to be clear.

Before and after the pre-laboratory exercises the result was that, majority of the students understood the manual, half of the students have the confidence to carry out the experimental work, practical work supported with quite adequate written instructions, quarter of the students were not in favour of working in their own but they were preferring to work in groups. On one side about half of the students view was that experiments encourage them to think about the Chemistry but on the other side one third has no confidence working in the laboratory. One third of the students have the idea that the purpose of the experiments was not clear to them.

However, the results of pre-laboratory exercises showed the deterioration. The introduction of the pre-laboratory exercises had not been great success, because this was considered to be extra work, more time consumable and too long to read. The demonstrators were not helpful and co-operative, so there arose a black market in correct answers, which ultimately detracted from the results of pre-laboratory exercises.

In many ways, the introduction of the pre-laboratory exercises did not seem to be improving student attitudes towards the laboratories. This suggests that merely adding on pre-laboratory exercises without making adjustments to the laboratory manual was not a useful way forward. This is consistent with the view that the laboratory experience must be seen holistically as an overall learning experience where the preparation, the actual laboratory and the follow-up must be planned as a meaningful whole. It also stresses the importance of all teaching staff being committed to change.

The surprising observation was the way the data from the interviews suggested a very different set of student perceptions. The students indicated that they saw the point of the pre-laboratory exercises and regarded them as effective and useful. This led to the rewriting of the laboratory manual, with the pre-laboratory exercises now integrated fully and post-laboratory exercises seen as a part of the learning experience. It was most unfortunate that this revised package could not be tested with students in the time available.

Another survey was designed to gather student perceptions of their school laboratory experiences before they had faced any university laboratories. This was useful in that it reflected student views in a system where laboratory work in schools is well established, and closely integrated with all other learning. This served as a model of the kind of school laboratory organisation towards which the less established systems in Pakistan might move. It also offered a set of standards which could inform teacher training programmes in laboratory work in the BEd and MEd programmes in Pakistan where school practical work is poorly developed.

At this stage, several surveys were carried out with Pakistan students. Care was taken not to compare the outcomes with those in Scotland in that the learning situations and cultural expectations are so very different. However, these surveys offered a useful view, showing where further development was needed. There were three surveys im Pakistan:

BSc first year chemistry students
BSc second year chemistry students
BEd students, completed their BSc in chemistry.

It was not always easy to see exactly what the Pakistan students were saying. Many appeared to have positive attitudes towards school and university laboratory work but some seemed to express aspiration rather than experience. It was also interesting to note how attitudes changed over the three groups (which reflected increasing experience in laboratories) and the growth of polarised views. The latter is a worrying problem, suggesting that laboratory experiences were increasingly negative for some students.

11.2 Overall Conclusions from Surveys

Looking at the overall pattern of outcomes from this survey of laboratory work at University level, the following conclusions are offered as ways by which laboratory learning might be made more effective.

(a) It is essential that **clear aims are agreed** for laboratory work and that these aims are communicated to the students. For example, some work might have the clear aim of illustrating what is being taught and making the chemistry real for the students. Other work might aim to show how specific techniques are used to gain information about chemical systems while some experiments might be employed to challenge student ideas and raise important chemical questions. The main point is that the students should know what the aims are and that the designers of the laboratory experiences should seek to ensure that the experiments are likely to achieve the specified aims.

(b) **Assessment must reflect aims.** This is not easy and the tendency is to measure what is easily measurable, usually by means of some kind of report. Thus, for example, if the aim is to illustrate the concepts being taught elsewhere, then the post-laboratory assessment must check if the concepts have been made more real, perhaps by exploring their application in parallel situations.

(c) **Keep practical practical.** The students seemed to wish for practical work which was genuinely practical and related to life. For example, from the interview results, the students view was that calculations in the laboratory work were difficult. If some theory and calculations are considered to be an essential part of the chemistry laboratory course for that year and they cannot be dealt with in the manual, then time should be allotted to students other than practical time to explain the theory and formulae. This would leave the practical course as such, perhaps for less time, but completely practical and might encourage the interest of the students.

(d) **Make the experiment relevant to students.** The content of the experiments should be examined and more topical items with more relevance to everyday life could be chosen, to encourage the students' interest. Frazer and Shotts (1987) have shown that 15 year old pupils in school were looking for more relevance in everyday life from the chemistry course on offer. Perhaps this relevance should be carried through to the university practical courses to stimulate the students more.

There is a danger here in that laboratories might become trivial and reflect student passing interests. This is not what is in mind. For example, in a traditional experiment in another laboratory, students drew the calibration curve for the absorption of a specific wavelength in order to develop a means to estimate the phosphate concentration in an 'unknown' solution, using the phospho-molybdate complex. This involved repeating a procedure about 5 times. In the modified experiment, four students obtained the calibration curve collaboratively (by doing two calibration experiments each, thus establishing the principle of reproducibility) and then each analysing a sample taken from the local river. The group then looked at their four results which were derived from various sampling points and, given a map, asked to offer an explanation of the pattern of results obtained in terms of the sources of phosphate pollution. In this way, a routine experiment was 'brought alive' in a simple way without any loss of rigour. This example (Johnstone and Vianna, 1999) perhaps reflects what the students were suggesting.

(e) Evidence shows that the value of **pre-laboratory experiences** in enabling students to make more sense of what is happening in the laboratory. Vianna (1994) showed that pre-laboratory work helped the students to understand the experiment and supports the contention that this kind of activity can enable students to construct links between their experiences. Al-Zaman (1998) also pointed out that the pre-laboratory has increased the frequency of positive attitudes towards the laboratory work and improved the performance of students in a Physics laboratory. However, it does seem that the pre-laboratory exercises must be integrated with the laboratory experiences and not be an 'add-on'. The importance of gaining wholehearted support from all staff and demonstrators is also important. How to avoid the 'black market' in pre-laboratory exercise 'answers' is not so easy.

(f) **Holistic experience.** Pre-laboratory tasks and post-laboratory exercises should be integrated with the manual. The use of pre-laboratory tasks may increase positive attitudes towards the laboratory work. Post-laboratory exercises almost certainly have an important function in consolidating what was learned in the laboratory and helping the students to link new learning to existing knowledge and understanding.

(g) The students show **positive attitudes** towards the school laboratory. Indeed, in Pakistan, there seem to be strong aspirations towards the development of school laboratory work. Laboratory work should be designed to help students and enrich their learning experiences at school level. To bring school up to the forefront of science education, the standards of teacher training need to be raised.

(h) From the results of the **surveys**, university laboratories are rated quite well too. However, there is a need to encourage the students to raise the level of learning at university level. Previous work has cast considerable doubt on the effectiveness of learning in the university laboratory (Johnstone and Wham, 1979). University laboratories, by their very nature, are overloaded with information. To increase learning, this information level must be reduced. This can be helped by the use of carefully constructed pre-laboratories experiences, fully integrated with laboratory manuals. The key feature at university level is to avoid the recipe following style of laboratory work in order to achieve more useful aims.

(i) **Teacher Training Programme.** While teacher training is not a major feature of the appointment of university staff, the development of good laboratory experiences may be largely dependant on inspiration and good luck. The situation at secondary school is, however, potentially different. To train the teacher for laboratory teaching, the aims described by Deborah (2003) are important: the teacher should possess knowledge about students and how they learn, and knowledge about teaching and teaching practices, how to guide the students in the laboratory. In general, the person after training should be able to handle the laboratory teaching and learning process. This is only possible if there is a good teacher training programme. This is particularly important in Pakistan where current school experiences are poor and new teachers have no model from their own school learning which they can apply when they start teaching. Encouragingly, the aspirations of the students in Pakistan are high. Hilosky *et. al.* (1998) pointed out that laboratory teacher should be trained to act more as facilitators by assisting students in solving their problems rather than simply giving answers.

(j) **The paper-labs** were tested in Pakistan on the sample of chemistry students, who were training to be teachers. Time did not allow the paper labs to be tested in terms of measuring gains in learning or their effect on school pupils. In addition, there is no evidence of the effectiveness and any relationship to the wet laboratories. The paper labs were designed to prepare the students (in teacher training) to be able to develop good laboratory experiences. It was encouraging to note the very positive attitudes of these students towards the paper labs.

11.3 Problems of Laboratories at University Level in General

The running of university laboratories do pose some problems.

(a) **Laboratory cost** is one of the problems facing developed and developing countries. Laboratory work is an expensive activity. Laboratories are costly to build and equip. The need for academic and technical staffing, instruments and consumables are a drain on resources. The Royal Society of Chemistry (1994), report concludes that "the restrictions on resources and the time allocated to practical work are causing a decline in the extent of practical work and the students achieved". To obtain maximum benefit from laboratory work and to ensure the standards of learning in the laboratory, adequate resources should be available for laboratory teaching.

(b) **The recipe driven nature of** laboratories has already been noted. It is important to re-think instructions so that students are encouraged to develop an appreciation of the process by which the understanding of chemistry progresses. With university laboratories and lecture courses not able to be synchronised easily, it is important to see pre-laboratory exercises as a vital component to enable students to enter the laboratory with the necessary understanding of underpinning ideas so that the experimental time can lead to meaningful learning.

(c) **Lack of clear agreed aims** is also a problem in the laboratory teaching and, in many laboratories, the aims are unclear or, perhaps, inappropriate. The need for clear specification of aims, the sharing of these and the assessment against these aims has been discussed.

11.4 Weaknesses of this Study

In the context of Allama Iqbal Open University, where secondary chemistry teachers are being trained, there is a real need to train teachers who are equipped to run school laboratories which are effective learning experiences. While all the signs are that the paper-labs were seen as useful, it was not possible to gain evidence about their effectiveness in developing teachers capable of running good laboratories.

Sadly, also, it was frustrating that it did not prove possible to test the re-written laboratory manual with its integrated pre and post lab exercises in the Glasgow setting to see if it improved student reaction.

It was not possible to test the relationship between the paper labs and wet laboratories in Pakistan. Thus, it would have been useful, had time permitted, to explore how students who had completed paper labs fared in their summer school 'wet' laboratories. The paper laboratories are not like the 'wet' laboratories. These laboratories are different from each other in many respects. In this study the effectiveness of the paper laboratory as a preparation for the actual laboratory could not be assessed.

The most fundamental problem in this kind of study is gaining access to students to make major changes in their laboratory experiences. It is not possible to make radical changes and test them out and it may even be ethically dubious. The idea of developing laboratory experiences which allow students to gain insights into the way chemistry, as a science, gains insights into chemical phenomena is highly attractive. However, as an outsider, it is almost impossible to attempt.

11.5 Future Study

Despite the limitations, some useful areas for further work have emerged, especially in the context of Pakistan. The plan would be to:

(1) Encourage learning by introducing the paper labs on a larger scale in the teacher training degrees in Pakistan and study the effectiveness on the learning of the students in the laboratory.

(2) Introduce the prelabs exercises in 'wet' laboratories in Pakistan and also to investigate the effectiveness on the learning of the students.

(3) Integrate pre and post laboratories with the laboratory manual and investigate about improvements in student perceptions.

(4) Investigate the relationship between paper labs and 'wet' labs: does the use of paper labs improve learning in the more traditional laboratory situations?

The future study planned on return to Allama Iqbal Open university does offer opportunities to make some radical changes and test to see the outcomes. This is an exciting prospect.

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Appendix A

Re-Cast Laboratory Manual

Experiment 1

pH Titrations

Aims

After completing the practical work and assignments before and after the laboratory, you should be able to:

(a) Use a pH meter with due care.
(b) Draw typical pH curves for a weak acid and strong acid, each reacting with a strong base.
(c) Link pH and pK relationships to experiments
(d) Use log relationships (with a calculator).

Introduction

You will probably have met titration experiments at school and may have used pipettes and burettes to find the molarity of acids and bases. You may have added acid from the burette to an alkali like sodium hydroxide in the flask and noted the *end-point* with the help of an indicator like bromothymol blue. The indicator changes colour when the pH corresponds to the complete formation of the salt.

It is also possible to follow the changes in the pH throughout acid-base titration using a pH meter. This is what you will be doing in this experiment. We can use a graph of pH against volume to find the point when the reaction of the base (e.g. sodium hydroxide solution) with the acid (e.g. hydrochloric acid) is complete. We can also try to understand the shape of the graph and use it in other ways.

pH and Hydrogen Ion Concentration

In aqueous solution the concentration of hydrogen ions can be very high (acids) or very low (alkalis). Thus, for example, in 0.1M HCl, the concentration of hydrogen ion is 0.1 (10^{-1}) moles per litre while, in 0.1M NaOH, the concentration of hydrogen ion is 10^{-13} moles per litre. To simplify numbers, a logarithmic scale is used. pH is defined by:

$$pH = -\log_{10}[H^+]$$

Hydrogen ion Concentration ([H+])	pH value	Example
10^{-13}	13	0.1M NaOH
10^{-7}	7	Pure water
2×10^{-3}	2.7	Dilute ethanoic (acetic) acid
5×10^{-5}	4.3	canned soft drink

In the experiment, you will follow the pH as the base is added to the acid and draw a graph of pH as a function of the volume of the base. This is know as a ***titration curve*** and it will be used to determine the equivalence point (the point when the base exactly neutralises the acid). The shape of the titration curve and also the pH value at the equivalence point, depend on the strengths of the acid and base.

Pre–Lab Exercise

You should complete this pre-laboratory exercise *before* coming to the laboratory. The purpose is to make it easier for you to complete the experimental work and understand what you are doing. To gain this benefit, complete the tasks ***on your own*** and write answers to questions in your laboratory notebook and show them to your demonstrator. You may wish to refer to the following sections in Ebbing: 4.2, 16.4, 16.6, 16.7.

(1) What volume of 1.00M sodium hydroxide solution is required to exactly neutralise 100ml of 0.05M ethanoic (acetic) acid solution?

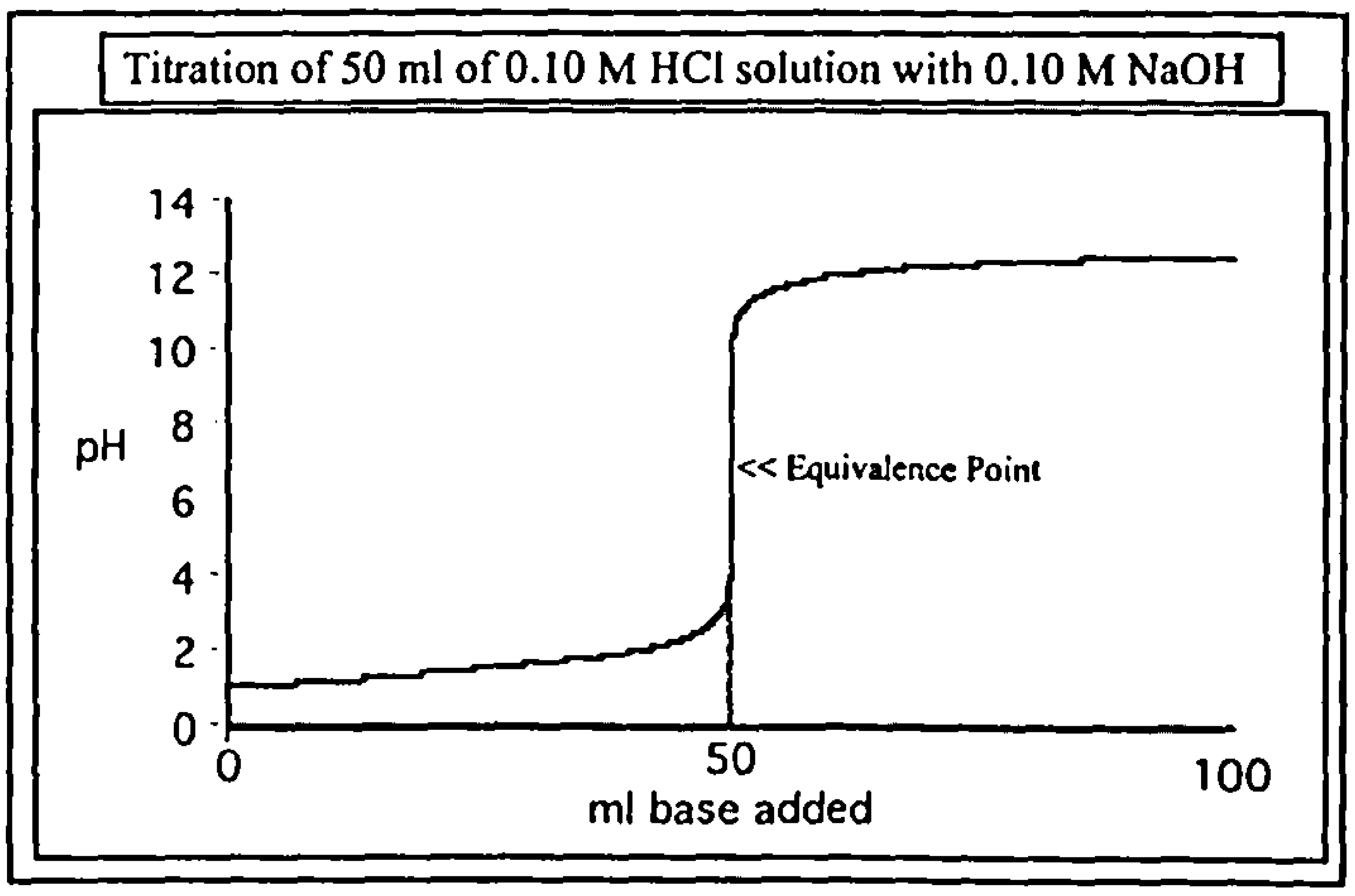
(2) The pH of blood is usually 7.4. What is the $[H^+]$?
If a blood sample is found to have a pH of 7.1, by how much has the $[H^+]$ changed ?

Strong and Weak Acids and Bases

When different acids at the ***same*** concentration are examined, they often give different pH values. For example, a 0.1 M solution of hydrochloric acid has a pH of 1 while a 0.1M solution of ethanoic (acetic) acid has a pH nearer 3. The different pH values mean that some acids produce H^+ ions more readily than others. Thus, hydrochloric acid dissociates into ions almost completely and is known as a strong acid (its ionisation is almost 100%) while the ethanoic acid is a weak acid with a much lower extent of ionisation (nearer 1%). Similarly, there are strong bases and weak bases. Sulphuric, nitric and hydrochloric are three strong acids while organic acids (like acetic) are weak. The hydroxides of metals in columns I and II of the periodic table are strong, most other bases are weak.

Titration Curve Strong acid – Strong base

When a solution of a strong acid is titrated with a solution of a strong base, the pH titration curve is of the shape shown below. It starts with a relatively low value of pH (for 0.1 M HCl, pH 1). As the base is progressively added the pH increases, slowly at first, but rapidly near the equivalence point. After that, it levels off gradually as more base is added.



When a weak acid is neutralised by a strong base, the titration curve is different. The pH at the beginning of the titration is not so low for a given acid concentration, and the equivalence point occurs at a pH value greater than 7. The differences arise because weak acids are not fully dissociated in solution and salts of weak acids and strong bases undergo hydrolysis in aqueous solutions.

Why do aqueous solutions of salts not all have a pH of 7 ?
The idea of salt hydrolysis

When a salt like sodium chloride is dissolved in water, it is completely ionised in solution. The sodium ions and chloride ions do not react with the hydroxide ions and hydrogen ions in the water and the number of hydrogen and hydroxide ions in the solution remains equal (at 10^{-7} moles per litre). Thus, the pH is 7.

When a salt like sodium ethanoate (acetate) dissolves in water, the sodium ions do not combine with hydroxide ions in the water (sodium hydroxide, being a strong base, is 100% ionised) but the ethanoate ions do combine with the hydrogen ions (this arises because ethanoic acid is a weak acid and is not fully ionised). As a result, the concentration of hydrogen ions in the solution falls and the pH rises above 7.

When a salt is dissolved in water and when ions react with the hydrogen or hydroxide ions in the water, the process is known as ***salt hydrolysis***. The pH of salt solutions will often not be 7. It dependson the salt.

Using the pH meter

There are two electrodes and a meter sensitive to small voltage differences. The meter has been calibrated beforehand and the position of the buffer control knob must not be altered. After each titration, the glass bulb should be *carefully* washed and, when not in use, the glass bulb must be immersed in distilled water. The glass bulb is ***very fragile*** and can be broken easily, even by touching the wall of the beaker. It is very expensive.

Do not attempt to use the pH meter until you have consulted a demonstrator.

Experiment A Titration of a solution of HCl with 1.00M NaOH

Before you start experiment, read the following instructions carefully.

(i) Rinse the burette carefully with 1.00 M NaOH and then fill with 1.00 M NaOH and adjust the liquid level to the zero mark.
(ii) Empty the titration beaker, rinse it with distilled water and pour into it about 50ml of distilled water.
(iii) Using a pipette, add 50ml of the approximately 0.1 M HCl.
(iv) Place the beaker on a magnetic stirrer and immerse the glass electrode (CARE).
(v) Stir well, switch off the stirrer, then measure the pH and record the result.
(vi) Start the titration by adding two 1ml portions of NaOH and then add 0.5 ml portions until about 1 ml before the expected equivalence point.
(vii) Then add 0.2 ml portions.
(iii) When the pH starts changing slowly again, revert to 0.5ml portions until about 8ml of NaOH in total has been used.
(ix) Finally, run in two 1ml portions.
(x) After each addition of the titrant (the sodium hydroxide), stir the solution and measure the pH.
(xi) Record the results in a table, showing the burette readings (ml NaOH) and the pH values observed.
(xii) Repeat the titration, if necessary, to obtain satisfactory results.

Experiment B Titration of a solution of CH_3COOH with 1.00M NaOH

Repeat the procedure used for experiment A, using 50 ml of distilled water and 50 ml of the approximately 0.1 M CH_3COOH in the beaker.

At the End

(1) Switch off the pH meter at the mains plug.
(2) Wash the titration beaker and the glass electrode (**CARE**), and leave the glass electrode immersed in distilled water or pH7 buffer.
(3) Clean the burette ***thoroughly*** with distilled water.

Post – Lab

Carry out the following assignments and record your answers in your lab notebook. Give your lab-book to your demonstrator for marking.

(1) For each titration, plot a graph in which the pH scale is the y-axis (ordinate) and the volume of sodium hydroxide added (ml) is the x-axis (abscissa). Use each graph and estimate the equivalence point (pH).

(2) From the equivalence points, deduce the volume of sodium hydroxide used to neutralise exactly the acid. From this, calculate the molarities of the acid solutions used in each experiment.

(3) Use the Henderson equation to predict the pH when
  (a) 20% of the ethanoic acid has been neutralised;
  (b) 80% of the ethanoic acid has been neutralised.
  Compare your predictions with your second graph.
  (c) Use the second graph to work out the pH of a 1:1 mixture of ethanoic acid and sodium ethanoate.

Henderson Equation

The equilibrium constant (K_a) for the ionisation of any weak acid (HA) is given by:

$$K_a = \frac{[H^+][A^-]}{[HA]}$$

Taking logarithms of both sides, this gives:

$$pH = pK_a + \log \frac{[A^-]}{[HA]}$$

This is known as the Henderson equation.

For ethanoic acid, the pKa is 4.74.

Experiment 2

Conductometric Titration

Aims

After completing the practical work and assignments before and after the laboratory, you should be able to:

(a) Use a conductance cell.
(b) Relate conductance values and changes to the ions present in solution during a reaction.
(c) Use conductance changes to determine end points for titrations.
(d) Understand how conductance measurements can assist in understanding what is happening in ionic solutions.

Introduction

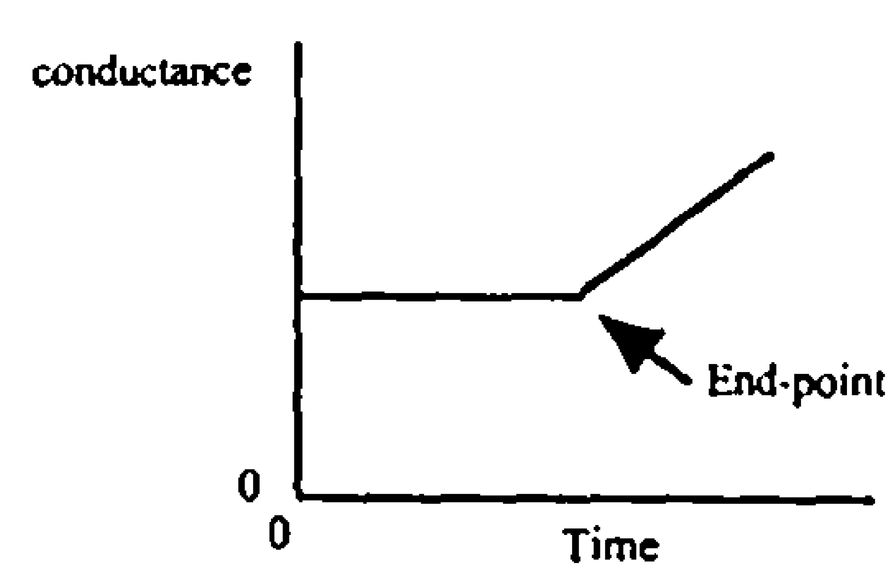
You will probably have met titration experiments at school and may have used pipettes and burettes to find the molarity of acids and bases. You may have added acid from the burette with an alkali like sodium hydroxide in the flask and checked the *end-point* with the help of an indicator like bromothymol blue. The indicator changes colour when the pH change corresponds to the complete formation of the salt.

It is also possible to investigate some reactions by following the conductance of the solution as the reaction proceeds. This is what you will be doing in this experiment. The conductance depends on the concentration of ions present and the speed (mobility) with which these ions can move. It is measured by applying an electric field cross a fixed distance of solution.

Consider a solution of sodium carbonate in water. The sodium ions and carbonate ions can conduct electricity. If hydrochloric acid is slowly added to the sodium carbonate solution, the following reaction takes place:

$$Na_2CO_3 \quad + \quad 2HCl \quad \longrightarrow \quad 2NaCl \quad + \quad CO_2 \quad + \quad H_2O$$

During the reaction, the carbonate ions are converted into carbon dioxide (which escapes as a gas) and chloride ions take their place. Each carbonate ion is replaced by two chloride ions and it so happens that this makes very little difference to the conductance. However, *when the reaction is completed*, adding further hydrochloric acid adds hydrogen and chloride ions and the conductance rises sharply.

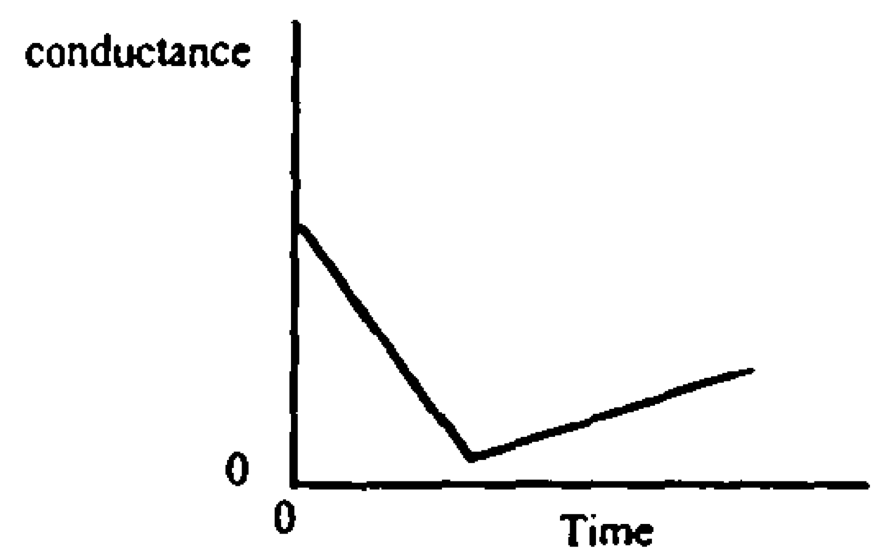


Pre–Lab Exercise

You should complete this pre-laboratory exercise *before* coming to the laboratory. The purpose is to make it easier for you to complete the experimental work and understand what you are doing. To gain this benefit, complete the tasks ***on your own*** and write answers to questions in your laboratory notebook and show them to your demonstrator. You may wish to refer to the following sections in Ebbing: *3.1*

(1) The conductance of some dilute sulphuric acid. is measured as dilute sodium hydroxide is added slowly. Draw the graph you would expect to obtain, explaining its shape.

(2) Some dilute barium hydroxide solution is added slowly to very dilute sulphuric acid and the graph below is obtained. What does the graph tell you about barium sulphate.



Units

The conductance of an electrolyte solution depends mainly on the concentration and mobility of the ions present. The mobility of ions is measured by the speed of their migration in a potential gradient of 1 volt cm^{-1}. Different ionic species show different mobilities in the same solvent. Hydrogen ions are the most mobile and are about twice as mobile as hydroxide ions. Other ions vary in mobility but tend to be about half as mobile as hydroxide ions.

You will have meet the ideas of current (in amps) and resistance (in ohms). With solutions, conductance is a measure of the ability of the solution to conduct electricity. Conductance is measured in ***siemens*** (S), where:

Siemens = 1 / Ohms

Experiment A **Titration of 0.0100 M solution of $AgNO_3$ with KCl solution**

Before you start experiment, read the following instructions carefully.
It is essential that distilled water is used throughout the experiment and that the apparatus is kept scrupulously clean.

(i) Rinse and fill the burette with the KCl solution (approximately 0.1M)
(ii) Wash the conductivity cell thoroughly (both the electrodes and beaker with distilled water.
(iii) Pipette into the beaker 50 ml of 0.100M $AgNO_3$ solution.
(iv) Insert the electrodes and add distilled water until the electrodes are *fully* immersed (essential).
(v) Turn on the magnetic stirrer to stir gently.
(vi) *Switch it off* and then take a reading of the conductance (K) of the solution.
(vii) Start the titration by adding 0.5 ml portions of KCl at a time, stir the mixture, and then measure K.
(viii) When you near the expected equivalence point (about 1 ml before it), decrease the portions to 0.2 ml. Keep adding them until until you are at 1 ml beyond the expected equivalence point. Stir after each addition and then measure K.
(ix) After that, continue adding 0.5 ml portions until about 5 ml beyond the expected equivalence point.
(x) Tabulate your results of KCl added (ml) and conductance (K).
(xi) Empty and wash the burette thoroughly.
(xii) Wash the conductivity cell. To remove any white deposit from the cell, rinse the electrodes and the beaker with dilute ammonia solution and then with distilled water.

Experiment B **Titration of 0.0100 M hydrochloric acid with NaOH solution**

(i) Rinse the burette and fill with the NaOH solution (approximately 0.1M).
(ii) Repeat the procedure outlined above but use approximately 0.1M NaOH in the burette and 50ml 0.0100M HCl in the beaker

At the End

(1) At the end of the each experiment empty, wash and rinse with distilled water, both the burette and the conductivity cell.
(2) Fill the cell with distilled water to immerse the electrodes. They must never be left for long periods, or overnight, in any solution, nor should any solution be allowed to dry out on them.

Post-Lab

(1) For each titration, plot a graph of conductance (K) against volume of the titrant added (ml) and estimate the equivalence point (ml). Do your results match your expectations ?
(2) Explain the slopes of the graphs before and after the equivalence points by considering relative ionic mobilities.
(3) Suggest any advantages and limitations of this method as compared with pH titration using chemical indicators.

Experiment 3

Solubility Product

Aims

After completing the practical and assignments before and after the laboratory, you should be able to:

(a) Calculate the solubility product given ion concentrations in a saturated solution.
(b) Use solubility product values to calculate the solubilities of ionic solids in water or in ionic solutions.
(c) Explain why solubilities of ionic solids might be affected by temperature and pH.

Introduction

Most of the substances which occur naturally are mixtures and have to be separated before we can use them. Chemical substances are often separated and purified by precipitation of solids from liquid solutions. Chloride ions, for example, can be removed virtually completely from water solutions by precipitation with silver ions as silver chloride. In this way they can be separated from other anions which form soluble silver salts, such as nitrate, sulphate or fluoride. Selective precipitation is an important technique both in chemical analysis and in numerous industrial processes.

The Idea of Solubility Product

Consider the following example.

When solid silver iodide, AgI, is in contact with water, the equilibrium is described by the equation:

$$AgI_{(s)} \rightleftharpoons Ag^+_{(aq)} + I^-_{(aq)}$$

It is found that the product of the concentrations of ions is always a constant at a given temperature:

$K_{sp} = [Ag^+ (aq)] [I^- (aq)]$ where K_{sp} is known as the solubility product

This is usually written as: $K_{sp} = [Ag^+] [I^-]$

At 25°C, $Ksp = 1 \times 10^{-16}$

Another example is when solid lead chloride, $PbCl_2$, is added to pure water, the equilibrium is described by the equation:

$$PbCl_2 \rightleftharpoons Pb^{2+}_{(aq)} + 2Cl^-_{(aq)}$$

The solubility constant is given by:

$$K_{sp} = [Pb^{2+}] [Cl^-]^2$$

In each case, the solubility 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.

Solubility Product and Solubility

Suppose we make saturated solutions of silver iodide in water at 25°C and we want to find out how many moles of AgI dissolved in 1 litre at equilibrium.

- Here: $[Ag^+] = [I^-] = x \text{ mol } l^{-1}$.
- Substituting into the expression for K_{sp} gives: $K_{sp} = [Ag^+][I^-] = x^2 = 1 \times 10^{-16}$
- Solving for x gives: $x = 1 \times 10^{-8} \text{ mol } l^{-1}$
- The solubility of silver iodide in water is, therefore: 1×10^{-8} moles per litre
- To convert the solubility in moles per litre to grams per litre, we multiply by the formula mass of the solid
- Thus: solubility of AgI in water at 25 °C $= [(1 \times 10^{-8}) \times 235]$ g per litre $= 2.35 \times 10^{-6} \text{ g } l^{-1}$ (2.35 micrograms per litre)

In the above discussion, we have looked at solubility in *water*. However, the solubility can change if another source of one of the ions is present. For example, suppose that silver iodide is added to water which already contains potassium iodide (0.05 moles per litre).

In the final solution, almost all the iodide ion in solution comes from the dissolved potassium iodide while the silver ion in solution comes from silver iodide which has dissolved. The value of K_{sp} at the same temperature does not alter.

Thus: $K_{sp} = 1 \times 10^{-16} = [Ag+][I^-] = [Ag+] \times (0.05)$

Giving: $[Ag+] = (1 \times 10^{-16}) \div 0.05 = 2 \times 10^{-14}$

The amount of silver iodide which has dissolved is, therefore: $[(2 \times 10^{-14}) \times 235] \text{ g } l^{-1} = 4.7 \times 10^{-12} \text{ g } l^{-1}$

The solubility is very much less than before because the $[I^-]$ is much greater than before.

Pre-Lab Exercise

You should complete this pre-laboratory exercise *before* coming to the laboratory. The purpose is to make it easier for you to complete the experimental work and understand what you are doing. To gain this benefit, complete the tasks ***on your own*** and write answers to questions in your laboratory notebook and show them to your demonstrator. You may wish to refer to the following sections in Ebbing: *12.2, 16.5, 17.1, 17.2.*

(1) The solubility product, K_{sp}, of silver chloride, AgCl, is 1.8×10^{-10} at 25°C. What is the solubility of silver chloride in moles per litre. [Relative atomic masses: Ag = 108 g mol^{-1}; Cl = 35.5 g mol^{-1}]

(2) What is the effect of changing the temperature on the value of the solubility product.

The Experiment

The aim is to find the value of the solubility product for potassium periodate (KIO_4) at around 25°C. The equilibrium is:

$$K^+(aq) + IO_4^-(aq) \rightleftharpoons KIO_4(s)$$

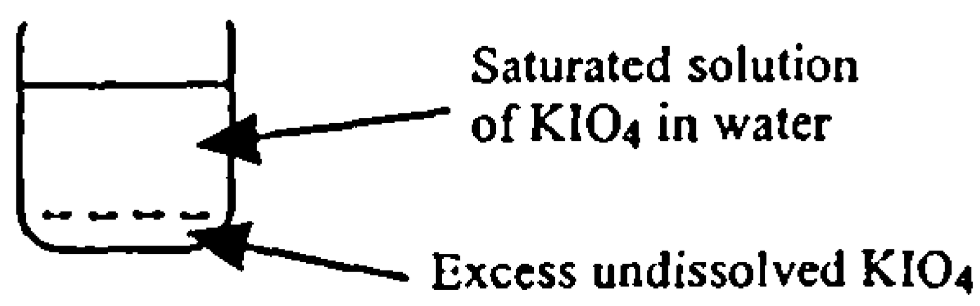
Two saturated aqueous solutions at 25°C of potassium periodate are prepared containing known concentrations of potassium ions. The concentration of periodate ion in each solution is found by allowing this ion to react with iodide ions in acid solution and then titrating the iodine released with standard sodium thiosulphate solution.

Instructions

Before you start experiment, read the following instructions carefully.

(i) Take 2 clean conical flasks and label them A and B. Put about 1g solid KIO_4 in each flask.
(ii) To flask A, add 100 ml distilled water using a measuring cylinder.
To flask B, add 100 ml 0.02 M KNO_3 solution using a measuring cylinder.
(ii) Place the flasks in the thermostat bath at about 25 °C and shake them frequently for at least 30 minutes. Record the temperature of the bath (T°C).
(iii) Remove flask A from the thermostat and filter the solution through a dry filter funnel into a conical flask.
(iv) Pipette a 25 ml portion of the solution into a clean conical flask and add 5ml 1 M H_2SO_4 and 1g solid KI.
(v) Titrate the iodine released with 0.10 M sodium thiosulphate, using the iodine as its own indicator.
(vi) Calculate the concentration of the periodate ion in the saturated solution.
(vii) Repeat the procedure from (iii) to (vi) for flask B

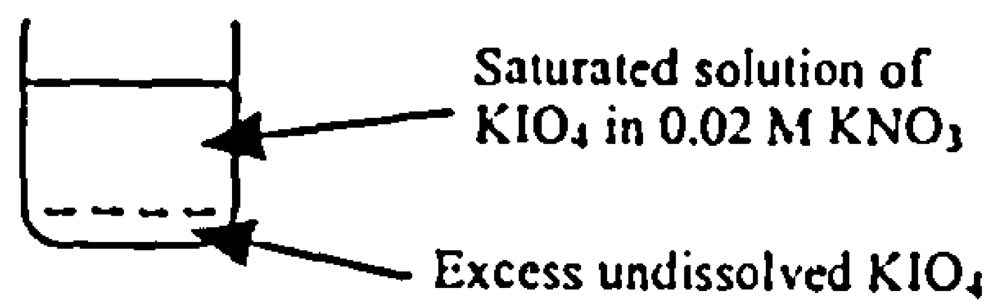
In flask A, we simply have potassium periodate in water. Thus the K_{sp} can be found by squaring the value of the periodate ion concentration found form the titration.



[$IO_4^-{}_{(aq)}$] found using I_2 release experiment.

$[K^+{}_{(aq)}] = [IO_4^-{}_{(aq)}]$

In flask B, the concentration of potassium ion is derived mainly from the potassium nitrate while the periodate comes from the titration value.



[$IO_4^-{}_{(aq)}$] found using I_2 release experiment.

$[K^+{}_{(aq)}]$ = 0.02 moles per litre

The Iodine Release Experiment

Periodate ions react with iodide ions according to the following equation:

$$IO_4^- + 7I^- + 8H^+ \longrightarrow 4I_2 + 4H_2O$$

The iodine released reacts with thiosulphate as follows:

$$I_2 + 2S_2O_3^{2-} \longrightarrow S_4O_6^{2-} + 2I^-$$

Thus, each mole of IO_4^- will produce enough iodine to require 8 moles of thiosulphate for reaction:

[volume of $S_2O_3^{2-}$ used] x [molarity of $S_2O_3^{2-}$] = 8 x [volume of IO_4^- in solution] x [molarity of IO_4^-]

At the end

(1) Wash and rinse all the apparatus with distilled water.

Post- Lab

Carry out the following assignments and record your answers in your lab notebook. Give your lab-book to your demonstrator for marking.

(1) Calculate the solubility product of potassium periodate at 25°C for each experiment. Comment on the agreement of your results.

(2) Calculate the solubility in g l^{-1} of KIO_4 in pure water.

(3) Fe^{3+} can be a contaminant in water.
  (a) Write the form of K_{sp} for $Fe(OH)_3$.
  (b) If a water sample (sample A) has ***twice*** the [H+] compared to a second sample (sample B), how many times more Fe^{3+} will be able to dissolve in the first sample compared to the second one.?

Experiment 4

Heat of Reaction

Aims

After completing the practical work and the assignments before and after the laboratory, you should be able to:

(a) Understand the meaning of ΔH and its significance.
(b) Understand a procedure for measuring ΔH.
(d) Interpret values, particularly for acid-base neutralisations

Introduction

When hydrochloric acid reacts with sodium hydroxide, the reaction is exothermic. Chemical energy is given out by the reactants in forming the products.

$$HCl\ (aq) \quad + \quad NaOH\ (aq) \longrightarrow NaCl\ (aq) \quad + \quad H_2O\ (l)$$

The energy is given out as heat and the temperature of the mixture rises. After a while, the temperature of the products falls to room temperature as the heat from the reaction is lost to the surroundings. The surroundings have gained energy but the reaction mixture has lost energy. Since the total energy of the products is less than that of the reactants, we say that the heat change for the reaction is negative. The Greek letter Δ (delta) is often used to mean 'change of'. So, the heat change of a reaction is given the symbol ΔH. The heat of reaction (the enthalpy of the reaction) is of great importance in many industrial processes which rely on heat of reaction as a source of energy (for example, in generation of electrical power from the combustion of coal or other hydrocarbon fuels).

As a chemical reaction proceeds, energy is either taken up or lost by the reaction system. In most reactions, this energy is in the form of heat. Occasionally other forms of energy (sound or light energy) may be involved but we are only concerned with heat here. Reactions are described as exothermic (when heat energy is given out: ΔH is negative) or endothermic (when heat energy is absorbed: ΔH is positive).

Calorimetry

Calorimetry is the measurement of heats of reaction. For a reaction in a well insulated glass flask , the heat energy released will go to heat up the reaction mixture and the glass. We can find by experiment the specific heat of the reaction mixture and the glass. The specific heat of a substance is defined as the amount of heat energy required to raise the temperature of 1 g of the substance by 1°C. For pure water the specific heat is $4.184\ J\ g^{-1}\ {}^{\circ}C^{-1}$.

In this experiment, the reaction will take place in a Dewar flask (like a thermos flask). Just mixing or diluting reagents can cause heat energy changes but we do not need to worry about this in this experiment as it is only a problem for fairly concentrated solutions. There are other sources of error. No calorimeter can be completely insulated, and consequently heat begins to leak away as soon as it is generated by the reaction. However, we d not need to worry that the insulation is not perfect. We can estimate the temperature rise by taking temperature readings as the mixture slowly cools.

Acid – base Reactions

When an acid neutralises a base, the essential reaction is:

$$H^{+}_{(aq)} \quad + \quad OH^{-}_{(aq)} \quad \longrightarrow \quad H_2O_{(aq)}$$

This reaction involves a release of heat energy. If a mole of hydrogen ions reacts with a mole of hydroxide ions, the energy released is about 57kJ.

However, if the acid or the base is weak (not 100% ionised), then the ionisation of the acid or base may involve a heat energy change and the neutralisation will release a different amount of heat energy.

Precautions

(1) The reagents to be used are potentially dangerous and must be treated with respect.
(2) Never add water to a concentrated acid !

Pre–lab

You should complete this pre-laboratory exercise *before* coming to the laboratory. The purpose is to make it easier for you to complete the experimental work and understand what you are doing. To gain this benefit, complete the tasks ***on your own*** and write answers to questions in your laboratory notebook and show them to your demonstrator. You may wish to refer to the following sections in Ebbing *6.2, 6.3, 15.1.*

(1) Calculate the temperature rise if 1200J of heat energy is added to 100 ml of water

(2) If 100ml of 1M HCl is mixed quickly with 100ml of 1M NaOH, a temperature rise of 6.2°C is observed. Predict the temperature rise if, under the same conditions, 10ml of 1M HCl is mixed quickly with 10ml of 1M NaOH

Experiment A Neutralisation of NaOH with HCl

Before you start experiment, read the following instructions carefully.

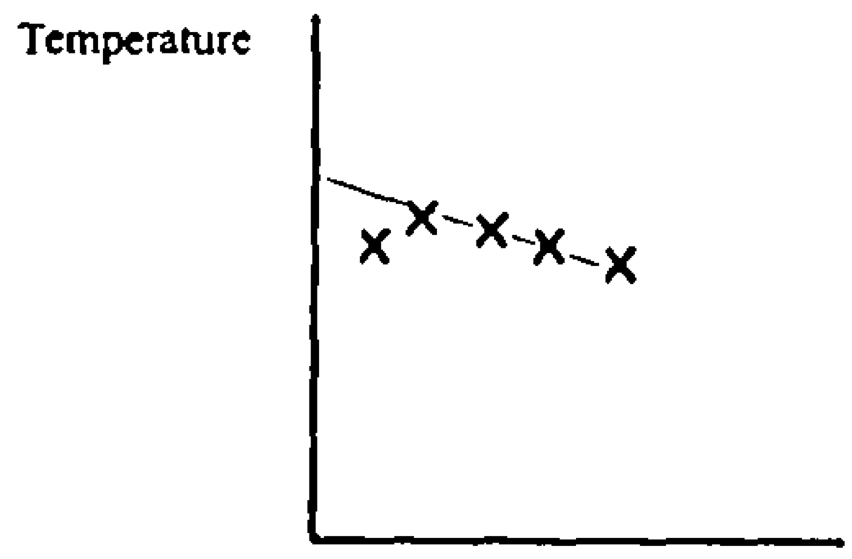
(i) Rinse the two Dewar flasks thoroughly with cold tap water and place them upright on the magnetic stirrers, utilising the cork rings.
(ii) Place the magnetic stirrer bar in each flask. There is a separate thermometer for each flask.
(iii) Select one of the flasks to be the reaction vessel, and use it for this purpose in both experiments.
(iv) Pipette 50 ml of 1 M NaOH solution into the reaction flask, and set the stirrer in motion.
(v) Pipette 50 ml of 1.1 M HCl solution into the other flask, and stir as for the first solution.
(vi) If you find that the two solutions have temperatures differing by more than 0.4 °C, consult a demonstrator as to how you may equalise them.
(vi) When the two solutions have been stirred for about 5 minutes, read the temperature of both solutions to the nearest 0.05 °C, and record them. The average is the starting temperature (T_1).
(vii) Remove the stirrer from the flask containing the HCl solution using a spatula.
(viii) Pour this solution quickly into the NaOH solution.
(ix) Start a stop-clock, and read the temperature of the stirred mixture every minute for five minutes. Record your data.

Experiment B **Neutralisation of NaOH with $NaHSO_4$**

Repeat the procedure outlined in experiment A, using 50 ml of 1.1 M $NaHSO_4$ solution instead of hydrochloric acid. Calculate the heat of neutralisation of 1 mole of NaOH with $NaHSO_4$.

To Calculate ΔH for the Reaction

The temperature of the mixture will rise rapidly, as the reaction takes place, but it will then immediately begin to fall because of the imperfect insulation of the calorimeter. We may assume that cooling of the system is linear with time. To obtain the temperature of the solution immediately after neutralisation, plot the measured temperatures of the mixture versus time, draw the best straight line through the points, and extrapolate it back to zero time.



The starting temperature rise is the average of the temperature of two solutions. The temperature rise (ΔT) produced by the neutralisation can be found by subtracting the starting temperature from the final temperature.

The heat evolved during the neutralisation reaction is equal to the sum of heat gained by the calorimeter and heat gained by the reaction mixture solution.

The thermal capacity of the Dewar flasks has been determined as 40 J $^{\circ}C^{-1}$.

Heat absorbed by flask = $40 \times \Delta T$

The specific heat of the reaction mixture in this case is 4.025 J ml^{-1} $^{\circ}C^{-1}$.

Heat absorbed by solution = $100 \times 4.025 \times \Delta T$

The total heat energy produced can be found by adding together the heat absorbed by the flask and the heat absorbed by the solution.

Finally, the heat of neutralisation of 1 mole of NaOH by multiplying by 20 (50 ml of 1M NaOH contains 1/20 of a mole).

The calculation of the ΔH for the neutralisation of NaOH with $NaHSO_4$ follows the same method as for experiment A. The specific heat of the reaction mixture is 3.895 J ml^{-1} $^{\circ}C^{-1}$ in this case.

Post -lab

Carry out the following assignments and record your answers in your lab notebook. Give your lab-book to your demonstrator for marking.

(1) Calculate the ΔH for the neutralisation of
 (a) Sodium hydroxide by hydrochloric acid;
 (b) Sodium hydroxide by sodium hydrogen sulphate

(2) Look at your measured heats of neutralisation of HCl and $NaHSO_4$ (in kJ/mol NaOH).
 (a) Deduce whether HSO_4^- a strong or weak acid in water.
 (b) Discuss whether the dissociation reaction

$HSO_4^-{}_{(aq)} \longrightarrow H^+{}_{(aq)} + SO_4^{2-}{}_{(aq)}$ is endothermic or exothermic.

Experiment 5

Activation Energy

Aims

After completing the practical work and assignments before and after the laboratory, you should be able to:

(a) Appreciate how one type of energy changes to another type.
(b) Know the effect of temperature on reaction rate.
(c) Know the quantitative relationship between the rate constant (k) and activation energy (E_a).
(d) Determine the activation energy of a reaction.

Introduction

In a reaction mixture, molecules of the reactants are colliding with each other. Since they move with different speeds, they possess different kinetic energies. The minimum kinetic energy that must be possessed by the colliding molecules, if a collision is to be effective in producing a chemical change, is known as the activation energy. Hence, only the molecules with kinetic energies higher than the activation energy are able to react.

It has long been known that, in nearly every instance, a rise in temperature increases the rate of a reaction. This is because in a system the fraction of molecules with sufficient kinetic energy to react increases with temperature.

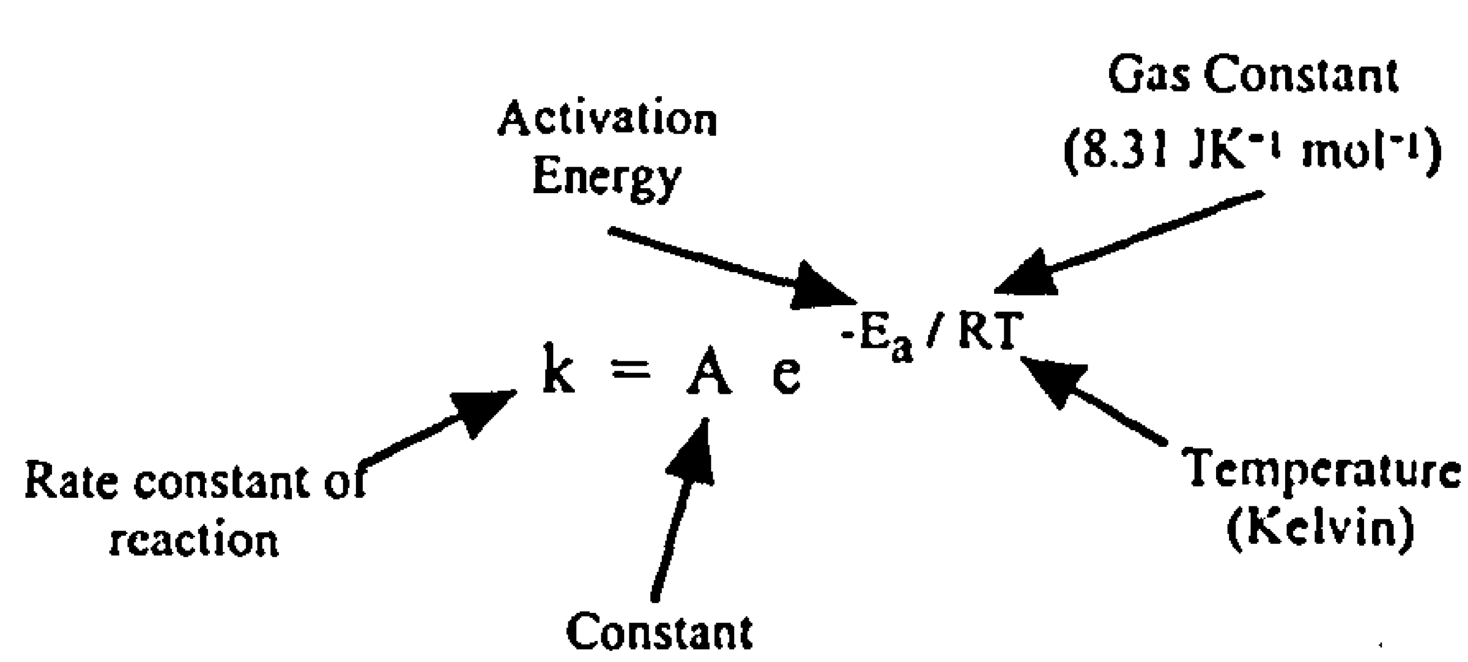
The rates of chemical reactions depend on the nature of the reactants and the concentrations of reactants. For a reaction:

$$A + B \longrightarrow \text{Products}$$

the rate of reaction will often be expressed by: rate = k [A] [B]

k is a proportionality 'constant' (called the *rate constant*) which depends on the reaction we are looking at and also on the temperature.

Arrhenius was the first chemist to suggest that there was a minimum energy required for reaction and that only a fraction of the molecules would possess this minimum. He suggested the quantitative relationship between the rate constant of reaction, k, the activation energy, E_a, and the absolute temperature, T:



$$k = A e^{-E_a / RT}$$

The symbol 'e' is the base of natural logarithm and has a value of 2.718.

Pre–lab

You should complete this pre-laboratory exercise *before* coming to the laboratory. The purpose is to make it easier for you to complete the experimental work and understand what you are doing. To gain this benefit, complete the tasks ***on your own*** and write answers to questions in your laboratory notebook and show them to your demonstrator. You may wish to refer to the following sections in Ebbing *5.2, 13.4, 13.5.*

(1) Given that the units of R are J mol^{-1} K^{-1} and that logarithms have no units, what will be the units of E_a?

(2) Write down the Arrhenius Equation and very briefly describe the significance of each term as well as those variables which influence the magnitude of the frequency factor.

Remember: Activation energy, E_a, is the minimum energy required for two molecules to react on collision. The value of E_a depends on the particular reaction.

Determination of activation energy is important, for it provides information about energy changes that occur during effective collisions. Furthermore, if E_a and k at a particular temperature are known for a given reaction, then the value of k at other temperatures can be calculated.

Background to the Experiment

We can write the Arrhenius equation at two different temperatures:

At temperature T_1 $$k_1 = A\ e^{-E_a / RT_1}$$

At temperature T_2 $$k_2 = A\ e^{-E_a / RT_2}$$

The problem is that reaction rates are constantly changing (the reaction slows down as the reagents get used up). One way to determine the activation energy of a reaction is to measure its rate constant at two (or preferably more) different temperatures. In this experiment, we will use a variation of this method. Suppose we carry out a given reaction at different temperatures, but each time start with the ***same reactant concentration*** and let the reaction proceed to the ***same extent***. It is possible to show that the product of the reaction rate with time is a constant:

$$kt = \text{constant}$$

You can see how this works by looking at the box overleaf

Why kt is constant

Consider a reaction in which the concentration of reactant, A, is decreasing with time, t.
The rate of the reaction can then be expressed as:

$$\text{Rate} = -d[A]/dt$$

Now the way in which the reaction rate varies with reactant concentration depends on the order of the reaction. If the concentration of A is initially $[A]_o$ and after some time, t, it reduces to $[A]_t$, the following relationships apply for the orders shown:

Zero order reaction	Rate = k	$kt = [A]_o - [A]_t$
First order reaction	Rate = k [A]	$kt = \ln[A]_o - \ln[A]_t$
Second order reaction	Rate = k $[A]^2$	$kt = 1/[A]_t - 1/[A]_o$

Whatever the order of a reaction, the product kt depends only on $[A]_o$ and $[A]_t$ and is a constant if $[A]_o$ and $[A]_t$ are given fixed values.

Thus, changes in the time (t) with temperature (T) will be useful as a way of finding E_a

Let us follow through the mathematics.

Let: $kt = B$

So: $k = B/t$

Substitution of k by B/t in the Arrhenius equation, ($k = A\ e^{-Ea/RT}$):

$$B/t = A\ e^{-Ea/RT}$$

Rearranging this gives:

$$t = C\,e^{E_a/RT}$$ where C = B / A. Remember B and A are both constants so C is a constant.

Taking natural logarithms, we obtain:

$$\ln t = \ln C + E_a/RT$$

This can written as: $\ln t = E_a/R \times (1/T) + \ln C$ (similar to: $y = mx + c$)

A plot of ln t against 1 / T gives a straight line with a gradient equal to Ea / R. The activation energy of the reaction , E_a, can therefore be determined from the gradient of this line since we know the value of R.

Reminder: A logarithm to the base ten is the power to which ten has to be raised to give the number.

Thus: $\log_{10}(17.4) = 1.24$ because: $10^{1.24} = 17.4$

Logarithms can be express to any base. A useful, if unexpected, base is e which has a value of 2.718. Logarithms to the base e are known as natural logarithms and are expressed as: ln.

Thus: $\ln(17.4) = 2.86$ because: $e^{2.86} = 17.4$

A useful connection between natural logarithms and logarithms to the base 10 is:

$$\mathbf{(2.303)\log_{10}(x) = \ln(x)}$$

The Experiment

The task is to determine the activation energy of the rather slow reaction between persulphate, $S_2O_8^{2-}$, and iodide, I^-, by observing the effect of temperature on the rate of the reaction.

$$S_2O_8^{2-} + 2I^- \longrightarrow 2SO_4^{2-} + I_2 \qquad \text{(Reaction 1)}$$

This will be carried out at different temperatures in the presence of starch as an indicator.

Before mixing the reactants, a little starch and given amount of thiosulphate, $S_2O_3^{2-}$, will be added to the I^- solution and thus any iodine, I_2, produced by reaction 1 will be *instantly* converted back to iodide:

$$I_2 + 2S_2O_3^{2-} \longrightarrow 2I^- + S_4O_6^{2-} \qquad \text{(Reaction 2)}$$

This will continue until all the thiosulphate has been oxidised. As soon as that happens the reaction mixture will turn deep blue, due to the formation of a complex of iodine and starch.

The starting reactant concentrations and the extent of the reaction must be kept constant. To achieve this, solutions with the *same* initial iodide, persulphate and thiosulphate concentrations will be prepared, together with starch indicator, for each experiment. The time it takes from the moment of mixing to the appearance of the blue iodine-starch complex colour, t, will be measured at each temperature.

The reaction will be carried out at 10, 15, 20, 25, 30 and 35°C .

Experimental Procedure

Before you start the experiment, read the following instructions carefully.

(i) Pipette into a boiling tube (A) 20 ml of 0.01 M $K_2S_2O_8$ and ten drops of starch solution. Pipette into another boiling tube (B) 20 ml of 0.5 M KI and 10 ml of 0.01 M $Na_2S_2O_3$ solution. Label the tubes.

(ii) Immerse the boiling tubes in a constant temperature bath. When both solutions have attained the bath temperature, pour the contents of tube A into the tube B, start the clock immediately, and mix the reaction mixture by stirring carefully with the thermometer. Monitor the temperature of the reaction mixture frequently, and take the average value as the temperature of the experiment (T°C).

Measure the time it takes for the blue colour to appear (t seconds).

(iii) Repeat the above procedure at each of the remaining five temperatures.

(iv) Draw up a table in the following way:

T(°C)	T(K)	1/T(K^{-1})	t(s)	ln t
10				
15				
20				
25				
30				
35				

Post-lab

Carry out the following assignments and record your answers in your lab notebook. Give your lab-book to your demonstrator for marking.

(1) Plot ln t against 1/T and determine the activation energy (in kJ mol^{-1}) for the reaction:

$$S_2O_8^{2-} \quad + \quad 2I^- \quad \longrightarrow \quad 2SO_4^{2-} \quad + \quad I_2$$

(2) The rate constant for decomposition of acetaldehyde (ethanal), CH_3CHO, when heated is: 0.105 mol l^{-1} s^{-1} at 759K and 2.14 mol l^{-1} s^{-1} at 836K.

(a) What is the activation energy for this decomposition?

(b) What is the rate constant at 865K?

(3) What can you say about the activation energy for the the reaction between thiosulphate and iodine compared to the reaction of persulphate with iodide ions ?

Appendix B

Questionnaires

To help with the planning of laboratories in the future, please complete the following questionnaire

Tick one box: ☐ 1st year student ☐ 2nd year student ☐ Trainee teacher

(1) What are your opinions about your school laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	☐	☐	☐	☐	☐	☐	Useless
Not helpful	☐	☐	☐	☐	☐	☐	Helpful
Understandable	☐	☐	☐	☐	☐	☐	Not understandable
Satisfying	☐	☐	☐	☐	☐	☐	Not satisfying
Boring	☐	☐	☐	☐	☐	☐	Interesting
Well organised	☐	☐	☐	☐	☐	☐	Not well organised
The best part of chemistry	☐	☐	☐	☐	☐	☐	The worst part of chemistry
Not enjoyable	☐	☐	☐	☐	☐	☐	Enjoyable

(2) In your school chemistry laboratory, which do you prefer ? (*Tick ONE box*)

Working individually ☐ Working in small groups ☐ Watching a demonstration ☐

(3) In your college chemistry laboratories, which do you prefer ? (*Tick ONE box*)

Working individually ☐ Working in small groups ☐ Watching a demonstration ☐

(4) Think about your past experiences in chemistry laboratory work.
Tick the box which best reflects your opinion.

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
(a) I believe that the laboratory is a vital part in learning chemistry....................................	☐	☐	☐	☐	☐
(b) I prefer to have written instructions for experiments..	☐	☐	☐	☐	☐
(c) All the chemicals and equipment that I needed were easily located.............................	☐	☐	☐	☐	☐
(d) I was unsure about what was expected of me in writing up my experiment....................	☐	☐	☐	☐	☐
(e) Laboratory work helps my understanding of chemistry topics....................................	☐	☐	☐	☐	☐
(f) Discussions in the laboratory enhance my understanding..	☐	☐	☐	☐	☐
(g) I only understood the experiment when I started to write about it afterwards................	☐	☐	☐	☐	☐
(h) I had few opportunities to plan my experiments..	☐	☐	☐	☐	☐
(i) I felt confident in carrying out the experiments in chemistry.......................................	☐	☐	☐	☐	☐
(j) I found writing up about experiments pointless..	☐	☐	☐	☐	☐
(k) The experimental procedure was clearly explained in the instructions given..................	☐	☐	☐	☐	☐
(l) I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing..	☐	☐	☐	☐	☐
(m) I feel that examinations should take account of laboratory experiments I have completed...	☐	☐	☐	☐	☐

(5) Here are several reasons why laboratory work is part of most chemistry courses.
Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

Experimental work makes chemistry more enjoyable for me ☐
Experiments illustrate theory for me ☐
Laboratory work allows me to test out ideas ☐
Experiments allow me to find out about how materials behave ☐
Experiments teach me chemistry ☐
Experimental skills can be gained in the laboratory ☐
Experiments assist me to plan and organise ☐
Experimental work allows me to think about chemistry ☐

Thank you for your help - Centre for Science Education, University of Glasgow, SCOTLAND

Questionnaire for Students Used After Physical Chemistry Laboratry

where there were no pre-lab exercises

To help with the planning of your laboratories in the future, please complete the following questionnaire.

(1) What are your opinions about your *school* laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	☐	☐	☐	☐	☐	☐	Useless
Helpful	☐	☐	☐	☐	☐	☐	Not helpful
Meaningful	☐	☐	☐	☐	☐	☐	Meaningless
Understandable	☐	☐	☐	☐	☐	☐	Not understandable
Satisfying	☐	☐	☐	☐	☐	☐	Not satisfying
Interesting	☐	☐	☐	☐	☐	☐	Not interesting
Well organised	☐	☐	☐	☐	☐	☐	Not well organised

(2) In your *school chemistry laboratory* which did you prefer ? (*Tick ONE box*)

Working individually ☐ Working in pairs or small groups ☐ Watching a class demonstration ☐

(3) In your *university chemistry laboratories* which do you prefer ? (*Tick ONE box*)

Working individually ☐ Working in pairs or small groups ☐ Watching a lecture demonstration ☐

(4) What are your opinions about your *overall university chemistry laboratory experiences* (inorganic, physical and organic) ?
Tick ONE box on each line.

Helpful	☐	☐	☐	☐	☐	☐	Not helpful
Useless	☐	☐	☐	☐	☐	☐	Useful
Meaningless	☐	☐	☐	☐	☐	☐	Meaningful
Understandable	☐	☐	☐	☐	☐	☐	Not understandable
Satisfying	☐	☐	☐	☐	☐	☐	Not satisfying
Interesting	☐	☐	☐	☐	☐	☐	Not interesting
Well organised	☐	☐	☐	☐	☐	☐	Not well organised

(5) Think about your *laboratory in Physical Chemistry* (which you have recently completed).

What are your opinions about the following statements?
Tick ONE box on each line.

	Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
(a) I find writing lab reports largely a waste of time	☐	☐	☐	☐	☐
(b) The experimental procedure was clearly explained in the manual	☐	☐	☐	☐	☐
(c) It was easy to see the relationship between the experiments and the lecture course	☐	☐	☐	☐	☐
(d) I felt confident in carrying out the experiments	☐	☐	☐	☐	☐
(e) These labs made me more interested in chemistry	☐	☐	☐	☐	☐
(f) The experiments encouraged me to think about the chemistry which was involved	☐	☐	☐	☐	☐
(g) I found the lab report difficult to write	☐	☐	☐	☐	☐
(h) I prefer working on my own	☐	☐	☐	☐	☐
(i) I am often confused by the lab manual	☐	☐	☐	☐	☐
(j) I feel confidant when I enter the chemistry laboratory	☐	☐	☐	☐	☐
(k) The purpose of the experiment was clear to me	☐	☐	☐	☐	☐
(l) I should like to do open-ended project work as part of mychemistry laboratories	☐	☐	☐	☐	☐
(m) I was so confused in the laboratory that I ended up following the manual without understanding what I was doing	☐	☐	☐	☐	☐
(n) I only understood the experiment when I started to write the report at the end of the experiment	☐	☐	☐	☐	☐

(6) Any other comments on Physical Chemistry Laboratory are welcome here.

Centre for Science Education, University of Glasgow

Questionnaire for Students Used at Start of Chemistry Course

looking back at School Laboratories

To help with the planning of your laboratories in the future, please complete the following questionnaire

(1) What are your opinions about your school laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	☐	☐	☐	☐	☐	☐	Useless
Not helpful	☐	☐	☐	☐	☐	☐	Helpful
Understandable	☐	☐	☐	☐	☐	☐	Not understandable
Satisfying	☐	☐	☐	☐	☐	☐	Not satisfying
Boring	☐	☐	☐	☐	☐	☐	Interesting
Well organised	☐	☐	☐	☐	☐	☐	Not well organised
The best part of chemistry	☐	☐	☐	☐	☐	☐	The worst part of chemistry
Not enjoyable	☐	☐	☐	☐	☐	☐	Enjoyable

(2) In your school chemistry laboratory, which do you prefer ? (*Tick ONE box*)

Working individually ☐ Working in small groups ☐ Watching a demonstration ☐

(3) In your university chemistry laboratories, which do you think you will prefer ? (*Tick ONE box*)

Working individually ☐ Working in small groups ☐ Watching a demonstration ☐

(4) Think about your past experiences in chemistry laboratory work.
Tick the box which best reflects your opinion.

		Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
(a)	I believe that the laboratory is a vital part in learning chemistry	☐	☐	☐	☐	☐
(b)	I prefer to have written instructions for experiments	☐	☐	☐	☐	☐
(c)	All the chemicals and equipment that I needed were easily located	☐	☐	☐	☐	☐
(d)	I was unsure about what was expected of me in writing up my experiment	☐	☐	☐	☐	☐
(e)	Laboratory work helps my understanding of chemistry topics	☐	☐	☐	☐	☐
(f)	Discussions in the laboratory enhance my understanding	☐	☐	☐	☐	☐
(g)	I only understood the experiment when I started to write about it afterwards	☐	☐	☐	☐	☐
(h)	I had few opportunities to plan my experiments	☐	☐	☐	☐	☐
(i)	I felt confident in carrying out the experiments in chemistry	☐	☐	☐	☐	☐
(j)	I found writing up about experiments pointless	☐	☐	☐	☐	☐
(k)	The experimental procedure was clearly explained in the instructions given	☐	☐	☐	☐	☐
(l)	I was so confused in the laboratory that I ended up following the instructions without understanding what I was doing	☐	☐	☐	☐	☐
(m)	I feel that school examinations should take account of laboratory experiments I have completed	☐	☐	☐	☐	☐

(5) Here are several reasons why laboratory work is part of most chemistry courses.
Tick the THREE reasons which YOU think are the most important for doing practical work in chemistry courses.

Experimental work makes chemistry more enjoyable for me	☐
Experiments illustrate theory for me	☐
Laboratory work allows me to test out ideas	☐
Experiments allow me to find out about how materials behave	☐
Experiments teach me chemistry	☐
Experimental skills can be gained in the laboratory	☐
Experiments assist me to plan and organise	☐
Experimental work allows me to think about chemistry	☐

Thank you for your help - Centre for Science Education

Appendix C

Use of Chi - Square

Chi-square Test (χ^2)

Chi-square test is said to to be one of the most widely used tests for statistical data generated by non-parametric analysis. There are two different of applications of chi-square test. These are used in this study.

(1) Goodness of Fit Test

This tests how well the experimental (sampling) distribution fits the control (hypothesised) distribution. An example of this could be a comparison between a group of experimentally observed responses to a group of control responses. For example, using raw numbers,-

	Positive	**Neutral**	**Negative**	
Experimental	55	95	23	N (experimental) = 173
Control	34	100	43	N (control) = 177

A calculation of observed and expected frequencies lead to

	Positive	**Neutral**	**Negative**
fo = observed frequency	*55*	95	23
fe = expected frequency	*33*	98	42

Where *fe* = [N(experimental)/N(control)] x N (control data)
or = (173/177) x (control data)

The degree of freedom (df) for this comparison is 2. This comparison is significant at two degrees of freedom at greater than 1%. (χ^2 critical at 1% level = 9.21 also shown as, $\chi^2 = 9.21$ $p< 0.01$)

(2) Contingency Test

This chi-square test is commonly used in analysing data where two groups or variables are compared and where neither can be considered as a control group. Each of the variable may have two or more categories which are independent from each other. The data for this comparison is generated from the frequencies in the categories. In this study, the chi-square as a contingency test was used, for example, to compare two or more independent samples like, year groups, gender, or ages. The data is generated from one population group. For example,

	Positive	**Neutral**	**Negative**	
Experimental	55	95	23	N (experimental) = 173
Control	34	100	43	N (control) = 177

	Positive	**Neutral**	**Negative**	**N**
Male (experimental)	55 (44)	95 (96)	23 (33)	173
Female (experimental)	34 (45)	100 (97)	43 (33)	177
Totals	89	195	66	350

The expected frequencies are shown in brackets ( ), and are calculated as follows:

e.g. 44 = (173/350) x 89

$$\chi^2 = 2.75 + 0.01 + 3.03 + 2.69 + 0.09 + 3.03$$
$$= \mathbf{11.60}$$

At two degrees of freedom, this is significant at 1%. (χ^2 critical at 1% level = 9.21).

The degree of freedom (df) must be stated for any calculated chi-square value. The value of the degree of freedom for any analysis is obtained from the following calculations:

$$\mathbf{df = (r-1) \times (c-1)}$$

where **r** is the number of rows and **c** is the number of columns in the contingency table.

Limitations on the Use of χ^2

It is known that when values within a category are small (i.e. 5, as proposed by some writers (Wiersma, 1995)), there is a chance that the calculation of $\chi 2$ may occasionally produce inflated results which may lead to wrong interpretations. In this study, in order to avoid dubious conclusions, a 5% category limit was imposed.

Appendix D

Pre-Laboratory Exercises

EXPERIMENT 1 pH Titrations

You should answer the questions in this pre-laboratory exercise before coming to the laboratory
Write the answers (which should be brief) in your laboratory notebook and show them to your demonstrator.
Before starting, read the following sections in Ebbing: 3.2, 16.4, 16.6, 16.7.

Reminder: A solution is said to be one Molar if it contains 1 mole of solute per litre of solution. Thus, a 0.3M solution of NaOH contains 0.3 moles of sodium hydroxide per litre of solution.

(1) Write down the number of moles of solute in:

(a) 1 litre of 0.1M sulphuric acid
(b) 0.5 l of 2M potassium hydroxide
(c) 250 ml of 0.4 M nitric acid

(2) What volume of 1.00 M sodium hydroxide solution is required exactly to neutralise 100 ml of 0.05M acetic (ethanoic) acid ?

Reminder: The units of concentration are moles per litre. When we talk of the ***strength*** *of an acid or base we are* ***NOT*** *describing the concentration. We are describing the extent of ionisation. A strong acid or base is one which is close to 100% ionised in aqueous solution while a weak acid or base has a low degree of ionisation (usually 5% or less). Sulphuric, nitric and hydrochloric are three strong acids while organic acids (like acetic) are weak. The hydroxides of metals in columns I and II of the periodic table are strong while most other bases are weak.*

When acids and bases are mixed, salts are formed. However, even if enough acid has been added to neutralise the alkali exactly, the pH will not necessarily be 7. The salts formed can react with the water (they are said to be 'hydrolysed'). Here is an example of such an equilibrium reaction – sodium ethanoate (acetate) reacting with water :-

$$CH_3COONa + H_2O \rightleftharpoons CH_3COOH + Na^+ + OH^-$$

(3) Because acetic (ethanoic) acid is weak, the equilibrium in the above equation lies well to the right. Explain why this will result in a solution of sodium acetate in water being alkaline.

(4) Suggest a likely pH (above 7, about 7, or below 7) for solutions of each of the following salts in water:

Sodium chloride; Ammonium chloride; Potassium acetate (ethanoate); Calcium nitrate

(5) If we know the approximate pH (above 7, about 7, or below 7) of the salt formed at the equivalence point of an acid / base titration , we can select an indicator which will change colour over the appropriate pH range. Given the following table of indicators, select the indicator you would choose for each of the following titrations:

(a) sodium hydroxide and sulphuric acid
(b) potassium hydroxide and acetic (ethanoic) acid
(c) ammonium hydroxide and hydrochloric acid

Indicators	Colour change	pH Interval
Methyl orange	Orange- Yellow	2.1- 4.4
Methyl red	Red - Yellow	4.2 - 6.3
Bromthymol blue	Yellow - Blue	6.0 - 7.6
Phenolphthalein	Colourless - Red	8.3 - 10.0

EXPERIMENT 2 Conductometric Titrations

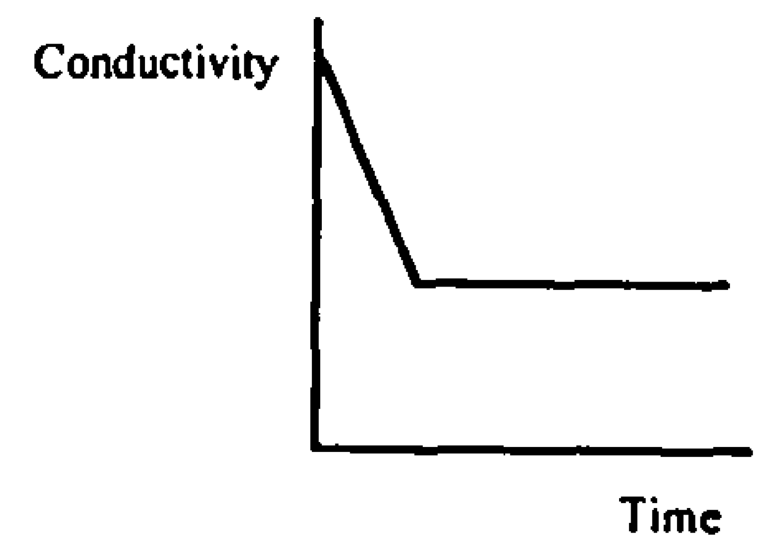
You should answer the questions in this pre-laboratory exercise before coming to the laboratory
Write the answers (which should be brief) in your laboratory notebook and show them to your demonstrator.
Before starting, read the following sections in Ebbing: 4.1

Dilute sulphuric acid conducts electricity extremely well. The conductivity of the solution is due to the motion of hydrogen ions and sulphate ions. When some magnesium powder is added to very dilute sulphuric acid, the conductivity of the solution falls rapidly. The magnesium forms magnesium ions while the hydrogen ions are removed as hydrogen gas. The magnesium ions are less mobile than hydrogen ions. The graph alongside illustrates what is observed.

(1) Refer to the graph and

 (a) Explain why the conductivity falls sharply to begin with.

 (b) Explain why the conductivity levels off after a short while.

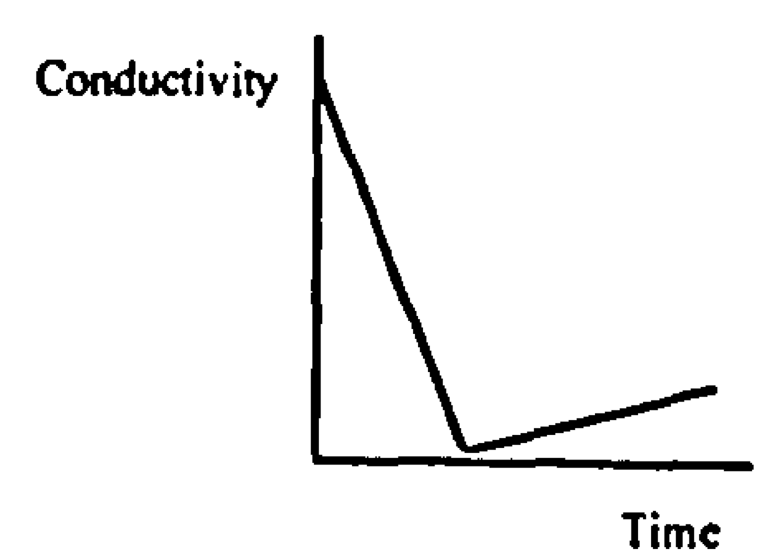


(2) Suppose the same experiment was repeated using very dilute sulphuric acid and copper oxide. A very similar graph is produced. Explain clearly why the graph has the same shape.

Reminder: Hydrogen ions are the most mobile and are about twice as mobile as hydroxide ions. Other ions vary in mobility but tend to about half as mobile as hydroxide ions.

(3) Next, the experiment is repeated using very dilute sulphuric acid and very dilute sodium hydroxide is gradually added. Draw the graph you would expect to obtain, explaining its shape.

(4) In a final experiment, very dilute barium hydroxide solution is added slowly to very dilute sulphuric acid and the graph alongside is obtained. What does the graph tell you about barium sulphate ?



EXPERIMENT 3 Solubility Product, K_{sp}

You should complete this pre-laboratory exercise before coming to the laboratory
Write the answers (which should be brief) in your laboratory notebook and show them to your demonstrator.
Before starting, read the following sections in Ebbing: 12.2, 16.5, 17.1, 17.2.

Reminder: *When a substance like silver iodide (which has a low solubility in water) is placed in water, an equilibrium is set up This can be represented by the equation, shown below and the solubility product (K_{sp}) is 1 x 10^{-16} at 25°C.*

$$AgI\,(s) \rightleftharpoons Ag^{+}\,(aq) + I^{-}\,(aq) \qquad K_{sp} = [Ag^{+}][I^{-}] = 1 \times 10^{-16}$$

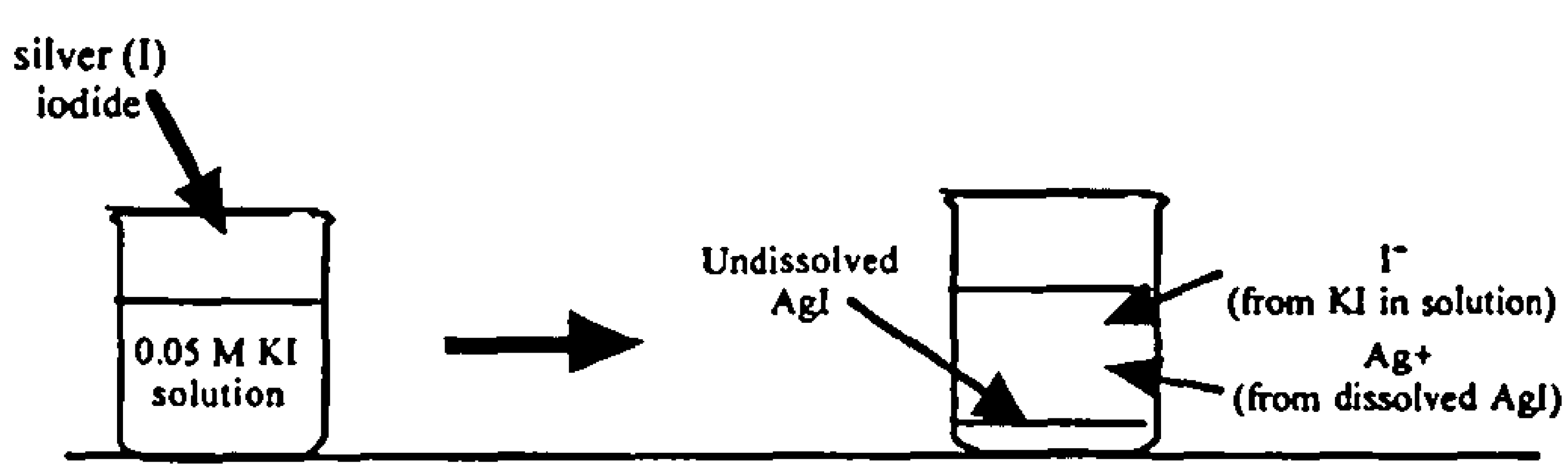
Suppose we dissolve enough silver iodide in water at 25°C to make a saturated solution and we find that there are x moles of AgI dissolved in 1 litre of water at equilibrium.

- Thus: $[Ag^{+}] = [I^{-}] = x \text{ mol } l^{-1}$.
- Substituting into the expression for K_{sp} gives: $K_{sp} = [Ag^{+}][I^{-}] = [x][x] = 1 \times 10^{-16}$
- Solving for x gives: $[x] = \sqrt{1 \times 10^{-16}}$ and, $x = 1 \times 10^{-8} \text{ mol } l^{-1}$
- The solubility of silver iodide in water is, therefore: $= 1 \times 10^{-8}$ moles per litre
- To convert the solubility in moles per litre to grams per litre, we multiply by the formula mass of the solid
- Thus: solubility of AgI in water at 25 °C $= [(1 \times 10^{-8}) \times 235]$ g per litre $= 2.35 \times 10^{-6} \text{ g } l^{-1}$

(1) The solubility product, K_{sp}, of silver chloride, AgCl, is 1.8×10^{-10} at 25°C. What is the solubility of silver chloride in moles per litre at the same temperature.

(2) What is the effect of changing the temperature on the value of a solubility product ?

Reminder : In the above discussion, we have looked at a single solute. However, the solubility of the original solute can change if a second solute is added. For example, suppose that silver iodide is dissolved in water which already contains potassium iodide (0.05 moles per litre). In the final solution, almost all of the iodide ion in solution comes from the dissolved potassium iodide, which is highly soluble, while the silver ions in solution come from the silver iodide which is sparingly soluble.The value of K_{sp} at the same temperature does not alter.



Thus: $K_{sp} = 1 \times 10^{-16} = [Ag^{+}][I^{-}] = [Ag^{+}] \times (0.05)$

Giving: $[Ag^{+}] = (1 \times 10^{-16}) \div 0.05 = 2 \times 10^{-14} \text{ mol } l^{-1}$

The amount of silver iodide which has dissolved is, therefore: $[(2 \times 10^{-14}) \times 235] \text{ g } l^{-1}$

(3) Calculate the solubility in moles per litre at 18°C of lead sulphate, $PbSO_4$, in:

(a) pure water

(b) 0.10 M $Pb(NO_3)_2$ K_{sp} of lead sulphate at 18°C is: 1.06×10^{-8}

EXPERIMENT 4 Heat of Reaction

You should answer the questions in this pre-laboratory exercise before coming to the laboratory
Write the answers (which should be brief) in your laboratory notebook and show them to your demonstrator.
Before starting, read the following sections in Ebbing: 6.2, 6.3, 15.1.

Reminder: *When thermal energy is added continuously to water, the temperature will rise until the water reaches its boiling point. The amount of heat energy required to raise the temperature of the water to bowling point will depend on the initial temperature of the water, the amount of water present, and the heat capacity of water. The heat capacity of water is the amount of heat required to produce a one Centigrade degree rise in the temperature. The heat capacity of water is 4.18 Joule ml^{-1} °C^{-1} (or 4.18 Joule g^{-1} °C^{-1})*

(1) Calculate:

(a) The temperature rise if 100 ml of water is heated with 1200 J of energy.

(b) The final temperature if 50g of water at 21°C is heated with 1000 J of energy.

(2) When solutions of acids and bases are mixed, energy is released (i.e. the reaction is exothermic). This energy raises the temperature of the water. What else might also be heated up ?

(3) If 100ml of 1M HCl is mixed quickly with 100ml of 1M NaOH, a temperature rise of 6.2°C is observed. Predict the temperature rise if, under the same conditions, 10ml of 1M HCl is mixed quickly with 10ml of 1M NaOH.

(4) When acids and bases are mixed, thermal energy is released. Here are some data.

(a) Explain why several of the values are almost the same.

(b) Suggest an explanation why one value (the value for HCN) is much higher (less exothermic).

(c) Suggest an explanation why one value (the value for for HF) is much lower (more exothermic).

Acid	Base	ΔH ($kJmol^{-1}$)
HCl	NaOH	-57.1
HCl	KOH	-57.2
HCN	KOH	-11.7
HNO_3	NaOH	-57.3
HNO_3	KOH	-57.2
HCl	KOH	-57.3
HF	NaOH	-68.6

EXPERIMENT 5 Activation Energy.

You should answer the questions in this pre-laboratory exercise before coming to the laboratory
Write the answers (which should be brief) in your laboratory notebook and show them to your demonstrator.
Before starting, read the following sections in Ebbing: 5.2, 13.4, 13.5.

(1) What is meant by activation energy ?

(2) In what way does absolute temperature relate to temperature on the Centigrade (Celsius) scale ?

(3) Explain clearly what you understand by first order reactions and second order reactions.

Reminder: *The logarithm of a number to the base ten is the power to which ten must be raised to give that number. Thus:*

$\log_{10}(17.4) = 1.24$ because: $10^{1.24} = 17.4$

Logarithms can be expressed to any base with respect to any number. A useful, if unexpected, base is e which has a value of 2.718. Logarithms to the base e are known as natural logarithms and are symbolised by ln. Thus:

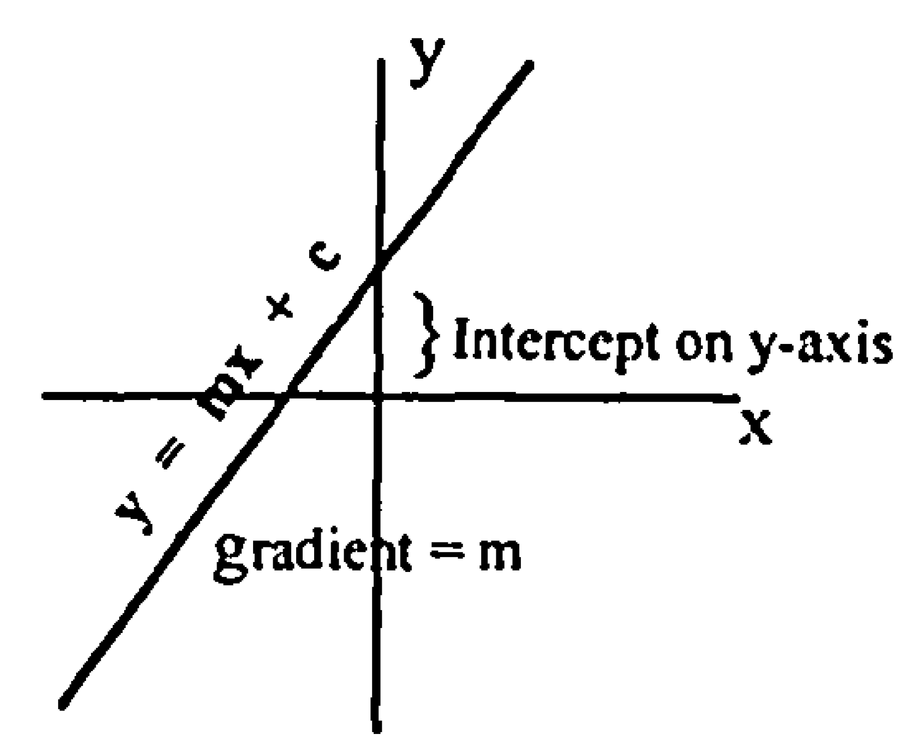
$\ln(17.4) = 2.86$ because: $e^{2.86} = 17.4$

A useful connection between natural logarithms and logarithms to the base 10 is:

$$(2.303)\log_{10}(x) = \ln(x)$$

(4) The equation of a straight line is: $y = mx + c$

A graph of this function shows that the intercept on the y-axis has a value of c and that the gradient of the straight line is m.



When looking at the speed of chemical reactions, it can be shown that a relationship which is very like $y = mx + c$ is obtained:

$$\ln(t) = Ea/RT + \text{constant}$$

where:

Ea	=	the activation energy for the reaction
t	=	time for reaction to reach a certain pomt
R	=	gas constant
T	=	temperature of reaction in degrees Kelvin

Using the y-axis for ln (t) and the x-axis for 1/T, sketch a graph similar to the graph for $y = mx + c$ shown above. Describe how you would calculate a value for the activation energy from such a graph.

Chemistry 1

Physical Chemistry Experiments

Demonstrators Marking Brief for Pre-Laboratory Exercises

5 marks are allocated for each pre-lab exercise and are allocated as shown.

Experiment No 1

Q.1 (a) 0.1 moles — If all correct give them 1 mark
(b) 1.0 moles — If two correct give them 1/2 mark
(c) 0.1 moles — Otherwise, no mark

Q.2 5 ml 1 mark

Q.3 If the equilibrium lies well to the right, there is an excess of hydroxides ions, raising the pH. 1 mark

Q.4

Sodium chloride + Water	pH = 7	If all correct - 1 mark.
Ammonium chloride + Water	pH < 7	If three correct - 1/2 mark
Potassium acetate + Water	pH > 7	Otherwise no marks
Calcium nitrate + Water	pH = 7	

Q.5 (a) Bromothymol blue
(b) Phenolphthalein.
(c) Methyl orange or methyl red

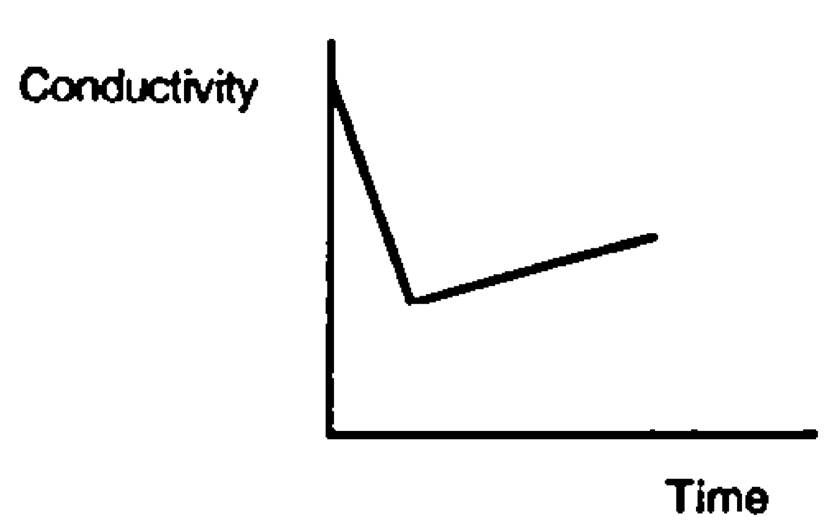
If all correct - 1 mark
If two correct - 1/2 mark
Otherwise no marks

Experiment No 2

Q.1 (a) H^+ replaced by Mg^{2+} — 1/2 mark
(b) No further reaction after all H^+ removed — 1/2 mark

Q.2 Replacement of H^+ by Cu^{2+} until reaction completed. 1 mark

Q.3



1 mark for reasonable graph

1/2 mark for each of any two relevant points of explanation: eg. fast hydrogen ions replaced by slower metal ions causes initial drop, point of graph represents end-point of reaction, slow rise due to more ions (sodium and hydroxide) being added

Q.4 $BaSO_4$ highly insoluble. 1 mark

Experiment No 3

Q.1 1.34×10^{-5} moles l^{-1} Correct answer - 2 marks
If not correct, give 1 mark if method right but arithmetical slip

Q.2 The value of solubility product may change 1 mark

Q.3 (a) 1.03×10^{-4} mol^{-1} 1 mark
(b) 1.06×10^{-7} mol l^{-1} 1 mark

Experiment No 4

Q.1 (a) 2.9 C° 1/2 mark
(b) 25.8 °C 1/2 mark

Q.2 Possible choices are: container, stirrer, air above the beaker, bench underneath
Any three - 1 mark
Any two - 1/2 mark
If they say 'surroundings' and nothing else - 1/2 mark

Q.3 Answer is 6.2°C 1 mark

Q.4 (a) In all cases water is produced, or: $H^+ + OH^- \rightarrow H_2O$
(b) HCN is a weak acid
(c) HF is a weak acid and its ionisation is exothermic (There are many other possible explanations here)

All three correct - 2 marks
Two correct - 1 mark
One correct - 1/2 mark

Experiment No 5

Q.1 The minimum kinetic energy that must be possessed by the reactants in order to give an effective collision (one that produces products). 1 mark

Q.2 Absolute temperature = °C + 273 (approx) 1 mark

Q.3 The sum of the exponents in the rate law is the overall order.

First order: rate = $k [A]^1$
Or some equivalent statement

Second order: rate = $k [A]^2$ or rate = $k [A] [B]$
Or some equivalent statement

1 mark overall, for clear description in verbal or symbolic form or overall statement

Q.4 (a) Same type of graph - gradient of line must be positive 1mark for reasonable graph (rough sketch)

(b) Measure gradient; gradient = E_a/R; hence, E_a found by multiplying gradient by value of R.
(1 mark for any coherent description of what to do)

Appendix E

Questionnaire
(after use of pre-labs)

To help with the planning of your laboratories in the future, please complete the following questionnaire.

(1) What are your opinions about your _school_ laboratory experiences in chemistry ?
Tick ONE box on each line.

Useful	☐	☐	☐	☐	☐	☐	Useless
Helpful	☐	☐	☐	☐	☐	☐	Not helpful
Meaningful	☐	☐	☐	☐	☐	☐	Meaningless
Understandable	☐	☐	☐	☐	☐	☐	Not understandable
Satisfying	☐	☐	☐	☐	☐	☐	Not satisfying
Interesting	☐	☐	☐	☐	☐	☐	Not interesting
Well organised	☐	☐	☐	☐	☐	☐	Not well organised

(2) In your _school_ *chemistry laboratory* which did you prefer ? (*Tick ONE box*)

Working individually ☐ Working in pairs or small groups ☐ Watching a class demonstration ☐

(3) In your _university_ *chemistry laboratories* which do you prefer ? (*Tick ONE box*)

Working individually ☐ Working in pairs or small groups ☐ Watching a lecture demonstration ☐

(4) What are your opinions about your _overall university chemistry laboratory experiences_ (all chemistry laboratories) ?
Tick ONE box on each line.

Helpful	☐	☐	☐	☐	☐	☐	Not helpful
Useless	☐	☐	☐	☐	☐	☐	Useful
Meaningless	☐	☐	☐	☐	☐	☐	Meaningful
Understandable	☐	☐	☐	☐	☐	☐	Not understandable
Satisfying	☐	☐	☐	☐	☐	☐	Not satisfying
Interesting	☐	☐	☐	☐	☐	☐	Not interesting
Well organised	☐	☐	☐	☐	☐	☐	Not well organised

(5) Think about your _laboratory in Physical Chemistry_ (which you have completed in January).

What are your opinions about the following statements?
Tick ONE box on each line.

		Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
(a)	I find writing lab reports largely a waste of time	☐	☐	☐	☐	☐
(b)	The experimental procedure was clearly explained in the manual	☐	☐	☐	☐	☐
(c)	It was easy to see the relationship between the experiments and the lecture course	☐	☐	☐	☐	☐
(d)	I felt confident in carrying out the experiments	☐	☐	☐	☐	☐
(e)	These labs made me more interested in chemistry	☐	☐	☐	☐	☐
(f)	The experiments encouraged me to think about the chemistry which was involved	☐	☐	☐	☐	☐
(g)	I found the lab report difficult to write	☐	☐	☐	☐	☐
(h)	I prefer working on my own	☐	☐	☐	☐	☐
(i)	I am often confused by the lab manual	☐	☐	☐	☐	☐
(j)	I feel confidant when I enter the chemistry laboratory	☐	☐	☐	☐	☐
(k)	The purpose of the experiment was clear to me	☐	☐	☐	☐	☐
(l)	I should like to do open-ended project work as part of my chemistry laboratories	☐	☐	☐	☐	☐
(m)	I was so confused in the laboratory that I ended up following the manual without understanding what I was doing	☐	☐	☐	☐	☐
(n)	I only understood the experiment when I started to write the report at the end of the experiment	☐	☐	☐	☐	☐
(o)	I found the pre-laboratory exercises a waste of time	☐	☐	☐	☐	☐

(6) Any other comments on Physical Chemistry Laboratory are welcome here.

Centre for Science Education, University of Glasgow

Appendix F

Original Physical Chemistry Laboratory Manual

University of Glasgow

Chemistry Department

Chemistry-1

Physical Laboratory

Manual

1999-2000

Name ....

Lab Session..

Chemistry I Laboratory
Physical Chemistry Course

INTRODUCTORY REMARKS

The Physical Chemistry Laboratory Course will be held in the Speakman Laboratory, Room A3-6, during academic weeks 8 to 12, inclusive.
The laboratory will be open from 1.55 p.m. till 5 p.m. on Mondays, Tuesdays, Wednesdays and Thursdays, and from 9.55 a.m. till 1 p.m. on Tuesdays, Thursdays and Fridays.

Students will be working in pairs as far as is possible. During each laboratory session students will complete one experiment, write the report in a hard backed report book, and present it to demonstrators or staff members for marking. The reports should be concise and clearly presented. They should consist of a title, a brief statement of the processes studied (where possible this can be done by simply stating appropriate chemical equations), results of measurements, graphs and results of calculations, and the outcome of any other assignments for the experiments.

Experiments will only be marked on the afternoon that they are completed - You cannot simply leave when you have finished the practical work, write up at home, and then expect your experiment to be marked in the following, or any subsequent, week.

At the end of each laboratory session students are expected to wash all glassware, place it in the drawers and leave the bench place tidy.

Before leaving the laboratory students should find from the notice board which experiment they will be doing a week later, so that they can read about the experiment and come to the laboratory prepared.

Safety glasses must be worn at all times in the laboratory. Not wearing safety glasses will result in exclusion from the laboratory.

All accidents, no matter how trivial they may seem, must be reported immediately to demonstrators or staff members.

Spillages of solutions or other chemicals must be dealt with promptly, and all equipment breakages must be reported immediately.

Never return reagent solutions to the stock bottles.

October 1999 Dr. D.N.J. White

EXPERIMENT 1

pH TITRATIONS (Ebbing pp 710-714)

In quantitative chemical analysis, acid-base reactions are often used to provide a basis for various titration techniques. The equivalence points of acid-base titrations can be estimated from the colour change of chemical indicators, such as phenolphthalein, methyl red, methyl orange and so on. The choice of an indicator suitable for a particular titration requires a detailed knowledge of the chemical properties of the acid and base. This difficulty can be avoided by using physical methods, which follow the change in some property of the solution as the titration proceeds. Such a property must show a rapid change at the equivalence point, or alternatively, the rate of change must be different before and after the equivalence point. Electrical conductivity and the concentration of hydrogen ions in solution provide two examples of such properties.

In aqueous solutions the concentration of hydrogen ions can vary by many orders of magnitude, and it is therefore convenient to consider it on a logarithmic scale by using the relationship:-

$$pH = -\log_{10} [H^+]$$

Although, strictly, the above relationship is an approximation it is sufficiently accurate for the purpose of this exercise. For the equilibrium:-

$$H_2O(l) \rightleftarrows H^+(aq) + OH^-(aq)$$

the ionic product at 25°C is:-

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

Thus in neutral solutions:-

$$[H^+] = [OH^-] = 1 \times 10^{-7} \text{ M}$$

and the pH value is

$$pH = -\log (1 \times 10^{-7}) = -(-7) = 7$$

Acidic and basic solutions can be distinguished in terms of their pH values:

	$[H^+]$	pH
Acidic solution	$>1 \times 10^{-7}$	<7
Neutral solution	1×10^{-7}	=7
Basic solution	$< 1 \times 10^{-7}$	>7

In acid-base titrations the pH of the titrated solution changes throughout the titration.

A graph of pH as a function of the volume of titrant, the *titration curve*, is used to determine the equivalence point. The shape of the titration curve and also the pH value at the equivalence point, depend on the strengths of the acid and base.

(a) Strong acid - strong base titrations

When a solution of a strong acid is titrated with a solution of a strong base, the pH titration curve is of the shape shown in Figure 1. It starts with a relatively low value of pH (for ~0.1M HCl, pH ~1). As the base is progressively added the pH increases, slowly at first, but rapidly in the vicinity of the equivalence point; after that it levels off gradually as more base is added.

For the titration shown in Figure 1, where 50 ml of 0.100 M HCl are titrated with 0.100 M NaOH, the equivalence point occurs *when 50 ml of NaOH are added. At this point* all the acid has been converted into a salt that does not hydrolyse (NaCl) and the titrated solution is therefore neutral (pH =7).

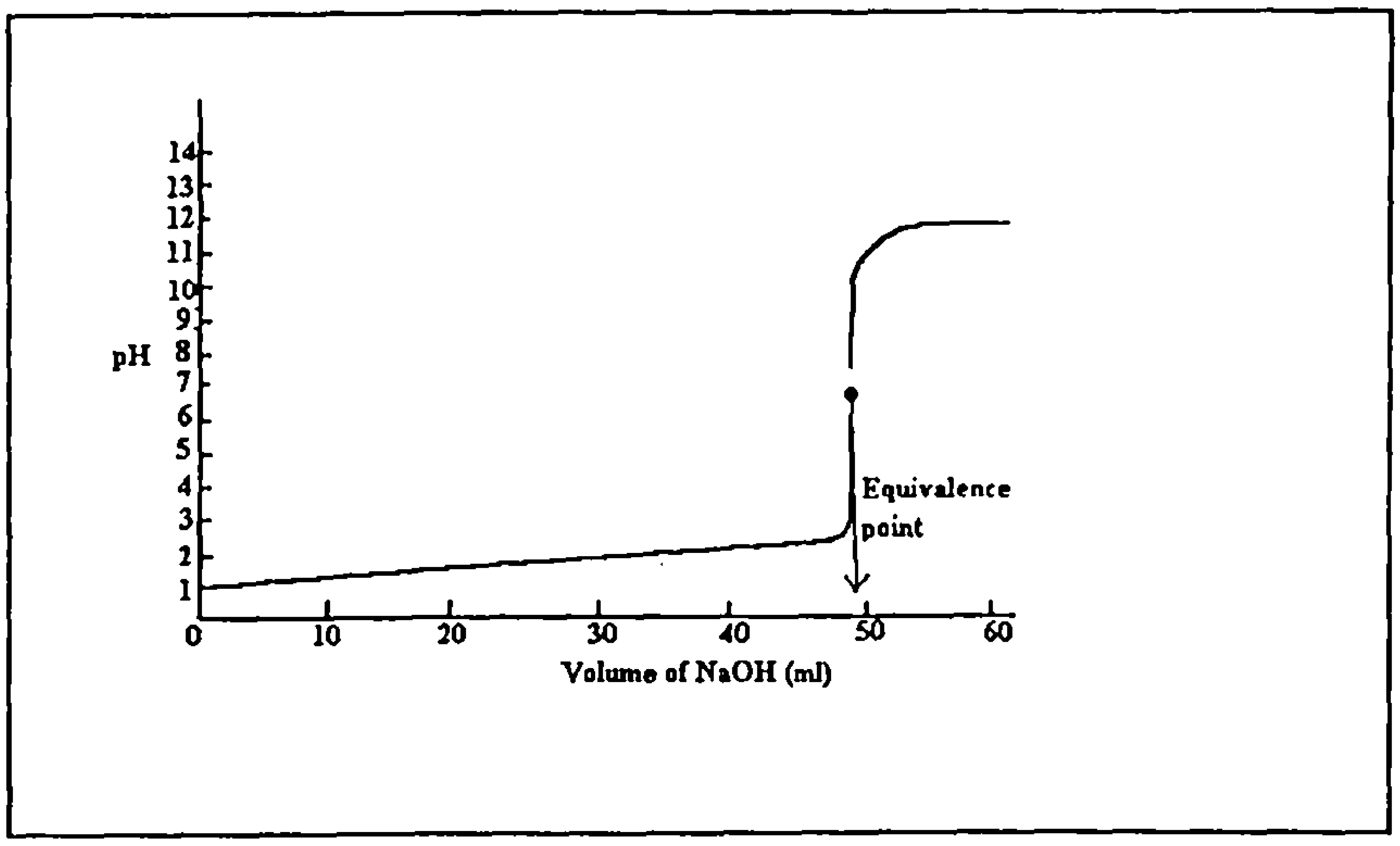


Figure 1. The pH curve for titration of 50 ml of 0.100 M HCl solution with 0.100 M NaOH

Titration of a solution of a strong base with a solution of a strong acid yields a pH curve similar in shape to that shown in Figure 1. The difference, however, is that the pH values are high at the start of the titration and low at its completion.

(b) Weak acid - strong base titrations

In acid -base titrations where one of the reactants is a strong electrolyte and the other is weak, the solutions are not neutral at the equivalence point. The reason for this is hydrolysis of the salt produced by the neutralisation reaction.

The pH curves resulting from titrations of weak acids with strong bases differ from those typical of strong acid - strong base titrations. Differences arise because (i) the weak acids are not fully dissociated in solution and (ii) the anions of the salts of weak acids and strong bases undergo hydrolysis in aqueous solutions. The pH at the beginning of the titration is not so low for a given acid concentration, and the equivalence point occurs at a pH value greater than 7.

In a titration of acetic acid with sodium hydroxide, for example, before the base is added the only solute is CH_3COOH and the equilibrium:-

$$CH_3COOH(aq) \rightleftarrows H^+(aq) + CH_3COO^-(aq)$$

is maintained. As the titrant is progressively added and the acetic acid molecules are gradually converted into acetate ions:-

$$CH_3COOH(aq) + OH^-(aq) \rightarrow H_2O(l) + CH_3COO^-(aq),$$

the solution becomes buffered and the pH increases slowly until the equivalence point is reached. At this point the solute is CH_3COONa, the anion of which undergoes hydrolysis:-

$$CH_3COO^-(aq) + H_2O(l) \rightleftarrows CH_3COOH(aq) + OH^-(aq)$$

and, as a result , the solution is slightly basic. Further addition of NaOH suppresses the hydrolysis of the anion (common ion effect) and the pH then depends only on the concentration of $OH^-(aq)$ ions supplied by the excess titrant.

The pH meter

The pH of a solution can be measured using the pH meter, which consists of two electrodes, usually a standard reference electrode and a glass electrode, and a meter sensitive to small voltage differences. The voltage difference between the two electrodes depends on the concentration of the $H^+(aq)$ions in solution. The instrument is calibrated so that the dial reading directly gives the pH value of the solution in which the electrodes are immersed.

Experimental

The object of this exercise is to determine concentrations of two acid solutions using the pH titration technique.

Caution!! - Do not attempt to use the pH meter until you have consulted a demonstrator. The meter has been calibrated beforehand and the position of the buffer control knob should not be altered. If the buffer setting is altered, inform a demonstrator, as the instument will have to be recalibrated.

After each titration the beaker used as a titration vessel must be removed from the apparatus, emptied and cleaned. The glass electrode should also be *carefully* washed. At all times when the apparatus is not in use, *fill the beaker with ample distilled water to cover the electrode.* Prolonged immersion of the electrode in solutions of high pH (strongly basic) must be avoided. Note that the glass electrodes are extremely fragile, as well as expensive; careless contact with the sides of the beaker can be enough to shatter the thin glass bulb.

(a) Titration of a solution of HCl with 1.00 M NaOH

Fill the burette with 1.00 M NaOH and adjust the liquid level to the zero mark.

Empty the titration beaker, rinse it with distilled water and pour into it about 50 ml of distilled water. Add, using a pipette, 50 ml of approximately 0.1 M HCl. Place the beaker on a magnetic stirrer and immerse the glass electrode. Stir well, *switch off the stirrer*, then measure the pH and record the result.

Start the titration by adding two 1 ml portions of NaOH and then add 0.5 ml portions until about 1 ml before the expected equivalence point. Then add 0.2 ml portions. When the pH starts changing slowly again, revert to 0.5 ml portions until about 8 ml of NaOH has been used. Finally, run in two 1 ml portions. After each addition of the titrant, stir the solution and measure the pH. Record the results in a table, showing the burette readings (ml NaOH) and the pH values of the titrand. Repeat the titration if necessary to obtain satisfactory results.

(b) Titration of a solution of CH_3COOH with 1.00 M NaOH

Repeat the above procedure, using 50 ml of distilled water and 50 ml of approximately 0.1 M CH_3COOH in the titration vessel and 1.00 M NaOH in the burette.

When the experimental work has been completed, switch off the pH meter at the mains plug, wash the titration beaker and the glass electrode, *and leave the glass electrode immersed in distilled water.* Clean the burette thoroughly.

Assignments

For each titration, plot a graph in which the pH scale is the ordinate and the volume of titrant added (ml) is the abscissa. Estimate the equivalence points (ml).

Calculate the molarities of the HCl solution used in titration (a) and of the CH_3COOH solution used in titration (b).

Methyl red changes colour in the pH range 4.2 - 6.3 and phenolphthalein in the range 8.3 - 10.0. Considering the pH curves you have obtained, state which of these indicators would be suitable for titrations (a) and (b).

Use the Henderson equation to predict the pH of the solution in titration (b) when 20%, 50% and 80% of the CH_3COOH has been neutralised. Take pKa for CH_3COOH to be 4.74. Compare these predictions with your graph.

EXPERIMENT 2

CONDUCTOMETRIC TITRATIONS

In volumetric titrations the equivalence points can often be detected with the required precision by the use of chemical indicators. Physical methods, based on observations of changes in the electrical conductance of solutions or electrical potential differences, are also available.

In conductometric titrations the titrant is added in small quantities and the conductance of the titrated solution is measured after each addition. A graph of the conductance as a function of the volume of added titrant shows a marked change of slope at the equivalence point. The shape of the graph depends on the nature of both the titrant and the titrated solution. However, any such graph can be considered as composed of straight lines, each point of intersection of two straight lines indicating an equivalence point.

The conductance of an electrolyte solution depends, among other factors, on the concentration and mobility of the ionic species present. Mobility of ions is measured by the speed of their migration in a potential gradient of 1 volt cm^{-1}. Different ionic species show different mobilities in the same solvent and in dilute aqueous solutions mobilities decrease in the order:-

$$H^+ > OH^- \gg Cl^- \sim K^+ \sim NH_4^+ > Ag^+ > Na^+ > CH_3COO^-$$

Conductometric titrations can be conveniently applied to precipitation and neutralisation (acid-base) reactions.

Let us first consider a precipitation reaction such as that, for example, in a titration of silver nitrate with potassium chloride:-

$$Ag^+ + NO_3^- + K^+ + Cl^- \rightarrow AgCl\downarrow + K^+ + NO_3^-$$

Both $AgNO_3$ and KCl are fully dissociated in water. Since the mobility of K^+ ions in water is much the same as that of Ag^+ ions and the mobilities of Cl^- and NO_3^- are also similar, the conductance of the titrated solution does not change markedly as AgCl is precipitated *until the equivalence point is reached.* After that it rises sharply, since ions are being added, but none are now being removed.

In a strong acid - strong base reaction, such as in a titration of hydrochloric acid with sodium hydroxide:-

$$H^+ + Cl^- + Na^+ + OH^- \rightarrow H_2O + Na^+ + Cl^-$$

the highly mobile H^+ ions are progressively replaced by relatively slow moving Na^+ ions and the conductance of the titrand therefore decreases. After the equivalence point it rises sharply, mainly as a result of a rapid build-up in the concentration of the highly mobile OH^- ions of the excess base.

If, on the other hand, hydrochloric acid is titrated with a weak base such as ammonium hydroxide:-

$$H^+ + Cl^- + NH_4^+ + OH^- \rightarrow H_2O + NH_4^+ + Cl^-$$

the conductance of the titrated solution will change very little after the equivalence point has been reached. This is because the salt now present in the titrand will tend to suppress dissociation of the excess weak base by the common ion effect.

Experimental

The object of this exercise is to determine concentrations of two electrolyte solutions using the conductometric titration technique.

Conductance of the solutions will be measured using a *conductivity cell*, which consists of inert platinum electrodes and a beaker made of hard glass and filled with titrand. The cell is connected to a conductance bridge, which is calibrated to give direct dial readings of the conductance, K, measured in siemens (S), or of the resistance, R, measured in ohms (Ω). These are related to each other as

$$K = R^{-1} \quad \text{and} \quad 1\ S = 1\ \Omega^{-1}$$

You are provided (at the bench) with detailed instructions for operating the conductance bridge - read them carefully.

To obtain the required results, distilled water must be used throughout the experiment, and the apparatus must be maintained scrupulously clean.

(a) Titration of 0.0100 M solution of silver nitrate with potassium chloride (approx. 0.1 M)

Rinse and then fill the burette with ~0.1 M KCl solution.

Flush the conductivity cell (both the electrodes and the beaker) with distilled water. Pipette into the beaker 50 ml of 0.0100 M $AgNO_3$ solution. Insert the electrodes and add distilled water until the electrodes are fully immersed (this is essential). Turn on the magnetic stirrer to stir gently, *then switch it off* and take a reading of the conductance, K, of the solution.

Start the titration by adding 0.5 ml portions of KCl at a time, stirring the titrand and measuring K, after each addition. When you are near the expected equivalence point (about 1 ml before it) decrease the portions of the titrant to 0.2 ml and keep adding them until you are at 1 ml beyond the equivalence point. After that continue adding 0.5 ml portions until about 5.0 ml beyond the equivalence point. Tabulate your results of titrant added (ml) and conductance, K (S) .

Empty and wash the burette. To remove any white deposit from the conductivity cell, rinse the electodes and the beaker, first with a dilute ammonia solution and then with distilled water.

(b) Titration of 0.0100 M hydrochloric acid with sodium hydroxide solution (approx. 0.1 M)

Rinse the burette with ~0.1 M solution of NaOH.

Repeat the procedure outlined in titration (a), but using ~0.1 M NaOH solution in the burette and 50 ml of 0.0100 M HCl in the titration vessel.

At the end of the experiment empty, wash and rinse with distilled water, both the burette and the conductivity cell. *Fill the cell with distilled water and immerse the electrodes* . They must never be left for long periods, or overnight, in any solution, nor should any solution be allowed to dry out on them.

Assignments

For each titration, plot a graph of K (S) against volume of the titrant added (ml) and estimate the equivalence point (ml).

Calculate the molarities of the KCl solution used in titration (a) and of the NaOH solution used in titration (b).

Explain the slopes of the graphs before and after the equivalence points by considering relative ionic mobilities.

EXPERIMENT 3

SOLUBILITY PRODUCT (Ebbing pp 726-733)

Chemical substances are often separated and purified by precipitation of solids from liquid solutions. Chloride ions, for example, can be removed virtually completely from water solutions by precipitation with silver ions as silver chloride. In this way they can be separated from other anions which form soluble silver salts, such as NO_3^-, SO_4^{2-}, F^-, or ClO_4^-. Selective precipitation is an important technique both in chemical analysis and in numerous industrial processes.

In industry, selective precipitation is particularly important in the purification of metal ores. If a solution containing two different metal ions is treated with hydrogen sulphide, for example, the metal sulphide which is less soluble will precipitate before the other one does. It is therefore of practical interest to put the solubility of salts on a numerical basis, and in this context the *solubility product* is particularly useful.

If a solute is progressively added to a fixed amount of solvent, a point will be reached when no more solute will dissolve, and the resulting solution is said to be saturated. The concentration of a solute in a saturated solution defines its *solubility* at a given temperature. When a saturated solution is in contact with pure solute, a dynamic equilibrium is established: the solute dissolves and precipitates at the same rate.

Let us consider the equilibrium of solid silver chloride and its saturated solution in water:-

$$AgCl(s) \rightleftarrows Ag^+(aq) + Cl^-(aq)$$

The equilibrium constant for this system is:-

$$K = [Ag^+][Cl^-] / [AgCl\ (s)] \qquad (1)$$

(Here we are assuming that the ion concentrations in the saturated solution are sufficiently low to allow us to express K in terms of concentrations, rather than activities, of ions.) . We can also write:-

$$K\ [AgCl(s)] = [Ag^+][Cl^-]$$

or, since the concentration of the solid is constant:-

$$K_{sp} = [Ag^+][Cl^-] \qquad (2)$$

where K_{sp} is another constant known as the *solubility product.*

The solubility product of AgCl represents the maximum value which the product of the concentrations of Ag^+ and Cl^- ions can have at a given temperature. A practical consequence of this is that if a relatively concentrated solution containing silver ions is mixed with a solution containing chloride ions, solid silver chloride will precipitate out until the concentrations of the silver and chloride ions conform to equation (2). Reverting to the solution of two metal sulphides referred to earlier, it is now obvious that the sulphide with the lower value of K_{sp} will precipitate first.

Experimental

The object of this experiment is to determine the solubility product of potassium periodate, KIO_4 at about 25°C.

In order to study the equilibrium:-

$$K^+(aq) + IO_4^-(aq) \rightleftarrows KIO_4\,(s)\ ,$$

saturated solutions of KIO_4 in pure water and in aqueous solutions containing known concentrations of potassium ions are prepared at 25°C. The concentrations of the periodate ion in the saturated solutions are then determined by allowing this ion to react with iodide ions in acid solution and titrating the iodine released with standard sodium thiosulphate.

$$IO_4^- + 8H^+ + 7I^- \rightarrow 4I_2 + 4H_2O$$

$$I_2 + 2S_2O_3^{2-} \rightarrow S_4O_6^{2-} + 2I^-$$

Therefore 1 mole IO_4^- $\equiv$ 8 moles $S_2O_3^{2-}$.

Once the IO_4^- ion concentrations are known for the saturated solutions the K^+ ion concentrations are simply determined and K_{sp} values can be calculated.

Procedure

Take 2 clean conical flasks and label them A and B. Put about 1 g solid KIO_4 in each flask and add

to flask A, 100 ml distilled water,

to flask B, 100 ml 0.02 M KNO_3 solution.

Place the flasks in the thermostat bath at about 25°C and shake them frequently for at least 30 minutes. Record the temperature of the bath (T°C).

Remove flask A from the thermostat and filter the solution through a dry filter funnel into a conical flask. Pipette a 25 ml portion of the solution into a clean conical flask and add ~5ml 1 M H_2SO_4 and ~1g solid KI. Titrate the iodine released with 0.10 M sodium thiosulphate, using the iodine as its own indicator. Calculate the concentration of the periodate ion in the saturated solution.

Repeat the procedure for flask B.

Calculations

Calculation of solubility product is as follows:-

Initial $[K^+]$	from KNO_3 taken as solvent	(a)
$[IO_4^-]$ in saturated solution from titration		(b)
$[K^+]$ in saturated solution	from KNO_3 plus KIO_4	(a) +(b)

The solubility product of potassium periodate at T°C is

$$K_{sp} = [(a) + (b)] \times (b) \quad mol^2\, l^{-2} \ .$$

Assignments

Calculate the solubility product of potassium periodate at T°C using the results obtained from flasks A and B. Comment on the constancy of your results.

Calculate the solubility in g l^{-1} of KIO_4 in pure water.

Write the form of K_{sp} for $Fe(OH)_3$ and explain why the solubility of this ionic solid is pH dependent.

EXPERIMENT 4

HEAT OF REACTION (Ebbing pp 231-254)

Chemical reactions are usually accompanied by changes in Gibbs Free Energy of the system (ΔG). This free energy change is made up of two components: the enthalpy change (ΔH), measured by the heat of reaction, and the entropy change for the reaction (ΔS). The heat of reaction is a particularly important quantity for understanding the thermodynamics of the system; it is also of great importance in many industrial processes which rely on heat of reaction as a source of energy (for example, in generation of electrical power from the combustion of coal or other hydrocarbon fuels).

As a chemical reaction proceeds, energy is either taken up or dissipated by the system. In most reactions this energy is in the form of heat; occasionally other forms of energy may be involved, particularly when the reaction is out of control. Thus in some reactions sound energy (explosions) or light energy (luminescence) may be generated. In the simplest cases, however, only heat changes take place and this provides a direct way to determine the enthalpy change for a chemical reaction.

In this experiment neutralisation of a base by an acid will be examined from a thermochemical point of view.

Calorimetry

Generation of heat in an exothermic reaction, or uptake of heat in an endothermic reaction, will result in a change of temperature of the system (ΔT). In a well insulated container (a *calorimeter*), ΔT will be directly proportional to the amount of heat released, or taken up, in the reaction. If we know the specific heat, and hence the heat capacity, of the system (calorimeter +contents), we can calculate the heat energy change of the reaction. The specific heat of a substance is defined as the amount of heat energy required to raise the temperature of 1 g of the substance by 1°C. For pure water the specific heat is 4.184 J g^{-1} $°C^{-1}$.

In accurate calorimetric experiments several corrections must be made to obtain a precise value for ΔT for a reaction. The most important of these are the "cooling correction", and correction for heat of dilution of reactants. The cooling correction arises because no calorimeter can be completely insulated, and consequently heat begins to leak away as soon as it is generated by the reaction. However, the calorimetric experiments are designed to take account of this effect. Heat of dilution is important, because dilution of the reactants upon mixing can give rise to significant heat effects over and above the heat of the reaction itself. Fortunately, this is only a problem for fairly concentrated solutions, which is not the case in this experiment.

The acid - base reactions

Since strong acids and strong bases are fully dissociated in water, the reaction of a strong acid and a strong base in water is simply:-

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(aq)$$

Therefore, the heat of neutralisation of 1 mole of *any* strong base, such as NaOH, by *any* strong acid should be the same and equal to the heat of formation of 1 mole of aquated H_2O from its ions. Let this quantity be Q ; its value will be determined in Part A of this experiment, by neutralising a known quantity of NaOH with a slight excess of hydrochloric acid.

In Part B of the experiment, the strength of the HSO_4^- acid in water will be examined by neutralising a known quantity of NaOH with a slight excess of $NaHSO_4$ (sodium hydrogen sulphate).

If HSO_4^- is a strong acid, then the heat effect of its reaction with 1 mole of NaOH will again equal Q. However, if HSO_4^- is a weak acid, it will dissociate only partially in water and the equilibrium:-

$$HSO_4^-(aq) \rightleftharpoons H^+(aq) + SO_4^{2-}(aq)$$

will be established. On addition of NaOH two processes will occur:

$$HSO_4^-(aq) \rightarrow H^+(aq) + SO_4^{2-}(aq) + Q_1$$

$$H^+(aq) + OH^-(aq) \rightarrow H_2O(aq) + Q$$

In this case the heat evolved on neutralisation of 1 mole of NaOH will be Q_2, where

$$Q_2 = Q_1 + Q$$

The value of Q_2 will be larger or smaller than Q, depending on whether the dissociation of HSO_4^- is an exothermic or endothermic process.

Experimental

Special precautions: The reagents to be used are potentially dangerous and must be treated with respect. **Never add water to a concentrated acid!!!**

Part A: Neutralisation of NaOH with HCl. Rinse the two Dewar flasks thoroughly with cold tap water and place them upright on the magnetic stirrers, utilising the cork rings. Place the magnetic stirrer bar, and then a 0°C - 50°C thermometer, in each flask. Select one of the flasks to be the reaction vessel, and use it for this purpose throughout the experiment.

Pipette 50 ml of 1 M NaOH solution into the reaction flask, and set the stirrer in motion. Pipette 50 ml of 1.1 M HCl solution into the other flask, and stir as for the first solution. If you find that the two solutions have temperatures differing by more than 0.4°C,consult a demonstrator as to how you may equalise them. When the two solutions have been stirred for about 5 minutes, read the temperature of both solutions to the nearest 0.05°C, and record them (T_I).

Remove from the stirrer the flask containing the HCl solution and remove the stirrer bar using a spatula. Pour this solution quickly into the NaOH solution. Start a stop-clock, and read the temperature of the stirred mixture every minute for five minutes.

The temperature of the mixture will rise rapidly, as the reaction takes place, but it will then immediately begin to fall because of the imperfect insulation of the calorimeter. We may assume that cooling of the system is linear with time. To obtain the temperature of the solution immediately after neutralisation, T_N, plot the measured temperatures of the mixture versus time, draw the best straight line through the points, and extrapolate it back to zero time. The temperature rise produced by the neutralisation, ΔT_N, is then obtained as:-

$$\Delta T_N = T_N - T_I$$

where T_I is the average value of the initial temperatures of the two reactant solutions.

The heat evolved during the neutralisation reaction is equal to the sum of heat gained by the calorimeter and heat gained by the reaction mixture solution:-

$$Q' = q\ (\text{calorimeter}) + q\ (\text{solution})$$

The thermal capacity of the Dewar flasks has been determined as 40 J °C^{-1}. The specific heat of the reaction mixture is 4.025 J ml^{-1} °C^{-1}. For neutralisation of 50 ml of 1 M NaOH with 50 ml acid:-

$$Q' = (40 \times \Delta T_N) + (100 \times 4.025 \times \Delta T_N)\ .$$

The heat of neutralisation of 1 mole of NaOH, Q, can then be readily calculated from Q'.

<u>Part B:</u> Neutralisation of NaOH with $NaHSO_4$. Repeat the procedure outlined in Part A, but using 50 ml of 1.1 M $NaHSO_4$ solution instead of hydrochloric acid. Calculate the heat of neutralisation of 1 mole of NaOH with HSO_4^-. The specific heat of the reaction mixture is 3.895 J ml^{-1} °C^{-1} in this case.

<u>Assignments</u>

Comparing the measured heats of neutralisation of HCl and $NaHSO_4$ (in kJ/mol NaOH), state:-

(i) whether HSO_4^- is a strong acid in water, and

(ii) whether the dissociation reaction $HSO_4^- \rightarrow H^+ + SO_4^{2-}$ is endo- or exothermic.

Suggest two quite different methods to find out if HSO_4^- is a strong or a weak acid.

EXPERIMENT 5

ACTIVATION ENERGY (Ebbing pp 571-579)

In a reaction mixture molecules of the reactants are colliding with each other, and during such collisions their kinetic energies are transformed into potential energy. Since they move with different speeds, and thus possess different kinetic energies, they yield different amounts of potential energy during collisions. The minimum kinetic energy that must be possessed by the colliding molecules, if a collision is to be effective in producing a chemical change, is known as the *activation energy*. Hence, only the molecules with kinetic energies higher than the activation energy are able to react.

It has long been known that in nearly every instance a rise in temperature increases the rate of a reaction. This is because in a reacting system the fraction of molecules with sufficient kinetic energy to react increases with temperature.

Arrhenius was the first chemist to suggest that in a reacting system there are 'normal' and 'active' molecules, and that only the latter are capable of taking part in reaction. He postulated the quantitative relationship between the rate constant of reaction, k, the activation energy, E_a, and the absolute temperature, T:-

$$k = A e^{-Ea/RT} \qquad (1)$$

where the constant A is called the *preexponential factor*, and R is the gas constant. This relationship is known as the *Arrhenius equation.*

Determination of activation energy is important, for it provides information about energy changes that occur during effective molecular collisions. Furthermore, if E_a and k at a particular temperature are known for a given reaction, then the value of its rate constant at other temperatures can be calculated. One way to determine the activation energy of a reaction is to measure its rate constant at two, or preferably more, different temperatures. In this experiment we will use a variation of this method as outlined below.

Consider a reaction in which the concentration of reactant, A, is decreasing with time, t. The rate of the reaction can then be expressed as:-

$$Rate = -\Delta[A] / \Delta t$$

if Δt is very small. Now the way in which the reaction rate varies with reactant concentration depends on the *order* of the reaction. If the concentration of A is initially $[A]_0$ and after some time, t, it reduces to $[A]_t$, the following relationships apply for the orders shown:-

Zero order reaction :	Rate $=k$:	$kt = [A]_0 - [A]_t$
First order reaction :	Rate $=k[A]$:	$kt = \ln[A]_0 - \ln[A]_t$
Second order reaction :	Rate $=k[A]^2$:	$kt = 1/[A]_t - 1/[A]_0$

We therefore note that, whatever the order of a reaction, the product kt depends only on $[A]_0$ and $[A]_t$ and is a constant if $[A]_0$ and $[A]_t$ are given *fixed* values.

If we carry out a given reaction at different temperatures, but each time start with the same reactant concentration and let the reaction proceed to the same extent ($[A]_0$ and $[A]_t$ are fixed), then:-

$$kt = \text{constant} = B$$

Since k varies with temperature (equation 1), the time it takes for the reaction to proceed to the same extent, t, also varies with temperature.

Substitution of k in (1) with B / t gives

$$B / t = A\, e^{-Ea/RT}$$

or:-

$$t = C\, e^{Ea/RT}$$

where $C = B / A$.

Taking the natural logarithm of this equation we obtain:-

$$\ln t = \ln C + E_a / RT$$

A plot of ln t against 1 / T gives a straight line with a gradient equal to E_a / R. The activation energy of the reaction, E_a, can therefore be determined from the gradient of this line.

Experimental

The object of this exercise is to determine the activation energy of the reaction between persulphate, $S_2O_8^{2-}$, and iodide, I^-, by observing the effect of temperature on the rate of reaction.

The reaction, which in aqueous solution takes place according to the stoichiometry:-

$$S_2O_8^{2-} + 2I^- \rightarrow 2SO_4^{2-} + I_2 \qquad \text{(i)}$$

will be carried out at different temperatures in the presence of starch as an indicator.

Before mixing the reactants, a given amount of thiosulphate, $S_2O_3^{2-}$, will be added to the I^- solution and thus any iodine, I_2, produced by reaction (i) will be instantly converted back to iodide:-

$$I_2 + 2S_2O_3^{2-} \rightarrow 2I^- + S_4O_6^{2-} \qquad \text{(ii)}$$

until all the thiosulphate has been oxidised. As soon as that happens the reaction mixture will turn deep blue, due to the formation of a complex of iodine and starch.

To keep the starting reactant concentrations and the extent of the reaction constant at all temperatures, solutions with the same initial iodide, persulphate and thiosulphate concentrations will be prepared, together with starch indicator, for each experiment. The time it takes from the moment of mixing to the appearance of the blue iodine-starch complex colour, t, will be measured at each temperature.

The reaction will be carried out at 10, 15, 20, 25, 30 and 35°C.

Procedure

1. Pipette into a boiling tube (A) 20 ml of 0.01 M $K_2S_2O_8$ and ten drops of starch solution. Pipette into another boiling tube (B) 20 ml of 0.5 M KI and 10 ml of 0.01 M $Na_2S_2O_3$ solution. Label the tubes.

2. Immerse the boiling tubes in a constant temperature bath. When both solutions have attained the bath temperature, pour the contents of tube A into the tube B, start the clock immediately, and mix the reaction mixture by stirring carefully with the thermometer. Monitor the temperature of the reaction mixture frequently, and take the average value as the temperature of the experiment (T °C). Measure the time it takes for the blue colour to appear (t seconds).

3. Tabulate the results in the following way:

T (°C)	T (K)	1 / T (K^{-1})	t (s)	ln t
-	-	-	-	-

4. Repeat the above procedure at each of the remaining five temperatures.

Assignments

1. Plot ln t against 1 / T and determine the activation energy of the reaction (i) in kJ mol^{-1} (R = 8.314 J K^{-1} mol^{-1}).

2. From your results determine the effect of a 10 degree rise in temperature on the rate of the reaction.

Appendix G

Paper Laboratories

Paper Lab 1

Making Simple Inorganic Compounds

Aims: To establish the simple rules for inorganic interconversions so that you can work out reasonable reaction routes.
To enable enable you to understand, plan and operate a laboratory experience at school level based on simple inorganic interconversions.

Part 1 Solubility and insolubility

Many inorganic compounds are ionic, especially those involving metals. Some of these compounds have low solubility in water (we call them insoluble) while others dissolve well (we call them soluble).

Many rocks are inorganic ionic compounds. As it rains, the more soluble rocks dissolve and are washed into the sea. Look at the sea. There are numerous different ions dissolved in sea water. Alongside, there is a list of the more common ions in the sea.

ion	% by mass in the sea
Chloride	1.935
Sodium	1.077
Magnesium	0.129
Sulphate	0.090
Calcium	0.041
Potassium	0.041
Bromide	0.007
Carbonate	0.003

Look at the table alongside.

(a) The amount of bromide ion in the sea seems very low but it is still worth extracting from the sea. Suppose you have 1 tonne (1000 Kg) of sea water. Calculate the mass of bromine which you could obtain from this.

Mass of bromine obtainable from 1 tonne sea water = ... g

(b) Think of 1 cubic kilometre of sea water. Estimate the mass of bromine in this volume of sea water?

Mass of bromine in 1 cubic kilometre of sea-water = ...

.... tonnes

(c) Almost all carbonates are insoluble in water. Suggest why there is so much carbonate ion in sea water by thinking from where it might have come.

....

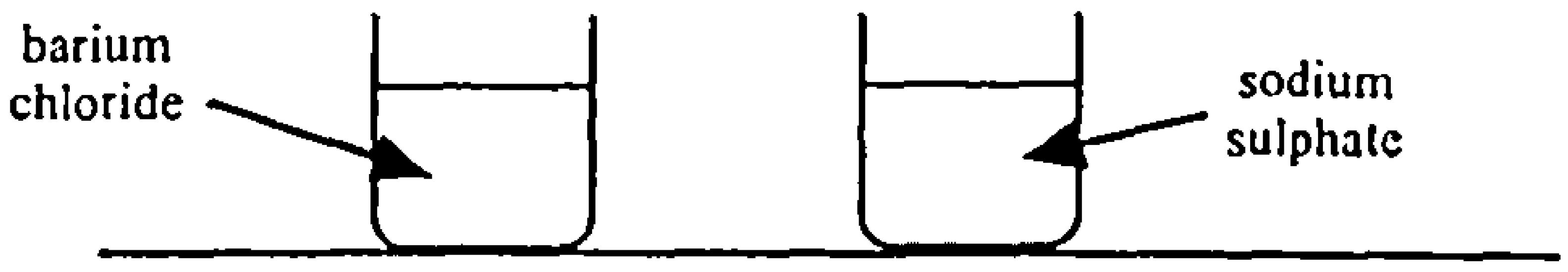
Now turn over for the answers

Answers to the questions

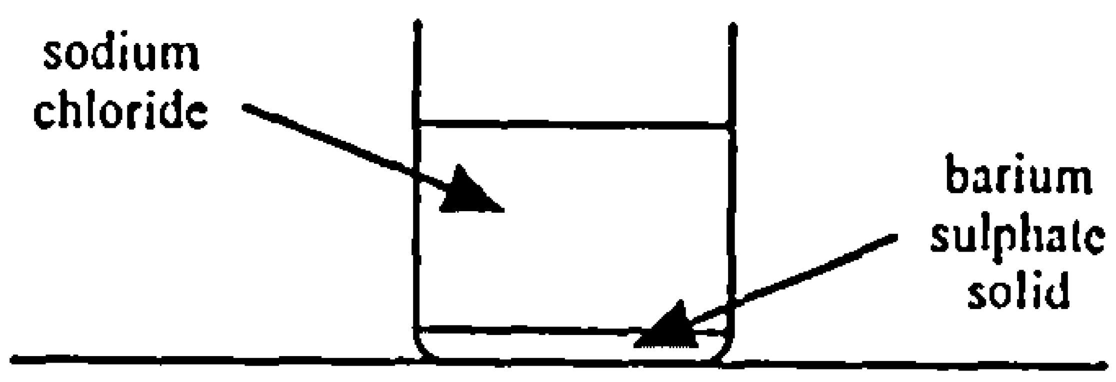
(a) 70g
(b) 7 X 10^4 tons
(c) Did you think of the atmosphere? Carbon dioxide dissolves slowly in sea water to give carbonate ions.

In solution in water, ions move around but they will form solids when the solid is insoluble in water.

Here are two solutions in two separate beakers:



In one beaker, there is a solution of barium chloride. Being soluble in water, the barium and chloride ions are free in the water. In the other beaker, sodium and sulphate ions are present in the water.



If the two solutions are mixed, the barium ions and the sulphate ions link together to form insoluble barium sulphate which, in a few minutes, settles to the bottom of the beaker as a precipitate, leaving the sodium and chloride ions free in the water above.

This gives us a very neat way to obtain barium sulphate, separated from the sodium chloride. All we have to do is to filter off the solid barium sulphate, wash it in clean water and we have obtained barium sulphate.

Here is another example. We wish to make copper (II) carbonate (which is insoluble) from copper (II) sulphate (which is soluble). We have to add a compound which contains carbonate ions but which is also soluble in water. Sodium carbonate is water soluble.

If we add sodium carbonate solution to copper sulphate solution, the copper ions form insoluble copper (II) carbonate with the carbonate ions. We can summarise the reaction:

$$\underset{\text{(soluble)}}{CuSO_4} + \underset{\text{(soluble)}}{Na_2CO_3} \longrightarrow \underset{\text{(insoluble)}}{CuCO_3} + \underset{\text{(soluble)}}{Na_2SO_4}$$

If we know the solubilities of compounds, we can work out simple ways to make compounds from each other

Remember:	**In solutions containing ionic compounds, the ions are free. If two ions form an insoluble compound, this allows us to separate this compound from the other ions in the solution.**

Please Turn Over

Here is a summary of the solubilities of some compounds:

(1) Compounds contained column I metals (eg sodium and potassium) are soluble in water;
(2) All nitrates are soluble in water;
(3) Most sulphates (except barium sulphate and lead sulphate) are soluble in water;
(4) Most chlorides (except silver chloride and lead chloride) are soluble in water;
(5) Most carbonates (except column I metal carbonates) are insoluble in water;
(6) Most oxides and hydroxides (except column I and II metals) are insoluble in water.

Now try the following:

(a) Given a solution of lead (II) nitrate [$PbNO_3$], how would you make lead (II) sulphate [$PbSO_4$] ?
(Write the equation for the reaction, showing which compounds are soluble and insoluble.)

....

(b) Given some crystals of calcium chloride, how would you obtain some crystals of calcium carbonate ?
(Describe what you would do clearly in words.)

....

....

....

(c) Describe how would you convert nickel (II) sulphate into nickel (II) nitrate

....

....

....

....

Your answers will be given in Part 2

Here are the answers

(a) $PbNO_3$ (*soluble*) + Na_2SO_4 (*soluble*) ⟶ $PbSO_4$ (*insoluble*) + $NaNO_3$ (*soluble*)

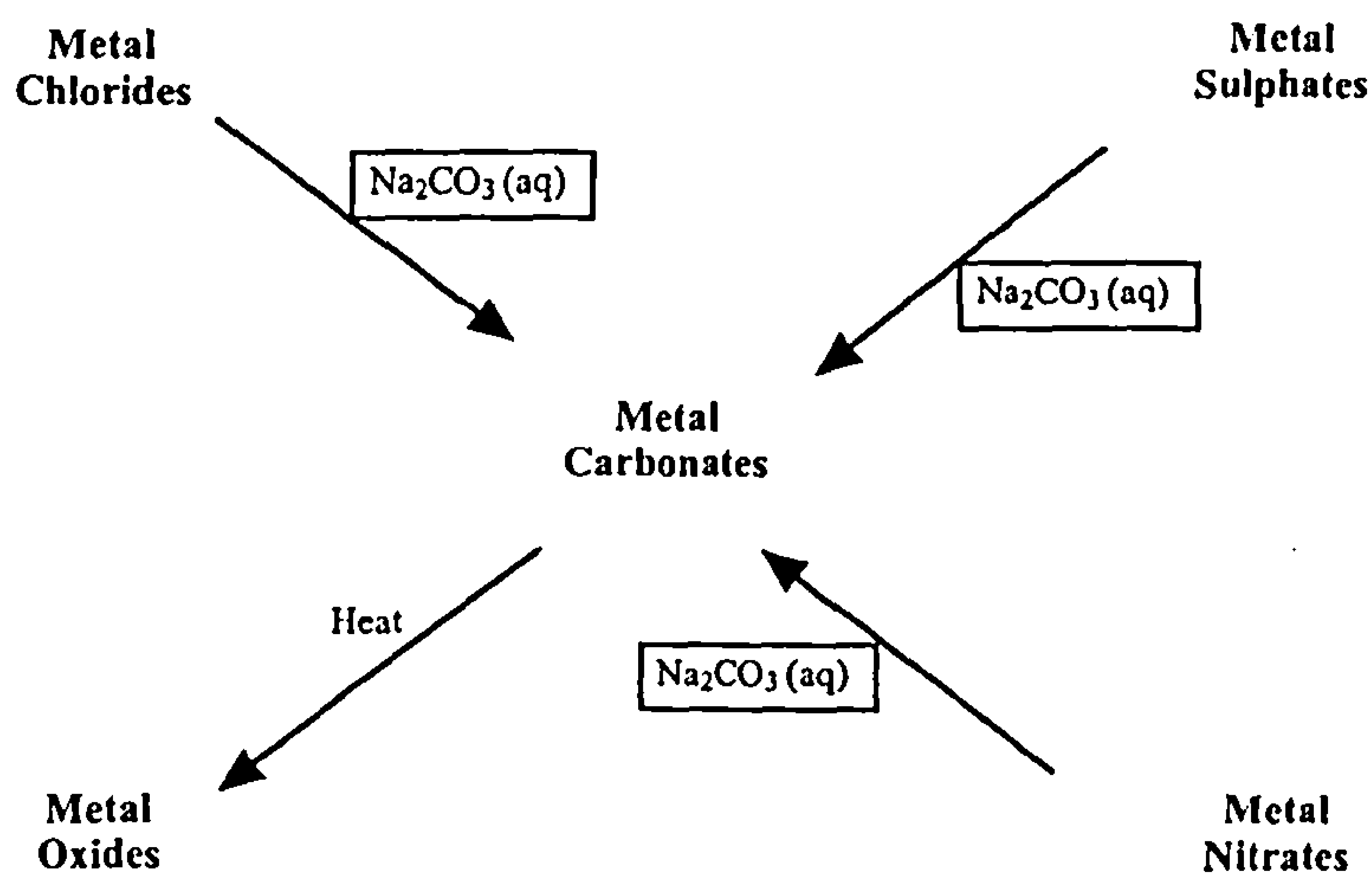
(b) Firstly, dissolve the calcium chloride crystals in some water. Add a solution of sodium carbonate. Calcium carbonate will form as tiny crystals. Filter off the calcium carbonate and wash the solid with some clean water. Leave to dry to obtain calcium carbonate crystals. [A useful trick is to heat the mixture before filtering. The heat energy allows the crystals to grow larger and it makes filtering quicker.]

(c) *In this case, both the nickel (II) sulphate and the nickel (II) nitrate are water soluble. Therefore, we must remove the sulphate ions as an insoluble sulphate (either lead sulphate or barium sulphate). Here we describe the method using barium sulphate.*

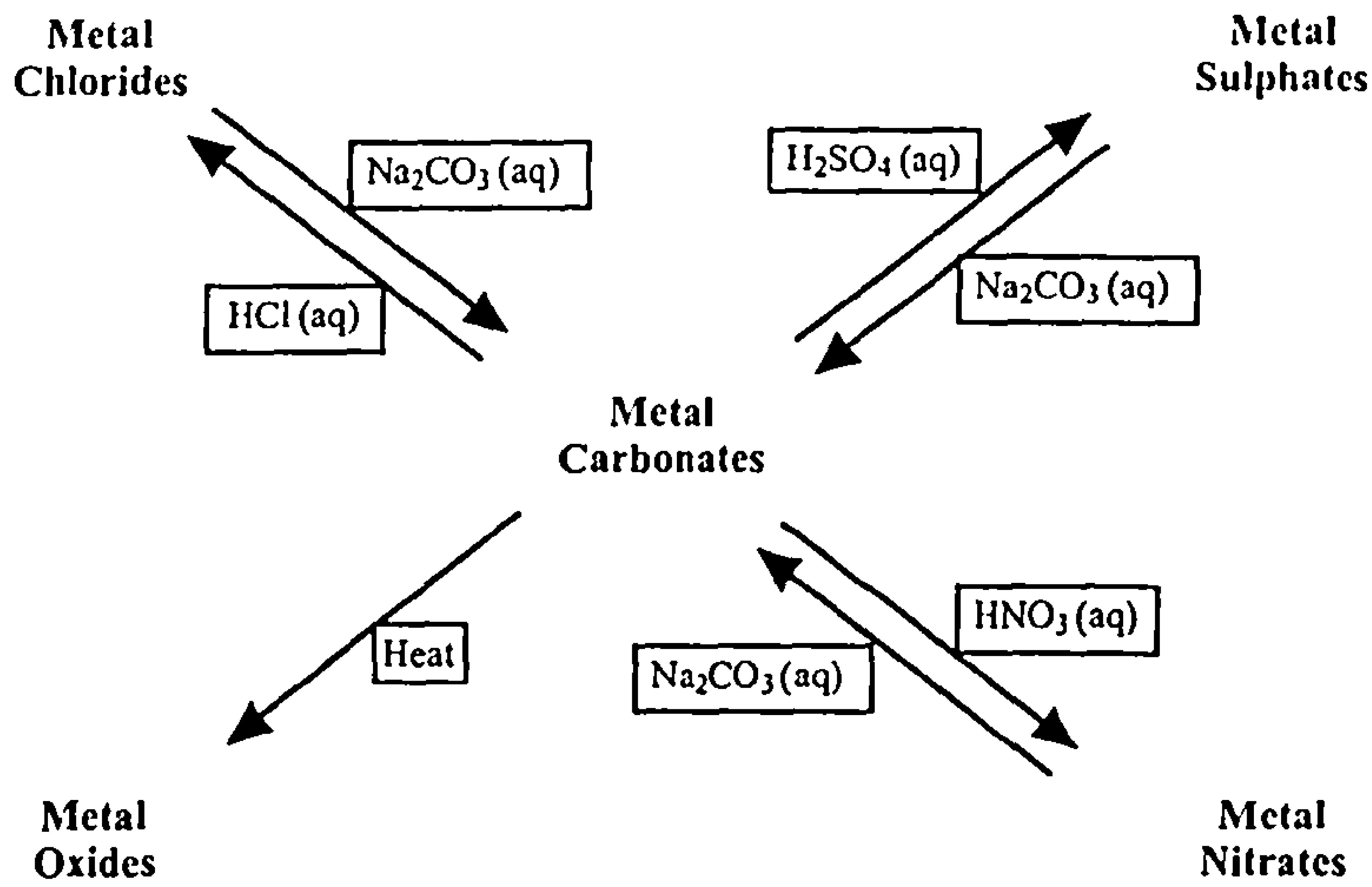
Dissolve the nickel (II) sulphate in water and add barium nitrate solution. Filter off the insoluble barium sulphate and collect the green solution of nickel (II) nitrate. Evaporate off half the water and then leave the solution to form green crystals of nickel (II) nitrate. [If we evaporate off all the water, the nickel (II) nitrate may decompose with the heat].

Making Inorganic Compounds

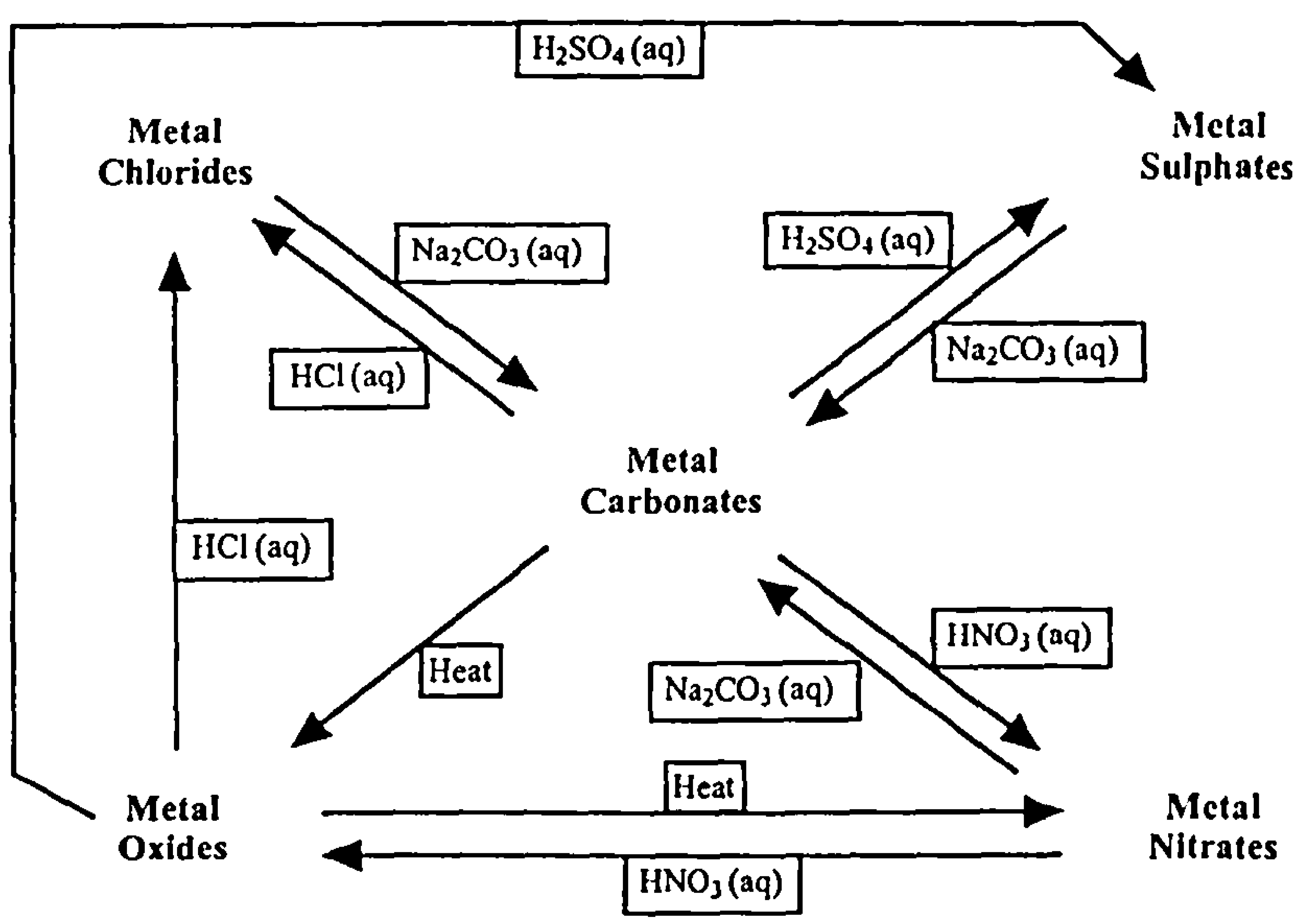
If we treat solutions of metal chlorides, nitrates or sulphates with sodium carbonate (a soluble carbonate), we obtain the insoluble metal carbonate which can be filtered off, washed and dried:



However, carbonates react with acids to forms salts, carbon dioxide and water. This gives us an easy way to make chlorides, nitrates and sulphates from metal carbonates. We can add this to our diagram:



Finally, you will remember that metal oxides react with acids to form salts and water. Also metal nitrates decompose with heat to give metal oxides. This allows us to complete the diagram.



Your Task

Imagine you are to write the instructions for an experiment which your school students will carry out in the laboratory. Your instructions must:

(a) Be in the correct order;
(b) Be simple and clear;
(c) Show your school students what to expect at each stage.

The experiment is:

> *Given some crystals of copper (II) sulphate, make some crystals of copper (II) carbonate and then convert these to give a solution of copper (II) nitrate. You are given beakers, a funnel, filter paper and a stirring rod, a bunsen and tripod stand, some sodium carbonate solution and some nitric acid solution.*

Write your instructions, as a series of steps, in the space below:

(a) ....

(b) ....

(c) ....

(d) ....

(e) ....

(f) ....

(g) ....

(h) ....

(i) ....

(j) ....

Your answer will be given in Part 3

Part 3 Applying the ideas

Here is the set of instructions for your school students.

(a) Dissolve some blue copper (II) sulphate crystals in a little water, stirring as necessary.
(b) Add sodium carbonate slowly to the copper sulphate solution until not more pale green copper (II) carbonate is seen to form.
(c) Heat the mixture very gently for a few minutes using the Bunsen, sitting the beaker on a tripod stand.
(d) Allow the mixture to cool for a few minutes and the pour carefully through the filter paper in the filter funnel.
(e) Wash the pale green solid with a little clean water.
(f) Scrape the green solid into another beaker.
(g) Add nitric acid very slowly until the green solid almost all dissolves.
(h) Filter the dark green solution to remove the last traces oil the pale green solid
(i) Heat the dark green solution and boil off half the water
(j) Leave the dark green solution for a few days until the water evaporates and you will obtain attractive needle like green crystals of $NiNO_3$

Magnesium from the Sea

Although magnesium occurs widely in rocks, it is easier to obtain magnesium compounds from the sea. The important compound we want is magnesium oxide. This has a wide range of uses including agriculture, glass manufacture, pigments, plastics and electrical insulation.

Ion	% by mass in the sea
Chloride	1.935
Sodium	1.077
Magnesium	0.129
Sulphate	0.090
Calcium	0.041
Potassium	0.041
Bromide	0.007
Carbonate	0.003

We have to find some compound of magnesium which will be sufficiently insoluble in water to be able to filter from the sea water as a solid. However, whatever we add to the sea water to form this compound must not also cause insoluble compounds of other metal ions to form.

Here are some data for solubilities at 25°C.

Magnesium Compound	Solubility (gl-1)	Calcium Compound	Solubility (gl-1)	Sodium Compound	Solubility (gl-1)	Potassium Compound	Solubility (gl-1)
$MgCO_3$	0.100	$CaCO_3$	0.015	Na_2CO_3	180	K_2CO_3	1120
$Mg(OH)_2$	0.009	$Ca(OH)_2$	1.56	NaOH	1090	KOH	1120
MgF_2	0.08	CaF_2	0.016	NaF	40	KF	950

(a) Work out which magnesium compound to form from the magnesium ions in the sea water. remember, it must be insoluble and not likely to be contaminated by other insoluble compounds.

Your choice: ....

(b) Work out what you might add to the sea water to obtain this magnesium compound.

Your choice: ....

(c) Having obtained this magnesium compound as a precipitate form the sea, how will you convert it into magnesium oxide:

Your reaction: ....

Part 4 Final Thoughts

(a) $Mg(OH)_2$ — It cannot be the fluoride because solid CaF_2 will also appear
It cannot be the carbonate because solid $CaCO_3$ will also appear.

(a) $Ca(OH)_2$ — In fact, you could use NaOH or KOH but $Ca(OH)_2$ is less expensive

(c) $Mg(OH)_2$ — decomposes with heat to give the oxide and water:

$$Mg(OH)_2 \longrightarrow MgO + H_2O$$

Some Interesting Extras

(a) Most rocks are silicates. Silicates, like carbonates, are highly insoluble in water and do not wash into the sea.

(b) Iodides, like chlorides and bromides, are usually,water soluble and wash into the sea. However, an analysis of sea water shows that there is almost no iodide ions in the sea. Certain types of sea weed have absorbed all the iodide ions and, in some countries, there is an industry to extract the iodine form the sea weed.

(c) All nitrates are water soluble and you would never expect to find nitrate rocks. However, in parts of Chile, it never rains and there are nitrate deposits. In the past, these were mined and explored as the basis of fertilisers.

(d) We have based everything in this paper lab on solubility. However, this is not quite correct. Strictly speaking, we have to talk about solubility product.

Consider an insoluble salt like magnesium hydroxide. Even insoluble compounds dissolve to some extent.

The solubility product for $MgOH)_2$ is: $k_{sp} = [Mg^{2+}][(OH^-]^2 = 1.2 \times 10^{-11}$

We want to remove the maximum amount of the magnesium ions form sea water and this is achieved by adding an excess amount of hydroxide ions (as calcium hydroxide). Because the solubility product is a constant at a given temperature, increasing the concentration of hydroxide ions means that the concentration of magnesium ions falls in solution falls.

Paper Lab 2

Corrosion and Electrolysis

Aims: To enable the students to investigate aspects of corrosion of metals.
To enable the students to relate electrolysis to the process of corrosion.

Part 1 Corrosion of Iron

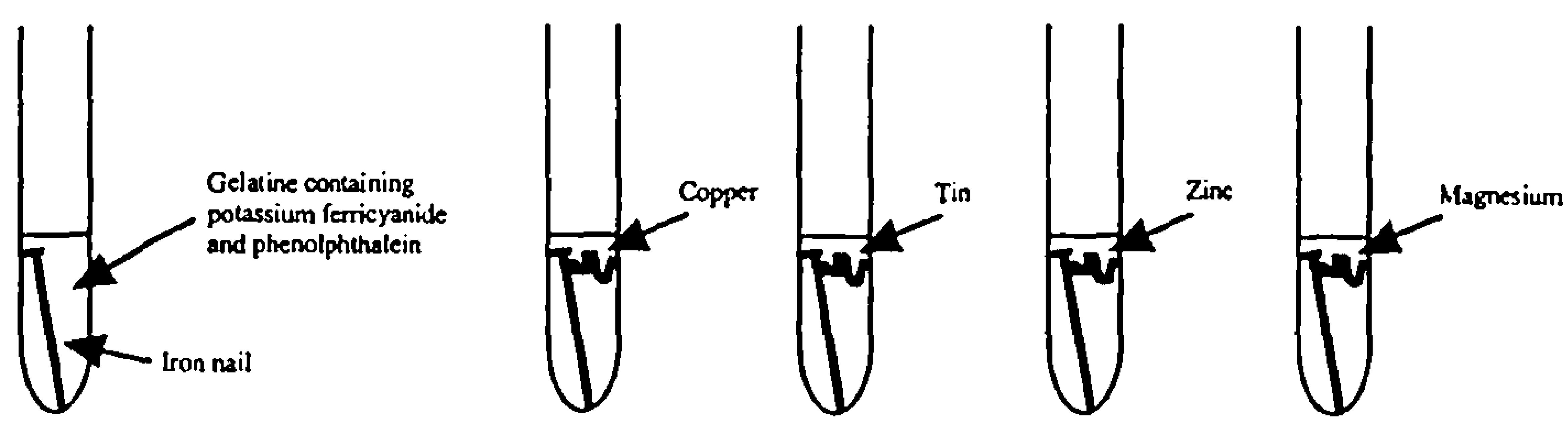
Metal corrosion is a most serious problem. Rain water usually contains acids by dissolving carbon dioxide and other industrial gases in the air. It has been estimated that over one-fifth of the annual production of iron in some countries goes to replace the iron lost by corrosion. Not surprisingly, chemists have given a great deal of thought to methods of reducing this loss.

Metals in the presence of water tend to shed electrons and change to metal ions. They undergo oxidation. During this process a loss of metal results. The general term applied to this change is corrosion and, in the special case of iron, it is called rusting.

Here is an experiment you can set up in which you can follow the corrosion that takes place when a piece of iron is coupled with various other metals in turn.

Take four shiny iron nails and to each attach a piece of different metals, such as copper, tin and zinc and magnesium (Figure 1).

Figure 1 Corrosion of Iron

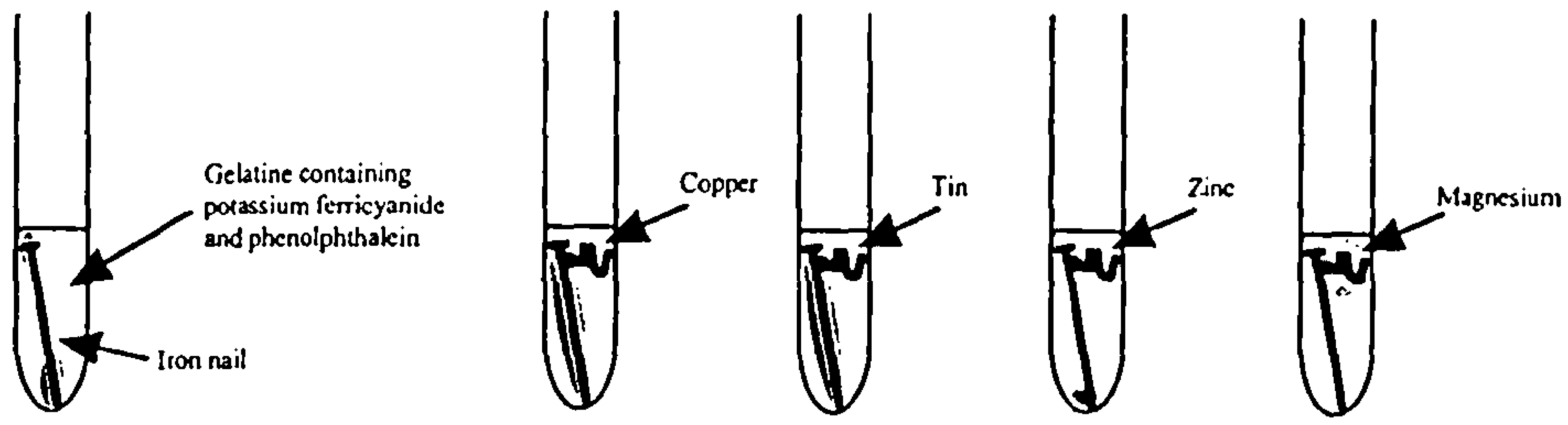


Remember:	5 gram of gelatine (jelly crystals) dissolved in 100 ml of hot water will give you 5% solution of gelatine in water. Add a small crystal of potassium ferricyanide and two drops of the indicator phenolphthalein

To Carry out the experiment

Cover each pair of metals with gelatine solution. Cool the test-tubes in cold water and allow them to stand until next day.

Potassium ferricyanide gives a strong blue colour with rust (Fe^{2+}) while phenolphthalein goes pink with hydroxide ions (OH^-). Here is what the tes tubes look like after a day or so.



Explain the following questions on the basis of your observations.

(a) Why is there so little rusting in the tubes containing magnesium and zinc ?

....

....

(b) Why does the pink colour appear in the tube containing magnesium but in no other tube ?

....

....

(c) Why is there more rusting in the tubes containing copper and tin ?

....

....

(d) Can you suggest another metal which would prevent the rusting of iron in the same way ?

....

Now turn over for the answers to part 2

Part 2 Reversing Corrosion

Here are the answers from the last part - how well did you do ?

(a) Mg and Zinc lose electrons more readily than Fe. The electrons move on to the iron. This prevents the iron from rusting by making the change Fe to Fe^{2+}(aq) +2e more difficult.

However, it speeds up the change from Mg to Mg^{2+}(aq) + 2e [or Zn to Zn^{2+}(aq) + 2e] because electrons are constantly being lost from the magnesium [or zinc].

(b) As the magnesium forms magnesium ions, some of the electrons react with hydrogen ions in the water in the jelly. If more H^+ are removed it means that there will be an excess of OH^- left in the solution.

(c) In these cases, the iron is more reactive than the other metals and passes electron to the other metals. The iron, having a way to lose electrons easier, rusts more rapidly.

(d) Any metal more reactive than magnesium but which will not react with the water in the jelly too fast (eg Aluminium).

> This method of preventing corrosion is referred to as 'cathodic protection' because of the negative charge (cathode) forced on to the iron. This has some important practical applications. One way in which underground iron pipelines are protected is by burying bags containing magnesium turnings near them at intervals. The magnesium is attached to the pipeline by a metal wire. The magnesium corrodes and electrons flow to the iron thus making it more difficult for iron (II) ions to form. The magnesium in time is destroyed and the known locations of the magnesium bags are checked periodically and replaced when necessary.

Norw Turn Over

The Idea of Electrolysis

You know that when metals go into solution they do so as positively charged metal ions or cations. The process is called oxidation.

For example : $Fe \longrightarrow Fe^{2+} + 2e$

The reverse process, reduction, causes a positively charged metal ion to gain electrons and appear as a recognisable metal.

For example : $Cu^{2+} + 2e \longrightarrow Cu$

During electrolysis, cations are being persuaded to accept electrons back again and so become neutral atoms. They receive these electrons at the negatively charged electrode (or cathode). The ease with which they undergo this reduction is in the order of the reactivity series backwards.

Copper will appear more easily than hydrogen and hydrogen more easily than all the metals above it. This explains why, during the electrolysis of the various salts solutions, the only metals you obtained were silver, mercury and copper, all below hydrogen in the reactivity series. In all other cases hydrogen was formed at the cathode.

Corrosion is the natural process. This reverse change is the unnatural one. Once in solution, cations have to be "dragged back", beginning with the "least reluctant" - the ones at the bottom of the reactivity series. These are the metals which were most reluctant to corrode in the first place.

But we must also think about what happens to anions at the anode during electrolysis. They too are discharged in a definite order. They lose electrons. We say that they undergo oxidation at the positively charged anode.

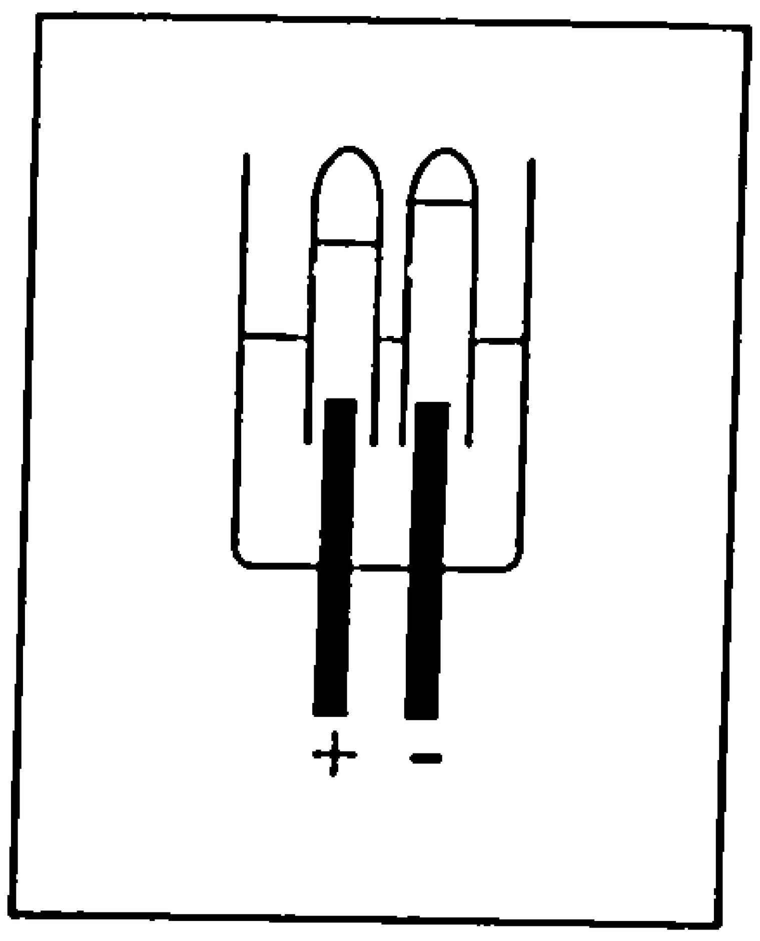
Remember: The order in which anions are discharged in experiments is:

(a)	I^-	The change here is from	$2I^-$	$\longrightarrow I_2 + e^-$
(b)	Br^-	The change here is from	$2Br^-$	$\longrightarrow Br_2 + 2e^-$
(c)	Cl^-	The change here is from	$2Cl^-$	$\longrightarrow Cl_2 + 2e^-$
(d)	OH^-	The change here is from	$4OH^-$	$\longrightarrow 2H_2O + O_2 + 4e^-$

Other anions, such as SO_4^{2-}, NO_3^- and F^- are not normally released from aqueous solutions..

Your Task

With the above knowledge you can now work out what would happen during an electrolysis. The apparatus is shown alongside. The electrodes are carbon. Can you explain the following examples and then check your results experimentally.



(a) The electrolysis of copper sulphate solution in water.

List all the ions present in the solution ?

....

What is formed at the cathode ? ....

What is formed at the anode ? ....

(b) The electrolysis of sulphuric acid solution in water.

List all the ions present in the solution ?

....

What is formed at the cathode ? ....

What is formed at the anode ? ....

(b) The electrolysis of an aqueous solution of sodium chloride.

List all the ions present in the solution ?

....

What is formed at the cathode ? ....

What is formed at the anode ? ....

Now turn over for the answers to part 3

Part 3 Applications of Experimental Ideas

Firstly, here are the results which would have been obtained from the experiments in Part 2.

(a) Cu^{2+} and SO_4^{2-} from the copper sulphate, and hydrogen ions, H^+ and hydroxyl ions, OH^- from the water.

At the cathode.	copper is deposited
	(*since copper is below hydrogen in the reactivity series*)
At the anode.:	oxygen is released

(b) H^+ and SO_4^{2-} from the sulphuric acid and H^+ and OH^- from the water.

At the cathode.	hydrogen is released
At the anode.:	oxygen is released

(c) Na^+ and Cl^- from the sodium chloride, and H^+ and OH^- from the water.

At the cathode.	hydrogen is released
At the anode.:	chlorine is released

Now Try these Problems

(a) In all the above experiments, it was assumed that water gave hydrogen and hydroyl ions. Of course, the concentration of these ions will be low as water ionises only to a small extent (in pure water the concentration of these ions is: $[H^+] = [OH^-] = 10^{-7}$)

Explain clearly what effect this might have on your predictions.

....

....

....

(b) If dilute sulphuric acid solution in water is electrolysed using an aluminium anode, what is released at the anode and what will be the effect on the aluminium ?

....

....

(c) In industry, copper metal is obtained as a block of metal containing small amounts of silver and lead. Work out a way, using electrolysis, to obtain a block of pure copper from the impure block. Draw a picture of the electrolysis cell. Show clearly where the impurities of each metal go.

....

....

....

....

Answers to Final Section

(a) In an electrolysis, all the positive ions will be attracted to the negative electrode (cathode).

Two main factors will decide which ion will be accept electrons:

In terms of energy, which ion is easiest to release (related to reactivity)
In terms of kinetics, what is the possible rate of release and this will depend in part on the ion concentration.

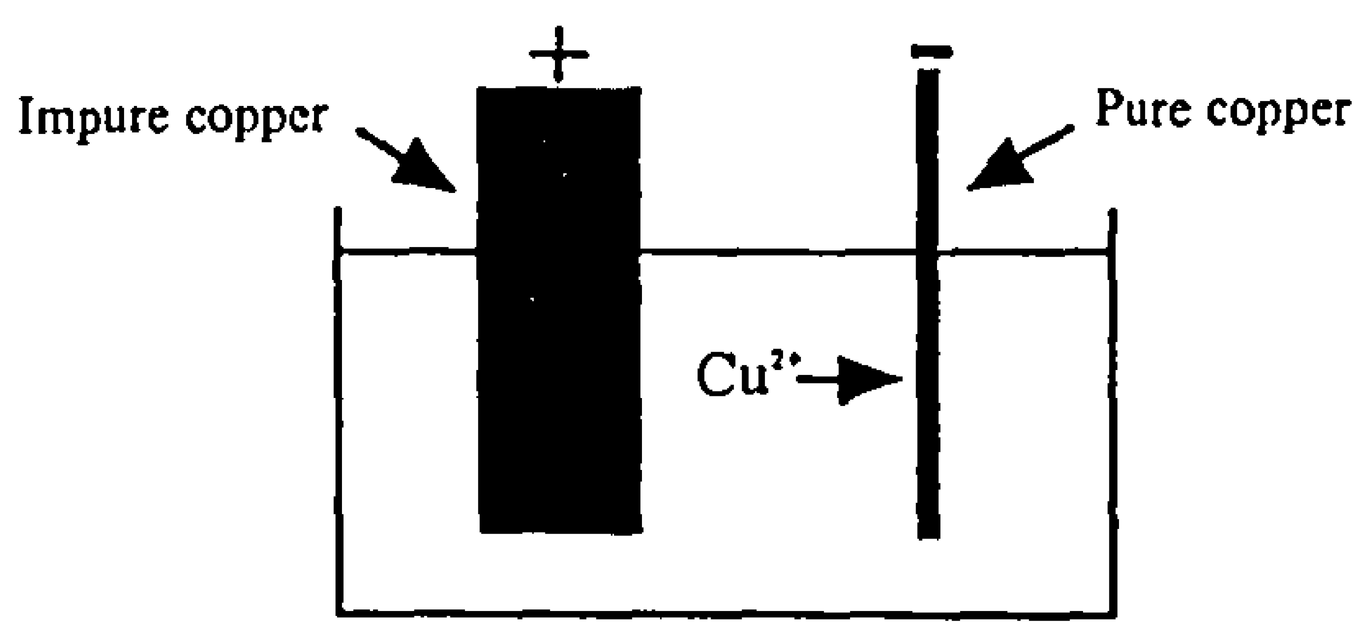
Despite the very low concentration of hydrogen and hydroxyl ions in water, these can still be discharged in that the kinetics of their discharge is more favourable than many metals.

However, if we change the kinetics (by, for example, adding complexing ions to the electrolysis mixture), we can change which ions are released. This is widely used in the metal plating industry.

(b) When sulphuric acid is electrolysed, oxygen is released at the anode. If this anode is made of aluminium, then the surface of the metal will react to form aluminium oxide. This can easily be tried in the laboratory. The surface of the aluminium goes slightly dull as the layer of aluminium oxide is thickened slightly. Aluminium oxide can be treated with coloured dyes and this is a useful way to make aluminium objects which are coloured and highly attractive. The aluminium object is made the anode of an electrolysis cell and then is dipped into a solution of dye. Again, this is easy to demonstrate in a school laboratory.

(c) The block of impure copper is made the anode of a cell where the solution is copper (II) sulphate. The anode is made of a thin wire of pure copper. As electricity is passed through, copper at the anode forms copper ions and these move into the solution. At the cathode, copper ions from the solution gain electrons and form copper.

Here is a diagram:



Any metals like silver in the impure copper will not form silver ions (silver is too unreactive) and will simply drop to the bottom of the cell to be collected at the end. Any metals like lead will form lead ions [Pb^{2+}]. However, these will not form lead on the negative electrode as lead is more reactive than copper. The lead ions will remain in the solution. Over several hours, the positive electrode will shrink in size and the negative electrode of pure copper will grow.

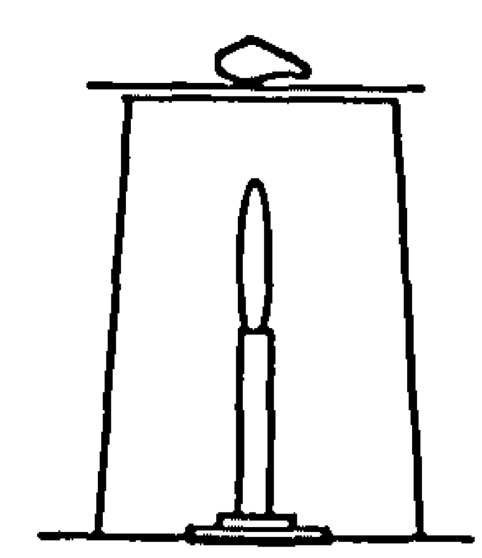
Paper Lab 3

Carbonate Rocks

Aims: To enable the student to prepare carbon dioxide from rock and other sources.
To enable the student to see the properties of carbon dioxide.
To enable the student to look the importance of carbon dioxide.

Part 1 Chalk and Carbon Dioxide

A student carries out the following experiment.



A piece of chalk (this is not always the the same material as blackboard chalk) is taken, placed on a watch glass and weighed. It is then placed carefully on to the comer of a wire gauze on a tripod stand.

The chalk is heated strongly for five minutes from below and above (by holding the burner at an angle). It is noticed that the lump glows with an intense white light (called limelight). After cooling the lump, it is tipped carefully back on to the same watch glass and reweighed.

(a) Do you expect it to gain or lose weight ? ☐ gain ☐ lose

(b) Do you expect the lump to look the same or different? ☐ same ☐ different

One drop of cold water is added to the cold lump.

(c) What do you expect to see ? ....

More water is added and the solution tested with litmus paper.

(d) What colour do you expect to see ? ☐ red ☐ blue

Now turn over for the answers

What Happens when Chalk is Heated

The chalk lost weight on heating and so some other substance must have escaped leaving an alkali-forming oxide. The white solid left after heating looks very like chalk but it dissolves inn water (producing heat energy as it does so) to give an alkali.

$$\text{Chalk} \xrightarrow{\text{Heat}} \text{Invisible gas} + \text{alkali-forming oxide}$$

The chalk has decomposed into two parts :

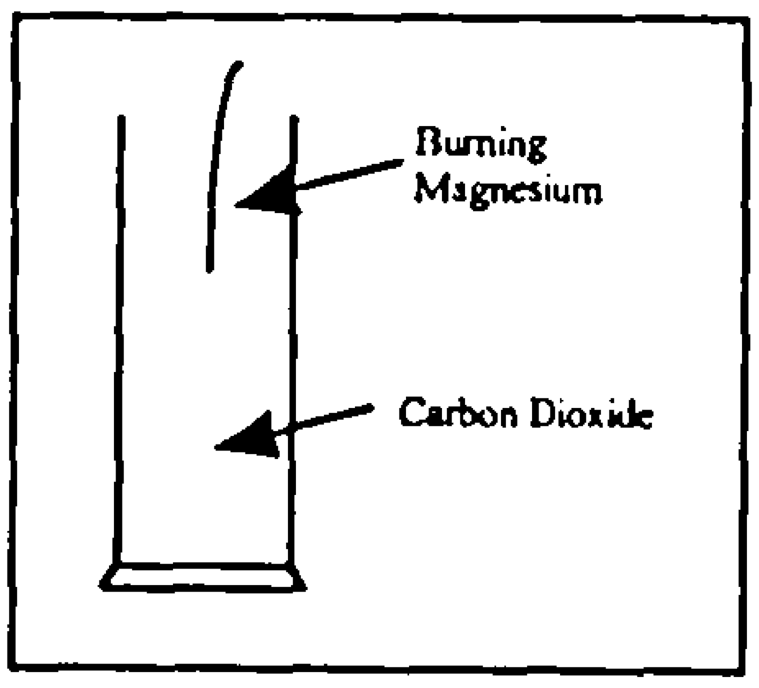
(a) A metal oxide which dissolves in water to give ab alkali.
(b) An invisible gas.

This invisible gas is called the carbon dioxide, one of the gases which animals and plants breathe out during respiration.

What Evidence is there that Carbon Dioxide contains Carbon

Here is another experiment.

It is possible to obtain a jar full of this gas.



A piece of burning magnesium held in a pair of tongs can be lowered into this jar of the gas.

The magnesium burns in the jar of carbon dioxide with a a crackling kind of sound. Specks of a black solid are observed along with a white powder. If the white powder is tested with damp litmus paper, the paper goes blue.

Write down the equation for the reaction you have observed.

....

What is the Solid left after heating the Chalk in the First Experiment ?

It is an alkali-forming solid. It has to be a metal oxide, containing a metal from columns 1 or 2 of the periodic table. But which metal ? What test would you use to find out which metal it was (the metals in the first two columns are shown alongside.

....

....

Column I	Column II
Lithium	Beryllium
Sodium	Magnesium
Potassium	Calcium
Rubidium	Strontium
Caesium	Barium

The Answers are given in Part 2

Part 2 The Nature of Chalk

Let us look at the evidence so far.

(a) When chalk is heated, it loses weight as an invisible gas, carbon dioxide, escapes.

(b) The white substance left is an oxide of a metal in column I or II - it dissolves in water to give an alkali.

(b) We can show that carbon dioxide actually contains carbon by burning magnesium in it when the following reaction takes place:

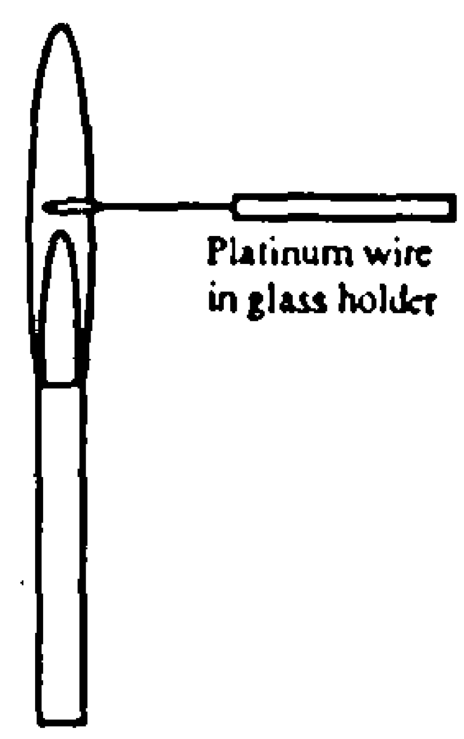
Carbon Dioxide + Magnesium ⟶ Carbon + Magnesium Oxide

(c) To find out what metal is in the oxide formed when chalk is heated, we can use a flame test.

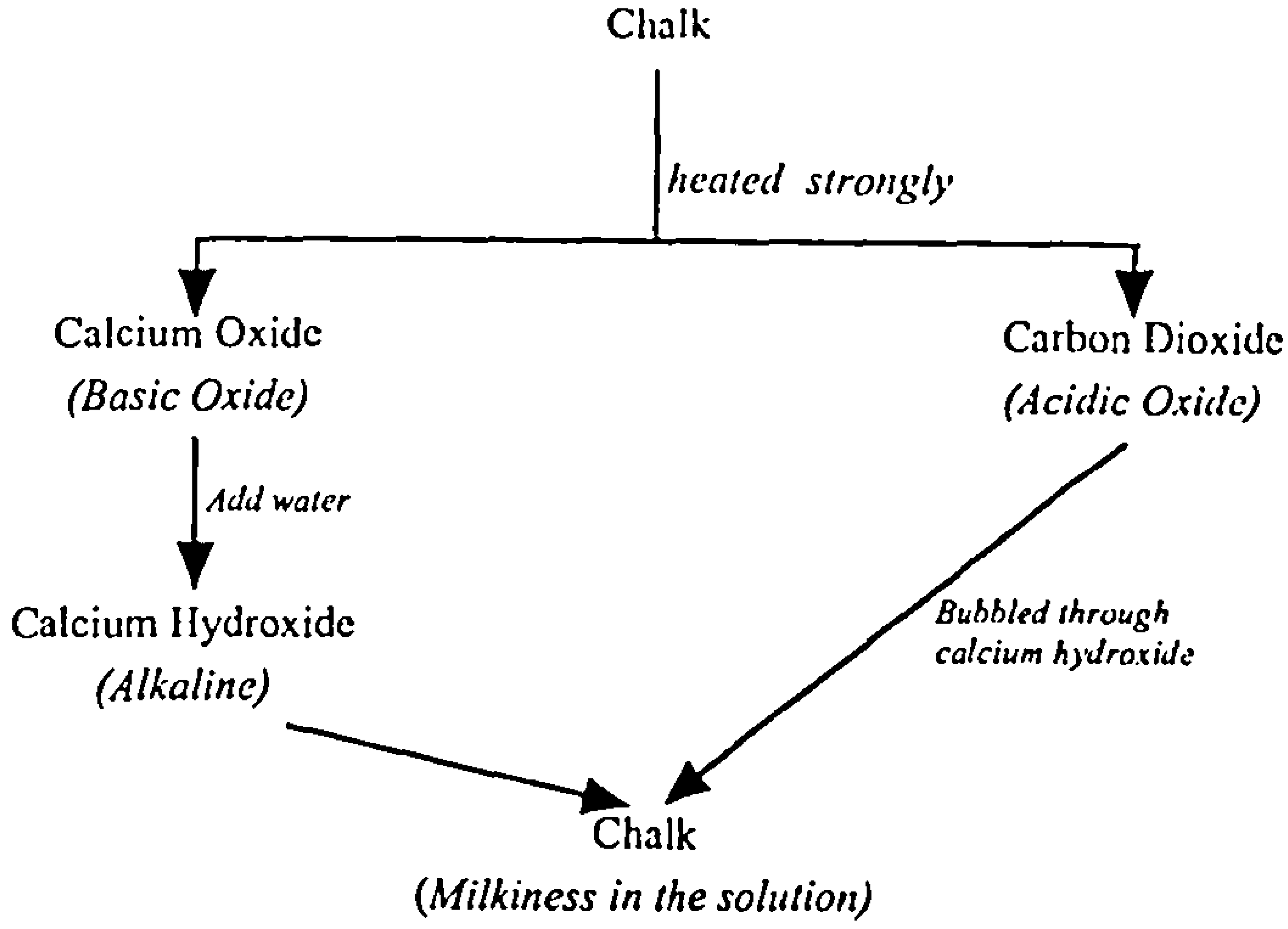
> The flame test is based on the fact that compounds containing metals, when heated in a hot flame, give a colour to that flame. Most metals release the light energy in the ultra violet and we cannot see it. However, several metals in columns I and II give light with a visible colour.
>
> To carry out the flame test, a loop of platinum wire is made, linked to a piece of glass (see diagram). The platinum wire is cleaned in concentrated hydrochloric acid and then dipped into a sample of the metal compound. The wire is placed in the hot flame (see picture). The colour is observed.
>
> The test takes practice to carry out. The problem is that the colour from sodium (strong orange -yellow) is so strong that it hides all other colours. Even a trace of sodium makes it impossible to see some of the other colours. To see potassium (which is a delicate pink-purple, called lilac), we observe the flame by looking through blue glass. This absorbs all the yellow light and we can see the colour for potassium. The calcium colour is a red colour which flickers in the flame. To see it, we need to put the platinum wire into the flame, back into the acid, and then back into the flame (perhaps several times) - it then shows clear as a clear reddish flicker before the yellow light shows.

Here are the colours we can observe:

Metal	Colour	Metal	Colour
Lithium	Crimson	Beryllium	Not visible
Sodium	Strong yellow	Magnesium	Not visible
Potassium	Pink-purple (lilac)	Calcium	Flickering Brick-red
Rubidium	Pink-purple	Strontium	Strong red
Caesium	Pink-purple	Barium	Light green



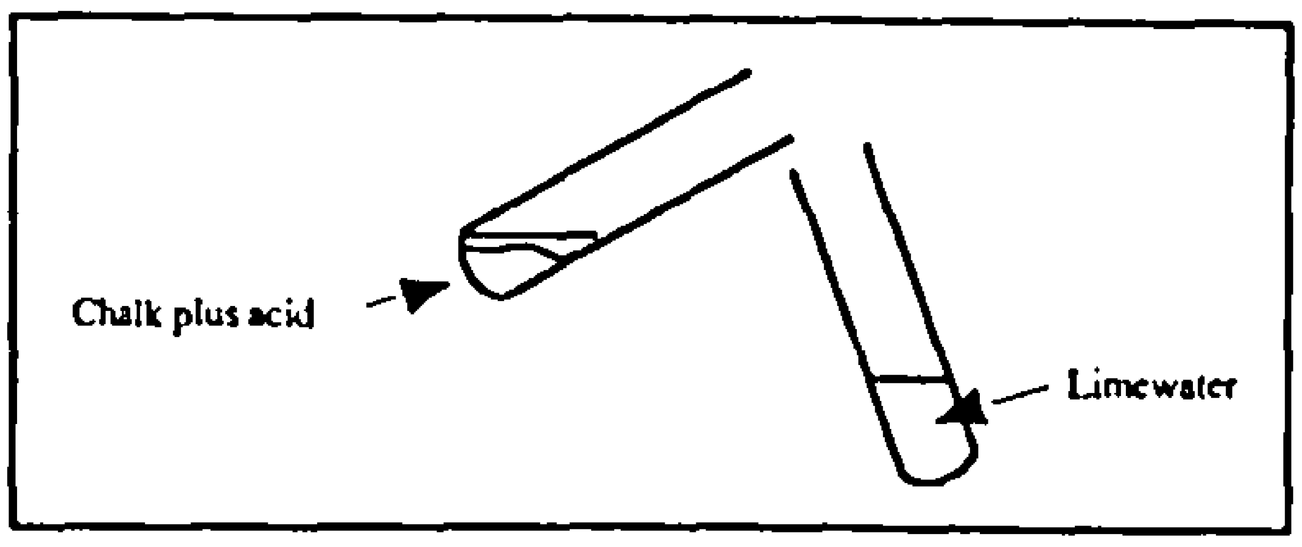
In fact, the metal oxide left after heating the chalk gives a flickering brick-red colour in the flame test, showing that it contains calcium.



Therefore, chalk is calcium carbonate

Another Method for Obtaining Carbon Dioxide

It is possible to obtain carbon dioxide from chalk (calcium carbonate) by adding acid to the chalk. Carbon dioxide is a dense gas and it can be poured from the test tube.



Now try the same experiment using sea shells. Take small piece of sea-shell and drop it into a little hydrochloric acid in a test tube. Pour the gas released into a second test tube (as shown) which contains some limewater. Now shake the lime water. Does it turn milky, showing that the gas released is carbon dioxide

Write the equation for the reaction:

....

Acids will release carbon dioxide form all carbonates:

Carbonate + Acid ⟶ Salt + Carbon dioxide + water

Part 3 Thinking Further

Your Tasks

(a) Look at the reaction of carbonates and acids. Here is a specific example:

$$SrCO_3 + 2HCl \longrightarrow SrCl_2 + CO_2 + H_2O$$

Strontium carbonate is found in a rock called strontianite. Dropping hydrochloric acid onto a sample of strontianite immediately gives a "fizz" of carbon dioxide escaping.

Think carefully about the reaction. Can you put forward an explanation why an acid like hydrochloric acid causes the release of carbon dioxide and the chloride to form.

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(b) Now try some materials at home to see if they are carbonates. You will add a few drops of acid to various materials and see if they "fizz". The most convenient acid at home is vinegar (which contains acetic or ethanoic acid).

Complete the following table.

Substance	Fizz observed?	Carbonate ?
Baking Powder		
Common Salt		
Washing Soda		
Sugar		
Self-raising flour		
Plain flour		

Part 4 Endpiece

Here are the answers to the questions in part 3.

(a) Your first thought might be to think in terms of reactivity and to think that hydrochloric acid is more reactive than carbonic acid.

In fact, it is nothing to do with reactivity. All reactions are equilibria and the reason why carbonates react with acids is simply that carbon dioxide escapes as a gas and cannot take the reaction backwards again. Thus, the reaction goes 100% one way to from the salt, water and carbon dioxide gas.

(b) Baking powder, washing soda and self-raising flour all contain carbonates and will 'fizz' with acid.

Other Information About Carbon Dioxide

Carbon dioxide is formed in our atmosphere by respiration and from the burning of fossil fuels. It is a greenhouse gas, and the increasing concentrations of the gas in our atmosphere are contributing to the warming up of the Earth.

It is removed by green plants during daylight and is absorbed by rainwater and the sea. It is extracted from the sea by many creatures who use the carbon dioxide and dissolved calcium to form calcium carbonate which makes their shells. Sea shells, coral, eggs shells all contain calcium carbonate. Huge deposits of such sea shells from past ages have been crushed under the sea and give rise to rocks like chalk, marble and limestone, all of which contain large amounts of calcium carbonate.

Carbon dioxide, when cooled sufficiently, turns to a solid. This solid is known as 'dry ice' and is used as a way of keeping things very cold. When under pressure, liquid carbon dioxide can be formed and this is used in some fire extinguishers. Passing the gas under pressure through water gives the basis of 'fizzy' drinks..

Carbon dioxide is formed during many cooking processes (such as the making of bread and cakes). As the gas escapes during cooking, the bubbles of gas cause the food to become lighter and more pleasant to eat.

Paper Lab 4

Fats and oils

Aims : To enable the student to know and understand fats, oils and their uses.
To enable the students to understand the chemistry of preparation of soap from fats and oils.
To enable the students to know the importance of soap and and the disadvantages.

Part 1 From Fats to Soap

Statistics show that people living in cold climates eat more fat than others in warmer countries. This is because fats, when digested, ultimately give more than twice the amount of energy as the same weight of carbohydrates.

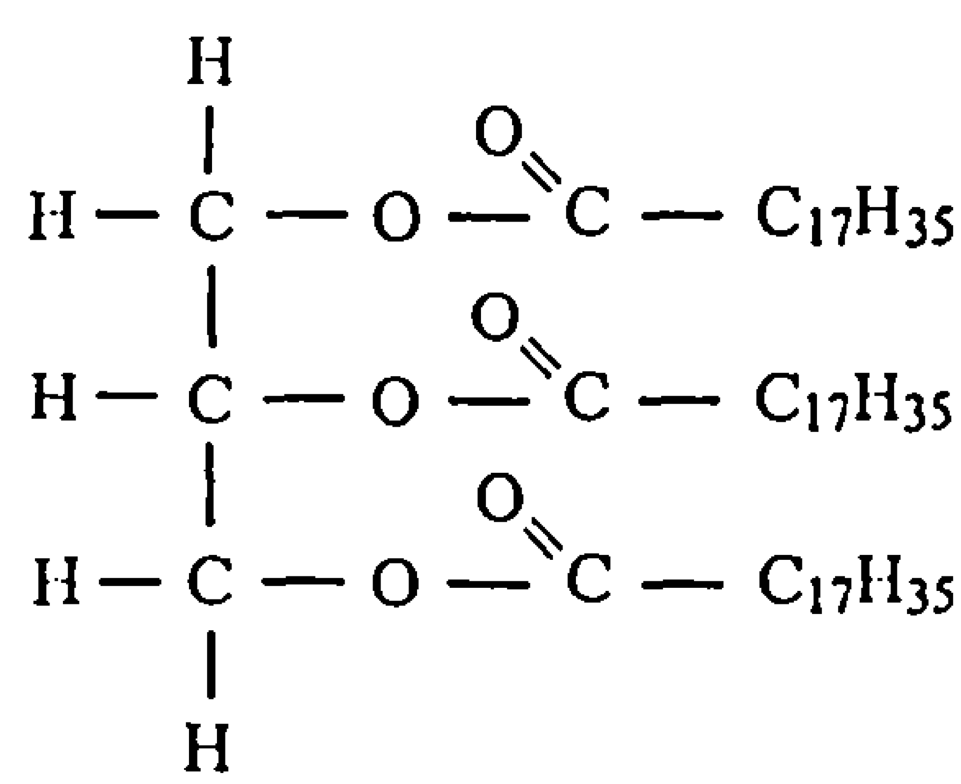
The breaking down of fats in the body takes about twice as long as the time required to break down carbohydrates. Perhaps you have noticed that you do not feel as hungry after having eaten a meal which included butter or cream as you would have done if these fats had not been included. Much of the fatty material which we eat is not burned up at once for energy purposes. It is broken down part-way only. This first stage in decomposition forms glycerine and an acid, both organic compounds.

$$\text{Fats} \xrightarrow{\text{first breakdown}} \text{Glycerol} + \text{Acid}$$

The acids are usually long chain carboxylic (alkanoic) acids with about 18 carbons in the chain. Typical is stearic acid [$C_{17}H_{35}COOH$] and Oleic acid [$C_{17}H_{35}COOH$]. Stearic acid is saturated while there is one double bond (half way along the carbon chain) in oleic acid. You can often see unsaturated fats being advertised and these are based on acids like oleic. Unsaturated acids tend to be liquids while their saturated counterparts are solids. Catalytic hydrogenation converts unsaturated acids into saturated acids.

From Fats to Soap

Fats are esters. Any ester can be broken down into the alcohol and acid by warming with acid or alkali for a short time. Here is the structure of a fat based on stearic acid and glycerol.



Tasks to Complete

(a) When fats are treated with acid or alkali and warmed, they break down (hydrolyse) to give glycerol (propan-1,2,3-triol) and the organic acid.

Write down the full equation for the hydrolysis of the fat shown above in:

(i) An acid solution:

(ii) A solution of an alkali like sodium hydroxide.

(b) Compare the products from the acid and alkaline hydrolysis.
In what way do the products differ ?

....

(c) The problem is to separate the glycerol from the stearic acid.

Look at the products from the alkaline hydrolysis. Can you think of a way to separate them ?

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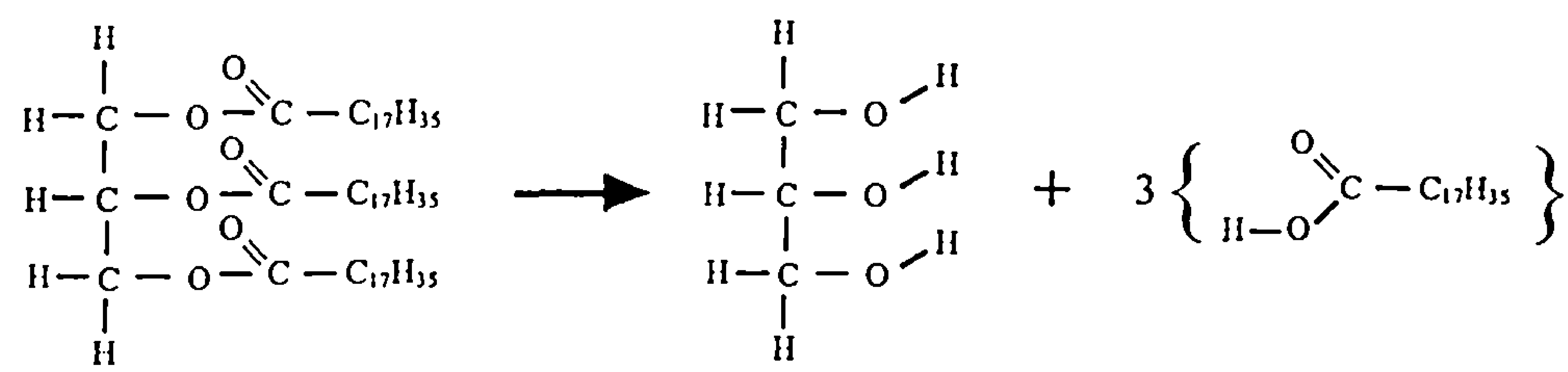
Now turn over to Part 2

Part 2 The Process of Hydrolysis

(a) (i) Here is the equation for acid solution, showing the molecules drawn out in full.



(ii) The reaction in alkaline solution is:

$$C_3H_5O_3\text{-}(C_{17}H_{35}COO)_3 \xrightarrow[\text{with NaOH}]{\text{warmed}} C_3H_5(OH)_3 \quad + \quad 3\ C_{17}H_{35}COONa$$

(b) With acid hydrolysis, glycerol and stearic acid are produced.
With alkaline hydrolysis, glycerol and sodium stearate are formed.

Sodium stearate is an ionic substance, the sodium salt of the acid. This forms as a solid in the reaction mixture, moving the equilibrium well to the right, to the formation of glycerol and the salt.

(c) Separation of glycerol and sodium stearate depends on solubility. The problem is that glycerol is very soluble in water. With three hydroxyl groups, hydrogen bonding possibilities are very large. Sodium stearate (one form of soap) is also water soluble although not as much.

However, if we add salt to the mixture, glycerol is still very soluble while sodium stearate has low solubility. This provides an easy way to separate them one form the other. Both are valuable. Sodium stearate for soap manufacture. Glycerol is used in the catering industry and also as the raw material to make nitro-glycerine (a useful explosive which is the basis of dynamite)

The Preparation of soap

You might like to try to make some soap in the laboratory. Thoroughly mix about 13 g of a cooking oil with 40 g of a solid fat (like an animal fat). Then, add a tiny amount from a bar of household soap – less than 0.5 g . While this mixture is being heated slowly to about 95°C in an evaporating basin, weigh out 6 g of sodium hydroxide pellets. Dissolve them very carefully in 20 ml of water.

Very carefully add this sodium hydroxide solution, two or three drops at a time, with constant stirring, to the hot fat mixture. When all the solution has been added keep stirring the mixture carefully until it stiffens to such an extent that it comes away from the basin. This takes about half-an-hour.

When the contents of the basin have cooled, transfer them to a 500 ml beaker and add 60 ml of hot water. Stir and heat over a small flame for another thirty minutes by which time the mixture will form a thick even paste. To salt out the soap, add an equal volume of a hot saturated solution of salt in water to the almost boiling paste. Stir thoroughly for a few seconds and then leave. Glycerol dissolves easily in salt water but soap can only do so to a very limited extent. This mixture should be left to stand for several hours and the soap will separate as a solid layer at the top.

The soap can be tested with shaking it with some water to see if it forms a lather. If you want to purify it, mix up the solid soap with hot water and stir until it forms an even paste. you can can some perfume if you like. Leave it for several hours and the soap will float upwards, leaving the impurities in the lower water layer. This soap can now be used to wash your hands.

Task for you do Complete

(a) In a few sentences, explain clearly, with diagrams where helpful, *WHY* glycerol (glycerine) is so water soluble and soap has a much lower solubility in water

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(b) Think about the molecule sodium stearate { $C_{17}H_{35}COO^- Na^+$ }

If a sample is dissolved in water, what pH would you expect:

☐ above 7 ☐ about 7 ☐ below 7

Explain your answer clearly:

....

....

(c) Think about the molecule sodium oleate { $C_{17}H_{33}COO^- Na^+$ }

This also works as a soap.

However, after a quite a while it can start to smell.

In what way does the molecule of sodium oleate differ that of sodium stearate ?

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Suggest what might be happening to the sodium oleate molecule after some time.

....

....

Now turn over to Part 3

Answers to the questions.

(a) Glycerol is a three carbon chain with three hydroxyl groups. These hydroxyl groups can form hydrogen bonds with water molecules and this enable glycerol to dissolve well in water.

Sodium stearate contains a 17 carbon hydrocarbon chain. Hydrocarbons do not mix with water as there is limited attraction between the covalent bonds and the highly polar water. The ionic sodium salt (at one end of the molecule) is attracted to water and allows the molecule to dissolve to a limited extent.

The hydrocarbon end of the molecule is attracted to oils, grease and dirt while the ionic end of the molecule is attracted to water. Soap works by bringing the grease and dirt into solution, held there by the hydrocarbon chain.

(b) Sodium stearate will be strongly alkaline. Pure rainwater has a pH about 5.8 (due to dissolved carbon dioxide). Soaps require to have their pH adjusted to nearer 5.8 by adding small amounts of acid.

Sodium stearate is based on a strong (100% ionised) alkali and weak (<5% ionised) acid. When it dissolves in water, it hydrolyses, thus giving the high pH.

(c) Sodium oleate contains two less hydrogens and, therefore, must contain a carbon-carbon double bond in the hydrocarbon chain(in fact, exactly half way along the chain. After a time, air oxidation takes place at the double bond and the molecule splits. The hydrocarbon chain gives the smell (oils like petrol and diesel are smelly).

Problems with Soap

In many parts of the world, soap does not form a lather with the tap water. Instead a grey scum appears which clings to fabrics and spoils their appearance. This kind of water is said to be 'hard'. The reason water is 'hard' is because it contains dissolved calcium ions. The dissolved calcium comes from limestone (containing calcium carbonate) rocks or rocks containing gypsum (which is calcium sulphate).

Calcium sulphate has a low solubility but rainwater passing over such rocks will dissolve small amounts. Calcium carbonate is not soluble in water but rainwater contains dissolved carbon dioxide. This means that rainwater is a very dilute solution of carbonic acid. This dissolves calcium carbonate slightly to form calcium hydrogen carbonate which is water soluble.

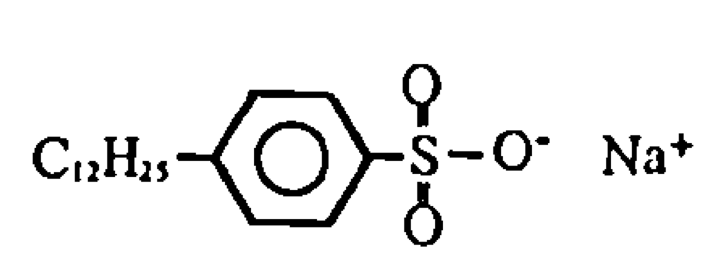
$$CaCO_3 \quad + \quad \underset{\{H_2CO_3\}}{H_2O + CO_2} \longrightarrow Ca(HCO_3)_2$$

The scum is formed because the calcium salt of soaps are insoluble in water.

There are two ways to approach the problem of hard water forming scum.

(a) Remove the calcium ions before soap is used.
  (i) Boiling causes the calcium hydrogen carbonate to decompose to calcium carbonate (insoluble)
  (ii) Adding sodium carbonate causes the calcium ion to form calcium carbonate (insoluble)
  (ii) Passing through ion exchange where the calcium ions are replaced by sodium or hydrogen ions

(*b*) *Re-design* the soap molecule to give a molecule whose calcium salt is water soluble
  (i) Detergents are re-designed soap *molecules which are unaffected* by calcium ions:. Here is the structure of a typical detergent molecule:



Your Task

As a teacher of secondary school, you are to write the instructions for an experiment which your students will carry out in the laboratory. Your instructions must :

(a) Be in the correct order;
(b) Be simple and clear;
(c) Show your school student what to expect at each stage.

The experiment is gaining evidence that hard water contains dissolved calcium.

> Give some sample of hard water to your students, evaporate a little of it to dryness and identify the metal ion in the solid by means of a flame test. Which ion is present ?

Write your instructions, as a series of steps, in the space below. Be precise with quantities and time.

(a) ....

(b) ....

(c) ....

(d) ....

(e) ....

(f) ....

(g) ....

(h) ....

An Extra Task

By referring to text books or the internet, find out how detergents are made in industry and give a summary of the process in the space below.

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Now turn over to Part 4

Part 4 Final Answers

(a) Fill a 500ml beaker two third full with hard water. Place the beaker on a tripod stand and heat until almost all the water is boiled away. This will take some time.

(b) Tip the small amount of water into an evaporating basin and gently heat to dryness. you will be left with a small amount of a grey white solid.

(c) Cool the basin and scrape the solid into a little pile.

(d) Your teacher will place a small amount of concentrated hydrochloric acid on a watch glass for you. Do not allow the aid to touch your clothes.

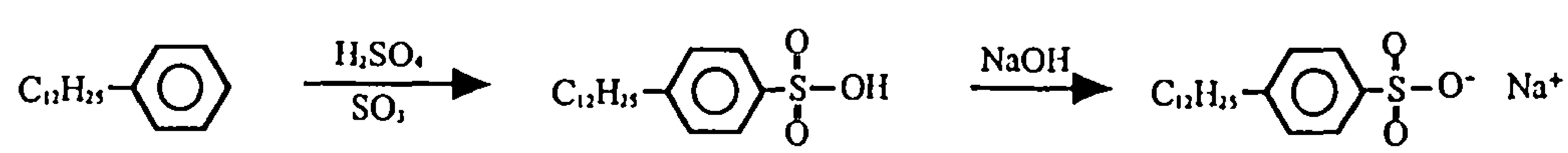
(e) Clean a platinum wire which is in a glass holder by dipping it into the acid and then into a hot Bunsen flame. Do this until almost no colour is seen in the flame.

(f) Now dip the wire into the acid, then into the little pile of grey white solid. Hold the wire in the flame for a few seconds, dip into the aid, then into the flame, then into the acid, then into the flame.

(g) Look for a flickering brick-red (slightly orangey-red) colour in the flame. This is the test for calcium.

(h) You may need to repeat (f) and (g) several times until you are sure you see the colour. When you have finished, clean the wire by dipping it into acid, then into the flame until no more colour is to be seen.

To make a detergent, the hydrocarbon is reacted with fuming sulphuric acid (This is concentrated sulphuric acid with dissolved sulphur trioxide in it: very reactive and very dangerous). The acid reacts with the end carbon of the benzene ring to form a sulphonic acid. This is then very carefully neutralised with sodium hydroxide until the pH is between 5 and 7. Here is an example of the type of reaction:



Appendix H

Evaluation of Paper Laboratories

Evaluation of the Paper Labs

Please use this sheet to indicate your responses to the paper labs you have already attempted.
Your responses can have a direct influence on the experience of future students in this course.
Please answer carefully and honestly!

Tick ONE box which best reflects your experience

		Strongly agree	Agree	Neither agree nor disagree	Disagree	Strongly disagree
(1)	The organisation of the paper labs was excellent	☐	☐	☐	☐	☐
(2)	The presentation of the material in these paper labs was clear	☐	☐	☐	☐	☐
(3)	The paper labs were too long	☐	☐	☐	☐	☐
(4)	I did *not* like the style of the paper labs	☐	☐	☐	☐	☐
(5)	The knowledge required to use the paper labs was reasonable	☐	☐	☐	☐	☐
(6)	The paper labs involved too much practical detail	☐	☐	☐	☐	☐
(7)	I found the paper lab useful to prepare labs in future	☐	☐	☐	☐	☐
(8)	The paper labs did *not* add to my understanding of chemistry	☐	☐	☐	☐	☐
(9)	The paper labs have altered my views of practical work	☐	☐	☐	☐	☐
(10)	I found paper labs to be little more than a cookbook	☐	☐	☐	☐	☐
(11)	Overall, I found useful information to help me as a teacher	☐	☐	☐	☐	☐
(12)	The style of the paper labs was different from my usual practical book	☐	☐	☐	☐	☐
(13)	I am even more confused about making simple inorganic compounds	☐	☐	☐	☐	☐
(14)	I never really understood corrosion and electrolysis until I completed the paper lab..		☐	☐	☐	☐☐
(15)	I understand about soaps and detergents much better now	☐	☐	☐	☐	☐
(16)	The paper lab on chalk gave me many ideas for my future school pupils	☐	☐	☐	☐	☐

(17) *Please make any comments you wish about the paper labs*

Thank you for your help. Centre For Science Education , University of Glasgow, Scotland.

Written Instructions

The administration of paper-labs and questionnaire in Pakistan

The survey scheme will divide into two parts;

1- Survey at Glasgow University.

2- Survey at Allama Iqbal Open University, Islamabad, Pakistan.

Your concern will be to the second survey.

Sample for this survey;

First year B.Sc. students,
Second year BSc. students, and
B Ed trainee students.

The aim of this survey is to explore students perceptions at both school and university level, in order to identify the areas where the students need help.

Apply the finding on open learning system.

1- Get the photocopies of all these questionnaires, Paper-labs and evaluation sheets. This University will pay you all the charges.

2- Mail these materials by post to the students and ask them to return you as early as possible.

3- Make sure that the students responses should be clear and honest.

4- Read the notes on each questionnaire by yourself and if there is any difficult in understanding to the students please clarify to them (if possible).

5- Paper laboratory is a new concept, which is very different from the wet laboratory. The aim of the paper-labs is to give some idea to the Distance students about actual laboratories and to think about practical problem solving.

Try your best to collect responses from a big sample as you know it help me to be more accurate at the end of the study.

Thank you for your help and cooperation.