THE EFFECT OF A MATHEMATICS CALCULATION SKILLS COURSE ON ACHIEVEMENT IN INTRODUCTORY CHEMISTRY

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Abstract

Four groups of introductory chemistry students at Memorial University of Newfoundland were studied to determine if mathematics skills remediation would positively affect their chemistry achievement. Two of the above four groups were designated experimental groups and two of the groups were designated corresponding control groups. The control groups were given regular introductory chemistry instruction plus other activity that was not intended to increase their mathematics competence. The experimental groups were given mathematics remediation. Total chemistry instruction time in the experimental versus the control groups on all topics was equal.

The mathematics skills of all subjects were evaluated with a mathematics skills test at the beginning of the one semester course. The same test was used to evaluate any change in mathematics skills at the end of the semester in all four groups.

An analysis of covariance on the mathematics posttest scores, with mathematics pre-test scores and Piagetian intellectual level scores as covariates showed the experimental groups had improved their mathematics skills in general when contrasted with the control groups.

The relationship between this improvement in mathematics skills for the experimental groups on achievement in chemistry was evaluated using an analysis of covariance in which the mathematics pre-scores and Piagetian intellectual level scores were used as covariates. No significant improvement in chemistry achievement was detected for the experimental groups versus the control groups.

An attempt was made to replicate a study done by Denny (1970) in which high correlations were reported between each of ten mathematics skills scores and chemistry scores, and between mathematics skills scores and mathematical chemistry scores. The results of this study, as did the results obtained by Denny (1970), showed a significant correlation between the overall scores obtained on the mathematics skills test developed by Denny (1970) and chemistry achievement scores but this correlation was not as high as the correlation found by Denny (1970). Also as in Denny's study a significant correlation was obtained between overall mathematics skills scores and mathematical chemistry scores but again, this correlation was not as high as the correlation found by Denny (1970).

The high correlations reported by Denny (1970) between each of the ten mathematics skills sub-scores with the chemistry achievement scores and the mathematical chemistry scores were not obtained in this study. Skill with ratio and proportion and skill with percent correlated significantly with chemistry achievement and mathematical chemistry achievement at the 0.01 level. Also skill with computation correlated significantly, at the 0.01 level, with chemistry achievement.

A post-hoc attempt was made at analyzing which mathematics skills, of the ten described in this study, are prerequisite for understanding some concepts found in introductory chemistry. This analysis indicated that the ability to apply fractions, decimals, and ratio and proportion was quite clearly prerequisite to the understanding of the eleven introductory chemistry skills defined in this study. General computation, use of parentheses, signed number usage, use of exponents, use of percentage, manipulation of one-varibale equations and producing x, y graphs also appeared by this analysis to be prerequisite to the understanding of the eleven introductory chemistry skills defined in this study.

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Chapter 1

INTRODUCTION

Numerous suggestions have been made that students beginning introductory chemistry at the high school or junior college level often appear to lack the necessary calculation skills to cope with problem-solving aspects of CHEM-Study and similar chemistry courses. (Thorpe & Lindblad, 1962; Webb, 1964; Washton, 1967; Denny, 1970.)

Being acquainted with high school mathematics but not thoroughly skilled in the mathematics necessary for dealing with chemistry calculations may seriously impede the progress of some students attempting to develop a correct understanding of some of the concepts in introductory chemistry particularly if they are not fully formal operational intellectually.

Evidence of a high correlation between performance of chemistry calculations and mathematical ability is provided in a study done by Denny (1970). The relationship of mathematics skills to chemistry calculations is better exemplified by a study done by Okey and Gagné (1970) in which a task analysis approach was used to evaluate which skills were prerequisite for a particular chemistry unit on solubility products. These skills were mostly mathematics skills. For example, the correct use of exponential notation was found to be necessary for the solution of many calculations involving solubility product.

There are other examples of chemistry concepts that, it would appear, need a thorough understanding of mathematics for their complete understanding. The calculation of the percentage composition by mass of a compound such as sodium hydroxide from its chemical formula is one such example. An understanding of percentage and a facility with calculating a percentage generally predominates in a problem such as this. Even for students who apply algorithmic procedures to such calculations a good understanding of percentage would perhaps allow a student to logically check the reasonableness of an answer obtained algorithmically. Knowing the mathematical principle rather than only knowing the required algorithm may have greater generalizability, and perhaps would make a greater variety of problems that are different in format rather than in principle solvable by a person capable of understanding the mathematical principle. It appears though that the ability to mentally acquire a principle which is universally applicable may be possible only by a formal operational individual. (Lawson & Wollman, 1976). Indeed there are persistent suggestions that problem solving (including computational applications) in science is strongly related to the ability to operate at a formal operational level (Karplus, 1977; Lawson & Renner, 1975). Hence it is necessary to consider potentially confounding effects of this variable when attempts are made to determine the relationship of other variables to problem-solving in science.

Another example of a typical chemistry problem that involves one or more mathematics concepts is the calculation of direct mole-mole ratio using a given balanced chemical equation and some principles of stoichiometry. Such a problem might be:

> Calculate, using the equation given, the number of moles of oxygen molecules produced when 3.75 moles of $KClO_3(s)$ are decomposed by heating.
>
> $$KClO_3(s) \rightarrow KCl(s) + 3/2\ O_2(g)$$

Many other examples of chemistry concepts that involve one or more mathematics concepts exist. (For example, molarity, empirical formulas and gas kinetic theory - all concepts taught in the introductory chemistry course used in this study.) For the purposes of this study eleven chemistry skills, each hypothesized to have a mathematics component are suggested. These are described fully in the section on Tests : Chemistry Achievement Test (Page 36).

Despite the extensive occurrence of computations in chemistry there is little evidence that authors of chemistry text-books or teachers of chemistry make a systematic and deliberate attempt to ensure the availability of the necessary mathematics skills within the context of chemistry courses. In fact, it is common to see appendices to introductory chemistry texts filled with exercises which would promote acquisition of calculation skills. However, these are rarely viewed as an integral part of the chemistry course. It appears to be assumed that the student will acquire the calculation skills he needs for chemistry (if he does not possess them) by doing chemistry.

Taking the exercises out of the appendices of introductory chemistry texts and integrating them with the bulk of the course may be a move that would lead to better student achievement in introductory chemistry. Such a move may help students who have not been high achievers in mathematics and who are not fully formal operational in the Piagetian sense, to improve their performance in chemistry.

In the present study it is hypothesized that it is possible to teach mathematics skills in chemistry classes and it is further hypothesized that when this teaching is successful it affects achievement positively in chemistry.

A detailed task analysis of the mathematics skills required for the chemistry course involved was not performed formally in the present study, but efforts during teaching of chemistry in the experimental groups were directed at evaluating mathematics skills needed for a particular topic followed by teaching and reteaching of the skills prior to teaching of a topic in science.

A preliminary study of 250 first year chemistry students at Memorial University indicated a correlation of 0.41 between upper range (50% and higher) high school mathematics grades (grade XI) and introductory chemistry. This observation and other studies to be reviewed in the next section suggest the possibility that mathematics achievement and chemistry achievement may correlate significantly. The present study concerns itself primarily with investigating the effect of teaching, and when necessary reviewing, calculation skills believed to be necessary for particular units in introductory chemistry. All instruction on calculation skills took place within the context of the regular chemistry classes.

The primary purpose of the study reported here is to determine whether or not deliberately remediating for specific calculation skills significantly enhances achievement in introductory chemistry. The greater efficiency of a remediation approach is supported by a study by Okey and Gagné (1970) in which they identified the subordinate skills needed to deal with solubility product calculations and then provided remediation exercises on the subordinate skills noted to be lacking in the students. Performance significantly improved. Of interest to this study is the fact that the majority of skills remediated were mathematics skills.

A secondary purpose of this study is to attempt to determine whether the calculation skills identified by Denny (1971) are necessary prerequisites for success on specific types of chemistry problems. An attempt is also made to identify relationships between the availability of selected formal operational schema and performance in introductory chemistry.

The following chapter includes a brief summary of a literature survey in the areas of mathematics and its relationship to science. This study is limited to an evaluation of the effect of mathematics remediation on achievement in chemistry; therefore the literature has been surveyed and reported accordingly. Also since some evidence exists showing that chemistry achievement perhaps is a function of student intellectual level the literature on Piaget's intellectual development theory and measurement of intellectual development has been surveyed and reported.

Chapter 2

RELATED LITERATURE

Mathematics and its Relationship to the Sciences

The need to assess the role of mathematics as it is applied in the sciences has been stressed by many authors (e.g., Thorpe & Lindblad, 1962; Kolb, 1968; Mayor, 1970; Boeck, 1972). These authors have proposed that the mathematics background of a substantial proportion of students is inadequate for work in the sciences, and some have proposed reasons for these deficiencies and methods for dealing with them.

Mayor (1970, page 293) suggests "...the goals of mathematics and of science are common goals and neither can adequately serve its purpose without the other". He goes on to say that science and mathematics are quite separate and suggests they should not be. Mayor even goes so far as to propose a timetable of change in mathematics and science curricula. He proposes that:

> By 1975 (or earlier), every school program should provide for the early introduction of graphing and of decimal fractions and for frequent opportunities to use these skills after they are introduced.
>
> By 1985, all elementary school science and mathematics programs should be carefully correlated, if not fully integrated.
>
> By 1995, mathematics, the language of science, must clearly also be the language of every citizen.
>
> (Mayor, 1970, page 297)

Mayor's proposals are supported by an experimental study by Kolb (1968) in which he investigated the effects of relating mathematics to science instruction on the acquisition of quantitative science behaviours. According to Kolb learning science requires the learner to have certain mathematical abilities. Using

128 fifth grade students randomly assigned to either a control group or an experimental group, Kolb exposed the experimental group to mathematics instruction directly relating to the science lesson in a highly specific manner prior to the science lesson. This group performed significantly better in science than the control group which studied mathematics as it occurred in the mathematics textbook normally used. The science topics taught are described as "quantitative".

Thorpe and Lindblad (1962) report that a survey of elementary and junior high school science teachers showed that many science teachers felt that there was either a real deficiency in mathematics competence or that the mathematics was learned in such a restricted atmosphere that the student was unable to generalize it to application in science situations. Further this belief that better mathematics training was needed for greater success in science led to many teachers spending three to nine weeks teaching mathematics used in their science course. Boeck (1972) suggests that this apparent incompetence in mathematics may be due to the lack of proper sequencing of mathematics and science courses.

Reviewing or remediating mathematics skills in science classes seems to be regarded as an accepted method of mentally preparing students for learning science concepts. The literature reviewed for this study with respect to sciences generally shows only some empirical proof for the pedagogical soundness of this approach to teaching science.

Mathematics in Chemistry

Generally it is taken to be obvious that some mathematics skills are needed for successful performance of calculations in chemistry. Not much experimental work has been done to attempt to identify the specific types of mathematical skills needed for chemistry calculations. Much speculation exists, though, largely in the way of simply blaming poor achievement in chemistry on students' inability to do mathematics.

In an empirical study by Webb (1964) it was found that success in college chemistry was related more to mathematics background than chemistry background and that "high school chemistry alone does not materially contribute to success in college chemistry". (Webb, 1964, page 14). Success in college chemistry was shown to be related more to a good background in mathematics than to a good background in chemistry. In this study Webb found that a substantial number of students with no high school chemistry background but a good high school mathematics background had greater success in college chemistry than students with a high school chemistry background included in their other high school training. Webb concludes that his findings support the theory that a mastery of the fundamentals of mathematics is necessary for academic success in chemistry at the college level. However Webb's findings may also be interpreted in terms of developmental level since high achievement in mathematics may be related to the students' ability to function intellectually at the formal-operational level - an ability which might also affect chemistry achievement.

In the opinion of the editor of Science News (1975, Volume 108) mathematics education in the United States is so pluralistic that a committee commissioned by the Conference Board of the Mathematical Sciences could hardly recognize the presence of any clearly defined mathematics curriculum for American schools. The committee stressed "the need for relating mathematics to its application at all levels of the curriculum". (Science News, 1975, Volume 108, page 325).

Similarly in Washton's (1967) view there is a necessity for teaching the mathematics skills used in chemistry because the skills needed are not mastered adequately by students enrolled in introductory chemistry. Herron (1975) discusses the problems of chemistry students in the context of Piagetian psychology. He notes a study done at the University of Oklahoma which showed that 50 percent of college freshmen tested were functioning completely at the Piagetian concrete operational level and that only 25 percent of the sample could be considered fully formal operational. He notes that many students are therefore not capable of dealing with mathematical problems involving ratio - a formal operational concept. This lack of ability to deal with ratio problems is critical, for as indicated in the introduction to this study, and as later it is shown in the analysis of data in this study, the concept of ratio is a fundamental concept found in a significant number of chemistry calculations. The inability of a chemistry student to handle ratio computations regardless of his developmental level therefore makes teaching of many concepts of chemistry to this student impossible. Observations such as this suggest the necessity of reviewing concepts such as ratio with junior college level students functioning at the concrete level. Review work may indeed have to begin at a concrete level with gradual advancement to a more formal and abstract level if this is indeed possible with a concrete level student.

Good and Morin (1978) in a paper dealing with mathematics and logic skills exhibited by college freshman chemistry students give strong support to the need to integrate simple mathematics skills instruction with regular introductory chemistry courses. Good and Morin (1978) evaluated the mathematical abilities and logical reasoning abilities of about 1,000 students - most of whom were at the college freshman level. In addition, they evaluated the relationship between the students' abilities in mathematics and logic and their success in introductory college chemistry. The mathematics skills tested included decimals and fractions, exponential numbers, equations with one unknown and problems involving percentages, averages, and ratios. These subsume seven of the ten skills proposed by Denny (1971) as being prerequisite for introductory chemistry at the high school level. The logic problems included matching two series of objects, selecting necessary premises for a given outcome, making combinations, perimeter-area relationships, equilibrium in a balance, displacement volume and probability and correlational reasoning. These were regarded by the authors as being similar to Piagetian-type task tests used to measure intellectual developmental level.

In their study Good and Morin found that even basic mathematics skills involving the conversion of fractions to decimals or solving simple equations with one unknown, were apparently not exhibited by about 25 percent of these students. About half of the nearly 1,000 subjects included in this study could not solve simple problems, involving exponential numbers (e.g. $(\frac{1}{4})^{\frac{1}{2}}(2^4 \times 2^{-3})^2$.

With regards to the items on logic, Good and Morin (1978) report that fewer than one student in four is capable of using combinatorial reasoning, relating perimeter to area, or making correlations from available data. Similar low levels of success were reported for other items of the logic tests. Further, following an analysis of variance contrasting students with grades of A or B with students obtaining D or F in chemistry in their chemistry course Good and Morin (1978) conclude that success in introductory chemistry is strongly related to selected mathematics skills and to logical ability.

Dence (1970) suggests that four "most important" mathematics skills are necessary in introductory chemistry. His suggestion is based on a prolonged survey of what he regards as typical introductory chemistry courses. These suggested skills are of interest to this study from the point of view that they are of higher difficulty level than the skills hypothesized in this study to be necessary for "introductory" chemistry. The ramifications of Dence's suggestions are discussed in the "Limitations" section of this study.

One skill Dence regards as important for solving chemical calculations is that of solutions to algebraic equations. An example of a problem involving a solution to an algebraic equation includes setting up and solving a problem dealing with determining the percentage contribution of the isotopes of Chlorine, (Cl, at. mass 34.980 and Cl at. mass 36.978) to the naturally occurring Cl_2 mixture having atomic mass of 35.453. Also in this skill category Dence includes use of the quadratic equation. A problem such as this would be regarded as being of a very difficult introductory chemistry level in the context of the present study and is regarded as atypical. The problem given below would be regarded as more typical of a "Solution to an Algebraic Equation" problem:

> In a 100g mixture of Fe and S_8, there is twice as much Fe as S_8. How many g of Fe are there? (Fe = iron; S_8 = sulphur)
>
> (a) 25 g
>
> (b) 33 1/3 g
>
> (c) 66 2/3 g
>
> (d) some other amount

The second skill Dence regards as necessary for introductory chemistry is "Functional Relationships Among Variables". This again includes not only simple linear graphs (regarded as typical in this study) but also plots such as: $y = \log x$, $y = \sin x$, $y = ax^3 + 6$. These would be regarded as very difficult concepts for the chemistry students in the present study.

The third topic Dence regards as important to introductory chemistry is that of "Operations and Logarithms". He suggests that students have very little facility with use of logarithms in spite of their rather frequent use in chemistry.

Lastly, Dence feels "Probability and Statistics" must be taught in high school if a student is to properly understand topics such as orbital theory. Students' abilities or lack of these abilities in probabilities and statistics generally are not regarded as crucial in this study since no evidence was found in the review of introductory chemistry text-books showing that statistical probability is used as a matter of course.

In a study by Denny (1970) the mathematical skills required for high school chemistry were investigated by firstly identifying the ten mathematics skills most commonly used in "recently" published high school chemistry textbooks. A 60-item test (MAST) produced by Denny to test these skills was administered to 276 first-year high school chemistry students. Correlations from 0.63 to 0.82 between the mathematics-skills sub-scores and ACS-NSTA High School Chemistry chemistry-calculation sub-score administered to 242 of the 276 students mentioned above. The correlation between the overall score and the ACS-NSTA test score was 0.80. The correlation between the MAST overall score and the ACS-NSTA calculation sub-score was 0.75.

The method Denny used to obtain sub-scores would appear to be quite invalid and should not be used for diagnostic and statistical purposes. A given question on Denny's mathematics test could require or be a test of two or three or even more skills. If a student correctly answered a question testing three skills, he received a point for each skill. It could be the case, then, that if a student did not have skill one he would not be able to answer a question in which skill one was needed even if he possessed skills two and three which also might be used in a given question. Hence he would fail to score for skills two and three as well. These sub-scores, then, certainly do not in fact measure the student's true score on a particular skill. Nevertheless, the total test score on this test may be a fairly good measure of general mathematics ability since the content validity of the mathematics skills test for purposes of measuring a student's abilities with respect to the ten skills defined by Denny was acceptable to four judges: two chemists and two mathematicians. Denny's test was modified for the purposes of the present study with sub-scores derived by using only those questions in which unique or predominating skills could be identified. Any given question was considered to measure one skill only.

There is evidence that curriculum planners do "water down" science courses for use with weaker students. In chemistry this is often in the form of removal of difficult mathematics computations. For example an attempt to make chemistry available to students of a broad range of abilities led to the production of the various CHEM-Study series of textbooks. The easiest of the series (O'Connor et al, 1968) has much less computational content than the most advanced CHEM-Study text (Parry et al, 1970). More recently this trend to a reduced computational emphasis may be observed in the Interdisciplinary Approach to Chemistry (IAC) (Gardner, et al, 1976) course, a course intended for a wide range of high school students. This course is much less mathematics oriented than any of the CHEM-Study texts.

The approach taken in the present study is contrary to the above strategy to design science courses for weaker students by almost eliminating computational content. Rather than trying to by-pass the computational aspects of the chemistry course a greater emphasis is placed on relevant mathematics skills. In other words, if a student is lacking certain prerequisites for a subject he is retaught these skills prior to being given further instruction in chemistry. It is hoped that additional practice might lead to greater competency and greater feeling of satisfaction on the part of the student.

A wide-scale application of such an approach to remediation in mathematics was taken in The Program of the College Education Achievement Project (CEAP) operated on fourteen campuses in the southern U.S.A. (Grigsby, 1971). In this project, students of low achievement were hypothesized to have achieved poorly academically partly because of a "poor self-image" resulting from the students' inability to do routine mathematics operations. The mathematics up-grading program offered intensive remediation with an emphasis on proficiency in operations of arithmetic as a starting point. This program included a handbook of objectives which was expected to be read and followed by any new teacher joining the program. A student was admitted to CEAP on the basis of his performance on a placement examination. A student directed to the CEAP program for remediation in a subject would continue in this program until he achieved a grade of A, B, C or D. If he could not achieve a grade of at least a D, a letter grade indicating the degree of progress made was reported for the student and he was then expected to return to a CEAP course and continue until a pass was achieved. The progress of each student was monitored closely since financial aid was terminated as soon as the student qualified for admission to a regular college course. The program was reported to be successful at least from the point of view that many students from the program continued college studies. It was noted that if they did not continue their college studies it was not due to failure academically but due to financial considerations and other vocational plan changes. Of course the CEAP remediation program and the success of this program has limited generalizability since the program was not intended for research purposes and was not structured as a research project but did involve a defined program of instruction.

Piaget's Theory of Intellectual Development

There are suggestions that problem-solving in chemistry might be related to the ability of students to function intellectually at the formal operations level (Karplus, 1977). Studies show that 50-60% of college freshmen often cannot function at the formal level. (Elkind, 1961; McKinnon, 1971; Towler & Wheatley, 1971). The necessity for a student to function mentally at the formal level if he is a student of a science such as biology, chemistry or physics is illustrated by a study done by Lawson and Renner (1975) in which they evaluated the concepts of these science courses and concluded that the majority of these concepts required formal thought.

Piaget's work on intellectual development characterizes the development of intelligence from birth to age 15 into three major stages: a sensorimotor period from birth to age two; a concrete operations period from ages seven to 11; and the commencement of formal operations and intellectual maturity in the age range of 11 to 15. The intellectually mature individual becomes capable of understanding and manipulating relationships between abstractions directly with no reference to concrete reality. This maturity is reached to varying degrees by different individuals after age 15 or 16.

Mathematical symbolic language of logic is used by Piaget in presenting his theory on intelligence. The following description of Piaget's theory on intelligence in this study focuses upon the general characteristics of adolescence; the period during which formal operational thought as defined by Piaget appears. According to Piaget the following differences may be observed between the formal and concrete thinker. Firstly, one main characteristic of the formal-operational child is the ability to make reality secondary to possibility. In contrast, a concrete-operational child may begin an analysis of the relationship between concrete objects with little foresight as to how each object might relate to the other after physical changes are imposed on some of the objects. Secondly, the concrete-operational child will not realize the need to hold all but one factor constant in experimental analysis while a formal-operational child would do so. A third difference is that the formal operational child will advance beyond the empiricism of a concrete-operational child. The formal-operational child exhibits thought that is "hypothetico-deductive". Fourthly the formal-operational child has the ability to exhibit combinatorial thinking. Piaget postulates that development of this ability involves what he calls "combinatorial schema" and suggests that the existence of these schema in a child's mind indicates logical thinking at the formal stage. This means, for example, with respect to the now classic chemical combinations task (Inhelder & Piaget, 1958) that the child will systematically seek all possible combinations of chemicals to give a predicted experimental result. Such an exhaustive approach suggests very diverse and flexible thinking on the part of the formal thinker. Piaget suggests that the cognitive structures needed to successfully perform this task are mostly developed by the end of adolescence at about age sixteen. Finally, unusual results in an experiment will not confuse the formal-operational child as much as the concrete-operational child as a greater number of possibilities (in terms of possible experimental results) exists for this child.

Karplus (1977) extends the above to suggest some "clues" that can be used to classify reasoning patterns of individuals into concrete intellect and those that are characteristic of a formal intellect. When using concrete reasoning patterns, the individual:

C1 applies classification and generalizations based on observable criteria.

C2 applies conservation logic.

C3 applies serial ordering and establishes a one-to-one correspondence between two observable series.

When using formal reasoning patterns, the individual:

F1 applies multiple classification, conservation logic, serial ordering, and other reasoning patterns to concepts, abstract properties, axioms, and theories

F2 applies combinatorial reasoning considering all conceivable combinations

F3 states and interprets functional relationships in mathematical form

F4 recognizes the necessity of an experimental design that controls all variables but the one being investigated

F5 reflects upon his own reasoning to look for inconsistencies or contradictions with other known information.

The following table given by Karplus (1977, page 171) describes the most important differences between concrete and formal reasoning.

Concrete and Formal Reasoning Patterns

	CONCRETE	FORMAL
(a)	Needs reference to familiar actions objects, and observable properties	Can reason with concepts, relationships, abstract properties, axioms, and theories; uses symbols to express ideas.
(b)	Uses reasoning patterns C1 - C3, but not patterns F1 - F5.	Uses reasoning patterns F1 - F5 as well as C1 - C3.
(c)	Needs step-by-step instructions in a lengthy procedure.	Can plan a lengthy procedure given certain overall goals and resources.
(d)	Is not aware of his own reasoning, inconsistencies among various statements he makes, or contradictions with other known facts.	Is aware and critical of his own reasoning; actively seeks checks on the validity of his conclusions by appealing to other known information.

The evidence for the different characteristics suggested above for formal and concrete thinkers has been derived from many studies carried out by Piaget and others over many years. Typically, tasks have been presented in a personal interview format. More recently some investigators have used group testing procedures because of the greater number of subjects who can therefore be tested. The evidence that such procedures are acceptable is encouraging.

Rowell and Hoffman (1975) used a combination paper and pencil-laboratory test composed of the chemical combinations task and the "pendulum problem" to establish the reliability of a group-administered developmental level test. Rowell and Hoffman hypothesized that a particular quality of thought demonstrated in one subject area tends to be demonstrated with problems possessing a similar structure in another subject area. Testing eight student groups made up of students from differing "ability" streams from a South Australian metropolitan high school these researchers found that the scores obtained on the two separate tests correlated moderately highly ($r = 0.56$, $p = 0.05$). Both tests showed a parallel increase in percentage of formal thinkers with increase in chronological age and a higher percentage of formal thinkers in the "upper stream" at the "various" grade levels.

Lawson (1978) used a testing format that is similar to that of Rowell and Hoffman (1975) to validate group administered Piagetian tests. Lawson produced a 15-item test, modelled on previously used Piagetian tasks involving the concepts of conservation, proportional reasoning, controlling variables, combinatorial reasoning and probability. The sample consisted of eighth and tenth grade students of one school and a group of ninth grade students selected from another school. All students (513 total) were administered the classroom test. A subsample of 72 students was randomly selected and individually administered a battery of four Piagetian tasks in an interview format. These involved the conservation of weight task (Piaget & Inhelder, 1962), displaced volume (Karplus & Lavatelli, 1969), bending rods (Inhelder & Piaget, 1958, Chap. 3), and the balance beam (Inhelder & Piaget, 1958, Chap. 11). Responses on all four tasks were used to factorially validate the classroom test. Responses on the bending rods and balancing beam tasks were correlated with scores on the group-administered tests. Pearson product-moment correlations between the group test total score and level of response on the bending rods and balance beam task correlated at 0.75 and 0.65 respectively. The factorial analysis yielded findings that the group test item scores and interview task scores "loaded heavily" on the same factors.

The results of Lawson's research suggest three identifiable psychological parameters were measured by the above tests. These three parameters Lawson suggests are: formal reasoning, early formal reasoning (intermediate) and concrete reasoning. The above-mentioned paper and pencil-laboratory test was face-validated by a group of six experts in the field of Piagetian psychology.

Other studies (Sheehan, 1970; Raven, 1974; Shayer & Wharry, 1974; Renner, 1977) have also used a large group format, with similar findings. In the present study the developmental testing was carried out by administering five tasks in this way.

A number of authors have referred to the relationship between developmental level and achievement in science. Two of these papers (Lawson & Renner, 1975; Sayre & Ball, 1975) are based upon empirical evidence collected in reasonably well controlled studies. Others such as studies by Herron (1975), Albanese (1976), Bauman (1976) are suggestive but are not sufficiently well controlled to be considered definitive.

Lawson and Renner used random samples of biology and chemistry students selected from the biology and chemistry classes of a high school of 2,000 students to study the relationship between these students' intellectual developmental level and their ability to understand concepts in biology and chemistry. For purposes of the study the concepts in the courses were classified as either concrete or formal.

The intellectual developmental level of each student was measured by a set of four Piagetian task tests. Each subject matter test consisted of 15 concrete and 15 formal multiple-choice questions. These tests were face-validated by six experts in science and science education. An intact class of 33 physics students was studied in a manner identical to the random samples of biology and chemistry students.

Lawson and Renner's study revealed that students categorized as "transitional-concrete" and "concrete-operational-II-B" showed they understood about 30 percent of the concrete-operational concepts and showed little or no understanding of formal operational concepts. An understanding of formal concepts was clearly not shown by students classed as concrete. Students categorized as transitional formal-operational or fully formal-operational demonstrated understanding of both concrete and formal concepts. (The majority of the concepts, in the three science courses involved above, were categorized as formal.)

A study by Sayre and Ball (1975) involved 214 students drawn from a random sample of students enrolled in junior high school science courses and a random sample of 205 students enrolled in senior high school science courses also sought to evaluate the relationship between intellectual developmental level and performance in science courses.

A battery of five Piagetian tasks was used to evaluate the intellectual developmental level of the students. Completion of at least four of the five tasks led to the students' being categorized as formal-operational. Overall course grades were used to represent scholastic achievement.

The findings of the above study showed that, in general, formal operational students receive higher scholastic grades in science than non-formal students. This study showed that there is a significant (at the 0.01 level) but low correlation between the number of tasks performed at the formal operational level and the scholastic grades of science students ($r = 0.33$ junior high school, $r = 0.46$ senior high school). Appropriately 32% of the biology students, 69% of the chemistry students and 81% of the physics students were considered formal.

It was also found that there is a significant relationship at the 0.01 level between the scholastic success of eighth and ninth grade, biology, and high school chemistry students and their performance on the Piagetian task tests. There was no significant relationship at the 0.05 level between scholastic success of high school physics and seventh grade science students and their performance on the Piagetian task tests. However, Herron (1976) in a commentary on the work of Sayre and Ball suggests that since only 8.6% of the seventh grade students were judged to be formal and 80.7% of the physics students were judged to be formal it is not possible for the value of the point biserial correlation to be large for these groups.

In a small-scale study of his own Herron (1975) found a correlation of 0.8 between total scores on a battery of Piagetian tasks and chemistry scores for 20 college students in an introductory chemistry course.

Albanese et al, (1976) attempted to confirm Herron's findings with the intention of adding some utility to the process and result of testing for intellectual level done by Herron. These authors anticipated that since such a high correlation existed between a placement test and the Piagetian tests perhaps better advise could be given to students regarding their selection of chemistry course for study on the basis of Piagetian test results. However the set of written Piagetian tasks used by Albanese et al were found to account for very little variance in course performance. Indeed the Piagetian scales above account for no more than 5.71% of the variance.

Novick and Menis (1978) analyzed the fifteen year old student's concept of the mole after a number of fifteen year old students were taught a unit in chemistry from a syllabus that used the mole as its basic measuring unit or quantitative expression. The results of this analysis indicated that most of these students had neither a coherent understanding of the mole concept as it is used in introductory chemistry, and its significance in interpreting chemical phenomena, nor the ability to use it effectively in solving problems. The conclusion reached by the above researchers was that these shortcomings on the part of the students were due to their inability to function intellectually at the required level to comprehend the mole concept. The Novick-Menis study is relevant to the present study since much of the chemistry taught in the experiment of Novick and Menis (1978) and in the classes used for this study directly or indirectly involves the mole concept, as do most introductory chemistry courses.

Summary

The present study attempts to investigate the relationship between chemistry achievement and remediation of relevant mathematics skills which are found to be lacking in a group of students in introductory chemistry. Literature pertaining to the relationship between mathematics skills and chemistry achievement has therefore been reviewed and discussed.

Concerned pedagogues and researchers alike, the literature shows, claim that a significant relationship exists between availability of mathematics skills and achievement in chemistry. Remediation of mathematics is often claimed to be necessary for improvement of chemistry performance. The effect of remediation of mathematics with the intent of improving computational skill in chemistry has not been studied empirically to any appreciably extent. Instead many authors simply infer that remediation of mathematics should cause improvement in chemistry after noting that much of introductory chemistry is computational or mathematical in nature.

Also other authors show that a high correlation does indeed exist between mathematics background and performance in chemistry. These authors too simply infer that up-grading the mathematical skill of a student will make this student more competent in chemistry. No strong empirical support is reported for this claim of greater competence due to mathematics remediation.

Further some authors suggest, usually without strong empirical support, that achievement in chemistry and mathematics is in some way a function of the intellectual developmental level of a student. The relationship is less strong than generally suggested, but developmental level does appear to contribute significantly to chemistry achievement. In order to control for this effect developmental level scores are therefore used as a covariate in the present study.

Chapter 3

DESIGN AND OPERATION

Population and Sample

The population includes all students selected during registration procedures for Chemistry 100F, an introductory chemistry course offered in the first year of a five year program at Memorial University of Newfoundland. This course includes students who do not fully qualify for entry into first year courses and are placed into "foundation" courses - courses that are truly introductory for a given subject. The criteria for entry to the course are:

(a) no chemistry and an overall grade XI average of less than 75%, or

(b) some high school chemistry but less than 65% in grade XI chemistry with an overall high school average below 75%. In practice 95% of this category are students who did not complete grade XI chemistry (ie, failed high school chemistry).

The sample studied was four intact foundation chemistry classes with a total (after attrition) of 68 students. Two of the classes were designated as the experimental groups and two of the classes were designated as the control groups. The investigator and one other instructor were involved in the study. Each instructor taught one experimental and one control class.

Design

The experimental design involves two components. First, the effect of mathematics remediation on mathematics achievement, and second the effect of the same treatment on chemistry achievement.

Each group was tested at the commencement and conclusion of the experiment by the same mathematics skills test (MAST). The experimental groups received mathematics remediation. The control groups received no mathematics remediation. All four groups of the study were intact introductory chemistry classes. The control groups and the experimental groups were tested for level of mathematical skill by the use of the mathematics skill test (MAST) at the beginning of the thirteen week semester. Only the two experimental groups received mathematics remediation. The control groups and the experimental groups were again tested for level of mathematical skill by the use of the mathematics skill test (MAST) at the end of the thirteen week semester, in order to allow determination of the effect of the experimental treatment. The pre-test MAST scores were used as a covariate in an attempt to control statistically for possible sampling. Both the experimental and control groups followed the same chemistry course with the experimental group receiving the above mathematics skills remediation and the control group receiving a "placebo" treatment. Only a posttest of chemistry achievement was possible since many of the subjects had never been exposed to chemistry instruction before. Achievement in chemistry was evaluated at the end of the thirteen week semester by administration of a teacher made chemistry achievement test to all four groups of the study.

The intellectual level of each student in all four groups was evaluated towards the beginning of the thirteen week semester by administration of a battery of Piagetian tasks. The scores derived from this test were entered as a covariate when determining the effect of treatment (mathematics remediation) on mathematics and chemistry achievement, respectively.

Procedure

The experimental classes received instruction and review of mathematics calculation skills believed to be prerequisite for topics covered in introductory chemistry. Calculation skills instruction was given, on the average, during one class period per week for a total of eight weeks in a thirteen week semester. Eight of thirteen weeks in this course are normally spent on calculation chemistry. Instruction, and sometimes necessary review, on specific mathematics skills preceded the unit in which the skills were applied. Short quizzes were given after classes on these remediated skills and before lessons on new related chemistry units began. If the results showed particular difficulty was being experienced by many students, further review and quizzing was done. By the end of the semester nearly all students scored at least 80% on mathematics skills quizzes given.

The experimental groups were assigned 6% of the total course grade to all exercises, quizzes, and tests on mathematics skills. The control groups were assigned 6% of the total course grade to an essay-type assignment done out of class. The average time spent on the essay, out of class, by the control groups was about equal to that necessary for the experimental groups to complete the mathematics skills homework. The methods used for making instruction time in chemistry (exclusive of mathematics skills instruction) equivalent in the experimental and the control groups involved the following steps:

(1) two lecture classes in each control group were cancelled,

(2) four films were shown in the control groups, in addition to those shown as part of the regular course,

(3) instruction on more advanced stoichiometry problems was given to the control groups in the last week of classes. (These were not tested on the final examination and the students were told this in the last class of the semester.)

All subjects had an opportunity to attend one tutorial class per week in addition to the three regularly scheduled classes. In addition each subject could receive individual tutorial help from his instructor. Attendance was taken in the tutorial sessions to determine if attendance for any particular student showed a bias for either the experimental or the control groups. None was found.

Materials

The following materials were used in this study.

1. Introductory Chemistry Course

The introductory chemistry course referred to in this study is defined by a course outline, a laboratory activities outline, behavioural objectives, a defined problem set for each unit of the course, and a reference textbook. All students and each instructor were aware of these. The course outline, objectives, and laboratory outline are included in Appendix D.

2. Calculations Skills Course

The ten skills that were taught and reviewed at appropriate times were derived from Denny (1970) and involved:

(1) general computation - addition, substruction, multiplication, division, including algebraic operations

(2) use of parentheses

(3) signed number usage

(4) use and manipulation of fractions

(5) use of decimals

(6) use of exponents, manipulation of numbers with exponents and logarithm equivalence

(7) use of percentage

(8) manipulation of one-variable equations

(9) use of ratio and proportions

(10) producing and interpreting x, y graphs

Definitions

Mathematics skills test (MAST):

The mathematics skills test as developed by Denny (1970). This test was designed to test ten particular mathematics skills, namely, general computation, use of parenthesis, signed number usage, use and manipulation of fractions, use of decimals, use of exponents, use of percentage, manipulation of one variable equations, use of ratio and proportion, and producing x, y graphs.

Piagetian total score:

The score obtained for each student on a set of five Piagetian tasks collectively designed to measure the intellectual level of each student. A score of zero, one, or two could be achieved on each one of the five tasks used, for a total possible score of ten for each student if all five tasks were performed perfectly. Two of the Piagetian tasks tested ratio and proportion (Karplus & Karplus, 1970); two of the Piagetian tasks tested combinatorial schema (Inhelder & Piaget, 1958 and Hobbs, 1975) and one Piagetian task tested conservation of displacement volume (Karplus & Lavatelli, 1969).

Mathematics pre-test scores:

The individual scores obtained from the MAST administered to all groups at the beginning of the experiment of this study.

Mathematics posttest scores:

The individual scores obtained from the MAST administered to all groups at the end of the experiment of this study.

Chemistry achievement test:

A criterion test designed to test the achievement of the objectives (included in the Appendix) of the introductory chemistry course used for this study.

Chemistry achievement score:

The score obtained by each student on the chemistry achievement test administered to all students at end of the one-semester chemistry course used for this study.

Mathematical chemistry score:

The sub-score obtained by each student on the questions from the chemistry achievement test judged to have a mathematical component. The sub-score contributed a possible 71 points of the possible 100 points on the chemistry achievement examination.

Tests

(1a) Mathematics Skills Test (MAST)

The students' prior knowledge of calculation skills was evaluated in all four groups by a standardized test developed by Denny (1970). The test was designed to diagnose calculation capabilities of students with respect to specific skills. The same test was used at the end of the semester to evaluate the students' progress in the acquisition of these calculation skills. The test was a 60-item multiple choice test designed to indicate the students' understanding of basic concepts or skills.

The test was a power test and could be completed by most of the students in an introductory chemistry class in 45 to 50 minutes. It is reproduced in Appendix A.

(1b) The Modified Mathematic Skills Test (M-MAST)

Complete information regarding the scoring procedure for Denny's mathematics skills test was not available until some time after the beginning of the study. The test (MAST) is considered by the present investigator to have sufficient content validity as a test of general mathematical competence to allow its use for this purpose in the present study. The reliability coefficient (KR-20) for this test was 0.85.

Denny's method of grading and evaluating this test to provide a sub-score for each of the ten skills was regarded as invalid. In most cases a point was scored for each of two or more skill categories if a given question was answered correctly.

In other words, a given question could be regarded by Denny as requiring the correct application of as many as four skills but if a student did not have any one of these skills he would be penalized (perhaps unjustifiably) in the other three skill categories.

However, examination of the items in the Mathematics Skills Test suggested that many of the questions had one predominating skill. This led to development of a marking scheme based on a one question - one skill concept for purposes of the present study. The placing of the particular questions from the mathematics skills test into particular mathematics skill categories was firstly done by two chemistry instructors and then by two mathematics instructors. No concensus could be reached on the placement in a particular skill category of ten out of sixty of the questions on the mathematics skill test. Of the remaining 50 questions a particular question was placed in a particular category only if three out of four validators agreed that it could be placed in a particular skill category.

On this basis, the following categorization resulted:

		Questions from MAST
Math Skill 1;	general computation:	26, 27, 55
Math Skill 2;	use of parenthesis:	2, 3, 5
Math Skill 3;	signed number usage:	7, 30, 46
Math Skill 4;	use and manipulation of fractions:	12, 28, 39
Math Skill 5;	use of decimals:	21, 24, 36
Math Skill 6;	use of exponents, manipulation of numbers with exponents and logarithm equivalence:	(1), (6), 13, (14), 20, (31), (32), (40), 44, (45), 48, (56)

Math Skill 7;	use of percentage:	(8), 16, 35, 37, 52, (59)
Math Skill 8;	manipulation of one-variable equations:	15, 19, (22), 42, 47
Math Skill 9;	use of ratio and proportions:	4, 6, 9, (25), 43
Math Skill 10;	producing and interpreting x, y graphs:	17, (18), 33, (34), 49, (50), 51
Questions that fit into none of the categories:		10, 11, 12, 29, 38, 41, 53, 54, 58, 60

A post-hoc analysis of mathematics skills prerequisite for chemistry computations was done in this study using a method of cross-tabulation. For this analysis no more than four questions could be scored for each of the ten mathematics skill categories therefore for some of the mathematics skills all but four questions were eliminated for the purpose of deriving a skill score. This elimination was done randomly and is indicated by parentheses around a particular question.

(2) Chemistry Achievement Test

A test of achievement of the objectives of the chemistry course involved was used. This test was a two-hour test of which 30% of the questions were multiple choice questions and 70% of the questions were structured-response questions. The test was produced and validated by a procedure that is used each semester. Three instructors teaching the course produced the test and it was validated by an examination committee of three other chemistry instructors against a set of objectives and a set of problems, both written for the course involved. The test was graded and evaluated by the six instructors of the course.

Eleven particular mathematical chemistry skills are described for the purposes of this study. Not all questions from the Chemistry Achievement Test were placed in one of the eleven categories representing mathematics skills as some questions on this test were evaluated as being totally descriptive with no mathematical content; these questions were included in the Chemistry Achievement Test score only. If mathematical chemistry skills questions were tested by only one question or if it was not obvious that a question had mathematical content, it was used only to determine the final score. The following skills were tested in the Chemistry Achievement Test. The questions testing each skill follow in parentheses. The complete test is reproduced in Appendix B.

1. Write chemical formulas from given chemical names. [B1]
2. Name compounds from given chemical formulas. [B2]
3. Balance a chemical equation given molecular formulas of all species. [B3]
4. Balance a chemical equation where some products have to be determined and no formulas are given for these products. [B4 and B5]
5. Use significant figures convention correctly in addition subtraction, multiplication and division of simple numbers. [A6 and B7]
6. Determine the relative number of moles of elements in a compound given its elemental composition by weight or weight percent or conversely calculate the percent composition of all elements of a compound given the chemical formula of the compound. [B10 and B12]

7. Convert the mass of a substance (represented as being monatomic, diatomic, molecular, or ionic) to number of moles of this substance. [B13(a); C1(a) - second step only, formula mass assumed to be correct as determined; C2(a); and C2(e)]
8. Calculate the formula mass of a compound, given its formula and a table of atomic masses. [B12 - first step only, correct formula mass; and C1(a) - correct formula mass only]
9. Given a balanced chemical equation solve problems that involve a direct mole-mole ratio calculation. [C1(b) - number of moles of nitroglycerin in C1(a) need not be correct, C2(d); C2(f); C2(g)]
10. Given a balanced chemical equation solve problems that involve a mole-volume relationship. [C1(c); C1(d) - volume at STP only needed for correct answer; C1(e) - answer in moles only is adequate]
11. Calculate one of the variables, molarity of a solution, the concentration of the solute by mass of the volume of the solution given the other two variables. [A7; C2(b); C2(c)]

Chemistry skills 1-11 are given the labels CSKILL 1 to CSKILL 11. The placing of the chemistry achievement test questions under 11 skill headings was first done by two instructors of chemistry. These skill-categories and the appropriateness of particular questions (or part of a question) were confirmed by two other chemistry instructors.

Generally this was done by a concensus approach rather than by a majority vote approach since the categories were created only after it was agreed by the first two instructors that a particular skill category existed and that the skill could be tested by at least two questions from the Chemistry Achievement Test. Had there been any strong objection by two of the remaining four instructors to a category being created modifications would have been made. No strong objections to the creation of the above categories were noted.

(3a) Intellectual Level Test

A battery of Piagetian tasks was administered to all students to determine the level of intellectual development of each student. The battery of tasks is reproduced in Appendix C. These include two tasks testing ratio and proportion (Karplus & Karplus, 1970), two tasks testing the combinatorial schema (Inhelder & Piaget, 1958 and Hobbs, 1975) and one testing conservation of displacement volume (Karplus & Lavatelli, 1969). The ratio and proportion tasks included two tasks: one a demonstration, using a shadow created by blocking light with a paper disk, followed by each student answering pertinent questions; the other included a sketch of a flask which each student measured using appropriate paper clips followed by the answering of pertinent written questions in writing. The combinations tasks included one that was completely a pencil and paper task and one that involved combining of chemicals by the student within a laboratory setting, followed by a description of observations and answering of pertinent written questions in writing. The conservation of volume task involved two cylinders of the same volume but of differing masses and a graduated cylinder with some water in it. Appropriate manipulations were made by the student followed by answering of written questions in writing. The tasks and scoring procedures are discussed below, following a description of general administration procedure.

Administration of the Intellectual Development Test

The chemical combinations task was administered in a laboratory setting while the other tasks were administered in a regular lecture room. All test administrations were preceded by verbal instructions. These instructions were taped for use by the next instructor. Instructions given by Instructor one were audited by Instructor two before the instructions were repeated by him to his group. Hence there was good reason to believe that the testing procedures were uniform.

The chemical combinations task was a bit more complex and required the assistance of laboratory demonstrators. In this test all four groups of students were supervised by one instructor and two laboratory demonstrators per testing session. All laboratory demonstrators were given the same instructions with regards to their responsibilities in the laboratory. Help given to students in the laboratory was limited to explanations of procedure only. No help was given with respect to interpretation of any results. Problems with undesired communication between students never occurred because of close supervision and because of the large spacing between occupied desks or laboratory benches.

(3b) Scoring of the Piagetian Tasks

The Shadows

In the shadows task a demonstration using a light bulb, a paper disk and a paper screen was involved. The light bulb and the paper screen were mounted opposite each other about three feet apart. The paper disk was mounted in a permanent position between the light bulb and the screen in such a way that the disk obstructed light from the light bulb and cast a shadow on the screen. The student was required to answer questions with regards to the change in shadow size if the paper disk were moved nearer and then further from the screen from its permanent position. Also questions were posed regarding a change in size of the paper disk and the effect this change would have on the size of the shadow cast on the screen.

Subjects who correctly predicted the change in size of the shadow cast if either the disk were moved or if it were changed in size and then explained why shadow size changes might occur were considered formal operational and were given two points. Subjects who predicted correctly the change in shadow size for both instances above but could not explain in writing why these changes occurred were considered intermediate between the concrete and formal stages and were given one point. Subjects who showed no consistency with regards to relating shadow size to disk position and disk size were regarded as being at the concrete stage and given a score of zero.

The Flasks

In this task a sketch of a small flask and measurement of this flask with small paper clips (as a unit of measure) were involved. The student was instructed, in writing, that a larger flask was measured with large clips and found to measure six large clips. The small flask (sketched for the student) was stated, to measure four large clips. The student was told to measure the small flask in small paper clips then predict the height of the large flask in small paper clips and explain how he arrived at his prediction. Subjects who both correctly predicted the size of the large flask in small paper clips and explained logically how they arrived at their answer were considered formal operational and were given two points. Subjects who only correctly measured the small flask with small clips and correctly predicted the size of the large flask in small paper clips but could not explain the results they obtained were regarded as intermediate between the concrete and formal stage and were given one point. A logical explanation with the wrong prediction for the size of the large flask in small clips also earned the subject one point. A subject who only measured the small flask correctly and made no prediction and offered no explanations was regarded as being at the concrete stage and was given a score of zero.

The Radio Problem

The radio problem task was an all pencil and paper task. The student was told (in writing only) that he was to make as many combinations as possible with a transistor radio and four accessories. In any one combination he could use from zero to four accessories. Subjects who systematically obtained all of the 16 possible combinations were considered formal and were given two points. Subjects who obtained eight to nine combinations in a systematic way or 12 - 14 combinations in a partly systematic way or obtained 15 combinations randomly were regarded as being intermediate between the formal stage and the concrete stage were given one point. A subject who appeared not to understand the objective or who randomly obtained less than 10 combinations was regarded as being concrete and given a score of zero.

The Two Solids

This task involved separately submerging two solids of equal volume but of differing masses into some water in a graduated cylinder. Subjects who after submerging the lighter solid into the water predicted that the heavier solid would displace an amount of water equal to that displaced by the lighter solid when it was submerged were regarded as formal and were given two points. Subjects who made the wrong prediction but after submerging the heavier solid into the water noted that an equal volume of water was displaced and offered a correct explanation as to why this was so were regarded as intermediate between the formal stage and the concrete stage and were given one point. Subjects who made the wrong prediction above and after submerging the heavier solid in the water, could not explain why the volumes of water displaced were equal were regarded as concrete and were given a score of zero.

The Chemical Combination Test

In the chemical combinations test the subjects were given five dropping bottles labelled one, two, three, four and g. The students were shown that addition of a few drops of g to a beaker A and to beaker B caused one of the two to turn yellow while the other remained colorless. This color, they were told, can be produced by combining g with one or some combination of solutions of one to four with g. The student was instructed both orally and in writing that he was to sytematically discover all individual liquids of one to four or some combinations of one to four that would produce the yellow colored solution. A subject who sytematically produced the yellow color and indicated he knew that solutions one, three and g were necessary to do so, and knew that solution two had no effect and that solution four removed or prevented the color from forming was regarded as formal and was given two points. A subject who made the color in at least one way and knew that either solution one, three and g were necessary or that solution two had no effect or alternately made the color in at least one way and knew that solution four removed the color was regarded as intermediate between the formal stage and the concrete stage and was given one point. A subject who simply made the color in one way with no systematic work was regarded as being concrete and was given one point.

Limitations of the Study

A number of limitations are recognized in this study.

1. With respect to the subjects of this study, four out of five classes available in introductory chemistry were used for the purposes of the experiment. Although no deliberate effort was made during registration of the students to direct students into a particular class, uniform "filling" of all five classes was obtained during the registration period of seven hours. Classes were allowed to randomly fill firstly to five members in all classes, then to ten members for all classes, etc., until thirty students per class resulted for all classes. The randomization and the statistical benefit resulting, achieved by this means, may have been partly negated by the dropping out of a considerable number of students from all classes. The number of drop-outs was not made equal for statistical purposes since class sizes became undesirably small

by the end of the semester. There is no reason to believe that dropping out was not also random.

2. With respect to the instructors and their teaching styles, there appeared to be little difference in approach to teaching of mathematics and chemistry during the experiment and every effort was made to ensure similarity of approach. However, some differences between instructors were inevitable and could cause an interaction between instructor and treatment.

3. With respect to the mathematics skills test, as far as testing general mathematical ability at a particular academic level, this test was adequate. As far as its ability to test for the existence of particular mathematics skills, after modification to a one skill - one question set-up, this test was adequate in the opinion of this writer. A wider range of difficulty for the mathematics items may have been more useful; perhaps some questions of the difficulty level suggested by Dence (1970) substituted for some of the questions on the MAST would have resulted in a mathematics skills test with a more appropriate range of questions.

4. With respect to the Piagetian tasks, the inherent weakness of these tests was revealed when it was noted that the chemical test correlated poorly, and in some cases negatively, with the other tasks and with the total task score (sum of five).
   This was taken to mean it was measuring a different aspect of formal operational thinking than the other tests.

5. With respect to the chemistry achievement test, no particular problems were revealed after the use of this test. It might have

been more convenient to have had a chemistry test that paralleled the chemistry skills defined in this study on a one skill - one question basis with perhaps three questions per skill category. This, though, might have represented a situation more suited to statistical procedures than to one of testing chemistry skills in a realistic setting in which a normally validated chemistry achievement test is used.

Delimitations of the Study

The generalizability of the results of this study is governed by the nature of the subjects of this study, the appropriateness and definability of the mathematics skills course, the appropriateness and definability of the chemistry curriculum, and the chemistry achievement test, and the appropriateness and definability of the developmental level test.

The subjects used for the study were from one university and are described as being of a weak background in chemistry or with no background in chemistry. The results of this study then would be generalizable to introductory chemistry students of a junior college level or grade XII level with little or no chemistry background and of average ability.

The particular mathematics skills comprising the mathematics remediation course as well as the procedures used are specific to this study. The results may not therefore be generalized to other skills, procedures and instructors.

A set of mathematics skills behavioural objectives would have helped to insure a uniformity of mathematics skills instruction particularly with respect to teaching the students to relate their acquired and/or reviewed mathematics skills to the content of chemistry. More definitive and generalizable results may have been obtained had behavioural objectives defining clearly when and how mathematics skills topics would be introduced to particular chemistry topics been used.

The chemistry course used in this study is defined expicitly by the use of course objectives, problem sets, a course outline, a laboratory outline and a laboratory manual. There is no reason to believe that the course is atypical. Nevertheless, the results may not be completely generalizable to other similar settings. The particular Piagetian tasks used and the mode of presentation of these necessitates the delimitation of any generalizations regarding student performance to those situations tested.

Hypotheses

The following research questions were considered in this study with respect to a population that is average in chemistry achievement:

(1) Can particular mathematics skills be taught in the context of an introductory chemistry course?

(2) Does a group of subjects exposed to remediation of mathematics skills related to the chemistry content in an introductory chemistry course exhibit greater achievement in introductory

chemistry, than an equivalent group of subjects not exposed to the mathematics remediation?

(3) Does a group of subjects exposed to remediation of mathematics skills related to the chemistry content in an introductory chemistry course exhibit greater achievement in mathematical chemistry than an equivalent group of subjects not exposed to the mathematics remediation?

(4) Can particular mathematical skills be identified as necessary prerequisites to the development of selected concepts normally met in introductory chemistry?

The following null hypotheses were derived from the above questions:

(1) There is no significant difference in achievement in mathematics between students exposed to remediation and those not exposed to remediation.

(2) There is no significant difference in achievement in chemistry between students receiving mathematics remediation and students not receiving mathematics remediation.

(3) There is no significant difference in achievement in mathematical chemistry between students receiving mathematics remediation and students not receiving mathematics remediation.

4(a) There is no significant relationship between ability to perform general computations correctly and achievement in chemistry.

(b) There is no significant relationship between ability to correctly use parentheses and achievement in chemistry.

(c) There is no significant relationship between ability to correctly use signed numbers and achievement in chemistry.

(d) There is no significant relationship between ability to correctly use fractions in calculations and achievement in chemistry.

(e) There is no significant relationship between ability to correctly use decimals in calculations and achievement in chemistry.

(f) There is no significant relationship between ability to correctly use exponents in calculations and achievement in chemistry.

(g) There is no significant relationship between ability to correctly use percent in calculations and achievement in chemistry.

(h) There is no significant relationship between ability to correctly use equations and achievement in chemistry.

(i) There is no significant relationship between ability to correctly perform ratio and proportion calculations and achievement in chemistry.

(j) There is no significant relationship between ability to interpret and use graphs and achievement in chemistry.

5(a) There is no significant relationship between ability to perform general computations correctly and achievement in mathematical chemistry.

(b) There is no significant relationship between ability to correctly use parentheses and achievement in mathematical chemistry.

(c) There is no significant relationship between ability to correctly use signed numbers and achievement in mathematical chemistry.

(d) There is no significant relationship between ability to correctly use fractions in calculations and achievement in mathematical chemistry.

(e) There is no significant relationship between ability to correctly use decimals in calculations and achievement in mathematical chemistry.

(f) There is no significant relationship between ability to correctly use exponents in calculations and achievement in mathematical chemistry.

(g) There is no significant relationship between ability to correctly use percent in calculations and achievement in mathematical chemistry.

(h) There is no significant relationship between ability to correctly use equations and achievement in mathematical chemistry.

(i) There is no significant relationship between ability to correctly perform ratio and proportion calculation and achievement in mathematical chemistry.

(j) There is no significant relationship between ability to interpret and use graphs and achievement in mathematical chemistry.

Chapter 4

ANALYSIS OF DATA

Introduction

The presentation and discussion of the analysis of the experimental results will begin with an evaluation of the effect of mathematics remediation instruction on mathematics achievement, followed by an evaluation of any interactions of intructor and treatment. Also the effect of the intellectual level scores and the mathematics pre-scores used as covariates, firstly separately then conjointly, on mathematics posttest scores will be evaluated. Such evaluation is necessary in order to determine the significance of the contributions of the intellectual level scores and mathematics pre-scores when used as covariates, in the regression equations in which the mathematics posttest scores and the chemistry achievement posttest scores, respectively, were used as dependent variables. It was intended that either or both covariates would be retained only for some parts of the analysis where their contribution was significant.

The computer program used in this study to analyze data by the method of covariance used a regression approach. In the analysis of covariance sums of squares, degrees of freedom, mean squares and the resulting F-ratio with the probabilities of obtaining these values are given. Probabilities of 0.05 or less were considered to render the F-ratios significant unless otherwise indicated.

For the purpose of describing the characteristics of the subjects of this study in terms of mathematics and chemistry achievement scores, means and standard deviations, for all four groups of the study are given for mathematics pretest and posttest scores, for the chemistry achievement scores and mathematical chemistry scores in Table 1.

The significance of the experimental group chemistry achievement means and the mathematical chemistry means being noticeably the highest of all groups for Instructor one is also later analyzed statistically with intellectual developmental level and the mathematics pre-scores used as covariates firstly separately and then conjointly.

Effects of Remediation on Achievement in Mathematics

Hypothesis one states that there is no significant difference in achievement in mathematics between students exposed to remediation and those not exposed to remediation. This was tested by an analysis of covariance in which mathematics achievement on the posttests between the experimental and control groups was contrasted. The mathematics pre-score and Piagetian total score were used as covariates in this analysis.

The results of this analysis are given in Table 2.

Table 1

Means and standard deviations for mathematics pre-test, mathematics posttest, chemistry achievement test, and the mathematical chemistry achievement test.

			Mathematics pre-scores	Mathematics postscores	Chemistry achievement scores	Mathematical chemistry scores x/71 x 100%
Instructor 1		N = 18	$\bar{X} = 66.89$	$\bar{X} = 69.56$	$\bar{X} = 39.40$	$\bar{X} = 36.11$
	Control		$S = 14.72$	$S = 11.77$	$S = 15.92$	$S = 16.90$
			$\Sigma = 1204$	$\Sigma = 1252$	$\Sigma = 711$	$\Sigma = 650$
			$\Delta = 2.67$			
			$\bar{X} = 71.79$	$\bar{X} = 78.74$	$\bar{X} = 50.87$	$\bar{X} = 51.42$
	Experimental	N = 19	$S = 11.18$	$S = 10.24$	$S = 13.41$	$S = 15.95$
			$\Sigma = 1364.0$	$\Sigma = 1496.0$	$\Sigma = 966.50$	$\Sigma = 977.0$
			$\Delta = 6.95$			
Instructor 2			$\bar{X} = 61.14$	$\bar{X} = 68.71$	$\bar{X} = 42.64$	$\bar{X} = 39.64$
	Control	N = 14	$S = 16.94$	$S = 13.45$	$S = 8.78$	$S = 13.17$
			$\Sigma = 856$	$\Sigma = 962$	$\Sigma = 597.0$	$\Sigma = 555.0$
			$\Delta = 7.57$			
			$\bar{X} = 57.94$	$\bar{X} = 67.35$	$\bar{X} = 39.12$	$\bar{X} = 38.06$
	Experimental	N = 17	$S = 12.00$	$S = 10.07$	$S = 11.77$	$S = 12.50$
			$\Sigma = 985.1$	$\Sigma = 1145.0$	$\Sigma = 665.0$	$\Sigma = 647$
			$\Delta = 9.41$			

Table 2

Analysis of covariance on mathematics posttest scores

Source of variation	Sum of squares	df	Mean square	F	Significance of F
Covariates					
Covariates combined	4165.01	2	2082.50	31.85	0.001
Mathematics pre-score	3090.58	1	3090.58	47.27	0.001
Piagetian total score	308.26	1	308.26	4.72	0.032
Main Effects					
Main effects combined	264.69	2	132.35	2.02	0.139
Instructor 1 vs Instructor 2	48.27	1	48.27	0.74	0.999
Experimental vs Control	264.66	1	264.66	4.05	0.046
Interactions					
2-Way Interactions	95.28	1	95.28	1.46	0.230
Instructor vs treatment	95.28	1	95.28	1.46	0.230
Explained	5628.42	5	1125.68	17.22	0.001
Residual	4053.78	62	65.38		
Total	9682.20	67	144.51		

The effects of using the mathematics pre-score and the Piagetian Total Score as covariates in the analysis are as expected. With regards to the mathematics pre-scores it is known that students usually have some background in mathematics before beginning junior college or Grade XII studies but the adequacy of this mathematics is being questioned in this experiment. It was therefore necessary to control the analysis for initial skills in mathematics while analyzing the final outcome of instruction in mathematics. Similarly as indicated in Chapter two, developmental level appears to affect achievement in science and mathematics sufficiently to warrant partialling out its effect as a covariate before examining the main effect. By controlling for the degree of intellectual development of each student in this part of the study the mathematics skill improvement is analyzed with the advantage of the effect of developmental level being controlled.

The significance of using the mathematics pre-score as a covariate when evaluating the difference in achievement in mathematics between the experimental and control groups on the posttest was evaluated statistically. This was done by an analysis of covariance in which the effect of the mathematics pre-score used as a covariate was tested with the effect of Piagetian total score, and any interactive effects controlled. The results in Table 2 show an F-value of 47.27 with an associated probability of less than 0.05 which indicates that using the mathematics pre-score as a covariate is statistically acceptable.

The significance of using the Piagetian total score as a covariate when testing for the main effect of mathematics achievement was similarly determined. This was tested by an analysis of covariance in which the effect of the Piagetian total score used as a covariate was evaluated with the mathematics pre-score and any interactive effects controlled. The results in Table 2 show an F-value of 4.72 with an associated probability of less than 0.05 which indicates that using the Piagetian total score as a covariate is acceptable statistically.

Finally the acceptability of using the mathematics pre-score and the Piagetian total score as conjoint covariates when testing for the main effect of mathematics achievement was evaluated. This was done by an analysis of covariance in which the effect of the Piagetian total score conjointly with the effect of the mathematics pre-score used as covariates was tested with the effect any interactive effects controlled.

The results of Table 2 show an F-value of 31.85 with an associated probability of less than 0.05 which indicates that using the mathematics pre-score and Piagetian total score conjointly as covariates is acceptable statistically.

With regard to the main effect for treatment the results in Table 2 show an F-value of 4.05 with an associated probability of less than 0.05, which indicates a significant difference in achievement in mathematics between the experimental and control groups as measured by the mathematics posttest. The difference favoured the experimental group. The null hypothesis, stated above, was thus rejected. Conversely there was no significant interaction between treatment and instructor.

These results confirm that it is possible to up-grade the mathematics skills of introductory chemistry students within the context of a chemistry class. This is a very encouraging result since only about two weeks out of a total of 13 weeks of one semester were used by each chemistry instructor for mathematics instruction. Also the mathematics skills instruction program by each instructor was successful with only an examination of a chemistry unit for possible mathematics skills needed, followed by instruction in these skills. Written quizzes in mathematics skills were the only written feed-back that guided the instructor in selecting mathematics exercises for presentation to the students for skills review purposes.

The fact that there was no interaction between instructor and treatment also is an encouraging result as this indicates that mathematics skills instruction need not be taught within the context of a highly organized remediation program. A rigorous task analysis of mathematics prerequisite skills for each student is not needed for the purpose of achieving significant mathematics skill up-grading, although it is possible it may effect further improvement.

Achievement in Chemistry

Hypothesis two relates to the effect of mathematics remediation on chemistry achievement. In its null form it states: there is no significant difference in achievement in chemistry between students not receiving mathematics remediation and students receiving mathematics remediation. This was tested by an analysis of covariance in which the mean chemistry achievement scores between the experimental and control groups were contrasted. The mathematics pre-score and the Piagetian total score were used as covariates. The results are reported in Table 3.

The correlation value of the mathematics pre-score with the chemistry achievement scores was relatively low ($r = .35$, $p = .002$) which supports its use as a covariate.

The acceptability of using the mathematics pre-score as a covariate when testing for the differences in chemistry achievement between the experimental and control groups was further tested by an analysis of covariance in which the effect of the mathematics pre-score used as a covariate was evaluated with the effect of the Piagetian total score effects controlled.

The results in Table 3 show an F-value of 5.30 with an associated probability of 0.025 which indicates that using the mathematics pre-score as a covariate is significant.

This is as expected as it was anticipated as indicated in the literature that ability in mathematics is related significantly to achievement in chemistry. These results indicate that the use of the mathematics pre-score as a covariate was justified. These results also suggest that the relationship between chemistry achievement and possession of the mathematics skills represented in the mathematics

Table 3

Analysis of covariance on chemistry achievement scores

Source of variation	Sum of squares	df	Mean square	F	Significance of F
Covariates					
Covariates combined	1968.97	2	984.49	6.53	0.003
Mathematics pre-score	799.21	1	799.21	5.30	0.025
Piagetian total score	524.48	1	524.48	3.50	0.067
Main Effects					
Main effects combined	232.84	2	116.42	0.77	0.466
Instructor 1 vs Instructor 2	15.87	1	15.87	0.11	0.747
Experimental vs Control	223.40	1	223.4	1.48	0.228
Interactions					
2-Way Interactions	575.85	1	575.85	3.82	0.055
Instructor vs treatment	575.85	1	575.85	3.82	0.055
Explained	2777.66	5	555.53	3.69	0.006
Residual	9346.77	62	150.75		
Total	12124.43	67	180.96		

pre-test is high as suggested by Denny (1970). This hypothesis is examined later.

The correlation of the Piagetian total score with the chemistry achievement scores is also relatively low ($r = 0.31$, $p = 0.005$) but statistically significant and necessary as a covariate. The acceptability of using the Piagetian total score as a covariate when testing for the effect of chemistry achievement was tested by an analysis of covariance in which the effect of the Piagetian total score used as a covariate was tested with the effect of the mathematics pre-score controlled.

The results in Table 3 show an F-value of 3.50 with an associated probability of 0.067 which indicates that using the Piagetian total score as a covariate is marginally insignificant. This is not an expected outcome as some researchers, as indicated in Chapter 2, claim chemistry achievement is highly dependent on intellectual level as measured by Piagetian task tests.

The effect of using the mathematics pre-score and the Piagetian total score as covariates conjointly when testing for the effect of chemistry achievement was tested by an analysis of covariance in which the effect of the Piagetian total score and the mathematics pre-score used conjointly as covariates was evaluated. The results in Table 3 show an F-value of 6.53 and associated probability of 0.003 which indicates that using the Piagetian total score and the mathematics pre-score as a conjoint covariate is quite meaningful.

This is a very encouraging result that lends support to the supposition of this study which is that achievement in chemistry is related to both mathematical skill and intellectual level. Perhaps achievement in chemistry is related to mathematical skill and intellectual level as a conjoint factor.

With regard to the main effects, for the effect of treatment the results in Table 3 show an F-value of 1.48 with an associated probability greater than 0.05 which indicates there was no significant difference in achievement in chemistry between the experimental and control groups. The null hypothesis was thus accepted. Similarly there was no significant interaction between instructor and treatment. ($F = 3.82$, $p = 0.055$)

Successful acquisition of related mathematics skills does not appear to be sufficient for the chemistry student to improve his performance in chemistry.

One could speculate that achievement in chemistry might only be positively affected by increasing the intellectual level of the students as well as increasing mathematical skill. In the present study nothing had been done with the specific intent of increasing the intellectual level of the students in the experimental groups.

Achievement in Mathematical Chemistry

Hypothesis three relates to the effect of mathematics remediation on mathematical chemistry achievement. In its null form it states: there is no significant difference in achievement in mathematical chemistry between students not receiving mathematics remediation and students receiving mathematics remediation. This was tested by an analysis of covariance in which the chemistry achievement scores of the experimental and control groups were contrasted. The mathematics pre-score and the Piagetian total score were used as covariates.

The correlation values of the mathematics pre-score and Piagetian total scores with the chemistry achievement scores are 0.35 ($p = 0.002$) and 0.31 ($p = 0.005$) respectively, making their use as covariates questionable because of the relatively low correlation values. The effect of using mathematics pre-score as a covariate when testing for the effect of mathematical chemistry achievement was tested by an analysis of covariance in which the effect of the mathematics pre-score used as a covariate was evaluated with the effect of the Piagetian total score controlled.

The results of Table 4 show an F-value of 3.97 with an associated probability of 0.05 which indicates that using the mathematics pre-score as a covariate is acceptable.

The effect of using the Piagetian total score as a covariate when testing for the effect of mathematical chemistry achievement differences between the experimental and control groups was tested by an analysis of covariance in which the effect of the Piagetian total score used as a covariate was evaluated with the effect of the mathematics pre-score controlled.

The results in Table 4 show an F-value of 2.19 with an associated probability of 0.144 which indicates that using the Piagetian total score as a covariate is not acceptable.

Again, this is not completely expected as use of the Piagetian total score in the analysis of covariance of the mathematics posttest scores was significant. Logically one would expect mathematical chemistry to have the same relationship to the Piagetian total scores as the mathematics skills scores.

The effect of using the mathematics pre-score and the Piagetian total score as covariates conjointly when testing for the significance of the difference in mathematical chemistry achievement between the experimental and control groups was tested by an analysis of covariance in which the effect of the Piagetian total score and the mathematics pre-score used conjointly as covariates was evaluated.

The results of Table 4 show an F-value of 4.60 with an associated probability of 0.014 which indicates that using the Piagetian total score and the mathematics pre-score as covariates conjointly is significant.

It appears that mathematical skill and intellectual level conjointly are useful in testing for the significance of differences in achievement, by experimental versus control groups, on mathematical chemistry.

With respect to the main effects, for mathematical chemistry an F-value of 1.75 with an associated probability greater than 0.05 was found which suggests there was no significant difference in achievement in mathematical chemistry between the experimental and control groups. The null hypothesis stated above could neither be accepted nor rejected since in contrast to this an interactive effect between instructor and

Table 4

Analysis of covariance on mathematical chemistry achievement scores

Source of variation	Sum of squares	df	Mean square	F	Significance of F
<u>Covariates</u>					
Covariates combined	829.38	2	414.69	4.55	0.014
Mathematics pre-score	361.20	1	361.20	3.97	0.051
Piagetian total score	199.30	1	199.30	2.19	0.144
<u>Main Effects</u>					
Main effects combined	161.23	2	80.62	0.89	0.418
Instructor 1 vs Instructor 2	0.266	1	0.27	0.00	0.957
Experimental vs Control	159.56	1	159.56	1.75	0.191
<u>Interactions</u>					
2-Way Interactions	362.76	1	362.76	3.98	0.050
Instructor vs treatment	362.76	1	362.76	3.98	0.050
Explained	1353.37	5	270.67	2.97	0.018
Residual	5647.84	62	91.09		
Total	7000.91	67	104.49		

treatment was found. Additional analyses on the mathematical chemistry scores are done separately for each instructor later in an attempt to identify the source of the interaction. The results of researchers such as Denny (1970) and others would suggest that achievement in mathematical chemistry would be affected positively for those students who received remediation in mathematics skills.

The interactive effect identified in mathematical chemistry achievement analyses may be the result of different content and different sequencing of chemistry topics during instruction in one of the instructor's classes. These may be possible causes of the interactions but are unlikely since the chemistry course is highly structured by the use of objectives and very little opportunity exists for deviating from the prescribed curriculum.

Method of instruction in chemistry could be a factor contributing to an interaction since two instructors participated in the project. The actual cause of the interactive effect is not clear.

Analysis of Mathematical Chemistry Scores for Instructor one and Instructor two

An analysis on the mathematical chemistry scores was done within the classes of Instructor one and then within the classes of Instructor two. The null-hypothesis statement is repeated for this part of the Analysis of Data section. The significance of each analysis within each instructor group is given. Hypothesis three is re-examined for Instructor one and Instructor two separately.

The hypothesis is: there is no significant difference in achievement in mathematical chemistry between students not receiving mathematics remediation and students receiving mathematics remediation.

This hypothesis was tested for Instructor one using an analysis of covariance as in the grouped analysis above on the mathematical chemistry scores. The results are indicated in Table 5.

Table 5

Analysis of covariance on the mathematical chemistry scores for Instructor one

Source of variation	Sum of squares	df	Mean square	F	Significance of F
Covariate					
Mathematics pre-score	1418.67	1	1418.67	7.78	0.009
Main Effects					
Experimental vs control	783.58	1	783.58	4.30	0.046
Explained	2202.25	2	1101.13	6.04	0.006
Residual	6198.63	34	182.30		
Total	8400.88	36	233.36		

The use of the mathematics pre-score as a covariate was found to be statistically significant ($p < .05$) in this analysis. The use of the Piagetian total score alone and the Piagetian total score used with the mathematics pre-score conjointly were found not to be statistically significant ($p > 0.05$), therefore the Piagetian total score was not used as a covariate in this analysis.

Table 5 indicates that achievement in mathematical chemistry was significantly greater at the 0.05 level in the experimental group versus the control group for Instructor one. ($F = 4.30$, $p = 0.046$). Thus the null hypothesis stated above was rejected.

The above result may have been the result of Instructor one emphasizing to the students of his class the importance (or supposed importance) of learning calculation skills for application in chemistry computations. This may have enticed the experimental group of Instructor one to learn the algorithms for solving the calculation problems which were later used to solve chemistry problems. This perhaps, they could do even if they did not genuinely understand the chemistry calculation problems on the chemistry achievement test provided that the problems they worked were similar to the test questions.

In a separate analysis of covariance done for Instructor two the mathematics pre-score and the Piagetian total score used as covariates when the achievement in mathematical chemistry was contrasted for the experimental group versus the control group were found singly and conjointly to be statistically unacceptable since all three associated probabilities were greater than 0.05. An analysis of variance was therefore done on the mathematical chemistry scores of Instructor two. The results of this analysis are reported in Table 6. The F-value of 0.90 with an associated probability of 0.35 shows that there clearly was not a difference in achievement between the experimental and control groups in mathematical chemistry for Instructor two. These results suggest that the mathematics skill improvement for these students definitely had no effect on improving performance in mathematical chemistry. It is possible that the instruction in mathematics skills in the experimental class differed markedly from the instruction in mathematics skills in the class of Instructor one.

Table 6

Analysis of variance on the mathematical chemistry scores for Instructor two

Source of variation	Sum of squares	df	Mean square	F	Significance of F
<u>Main Effects</u>					
Experimental vs control	54.14	1	54.14	0.90	0.351
Explained	54.14	1	54.14	0.90	0.351
Residual	1745.80	29	60.20		
Total	1799.93	30	60.00		

Intellectual Level, Mathematics Skills and Chemistry Achievement

Introduced here is the correlation between Piagetian total scores with chemistry and mathematical chemistry scores as well as the correlation between Piagetian total scores with mathematics pre-test and posttest scores. These data are presented in Table 7.

Table 7

Intercorrelations of Piagetian, mathematics, chemistry and mathematical chemistry scores.

N = 68

	Piagetian total scores	Mathematics pretest scores	Mathematics posttest scores	Mathematical chemistry scores	Chemistry achievement scores
Piagetian total score	1.0				
Mathematics pretest scores	0.33 (.003)	1.0			
Mathematics posttest scores	0.43 (.001)	0.72 (<.001)	1.0		
Mathematical chemistry scores	0.26 (0.17)	0.30 (.006)	0.40 (.001)	1.0	
Chemistry achievement scores	0.31 (.005)	0.35 (.002)	0.44 (.001)	0.95 (<.001)	1.0

Hypotheses 4(a) - (j) and hypotheses 5(a) - (j) stated earlier are examined here. Correlations between the ten mathematics sub-skill scores, described earlier, and chemistry and mathematical chemistry scores are reported in Table 8. Correlations between the ten mathematics sub-skill scores derived by Denny's procedures are presented in Table 9.

The results in Table 7 show that the correlation between the Piagetian total scores and the chemistry achievement scores was 0.31 ($p = 0.005$). The correlation between the Piagetian total scores and the mathematical chemistry scores was 0.26 ($p = 0.017$). The correlations between the Piagetian total scores with the mathematics pre-test scores and mathematics posttest scores were 0.33 ($p = 0.003$) and 0.43 ($p = 0.001$) respectively. The above correlations are not very high but are suggestive of hypotheses that might be examined further empirically in other studies. The high correlations between chemistry achievement scores and intellectual level scores (obtained using Piagetian task tests) reported in the literature were not replicated in the present study.

Also the results of Table 7 show a correlation of 0.44 ($s = 0.001$) and 0.40 ($s = 0.001$) between mathematics posttest scores with chemistry achievement scores and mathematical chemistry scores respectively. The correlations between each of the ten mathematics skills scores with chemistry achievement scores and mathematical chemistry scores are examined below.

Table 8

Correlations between chemistry achievement scores and mathematical chemistry scores with the ten *modified* mathematics skills scores

Mathematics skill	Chemistry achievement score		Mathematical chemistry scores
Skill 1 (Computation)	0.29 (68) S = 0.009	Skill 1	0.26 (68) S = 0.017
Skill 2 (Parentheses)	0.14 (68) S = 0.126	Skill 2	0.16 (68) S = 0.091
Skill 3 (Signed numbers)	0.27 (68) S = 0.015	Skill 3	0.26 (68) S = 0.016
Skill 4 (Fractions)	0.11 (68) S = 0.187	Skill 4	0.14 (68) S = 0.134
Skill 5 (Decimals)	0.08 (68) S = 0.267	Skill 5	0.14 (68) S = 0.136
Skill 6 (Exponents)	0.14 (68) S = 0.123	Skill 6	0.16 (68) S = 0.096
Skill 7 (Percent)	0.36 (68) S = 0.001	Skill 7	0.28 (68) S = 0.009
Skill 8 (Equations)	0.08 (68) S = 0.254	Skill 8	0.08 (68) S = 0.270
Skill 9 (Ratio & Proportion)	0.36 (68) S = 0.001	Skill 9	0.28 (68) S = 0.010
Skill 10 (Graphs)	0.25 (68) S = 0.019	Skill 10	0.16 (68) S = 0.092

Table 9

Correlations between chemistry achievement scores and mathematical chemistry scores with the ten mathematics skills scores derived by use of Denny's procedures.

Mathematics skill	Chemistry achievement score		Mathematical chemistry scores
Skill 1 (Computation)	0.43 (68) S = 0.001	Skill 1	0.41 (68) S = 0.001
Skill 2 (Parentheses)	0.17 (68) S = 0.088	Skill 2	0.15 (68) S = 0.112
Skill 3 (Signed numbers)	0.23 (68) S = 0.027	Skill 3	0.21 (68) S = 0.040
Skill 4 (Fractions)	0.46 (68) S = 0.001	Skill 4	0.40 (68) S = 0.001
Skill 5 (Decimals)	0.37 (68) S = 0.001	Skill 5	0.37 (68) S = 0.001
Skill 6 (Exponents)	0.27 (68) S = 0.013	Skill 6	0.28 (68) S = 0.011
Skill 7 (Percent)	0.32 (68) S = 0.004	Skill 7	0.25 (68) S = 0.019
Skill 8 (Equations)	0.25 (68) S = 0.021	Skill 8	0.22 (68) S = 0.037
Skill 9 (Ratio & Proportion)	0.52 (68) S = 0.001	Skill 9	0.44 (68) S = 0.001
Skill 10 (Graphs)	0.20 (68) S = 0.052	Skill 10	0.14 (68) S = 0.133

Correlations between the scores for the ten individual mathematics skills described by Denny and indicated earlier (page 30) are reported in Table 8 and Table 9. In Table 8 the modification of Denny's scoring procedure which is indicated on page 34 has been used to determine a score for each sub-skill. For the data used to produce Table 9, scores for the sub-skills were derived by Denny's own procedure. These correlations are reported for comparative purposes.

Statistically significant correlations were obtained for the sub-tests involving skill one (computations) (.29), skill seven (percent) (0.36) and skill nine (ratio and proportion) (0.36) with chemistry achievement scores at the 0.01 level of probability. Also statistically significant correlations were obtained for the sub-tests involving skill seven (percent) (0.28) and skill nine (ratio and proportion) (0.28) with the mathematical chemistry subtest scores at the 0.01 level of probability.

Of the hypotheses 4(a) - (j) three were rejected. Of the hypotheses 5(a) - (j) two were rejected.

The hypotheses rejected were:

4(a) There is no significant relationship between ability to perform general computations correctly and achievement in chemistry.

4(g) There is no significant relationship between ability to correctly use percent in calculations and achievement in chemistry.

4(i) There is no significant relationship between ability to correctly perform ratio and proportion calculations and achievement in chemistry.

5(g) There is no significant relationship between ability to correctly use percent in calculations and achievement in mathematical chemistry.

5(i) There is no significant relationship between ability to correctly perform ratio and proportion calculations and achievement in mathematical chemistry.

Overall the hypothesis that certain mathematical skills can be identified as necessary for success in introductory chemistry is given qualified support by the correlations reported above, and rejection of the above stated null hypothesis that particular mathematics skills cannot be identified as prerequisite for success in chemistry is in order at least in part.

Denny (1970) suggests that high correlations between mathematics skills scores and chemistry scores indicate that the mathematics skills are prerequisites to understanding of chemistry. However, while such correlations may be consistent with the prerequisite nature of the relationship between mathematics skills and chemistry they are not sufficient. Several methods (White & Clark, 1973; Bart & Krus, 1973)are currently being applied to determine the existence of hierarchical connections between skills. The method due to Bart and Krus has been applied to the data in the present study. This point of the analysis was considered to be post-hoc, and interpretation must be approached with caution. However, it is included as suggestive of an avenue for further research. Essentially, the Bart and Krus test focuses on the percentage of exceptions to the existence of an hierarchical link between two skills. Exceptions are considered to occur when an individual exhibits an hypothesized higher skill but fails to exhibit an hypothesized lower skill. Figure 1 illustrates this.

Upper skill (Chemistry)

		0	1	2
Lower	0			X
skill	1			
(Mathematics)	2			

Figure 1. Exceptions to hierarchical relationship between chemistry and mathematics skills.

The cell marked X represents an exception to the hierarchical link. Bart and Krus suggest that if the number of exceptions exceeds 5% of the sample the connection is not hierarchical.

In order to categorize subjects as having or not having a particular skill subjects who were successful on no more than one of the items testing a particular mathematics skill were considered to lack that skill. Subjects who were successful on at least 3 of the 4 items testing a chemistry skill were considered to possess that skill. Table 10 indicates the percentage of subjects who exhibit each particular chemistry skill while failing to exhibit a particular mathematics skill.

Table 10

Percentage of subjects who exhibited a particular chemistry skill but did not exhibit a particular mathematics skill

		Chemistry Skills										
		1	2	3	4	5	6	7	8	9	10	11
	1	0	0	0	0	0	0	0	0	0	0	0
	2	1	6	9	0	4	9	4	9	4	3	0
	3	0	0	1	0	1	1	0	1	0	0	0
Mathematics	4	0	6	10	1	4	12	4	9	1	1	1
Skills	5	0	1	6	0	1	4	1	3	0	1	1
	6	0	1	9	1	0	0	0	0	0	0	0
	7	0	4	16	1	9	13	4	12	4	3	0
	8	0	0	0	0	0	0	0	0	0	0	0
	9	0	4	12	3	4	10	4	9	0	1	1
	10	1	1	7	0	3	7	10	4	0	0	1

Using the above method for determination of mathematics skills that are prerequisite for chemistry calculations, most of the mathematics skills suggested by Denny (1971) indeed appear to be prerequisite for most of the chemistry skills defined in this study. This finding is not considered definitive though, but offers an interesting avenue for further research.

Chapter 5

CONCLUSION

Summary

Teaching particular mathematics skills to introductory chemistry students within the context of a chemistry class, with a minimum sacrifice in chemistry instruction time, is possible. The successful remediation of ten particular mathematics skills with introductory chemistry students does not affect their achievement in chemistry or in mathematical chemistry positively.

Attempts at identifying the particular mathematics skills that are prerequisite for the learning of chemistry led to only marginal success although mathematics problems having a ratio and proportion skills component or a percent component appeared quite definitely to be related to chemistry achievement. Whether this may be explained in terms of a subject's ability to recall this mathematical skill or in terms of his ability to learn it in the first place is open to question.

Significant but by no means high correlations between achievement in chemistry, achievement in mathematical chemistry, and mathematics skills scores each with intellectual level scores suggest, not surprisingly, that low intellectual level is negatively related to achievement in mathematics and chemistry. It is not possible to infer whether these relationships are causal though. Further research is suggested to establish whether there relationships are indeed causal.

Conclusions

Hypothesis one, that particular mathematics skills can be taught in the context of an introductory chemistry course must be accepted. An analysis of covariance clearly indicates that the groups given mathematics remediation performed better on a mathematics skills posttest than equivalent groups not given mathematics remediation.

Hypothesis two, that achievement in chemistry will be positively affected due to the successful remediation of the ten mathematics skills described in this study, and hypothesis three, that achievement in mathematical chemistry will be positively affected due to successful remediation of the ten mathematics skills described in this study, must both be rejected.

In the testing of hypothesis two a treatment-instructor interaction effect was identified. Retesting of hypothesis two by an analysis of covariance for each instructor separately did not clearly identify the source of the interaction except that performance in mathematical chemistry for the experimental group of Instructor one was significantly better that the performance in mathematical chemistry of the control group of Instructor one. Performance in mathematical chemistry in the experimental group of Instructor two was clearly not different from the performance in mathematical chemistry of control group of Instructor two. The reason for this difference between the experimental classes of Instructor one and Instructor two is not clear but is possibly related to a difference of approach between the two instructors in relating mathematics to chemistry within their respective experimental classes.

Hypotheses 4(a) - (j), that particular mathematical skills can be identified as being prerequisite for success in introductory chemistry must be accepted but only for a small proportion of the skills tested.

Likewise hypotheses 5(a) - (j) that particular mathematical skills can be identified as being prerequisite for success in mathematical chemistry must be accepted but only for a small proportion of the skills tested.

Correlations between the ten mathematics skills defined in this study with mathematical chemistry and chemistry were all much lower than those reported by Denny (1971). The test produced by Denny (1970) regarded as being valid for measuring overall mathematical skill was modified in terms of a one question - one skill concept for use in this study. Many of the questions on this test appeared to this researcher to have one predominating mathematical skill. Because of this difference in scoring between this study and Denny's, it is inconsequential to attempt to draw any meaningful conclusions regarding differences in correlation between skill scores and chemistry mathematical achievement scores in this study versus those in Denny's study. However the overall MAST scores were obtained in this study in the same way as they were in Denny's study. Denny (1971) reports a correlation of 0.799 between the MAST overall scores and the ACS-NSTA 1969 High School Chemistry Test scores. Also Denny (1971) reports a correlation of 0.750 between the MAST overall score and the mathematical chemistry ACS-NSTA subscore. The correlation between the MAST overall scores and the chemistry achievement test of this study was 0.40. The correlation between the MAST overall scores and the mathematical chemistry subscores of the chemistry achievement test of this study was 0.44. These are much lower than the correlations of 0.799 and 0.750 reported above by Denny (1971) but the significance in the difference of these correlations cannot be evaluated conclusively since different chemistry achievement tests were used for the two studies. It should be noted also that the sample size in Denny's study used for the MAST-ACS test score correlations was 242. The sample size in this study was 68. The correlation coefficients obtained in the present study are all significant at the 0.001 level of probability, which suggests a significant relationship does exist between overall mathematical skill and chemistry achievement as well as mathematical chemistry achievement.

It is suggested, however, that an approach using pass-fail contingency table criteria to determine prerequisite mathematics skills for chemistry is more appropriate than an approach using a determination of correlations between mathematics skills scores and chemistry achievement scores.

Attempting to more conclusively establish that certain mathematical skills are prerequisite for certain chemistry skills was done by reference to contingency tables using pass-fail relationships. The ability to apply fractions, decimals, and ratio and proportion is indicated by this method quite definitively to be prerequisite to the application of many chemistry skills or concepts found in introductory chemistry courses. However other mathematics skills such as general computation (addition, substraction, etc.), use of parentheses, signed number usage, use of exponents, use of percentage, manipulation of one variable equations, and producing and interpreting x, y graphs, apparently are prerequisite for success in much of introductory chemistry. Both of the above findings which arose post-hoc out of the present study are considered to offer suggestions for further research rather than being definitive in themselves.

For Further Research

The results of this experiment, the analysis of these results and the literature reviewed suggest research that could be done in the following areas:

1. A better mathematics skills test, testing a higher level of mathematics, should be developed and used in a study similar to the present one. This test should use at least three questions for testing a given skill.
2. Mathematical skill and intellectual development as a conjoint factor influencing achievement in chemistry might be researched.

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APPENDICES

APPENDIX A

MATHEMATICS SKILL TEST

Directions to Student: Do NOT write in this booklet. Write your name and mark your answers on your separate answer sheet, in the row on your answer sheet that is numbered the same as the number of the question. Blacken the space having the same letter (A, B, C, D, or E) as your answer. If you want to change an answer, erase your first mark completely. Make no stray marks; they might count against you. If you cannot answer a question by inspection, figure out the answer on your scratch paper. Answer questions even when you are not perfectly sure that your answer is correct, but avoid wild guessing. There is only one correct answer to each question. Do not spend too much time on any one question. Answer the easier ones first; then go back to the harder ones if you have time.

You have 45 minutes to do this test.

Open your booklet and begin, when your instructor says to start.

1. Express 4520 as a number times a power of 10.

a) 4.52×10^2

b) $.452 \times 10^3$

c) 4.52×10^3

d) $.452 \times 10^2$

e) 4.52×10^4

2. $2(\frac{3}{4}) + 3(\frac{4}{12}) =$

a) $1\frac{1}{2}$

b) $2\frac{1}{3}$

c) $2\frac{1}{2}$

d) 6

e) $6\frac{1}{12}$

3. 2(2 + 3 - 1) =

a) 4

b) 6

c) 8

d) 10

e) 12

4. If 5 yards of material cost $2.50, how much will 2 feet cost?

a) $ .34

b) $ .67

c) $1.00

d) $1.50

e) $1.75

5. 2[3(2Y)] =

a) 7Y

b) 8Y

c) 10Y

d) 12Y

e) some other amount

6. A car goes 3 miles an hour. How many feet will it go in 30 minutes? (5280 ft. = 1 mile)

a) 2740 ft.

b) 3520 ft.

c) 5280 ft.

d) 7920 ft.

e) some other amount

7. -53°C. + 273°C. =

a) 326°C.

b) 230°C.

c) 226°C.

d) 220°C.

e) some other amount

8. If you earn $4552 a year and must pay 12% of this in federal income tax and 3% in wage tax, what is your net income after these taxes have been paid?

a) $3859.20

b) $3869.20

c) $3985.20

d) $4005.76

e) $4483.72

9. If 2 apples cost 20 cents, how much will 7 apples cost?

a) $ .35

b) $ .70

c) $1.00

d) $1.40

e) some other amount

10. $-\log_{10} 10^{-4} =$

a) -40

b) 40

c) 10

d) -4

e) 4

11. If .045 is subtracted from 24.6 the result is

a) 23.15

b) 24.15

c) 24.55

d) 24.555

e) 24.655

12. The decimal equivalent of $\frac{4}{50} + \frac{2}{25}$ is

a) $\frac{8}{50}$

b) .08

c) .016

d) .16

e) 1.6

13. Which is the largest quantity?

a) 10^2

b) 10^1

c) 10^0

d) 10^{-1}

e) 10^{-2}

14. $3(12 - 15) - 5 =$

a) -14

b) -8

c) -2

d) 4

e) 16

15. If $\frac{12\ C^2}{C^3} = 1$, C =

a) 0

b) 1/12

c) 1

d) 12

e) 144

16. In 2000 lbs. of coal ore, 79% is pure coal. You have sufficient oxygen available to burn 50% of the coal ore. How many lbs. of pure coal is available from the remaining unburned ore?

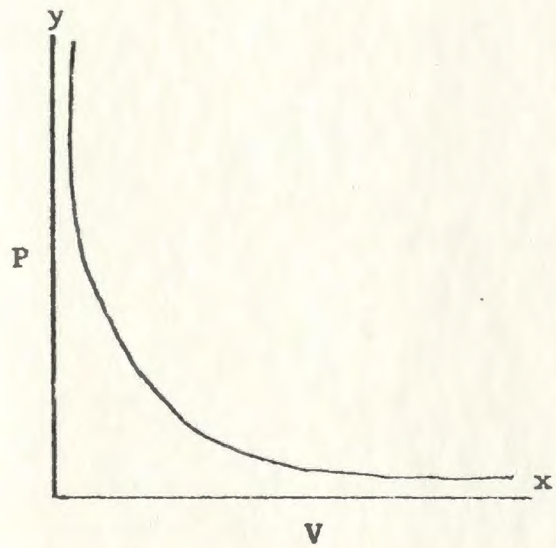
a) 1000 lbs.

b) 990 lbs.

c) 800 lbs.

d) 790 lbs.

e) 700 lbs.



17. In the graph at the left, as the volume (V) increases, the pressure (P)

a) increases

b) decreases

c) remains the same

18. In the graph at the left, as the pressure (P) increases, the volume (V)

a) increases

b) decreases

c) remains the same

19. If PV = k is the equation for a line and k = 4, which of the following pairs of values satisfies this relationship?

a) (1,4)

b) (¼,1)

c) (1,¼)

d) (1,-¼)

e) (-1,¼)

20. $\frac{4 \times 10^{-2}}{2 \times 10^{-3}}$

a) 2×10^{-5}

b) 2×10^{-1}

c) 2×10^{1}

d) 2×10^{5}

e) some other number

21. 3.25 ÷ .25 =

a) .013

b) .13

c) 1.3

d) 13

e) some other amount

Question 22 refers to the formula below in which G is a constant.

$$F = G \frac{m_1 m_2}{r^2}$$

22. If the values of r and m_2 remain constant and the value of m_1 doubles, F is

a) multiplied by 4

b) multiplied by 2

c) divided by 2

d) divided by 4

e) not changed

23. $\frac{4^3}{4^8} =$

a) 1^{-5}

b) 4^{-5}

c) 1^5

d) 4^5

e) 4^{11}

24. $7.5 \overline{) .375} =$

a) .005

b) .05

c) .5

d) 5

e) 50

25. If 2 apples cost 20 cents, the largest number of apples I can buy with 50 cents is:

a) 1

b) 2

c) 3

d) 4

e) 5

26. 2280 ÷ 760 =

a) 5

b) 4

c) 3

d) 2

e) some other number

27. $\frac{625}{25} =$

a) 20

b) 24

c) 25

d) 30

e) 35

28. $\frac{\frac{320}{1.6}}{\frac{4.8}{.8}} =$

a) $\frac{1}{3}$

b) $3\frac{1}{3}$

c) $33\frac{1}{3}$

d) $333\frac{1}{3}$

e) some other amount

29. $\frac{(.2)\ (.03)}{.1} \times \frac{5(2.2)}{11} =$

a) .006

b) .012

c) .06

d) .12

e) .6

30. -25^0K. minus 173^0K. equals

a) -198^0K.

b) -178^0K.

c) -158^0K.

d) 148^0K.

e) 158^0K.

31. If 100,000 square feet are multiplied by 4 the result is:

a) 4×10^6 sq. ft.

b) 4×10^5 sq. ft.

c) 4×10^4 sq. ft.

d) 4×10^3 sq. ft.

e) 4×10^2 sq. ft.

32. $9^{\frac{1}{2}} =$

a) 3

b) 6

c) 9

d) 81

e) some other amount

33. In the graph at the right which graphed line segment has a negative slope?

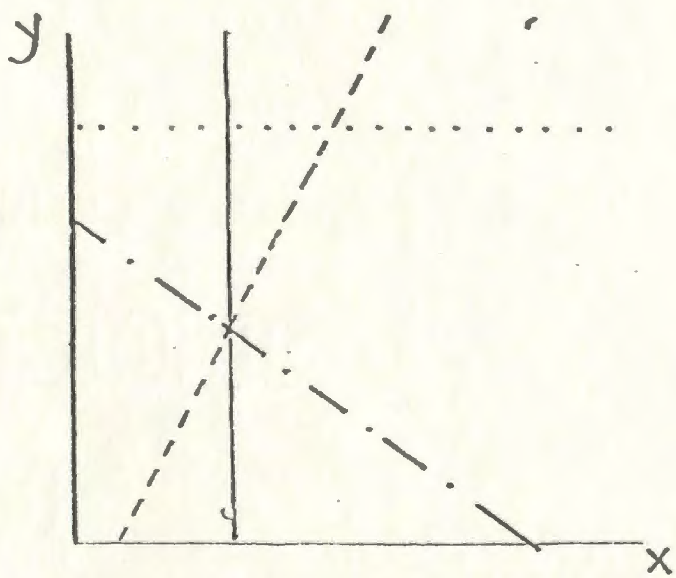
a) - - - - -

b) —.—.

c) ....

d) ————

e) none of these



34. In the graph at the right which graphed line segment has a slope equal to zero?

a) - - - - -

b) —.—.

c) ....

d) ————

e) none of these

35. In a chemical reaction $\frac{4}{5}$ of 32 lbs. of sulfur is consumed. The percentage of sulfur remaining is:

a) 20%

b) 25%

c) 50%

d) 75%

e) 80%

36. $25 \times .30 =$

a) .750

b) 7.50

c) 75.0

d) 750

e) some other amount

37. With a 6% sales tax, how much tax would you have to pay on $10.00?

a) $6.00

b) $ .60

c) $ .06

d) $ .12

e) $1.20

38. .052 + 37.5 =

a) 42.7

b) 38.12

c) 38.02

d) 37.02

3) some other amount

39. $\dfrac{\frac{3}{4}}{\frac{4}{9}}$ =

a) 27/16

b) 7/4

c) 3/4

d) 1/2

e) 1/3

40. 3^2 =

a) 3 x 3

b) 3 + 3

c) 3 x 2

d) 3 ÷ 2

d) some other amount

41. 3(12)(36) ÷ 6(72) =

a) 3

b) 4

c) 6

d) 12

e) some other amount

42. If 3X + 5 = 2X + 8 , X =

a) $\frac{13}{5}$

b) $\frac{3}{5}$

c) 3

d) 13

c) some other number

43. In a 100 lbs. mixture of sand and rock, there is twice as much sand as rock. How many lbs. of sand are there?

a) 25 lbs.

b) $33\frac{1}{3}$ lbs.

c) 50 lbs.

d) $66\frac{2}{3}$ lbs.

e) some other amount

44. $3^{-2} =$

a) $-(3 \times 2)$

b) $-(3 \times 3)$

c) $\frac{1}{3^2}$

d) $\frac{1}{3 \times 3}$

e) $\frac{1}{3 \times 2}$

45. $(3^2)^3 =$

a) 3×3

b) $(3 \times 2)\ (3 \times 2)$

c) $(3 \times 2)\ (3 \times 2)\ (3 \times 2)$

d) $3 \times 3 \times 3 \times 3 \times 3$

e) $3 \times 3 \times 3 \times 3 \times 3 \times 3$

46. $-2575 + 45321 =$

a) 42746

b) 42756

c) 42846

d) 42856

e) 43746

47. If $\frac{X}{20} = \frac{4}{5}$, $x =$

a) 16

b) 20

c) 25

d) 30

e) some other amount

48. Which one of the quantities below is larger than $\sqrt{256}$?

a) 256^2

b) 1/256

c) $256^{-\frac{1}{2}}$

d) $256^{\frac{1}{2}}$

e) $256^{\frac{1}{4}}$

Plot the following data, with "concentration" measured on the y-axis and "time" indicated on the x-axis. Sketch a line through the points you have plotted.

Concentration	Time
2 g	1 sec
4 g	2 sec
6 g	3 sec
8 g	4 sec

49. From the graph, the concentration at 1.5 sec is

a) 1 g

b) 1.5 g

c) 2 g

d) 2.5 g

e) 3 g

50. The time for a concentration of 5 g is

a) 1.5 sec

b) 2 sec

c) 2.5 sec

d) 3 sec

e) 3.5 sec

51. In 5 sec the concentration would probably be

a) 7 g

b) 8 g

c) 9 g

d) 10 g

e) 11 g

52. In a screw cap bottle, you have 2 ounces of tincture of Iodine, a weight mixture of 98% alcohol and 2% dissolved Iodine. By accident you spill half the mixture. How much alcohol do you have left?

a) .098 oz.

b) .98 oz.

c) 1 oz.

d) 1.96 oz

e) some other amount

53. The decimal equivalent of $2(10^7)(10^{-3})$ is

a) 2

b) .2

c) .02

d) .002

e) some other number

54. $\frac{7.2 \times 10^{-3}}{.6 \times 10^4} =$

a) 1.2×10^1

b) 1.2×10^{-7}

c) 12×10^1

d) 12×10^{-7}

e) some other number

55. $5280 \times 12 =$

a) 6336

b) 63260

c) 63460

d) 64360

e) some other number

56. Express .72 as a number times a power of 10

a) 7.2×10^2

b) 7.2×10^1

c) 7.2×10^0

d) 7.2×10^{-1}

e) 7.2×10^{-2}

57. $10^0 =$

a) 1

b) 0

c) 100

d) 10

e) some other amount

58. 10^{-1} expressed as both a fraction and as a decimal is

a) $\frac{1}{100}$ and .1

b) $\frac{1}{100}$ and .01

c) $\frac{1}{10}$ and .001

d) $\frac{1}{10}$ and .01

e) $\frac{1}{10}$ and .1

59. If the $5.60 you have in your wallet is 25% of your wages, how much did you earn?

a) $10.20

b) $14.00

c) $21.40

d) $27.40

e) some other amount

60. $2 \times 10^{-2} =$

a) .02

b) .2

c) 2

d) 20

e) 200

APPENDIX B

MEMORIAL UNIVERSITY OF NEWFOUNDLAND
St. John's, Newfoundlrd

Final Examination
December, 1976

Time: 2 hours

CHEMISTRY 100F

Name: ____________________ M.U.N. No. ____________

Slot: ____________ Instructor ____________

READ THE FOLLOWING CAREFULLY.

This paper is divided into 3 sections. Answer ALL questions.

SECTION A: Multiple Choice (14 questions worth 2 marks each: Total = 28 marks).

Answer each question by printing the appropriate letter on the answer sheet (page 2). Only ONE answer is correct in each case.

Should you change your answer to any questions make it quite clear that you have done so.

There is no penalty for incorrect answers.

This section should take a maximum of 30 minutes.

SECTION B: 13 questions: Total 34 marks

This section should take 45 minutes

SECTION C: 3 questions: Total 38 marks.

This section should take 45 minutes.

HAND IN THIS PAPER IN ITS ENTIRETY AND THE PERIODIC TABLE AT THE END OF THE EXAMINATION. THIS EXAMINATION PAPER SHOULD HAVE 12 PAGES!

NOTE: A Periodic Table and tables of logarithms are attached after the last page of the examination paper and may be detached if desired. Slide rules and calculators are allowed.

SECTION A	
SECTION B	
SECTION C-1	
SECTION C-2	
SECTION C-3	

Chemistry 100F
Final Examination

December, 1976

Name: ______________________________

M.U.N. No. ____________

Slot ________________

Instructor ________________

Answers to Multiple Choice Items: Print the appropriate letter beside the question number CLEARLY.

1. ________
2. ________
3. ________
4. ________
5. ________
6. ________
7. ________
8. ________
9. ________
10. ________
11. ________
12. ________
13. ________
14. ________

Chemistry 100F
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SECTION A - Answer all questions. Only ONE answer is correct. Write the appropriate answer on the answer sheet (page 2).

1. Which of the following is NOT a physical change?

   A. Sublimation
   B. Combustion
   C. Evaporation
   D. Freezing
   E. Boiling

2. An ion has 13 electrons, 12 protons, and 14 neutrons. What is the approximate mass of the ion?

   A. 14 amu
   B. 25 amu
   C. 26 amu
   D. 27 amu
   E. 39 amu

3. Of the following groups of three, the elements whose properties are most nearly alike are those having atomic numbers

   A. 1, 2, 2
   B. 5, 6, 7
   C. 13, 31, 49
   D. 12, 14, 16
   E. 16, 17, 18

4. If XF_2 is the formula for a metallic fluoride, the formula for the oxide of X is

   A. X_2O
   B. XO
   C. X_2O_3
   D. XO_2
   E. XO_4

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5. Given five beakers each containing one of the following solutions

   (1) water solution of sodium chloride
   (2) water solution of a sugar
   (3) pure water
   (4) water solution of silver nitrate
   (5) hydrochloric acid

   Which of these solutions are good conductors of electricity?

   A. 1, 2, 3, 4, 5
   B. 1, 2, 3, 5
   C. 1, 4, 5
   D. 2, 3
   E. 2, 5

6. Three lengths of copper wire, A, B, and C, are measured with different instruments. The lengths are

   A = 5.32 cm
   B = 1.073 cm
   C = 211.1 cm

   The total length of copper wire, expressed to the correct number of significant figures, is

   A. 217 cm
   B. 217.4 cm
   C. 217.493 cm
   D. 217.5 cm
   E. 217.50 cm

7. If 196 g of H_3PO_4 (98.0 g mole^{-1}) is dissolved in water and the solution is diluted to 3.0 liters, what is the molarity of the solution?

   A. 0.33 M
   B. 0.67 M
   C. 1.5 M
   D. 2.0 M
   E. 3.0 M

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8. Which ONE of the following is NOT indicated by the chemical equation given below?

$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(g) + \text{heat}$$

As methane is burned

A. molecules are conserved
B. atoms are conserved
C. mass is conserved
D. the reaction is exothermic
E. oxygen is used us

9. $2Al(s) + 3H_2SO_4(aq) \longrightarrow Al_2(SO_4)_3(aq) + 3H_2(g)$

How many grams of hydrogen will be produced when 2.7 grams of aluminum are dissolved in sulfuric acid?

A. 0.030 g
B. 0.067 g
C. 0.134 g
D. 0.15 g
E. 0.30 g

10. When 1 mole of magnesium chloride ($MgCl_2$), an ionic solid, is dissolved in water, the resulting aqueous solution will contain

A. 1 mole Mg^{2+} ions + 2 moles Cl^- ions
B. 1 mole Mg^+ ions + 1 mole Cl_2^- ions
C. 1 mole Mg^{2+} ions + 1 mole Cl_2^{3-} ions
D. 1 mole $MgCl_2$ molecules
E. 1 mole Mg atoms + 1 mole Cl_2 molecules

11. The volume of a confined gas can be reduced by the application of pressure at constant temperature. Which of the following explains why the change in volume is possible? Gaseous molecules

A. take up space
B. have varying masses
C. are in constant motion
D. are relatively far apart
E. collide without loss of energy

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12. One mole of nitrogen, two moles of neon, and four moles of argon are sealed in a cylinder. The combined pressure of this mixture of gases is 1400 mm Hg. What is the partial pressure of the nitrogen?

A. 100 mm Hg
B. 200 mm Hg
C. 400 mm Hg
D. 500 mm Hg
E. 1400 mm Hg

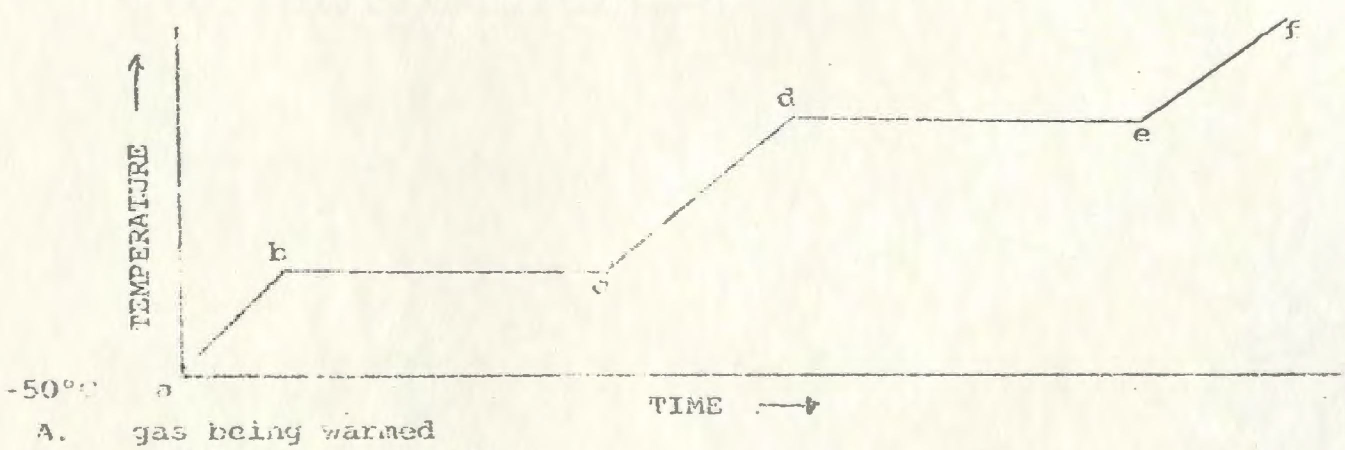
13. The equation for the complete combustion of butane gas, C_4H_{10}, is

$$2C_4H_{10}(g) + 13O_2(g) \longrightarrow 8CO_2(g) + 10H_2O(g)$$

How many liters of carbon dioxide are produced when a mixture of 1.00 liter of butane gas and 13.0 liters of oxygen are burned? (Assume the temperature and pressure remain constant.)

A. 1.00 liter
B. 1.63 liters
C. 4.00 liters
D. 8.00 liters
E. 13.0 liters

14. In this temperature vs time graph which represents the heating of H_2O at a constant rate, the segment de represents the



A. gas being warmed
B. solid being warmed
C. liquid being warmed
D. liquid changing to gas
E. solid changing to liquid

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SECTION B

MARKS

[2] 1. Write the correct formula for each of the following compounds.

a. iron(II) chloride, ferrous chloride ____________

b. magnesium phosphate ____________

c. nitric acid ____________

d. sodium perchlorate ____________

[2] 2. Name the following compounds.

a. KOH ____________

b. P_4O_{10} ____________

c. $(NH_4)_2CO_3$ ____________

d. LiBr ____________

[4] 3. Balance the following equations.

a. $\_\_Al_2O_3(s) + \_\_C(s) + \_\_N_2(g) \longrightarrow \_\_AlN(s) + \_\_CO(g)$

b. $\_\_Cu(NO_3)_2(s) \xrightarrow{heat} \_\_CuO(s) + \_\_NO_2(g) + O_2(g)$

[3] 4. When a solution of lead nitrate [$Pb(NO_3)_2(aq)$] and sodium iodide [$NaI(aq)$] are mixed, the only insoluble product is lead(II) iodide. Write the balanced net ionic equation for the reaction.

[2] 5. Write a balanced chemical equation to represent the reaction of sodium metal with water.

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MARKS

[3] 6. Name the type of physical or chemical process occurring in each of the following,

e.g., $H_2O(s) \longrightarrow H_2O(\ell)$ melting

a. $2HgO \xrightarrow{heat} 2Hg(s) + O_2(g)$ ______________

b. $Na(g) \longrightarrow Na(\ell)$ ______________

c. $C_3H_8(g) + 5O_2(g) \longrightarrow 3CO_2(g) + 4H_2O(g)$ ______________
Propane

[1] 7. Mutliply 30.8 x 40.10 cm and express the answer to the correct number of significant figures with teh appropriate units.

[2] 8. A college basketball player, playing forward, is generally 6 ft 6 in tall. How many centimeters is this height?

[2] 9. Some very old Roman coins were made of iron. What is the density of a coin with a mass of 49.14 g and a volume of 6.3 cm^3?

[4] 10. A red-orange dye called alizarin is an organic compound consisting of 70.02% carbon, 3.36% hydrogen, and 26.64% oxygen. What is the empirical formula for alizarin?

[2] 11. The molecular mass of alizarin is 240.2 amu. What is its molecular formula?

[4] 12. Calculate the percentage composition by mass of $Ca(OH)_2$.

[3] 13. (a) Flask A contains 0.050 g of hydrogen gas. How many moles of molecules of hydrogen are present?

(b) Flask B has the same volume as flask A and contains gas X. Both gases are at the same temperature and pressure. How many <u>molecules</u> of gas X are in flask B?

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SECTION C

MARKS

1. When one mole of nitroglycerin, $C_3H_5(NO_3)_3$, explodes 431.3 kcal of energy are released. All products formed are gaseous.

$$4C_3H_5(NO_3)_3(\ell) \longrightarrow 12CO_2(g) + 6N_2(g) + O_2(g) + 10H_2O(g)$$

The following questions relate to the explosion of <u>11.35 g of nitroglycerin</u> which is contained in a glass vial.

[2] (a) How many moles of nitroglycerin are involved in this explosion?

[2] (b) Calculate the number of moles of water produced.

[3] (c) What volume of carbon dioxide, measured at STP, is produced in the explosion?

[4] (d) What would be the volume of oxygen produced in this reaction if the temperature were at 27°C and 740 mm Hg?

[3] (e) Calculate the number of nitrogen molecules produced in the reaction.

[1] (f) How much energy (kcal) is released?

2. The following question is related to one of the laboratory experiments completed this semester.

The experiment was carried out to determine the reaction between solid copper and an aqueous solution of silver nitrate. In the experiment a weighed sample of copper wire was immersed in a measured volume of silver nitrate solution. There was more than enough copper to react with all of the silver nitrate. Some of the copper dissolved, and silver metal was deposited. At the end of the experiment the remaining copper wire and silver metal were weighed separately.

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Final Examination

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MARKS

2. (cont'd)

Results

Mass of copper wire consumed in the experiment = 0.635 g

Volume of silver nitrate solution = 20.0 ml

Concentration of silver nitrate solution = 169.9 g $liter^{-1}$

Mass of silver produced = 2.160 g

[2] (a) How many moles of copper were consumed in the experiment?

[2] (b) What was the molarity of the silver nitrate solution?

[2] (c) How many moles of silver nitrate were present in the 20.0 ml of solution which reacted with the copper?

[2] (d) How many moles of silver nitrate would react with one mole of copper?

[2] (e) How many moles of silver metal were produced in this experiment?

[2] (f) How many moles of silver metal would be produced from one mole of silver nitrate?

[1] (g) Using the above information balance the equation for the reaction

$$\_\_\_AgNO_3 + \_\_\_Cu \longrightarrow \_\_\_Cu(NO_3)_2 + \_\_\_Ag$$

Chemistry 100F
Final Examination

December, 1976

MARKS

3. Comment briefly on each of the following.

[2] (a) Explain why it is impossible to find an ion which contains the same number of protons and electrons.

[2] (b) Although lithium and fluorine are within the same period of the periodic table, lithium is a metal and fluorine is a nonmetal. Explain.

APPENDIX C

PIAGETIAN TASK TESTS

NAME____________________________

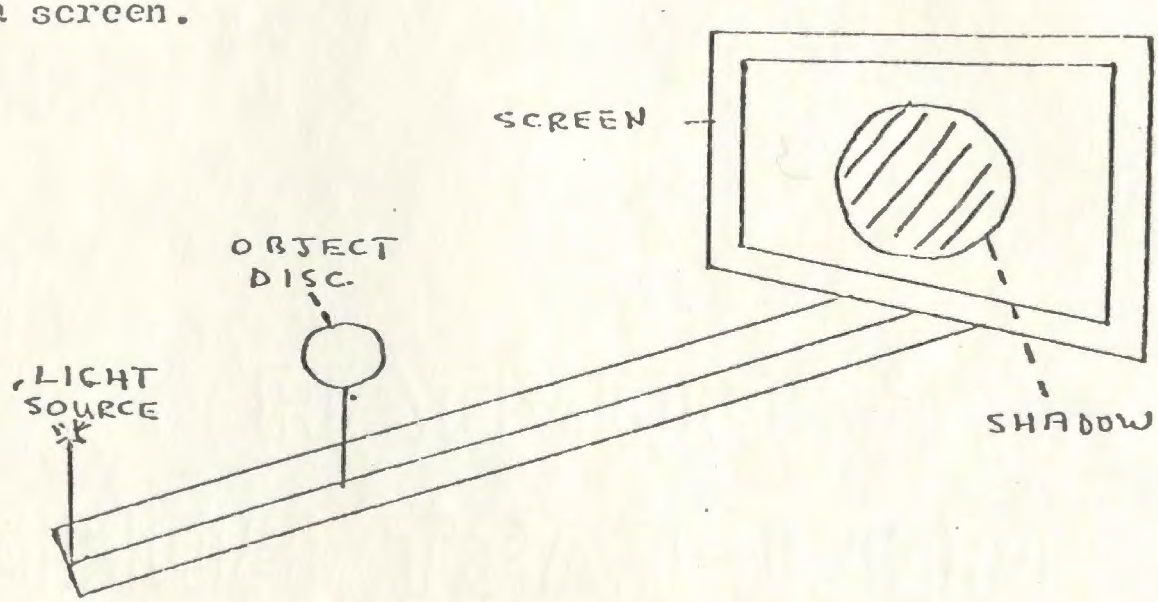
CLASS____________

DATE_____________

This booklet consists of four exercises. <u>IT IS NOT A TEST</u> However we would like to see the approach you use in arriving at your solution to each task. It is therefore <u>essential</u> that you show all your work clearly.

THE SHADOWS

The following diagram represents the apparatus set up at the front of the room. It can be used to produce shadows on a screen.



In the present case the distance between the light source (a small bulb) and the screen is set at 100 centimeters. It does not change in any of the questions which follow. Only changes in the size of the object disc and it's position along the line joining light source to screen will be allowed. Please answer the following questions very carefully.

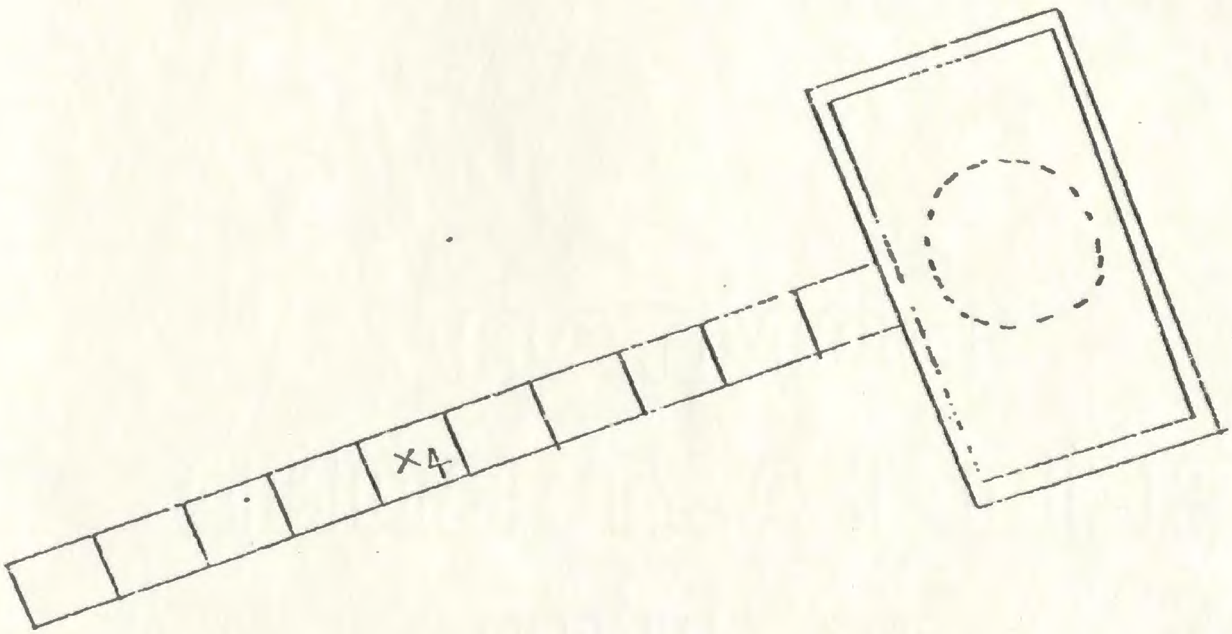
1. Do you expect the size of the shadow to change if the same disc is moved nearer the light source and further from the screen?____________________ If it does change, carefully describe in what way.

2. Do you expect the size of the shadow to change if the same disc is moved nearer the screen and further from the light source?__________ If it does change, carefully describe in what way.

3. Do you expect the size of the shadow to change if the disc is replaced by one of larger diameter?___________ If it does change, carefully describe in what way.

4. Do you expect the size of the shadow to change if the disc is replaced by one of smaller diameter?____________ If it does change, carefully describe in what way.

5. This question is concerned with making shadows of equal size. Suppose that in the demonstration apparatus the diameter of the object disc is 4 centimeters, and that it is placed in the position represented by X4 in the following diagram (the centre of the X represents the position of the disc).



Without changing the apparatus in any other way, where would you place object discs of diameter 2,6,8, centimeters respectively to produce <u>exactly the same size shadow</u> as that produced by the 4 centimeter object in the position shown. Answer by marking in the diagram immediately above, with an X and the relevant number. (the centre of the X represents the position you choose). If more than one is to be placed in the same position, say so. Please explain carefully how you reasoned your answer.

The Flasks.

The figure drawn below represents a SMALL chemical flask. When measured with large paper clips, the height of the small flask was found to be 4 clips. When a similar LARGE flask(not shown in the diagram) was measured with the same large paper clips, it was found to be 6 clips high.

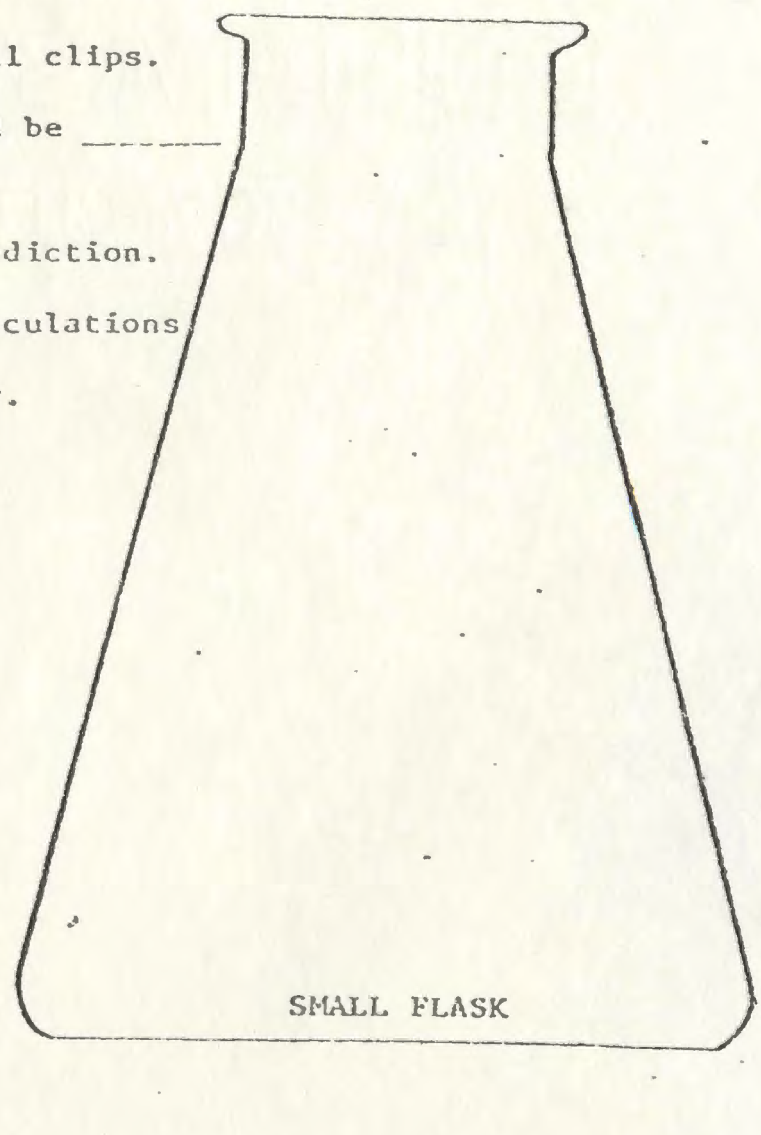
Now please do these things:

1. Measure the height of the small flask on the right using the SMALL paper clips provided. The height is ______ SMALL paper clips.

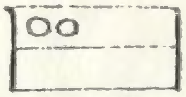
2. PREDICT the height of the LARGE flask if it were measured with the same small clips. The height of the LARGE flask would be ______

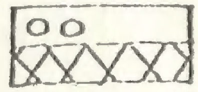
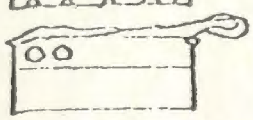
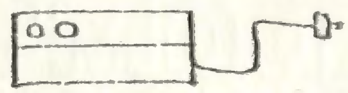
3. EXPLAIN how you arrived at your prediction. You may use diagrams, words, or calculations. Please explain your steps carefully.

   EXPLANATION (Be precise)

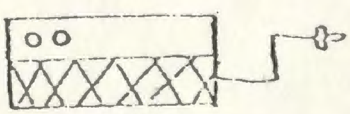
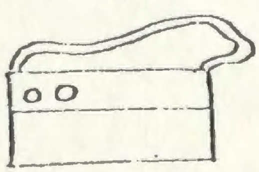


The Radio Problem

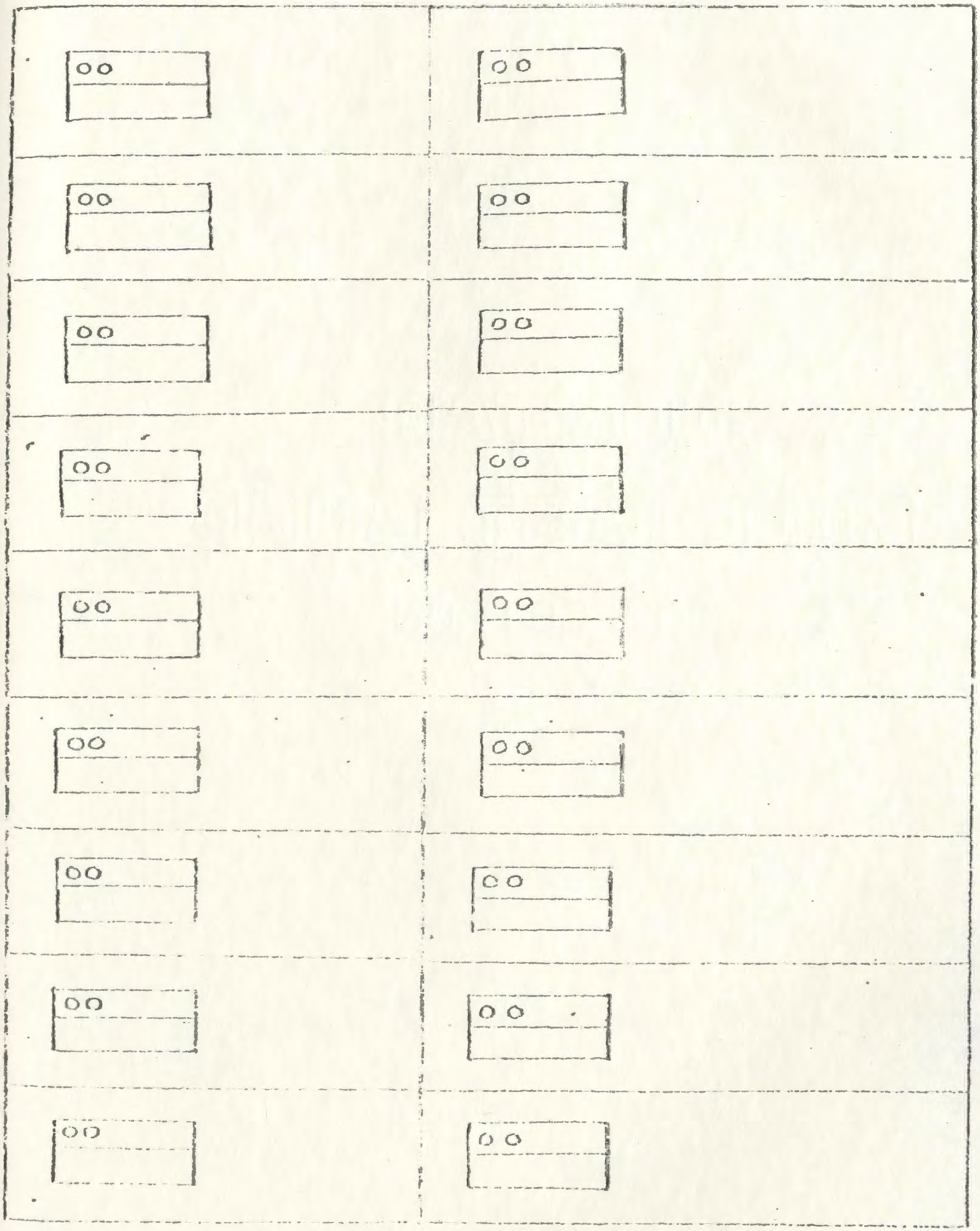
A transistor radio  costs $40, but you can buy any of the following "extras" if you want to:

	leather case - C		$10.
OR	carrying strap - S		$5.
OR	extra battery - B		$2.
OR	ear phone - P		$1.

Suppose you want to buy a radio. Write down or draw as many different choices as you can think of, and the prices. For example

	radio + case + earphone	$51.
	radio + strap	$45.

Put your answers on the special answer sheets



This task involves separately submerging two solids in some water in a graduate. Read the instructions carefully. DO NOT answer any questions until you are ready, BUT once you have begun a new question DO NOT change any previous answers. Answer the questions in the order in which they appear.

1. Compare the two solids e.g. Are they the same colour, how do their weights compare, are they the same size,.....?

2. Write down the number on the graduate which corresponds to the water level, i.e., record the volume. Record it accurately!

3. Very carefully lower solid A into the water until it rests on the bottom. Write down the new water level

4. WITHOUT DOING IT, predict what water level you would expect if solid B had been put in the water instead of solid A

5. Explain as carefully as you can how you arrived at your answer to question 4 .

6. Carefully remove solid A from the graduate, and replace it with solid B. Write down the new water level

7. Explain any differences in your answers to 4 and 6

8. Assuming that cylinder A and cylinder B are of the same volume and of different masses, what would have to be done to A or B (in terms of its size and shape) to make both the same mass?

9. If you make the cylinders attain an equal mass which one now has the larger volume?

Chemical Combinations Task

NAME ____________________

INSTRUCTOR ____________________

LAB. SLOT ____________________

This booklet contains information on an exercise in combining liquids. <u>IT IS NOT A TEST</u>. However we would like to see the approach you use in arriving at any conclusion. It is therefore essential that you show all your work clearly.

You are not permitted to observe the work of any other student!

INSTRUCTIONS

In front of you are five dropping bottles marked 1, 2, 3, 4 and g. Each of the five bottles contains a colorless liquid. Also in front of you are two beakers containing colorless liquids - these are marked A and B. Addition of a few drops of g to beaker A and to beaker B causes one of the two (of A or B) to turn yellow while the other remains colorless. A demonstrator will add a few drops of liquid g to each beaker for you.

The liquids in the five dropping bottles can be used to produce a similar yellow coloured solution. Your task is to produce a yellow coloured solution by combining the appropriate liquid or liquids from dropping bottles 1, 2, 3, and 4 with a few drops of liquid g. Do all mixing in the small test tubes provided. For example 3 and g might be combined to give you a yellow solution.

You may methodically or otherwise combine any number of solutions from 1, 2, 3, 4 and g but you must record all steps you take and your reason for taking a given step.

Try to be systematic!

A wash bottle is provided for rinsing out test tubes. They do not have to be dry. Wash your test tubes into the large beaker provided.

When told to do so turn the page and attempt to produce the yellow color.

Record all steps you take!

On the last page describe in summary form what you found you had to do to obtain the yellow color and why.

Record all steps you take!

	Combinations you used (show numbers and g)	Results, Conclusions and your Reasoning. Note all of your observations.
Trial 1		
Trial 2		
Trial 3		
Trial 4		
Trial 5		

Record all steps you take!

	Combinations you used (show numbers and g)	Results, Conclusions and your Reasoning. Note all of your observations.
Trial 6		
Trial 7		
Trial 8		
Trial 9		
Trial 10		

Summary of your results!

APPENDIX D SYLLABUS

Introductory Chemistry Proposed Syllabus

Reference: In Preparation for College Chemistry, Wm. S. Seese, Prentice-Hall, 1974.

Seese Reference		
	A.	Matter and Energy
2-1		Physical States of Matter
2-2		Homogeneous and Heterogeneous Matter Pure Substances, Solutions, and Mixtures
2-3		Compounds and Elements, Symbols of Common Elements
2-4		Properties of Pure Substances, Physical vs Chemical
2-5		Changes of Pure Substances, Physical vs Chemical, Simple Kinetic Theory
2-6		Elements and Atoms
2-7		Compounds, Formula Units, and Molecules
	B.	Atoms, Ions and Molecules
3-1		Atomic Mass (Atomic Weight)
3-2		Dalton's Atomic Theory
3-3		Subatomic Particles. Electrons, Protons, and Neutrons
3-4		General Arrangement of Electrons, Protons, and Neutrons. Atomic Number
3-5		Isotopes
3-7		Electron-Dot Formulas of Elements
4-1		Valence and Oxidation Numbers. Calculating Oxidation Numbers
4-2		Chemical Bonds.
4-3		The Electrovalent or Ionic Bond
4-4		The Covalent Bond
4-5		The Coordinate Covalent Bond
4-6		Electron-Dot Formulas of Simple Molecules
4-7		Writing Formulas
	C.	Units of Measurement and Chemical Calculations
		Units: mass, length, time and amount (the Mole).
1-1		Significant Digits
1-2		Mathematical Operations Involving Measurements and Significant Digits
Appendices I, II, III		Exponents and Scientific Notation. The Slide Rule
1-3		The Metric System
1-4		Conversion Within the Metric System

Seese Reference		
1-5		The English System
1-6		Conversion from the Metric System to the English System and Vice Versa
1-7		Temperature, Heat vs Temperature
1-8		Density
7-1		Calculation of Formula or Molecular Masses (Weights)
7-2		Calculation of Moles of Particles. Avogadro's Number (N)
7-3		Molar Volume of a Gas and Related Calculations
7-4		Calculation of Percent Composition of Compounds
7-5		Calculation of Empirical and Molecular Formulas
12-1		Concentrations of Solutions
12-4		Molarity
	D.	Chemical Nomenclature
6-1		Systematic Chemical Names
6-2		Binary Compounds Containing Two Nonmetals
6-3		Binary Compounds Containing a Metal and a Nonmetal
6-4		Ternary and Higher Compounds
6-5		Special Ternary Compounds
6-6		Acids, Bases and Salts
	E.	The Periodic Table and Properties of Common Elements and Compounds
5-1		The Periodic Law
5-2		The Periodic Table. Periods and Groups
5-3		General Characteristics of the Group
5-4		The Use of the Periodic Table for Predicting Properties, Formulas, and Types of Bonding
		Properties of Common Elements
		Alkali Metals
		Halogens
		O_2, H_2, N_2, CO_2, Mg, Al
		Acids and Bases

Seese Reference

F. Chemical Equations

Conservation rules for mass, energy, charge.

8-1	Definition of a Chemical Equation Balancing a Chemical Equation
8-2	Terms, Symbols, and their Meanings
8-3	Guidelines for Balancing Chemical Equations
8-4	Examples Involving the Balancing of Equations Word Equations
8-5	Completing Chemical Equations The Five Simple Types of Chemical Reactions
8-6	Combination Reactions
8-7	Decomposition Reactions
8-8	Replacement Reactions. The Electromotive Series
8-9	Metathesis Reactions. Rules for Solubility in Water
8-10	Neutralization Reactions
9-1	Electrolytes vs Nonelectrolytes
9-2	Guidelines for Writing Ionic Equations
9-3	Examples of Ionic Equations

G. Stoichiometry

10-1	Information Obtained from a Balanced Equation
10-2	The Mole Method of Solving Stoichiometry Problems The Three Basic Steps
10-3	Types of Stoichiometry Problems
10-4	Mass-Mass (Weight-Weight) Stoichiometry Problems
10-5	Mass-Volume (Weight-Volume) Stoichiometry Problems
10-6	Volume-Volume Stoichiometry Problems

H. Gases

11-1	The Kinetic Theory
11-2	Pressure of Gases
11-3	Boyle's Law. The Effect of Pressure Change on the Volume of a Gas at Constant Temperature
11-4	Charles' Law. The Effect of Temperature Change on the Volume of a Gas at Constant Pressure
11-5	Gay-Lussac's Law. The Effect of Temperature Change on the Pressure of a Gas at Constant Volume
11-6	The Combined Gas Laws
11-7	Dalton's Law of Partial Pressure, Vapour Pressure

Introductory Chemistry

Proposed Course Objectives

A: MATTER AND ENERGY

1. State the characteristics of (a) solids (b) liquids (c) gases.

2. Identify the change of phase from observation or description of the effect of heat or pressure changes on a substance.

3. Explain what is happening at a molecular level in specified phase changes, in terms of molecular velocities and intermolecular attractions.

4. Define: Boiling, Melting (Fusion), Evaporation, Sublimation, Boiling Point, Melting Point, Vapour Pressure.

5. Predict the likelihood and nature of a phase change as the pressure and/or temperature of a specified system is changed.

6. State three factors which affect the value of the vapour pressure of a liquid, indicate what effect might be observed in each case, and explain in terms of kinetic theory.

7. List 10 physical properties and 5 chemical properties often used in identifying various pure substances.

8. Differentiate between:
   (i) physical and chemical properties
   (ii) physical and chemical changes

9. Define the terms: Homogeneous and heterogeneous, Pure Substance, Solution, Mixture, Compound, Element, Atom, Molecule, Formula Unit, and allotrope.

B: ATOMS, IONS AND MOLECULES

1. State the relative charges and masses of electrons, protons and neutrons.

2. Determine the atomic number and mass number of an isotope of an element, given the number of electrons, protons, and neutrons in an atom of the isotope; or given the atomic number and mass number, determine the number of electrons, protons and neutrons.

3. Define the term isotope.

4. Illustrate the arrangement of electrons in principal levels for elements 1 to 20. (the "octet" rule).

5. Determine the difference between positive ions, negative ions, and neutral atoms in terms of their composition with respect to protons, electrons and neutrons, and to distinguish between the formation of these ions from neutral atoms in terms of electron transfer.

6. Calculate the charge on an ion, given the number of protons and electrons it contains.

7. Construct simple electron dot formulas for common elements and their most probable ions. Define Ionization Energy.

8. Identify common polyatomic ions: ClO_3^-, NO_3^-, MnO_4^-, CO_3^{2-}, SO_4^{2-}, PO_4^{3-}, OH^-, NH_4^+

9. Differentiate between an ionic and a covalent bond.

10. Compare the properties of ionic and covalent compounds.

11. Construct electron dot formulas for some simple molecules.

C: UNITS, MEASUREMENTS AND CHEMICAL CALCULATIONS

1. Identify the four fundamental measurable quantities and indicate the common units in which they are measured.

2. Perform conversions within the Metric and British systems, and between the Metric and British systems. Convert temperatures from Centigrade to Kelvin Scale.

3. List, in exponential notation, a set of numbers given in decimal notation.

4. List, in decimal notation, a set of numbers given in exponential notation.

5. Construct solutions to calculations involving the use of exponential notation.

6. State the number of significant figures in a given number.

7. Distinguish between accuracy and precision in a group of measurements, and/or describe the difference for a specified instrument.

8. Construct, using the "significant figure" rules, solutions to sample calculations involving each of the operations, addition, subtraction, multiplication, and division of measurements, and/or a combination of these operations.

9. Construct solutions to calculations using the rules governing the use of logarithmic notation for the multiplication and/or division of answer by Dimensional Analysis.

10. Solve problems requiring unit conversion and check reasonableness of answer by Dimensional Analysis.

11. Differentiate between mass and weight, heat and temperature.

12. Calculate one of density, mass or volume, given any two of the variables.

13. Calculate the formula weight of a compound, given its formula and a table of atomic weights.

14. Calculate one of the variables, number of moles, number of particles (atoms, molecules, or ions), weight in grams, for a sample of an element or compound given the formula of the element or compound, a table of atomic weights, and the value of any one of the specified variables.

15. Differentiate between molecular weight and formula weight.

16. Construct the empirical formula of a compound given its elemental composition by weight, or weight-percent.

17. Construct the molecular formula given the empirical formula and molecular weight.

18. Calculate percent composition of all elements of a compound given the chemical formula.

19. State and/or apply the rule known as Avogadro's Hypothesis to calculate the molecular weights of gases, given the relative weights and volumes of the gases and a standard.

20. Calculate one of the variables formula weight of a gas, mass of gas present, volume under specified conditions, when the other two variables and the molar volume under the specified condition are given. The value for the molar volume at $0^{o}C$. and 1 atm. will be assumed known.

21. Define the terms, solution, solute, solvent, concentration, concentrated solution, and saturated solution.

22. Calculate one of the variables, molarity of a solution, the concentration of the solute by weight, or the volume of solution, given the other two variables.

D. CHEMICAL NOMENCLATURE

1. Identify the common symbols for elements, ions and molecules.

2. Employ the systematic nomenclature rules to name common chemical compounds
   - (i) Binary Compounds Two Nonmetals
   - (ii) Binary Compounds Metal and Nonmetal
   - (iii) Ternary Compounds
   - (iv) Acids, Bases and Salts

E: PERIODIC TABLE AND PROPERTIES OF COMMON ELEMENTS AND COMPOUNDS

1. Differentiate between Periods and Groups.

2. Differentiate between metals and non-metals.

3. Describe both Periodic and Group variations in ionization energies of elements 1-20.

4. Describe the general physical and chemical characteristics of the alkali metals and Halogen groups.

5. Use the periodic table to predict properties, formulas and Bonding Type.

6. Discuss the physical and chemical properties of some common elements and compounds: H_2, O_2, N_2, CO_2, He, Mg, Aℓ, Common Acids and Bases.

F: CHEMICAL EQUATIONS

1. State the conservation laws for mass, energy and charge.

2. Identify reactions as being exothermic or endothermic.

3. Construct a balanced equation for a chemical reaction given:
   (i) the formulas of the reactants and products
   (ii) a word equation

4. Identify the 5 simple types of chemical reactions: combination, decomposition, replacement, metathesis and neutralization.

5. Describe without giving experimental details, one method to determine the existence of ions in a melt or an aqueous solution, or interpret such evidence in terms of ions.

6. Define: electrolyte, nonelectrolyte

7. Write a balanced net ionic equation for a reaction for which names of reactants and products are given, and for the dissolving or precipitation of an ionic solid.

G: STOICHIOMETRY

1. Identify the basic information contained in a balanced chemical equation.

2. Employ the mole method to solve problems in stoichiometry given the balanced chemical equation.

H: GASES

1. (Prerequisite) Construct a line graph given a set of paired data for two variables, or apply such a graph to determine the relationship between the variables. Identify a linear relationship and express it mathematically.

2. Calculate the pressure of a gas, given suitable barometric or manometric data.

3. Convert temperatures on either the Centigrade or Kelvin scales, to the other.

4. Apply Boyle's Law, Charles' Law, the general gas equation, and the definition of molar volume, as appropriate to the solution of typical gas calculations involving the relationships between concentration, volume, temperature, and pressure, including when conditions are quoted as STP.

5. Calculate the partial pressure of each gas in a mixture, given the mass, molar or volume concentrations of the constituents, and given the total pressure or sufficient data to calculate it.

6. Calculate any one of the partial pressure of an individual gas in a mixture, the total pressure, and the combined pressure of every other gas, given the values of the other two variables.

7. Specify the changes occurring on the molecular level in a gas, when one of the variables pressure, volume, temperature, mass of gas present, is considered the dependent variable and one or more of the others is changed.

Introductory Chemistry - Lab Schedule

EXPERIMENT

1	Operation of a Bunsen Burner and Effect of Heat on Solids
2	Some Reactions Involving Evolution of Gases
3	Weighing Mole Quantities
4	Empirical Formula of Magnesium Oxide
5	Preparation, Collection and Reactions of Oxygen
6	Preparation and Properties of Carbon Dioxide
7	Finding the Equations for Some Simple Reactions
9	Weighing Equal Volumes of Gases
11	Reactions Involving Formation of a Precipitate
12	Chemical Transformations
8	Relation Between Temperature and Volume of Gases