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ABSTRACT

THIS STUDY WAS DESIGNED TO IDENTIFY THOSE SCIENCE CONCEPTS AND MATHEMATICAL SKILLS THAT MAY BE THE SOURCE OF STUDENT DIFFICULTY IN LEARNING CHEMISTRY AS DEVELOPED BY THE CHEMICAL EDUCATION MATERIALS STUDY (CHEMS). THE INSTRUMENTS UTILIZED WERE FOUR ACHIEVEMENT TESTS PREPARED BY CHEMS. EACH TEST ITEM WAS ANALYZED TO DETERMINE THE CONCEPTS AND/OR SKILLS NECESSARY TO GIVE THE DESIRED RESPONSE TO THAT ITEM. THESE CONCEPTS AND SKILLS WERE DISCUSSED DURING STUDENT INTERVIEWS HELD FOLLOWING EACH OF THE FOUR TESTS. THE STUDENTS INTERVIEWED EARNED SCORES THAT RANKED AMONG THE LOWER 20 PERCENT IN SCHOOL A OR THE LOWER 30 PERCENT IN SCHOOL B. FROM THESE INTERVIEWS, SELECTED QUESTIONS WERE CHOSEN AND WERE ASKED OF THOSE STUDENTS WHO HAD EARNED SCORES WHICH RANKED WITHIN THE TOP 20 PERCENT IN SCHOOL A AND THE TOP 30 PERCENT IN SCHOOL B ON TWO OUT OF THE FIRST THREE EXAMINATIONS. THE RESULTS SHOWED THAT THE STUDENTS EARNING LOW SCORES WERE (1) UNABLE TO DEFINE MANY TECHNICAL TERMS, (2) COULD NOT VERBALIZE KEY CONCEPTS, (3) DID NOT POSSESS THE ABILITY TO SOLVE SIMPLE ALGEBRAIC EQUATIONS, (4) COULD NOT SOLVE PROBLEMS OF A QUANTITATIVE NATURE, AND (5) LACKED THE SKILLS NECESSARY TO INTERPRET GRAPHS AND CHARTS. THESE SAME DIFFICULTIES WERE PRESENT TO A LIMITED EXTENT AMONG STUDENTS WHO PERFORMED AT A SATISFACTORY LEVEL. (RR)

Technical Report No. 77

LEARNING DIFFICULTIES ENCOUNTERED BY STUDENTS STUDYING THE CHEM STUDY PROGRAM

Report from the
Science Concept Learning Project

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This Technical Report is from the Prototypic Instructional Systems in Elementary Science Project in Program 2. General objectives of the Program are to establish rationale and strategy for developing instructional systems, to identify sequences of concepts and cognitive skills, to develop assessment procedures for those concepts and skills, to identify or develop instructional materials associated with the concepts and cognitive skills, and to generate new knowledge about instructional procedures. Contributing to these Program objectives, the Science Project is developing a taxonomy of concepts in the conceptual schemes environmental management and the particle nature of matter and is conducting research to determine the content, instructional, and learner factors influencing the level of sophistication attained by pupils in their study of those schemes.

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ABSTRACT

This study was designed to identify those science concepts and mathematical skills that may be the source of student difficulty in learning chemistry as described by the CHEMS program.

The instruments utilized were the Achievement Tests, 63-64 edition, prepared by the Chemical Education Materials Study. The specific tests used were those designed for administration after the completion of Chapters 4, 7, 10 and 13 in Chemistry, An Experimental Science. The students were drawn from two high schools near Madison, Wisconsin, who included the CHEMS program in the curriculum.

A clinical approach was utilized to determine whether the students possessed the concepts and/or skills needed to respond acceptably to a test item. Each item on each test was analyzed to determine the concepts and/or skills necessary to give the desired response to that item. These concepts and skills became the topics discussed during personal student interviews held following each of the four tests. Interviews were held with those students who earned scores that ranked among the lower 20 percent in School A or the lower 30 percent in School B. The percent of the population was 30 percent of School B in order to include students with the same ranked scores from both schools. A fifth interview was developed which included the use of previously prepared interview questions selected from

those that were answered incorrectly during the first four interviews by 50 percent or more of the students in either of the two schools. The students participating in this fifth interview were those who earned scores ranked within the top 20 percent in School A and the top 30 percent in School B on two out of the first three examinations.

The scholastic ability of the students as measured by IQ was slightly above average. Based upon scores earned on the Watson-Glaser Critical Thinking Appraisal the students were judged as average or above in critical thinking.

Based upon findings within the limited population involved in this study, it appears that the students earning low scores on the CHEMS examinations were unable to define many technical terms, could not verbalize key concepts, did not possess the ability to solve simple algebraic equations, could not solve problems of a quantitative nature and lacked the skills necessary to interpret graphs and charts. These same difficulties were present to a limited extent among students who performed at a satisfactory level.

I

PROBLEM

Introduction

The development of science education in the twentieth century, from the publication of the Third Yearbook of the National Society for the Study of Education (1904) to the recent curriculum development programs financed by the National Science Foundation, is historically recorded. Jackman (1904) described the philosophy of the nature study movement.

> The spirit of nature-study requires that the pupils be intelligently directed in the study of their immediate environment in its relation to themselves; that there shall be, under the natural stimulus of the desire to know, a constant effort at a rational interpretation of the common things observed. If this plan be consistently pursued, it will naturally follow that the real knowledge acquired, the trustworthy methods developed, and the correct habits of observing and imagining formed will lay a sound foundation for the expansive scientific study which gradually creates a world-picture, and at the same time enables the student, by means of the microscope, the dissecting knife and the alembic, to penetrate intelligently into its minute details (Jackman, 1904, p.9).

In the Thirty-First Yearbook of the NSSE (1932), more than 25 years later, a committee listed the objectives of secondary school science as those which will provide the pupil with the ability

1) To interpret the scientific phenomena of common experiences,
2) To think clearly in problematic situations in which ideas from the field of science are used,
3) To use as need arises the methods of study that have been developed in the field of science, and
4) To gain some appreciation of the scientific attitudes that have functioned in freeing mankind from fears and from the errors in thinking that stand in the way of happiness and rich living (NSSE, 1932, p. 129).

The purposes advocated by the committee that wrote the Forty-Sixth Yearbook were predominately science for life adjustment as indicated by: "An attempt has been made to formulate objectives that will bridge the gap between classroom activities and socially desirable types of human behavior (NSSE, 1947, p. 39)" and "The intellectual aspects of this responsibility are at least coequal in importance with the material (NSSE, 1947, p. 39)."

In Rethinking Science Education (1960) it is stated that little change has taken place in the objectives of science education but there has been a change in the nature of the sciences taught.

> There are two major aspects of science-teaching; one is knowledge, and the other is enterprise. From science courses, pupils should acquire a useful command of science concepts and principles. Science is more than a collection of isolated and assorted facts; to be meaningful and valuable, they must be woven into generalized concepts. A student should learn something about the character of scientific knowledge how it is quite likely to shift in meaning and status with time (NSSE, 1960, p. 34).

One of the more recent changes in the history of science education includes the development of programs in chemistry such as the Chemical Bond Approach (CBA) and the Chemical Education Materials Study (CHEMS). These two programs, developed for the most part concurrently, have different philosophic bases, methods and organizations.

The course named The Chemical Bond Approach was developed at Earlham College in Richmond, Indiana, and Reed College in Portland, Oregon, in 1959. It is, according to Strong, an attempt to

> . . . develop an introductory chemistry course which presents modern chemistry to beginning students. The presentation is intended to give students a preliminary understanding of what chemistry is about, rather than simply an encyclopedic collection of chemical reactions and laboratory techniques, or a mere overview of diverse conclusions held by chemists today. Such a course must be an organized one in which the pattern reflects the structure of the discipline itself. Since conceptual schemes play a major role in the organization of chemistry today, the organization of a course in chemistry is best based on conceptual schemes (Strong, 1962).

The CHEM Study program was begun in 1960 at Harvey Mudd College in Claremont, California. The philosophy of the Chemical Education Materials Study includes the belief that the course should be primarily experimental in approach and structured around "the irreducible minimum of basic fundamentals that could and should be taught in the high school course and on which the college course would then be built (Garrett, 1961)." The fundamental concept should be taught where applicable utilizing a discovery approach and the development of models to explain the concepts (Bennett, 1966, Pyke, 1966, Pode, 1966, Merrill, 1963 and Campbell, 1962).

Experience with this course, in terms of pupil success, is presently limited to the opinions of the committee (CHEMS) and teachers of the course. In a study of effects of CHEMS and CBA on achievement in chemistry, Heath and Stickell determined that the students studying the CHEMS and CBA programs earned higher scores than the students studying the traditional courses on the tests which were designed for the expermental approach and the control students earned higher scores on the tests designed for the traditional curriculum (Heath and Stickell, 1963). Uricheck (1967) called for an attempt to evaluate the success of the CBA and CHEMS chemistry courses.

> It appears, however, that many have the attitude that change is necessarily good or beneficial. Many teachers of the new approaches are convinced that these offerings are superior to traditional ones. Their conclusions are not based on objective evidence, for very little research has actually been carried out in this area. Certainly data are needed, for school systems are making large investments in converting to new materials, and much time is being spent in in-service programs for teachers in order to prepare them for teaching the new programs.
>
> It is my hypothesis that the success of these programs has been taken for granted, and that they are not more successful than the traditional courses. It is the author's opinion that it is the teacher who primarily determines the success or failure of a course, not the method (Uricheck, 1967).

Homman and Anderson studied several factors and their relationship to achievement in high school chemistry. The results of the study indicated

> . . . while prior experiences in science and mathematics were not significant factors in student achievement in chemistry, they lead one to believe that there must be other intrinsic or extrinsic factors not yet accounted for which influence achievement in terms of "apparent motivational value" of career plans. Quality of prior preparation is undoubtedly a factor more important than quantity of prior preparation (Homman and Anderson, 1962).

In the teaching of chemistry in the high school it is soon apparent that there are some students who have high levels of intellectual capability but do not enjoy academic success in chemistry.

Problem

To identify those science concepts and mathematical skills that may be the source of student difficulty in learning chemistry as described by the CHEMS Program.

Background

The importance of concepts in science has been discussed at length by science educators. According to Pella (1966)

> A concept may be viewed initially as a summary of the essential characteristics of a group of ideas and/or facts that epitomize important common features or factors from a larger number of ideas. Because of their comprehensive nature, concepts are useful to the individual in gaining some grasp of a much larger field of knowledge than he has personally experienced. He is able to interpret and assimilate new information into the old schemes through the modification of existing concepts.

The importance of concepts in the learning process is stated by Phenix as "The only satisfactory answer to the crisis in learning . . ." and "Discovery of powerful key concepts applicable to a given group of ideas is the best way of defining a field of knowledge (Phenix, 1956)." According to Garone, "Concept development is essential to effective thinking and learning. Because concept development is so intricately related to children's total development, teachers and parents need to know and understand more about it (Garone, 1960)."

In a recent essay Professor Derek A. Davenport (1968) expressed concern for students comprising the lower 90 percent in terms of high school achievement who enter college today. Davenport argues that contrary to popular opinion the student of the post-Sputnik era is not better prepared than his pre-Sputnik counterpart. The student who has completed a course in high school chemistry in one of the new curricula is "much of the time as confused as ever--but about different things than previously." Davenport continues

> But the problems with basic (not simple) physical concepts seem to me to be almost unsurmountable. If a student does not feel in his bones the qualitive nature (and not merely the formulae and units) of momentum, energy, work potential and the like, it

> is vain to believe that any fundamental understanding of, say, the viscosities of gases or the intracacies of molecular orbital theory can reasonably be achieved (Davenport, 1968).

Eight years earlier, Smith, the director of general chemistry at The Pennsylvania State University described the difficult concepts in chemistry as those difficulties which can be referred to as "general or background" and those which are "specific conceptual difficulties." Smith continues

> Background difficulties must be recognized and considered in planning the teaching program; they can be resolved effectively and automatically by the competent teacher. Specific conceptual difficulties may be alleviated through appropriate methods of handling troublesome course topics through appropriate introductory materials and definitions (Smith, 1960).

In addition Smith warns that the student studying chemistry is not only learning selected concepts in science but a "large new vocabulary of 'foreign' words and terms."

Considering the above statements it is anticipated that the following factors may affect the success of the student of chemistry as indicated by scores attained on CHEM Study tests:

1. Lack of comprehension of prerequisite science knowledge.
2. Deficiencies in mathematical abilities.
3. Inadequate vocabulary-technical and general.
4. Inability to visualize theoretical models utilized in explaining chemical phenomena.
5. Inadequate ability to select facts critical to the solution of the problem.

II

RELATED LITERATURE

Student achievement in chemistry, concept attainment, concept understanding and curriculum development have been topics of interest to science educators in recent years.

Porter and Anderson (1959) using the Anderson Chemistry Test compared the achievement of three groups of students classified according to intelligence to determine whether a relationship exists between parts of the test and intelligence. They found that superior students performed better in terms of the total chemistry test than did the average, and the average performed better than the lower group.

> However, this hierarchy did not exist to the same degree when the total achievement and ability in chemistry was broken down into specific abilities or parts, except for the ability to understand and apply the elements of the scientific method together with its associated attitudes (Porter and Anderson, 1959).

The investigators concluded that specific abilities were not related to each other or to intelligence as it was measured and that apparently other factors were involved.

Homman and Anderson (1962) studied the effect of sex, professional goals, science courses before chemistry and mathematics courses before chemistry on the achievement in high school chemistry courses. The results of this study indicate that sex and professional goals are not a factor in achievement. Of more interest is that this study indicated that prior preparation in science and mathematics were not significant factors in student achievement in chemistry. The investigators postulated that the quality of prior preparation is a more important factor than the quantity of prior preparation.

In an attempt to measure the residual knowledge of high school chemistry of students taking college chemistry and the factors which might affect this, Lamb, Waggoner and Findley (1967) noted that:

1. The value of high school chemistry is questionable.
2. Two years of high school chemistry is not necessarily better preparation for college chemistry.
3. Older students made better scores even if they had not had high school chemistry.
4. Students who had mathematics or science courses other than chemistry prior to enrollment in chemistry made better scores on the test.
5. Students with better high school academic records made better scores on the test.

These investigators tested 50 concepts with a 50 item test. The concepts found to be most difficult were those that required some mathematical computation. According to the investigators, the implications of this study are that high school chemistry should place more emphasis on the quantitative aspects of chemistry and that the less promising student should be encouraged to delay the study of chemistry until he has had other courses in science and mathematics.

The problem of concept understanding and concept development has been studied by Garone (1960), Keuthe (1963), Adler (1965) (1966) and Glassman (1967).

Garone studied children's concept development using tape recorded accounts of "anecdotal records of children's percepts, interpretations, problem solving and concepts." Garone reported the following:

> It was found that by providing the children with problem solving experiences within their level of ability and comprehension, and by making the children aware of the values of reliable procedures and critical attitudes their problem solving abilities and their concept development were improved.

Kuethe (1963) considered the concepts that the students had already formed and which were in error. The objectives of this study were to

> . . . show the prevalence of 'sophisticated' errors in the retention of science concepts. . . (and). . . to suggest that if the teacher is aware of which concepts are especially subject to confusion, teaching can be directed toward a clear differentiation of a concept from other concepts that have been shown to have a high probability of intrusion.

The author feels that the most significant cause for concern is that the students believe that they do understand the concepts and have given correct answers.

> However, regardless of whether or not one believes that the understanding of these concepts is important in a general science education, it must be conceded that there is something amiss in a science education that produces individuals that believe they understand the common natural phenomena when in fact they do not (Kuethe, 1963).

Adler (1966) conducted a study which was in part to determine "the nature and extent of changes in understanding of concepts of space, matter, and energy in college students." The study indicated that

> The average college student enters and leaves college with very little understanding of concepts of space, matter, and energy in their scientific sense. Although science courses make significant contributions in a statistical sense, their contributions are actually very small from the standpoint of education. The growth of the understanding of science concepts is slow.
>
> A substantial number of students are concept resistant. Their science concepts remain virtually unchanged by science instruction (Adler, 1966).

In an earlier report, Adler (1965) reported upon some "serendipitous findings related to semantics" that were a result of the study mentioned above. The author came to the following conclusions:

> In designing science programs in terms of sequential conceptual development, educators must always assume a certain common background of previous knowledge, concepts and vocabulary. Most science teachers soon recognize that such an assumption is not justified.
>
> Unless the teacher is dealing with superior students he would be well advised to assume that his students are vague in their understanding of scientific terms.
>
> This admonition pertains to much of the vocabulary used in measurement, such as: area, volume, diameter, mile, meter and so on. References to matter are often beclouded by the vague understanding of such terms as element, compound, molecule, homogeneous, vapor, dew, chemical change, evaporate, and condense (Adler, 1965).

Glassman (1967) studied the nature of the ideas concerning formulas, equations and related concepts that were held by three groups of high school students. Of the six concepts studied:

1. the Law of Conservation of Mass
2. the nature of chemical equations
3. the nature of chemical formulas
4. the nature of molecules
5. the nature of chemical change
6. the nature of molecular weight

Glassman reports that the students of chemistry found the greatest difficulty with the concept of molecular weight and the least with chemical change. Despite gains on pre-test post-test scores

> . . . a large proportion even of the chemistry group responses at the end of the semester were vague and a large proportion contained misconceptions. Such vagueness and misconception were present in responses in upper deciles in some questions.
>
> In addition to vagueness and inaccuracy, the responses of the chemistry group at the end of the semester showed very little awareness of the quantitative aspects of the concepts, and in the case of some questions, very little awareness of the relation of the concepts to experiment and observation (Glassman, 1967).

Considering the difficulty that students appear to have with respect to certain concepts, it is interesting to read the suggestions of Smith (1960), a college teacher, to high school chemistry teachers.

> As a chemistry teacher, you must consciously introduce terminology to your students in dosages and in a manner which they can follow with understanding. This is not easy. Each technical term must be introduced meaningfully; it must be used over and over again in the same manner; and the students themselves must use it until it becomes an integral part of their language.
>
> Students are often inclined to believe that the best definition is always the ready made one in the text book, or the one given by the teacher. Instead of employing memorization, students should be encouraged--perhaps compelled--to express definitions and concepts in their own words. It is most important that the student has a clear understanding of the subject regardless of his ability to express it in the most elegant manner possible.

We are reminded that we are often asking the student to become acquainted with substances with which he is not familar. In the case of gases in particular we assume that the student already knows what a gas is. But this is a material that "he usually cannot <u>see</u>, cannot <u>touch</u>, cannot <u>hold</u>, cannot associate with definite <u>shape</u>, characteristic <u>size</u>, or any of the other criteria with which he is accustomed to associate familiar objects (Smith, 1960)."

> Smith continues . . . I would certainly exclude the general acid-base theory, activity and activity coefficient, calculations of chemical equilibria, and the concept of the hydrogen bond to name a few. I would include as pertinent, interesting materials, suitable examples which tie the study of chemistry in with everyday living and personal experiences. This type of material offers much of the 'spice' of the course and leads to a better understanding of the more abstract concepts.

The confusion of beginning college students of science is discussed by Davenport (1968).

> The reasons are not far to seek. As a result of the various curriculum reforms, the teaching of high school chemistry, physics and biology has irreversibly been made more logical, more rigorous, and more abstract. Now logic, rigor, and abstraction are no doubt suitable for the typical high school girl or boy who just happens to be destined to be a professor of chemistry, physics, or biology. They are also suitable for the less fortunate providing the chill winds of logic, rigor, and abstraction are tempered to the somewhat vulnerable (if these days not exactly shorn) lambs of learning. On the whole CBA and, particularly, CHEMS seem to me to be a little more considerate than their acronymic cousins in biology and physics, but by no stretch of the imagination are they easy even for the good student. In fact I would be reasonably content if my students mastered the contents of the CHEMS test (all of it) by the end of their freshman year.

Merrill (1962) reported that the CHEM Study curriculum offered a challenge to the best students. It was not clear, according to Merrill, if the course was appropriate for the average and below average high school student of chemistry.

> It is a long step from candles to orbitals, and there is real question in the mind of this teacher as to whether the course offers enough content of intermediate difficulty, such as is perhaps provided by the history and technology of traditional courses. One has the feeling that more needs to be done to relate some of the more abstract concepts to problems and processes which are of day-to-day significance to high school students. Despite the excision of much descriptive chemistry, the course still probably contains more than can be taught in one year under ordinary high school conditions (Merrill, 1962).

One of the assumptions underlying the CHEM Study curriculum is ". . . that a student going into high school chemistry already believes firmly that atoms and molecules and nuclei and electrons exist (Campbell, 1962)." Campbell continues:

> We would hope that a student when he leaves the course will think of any chemical system with which he comes in contact in terms of the structure of the system. By structure here I mean not only electron structure, but the geometrical arrangements of the atoms, the relative sizes and shapes of the atoms, forces between them, and how these affect their chemistry. He will also think in terms of dynamics. He will not only have organized a great deal of factual information, but just as important, he will be able to interpret his own new observations in terms of these concepts of structure and dynamics (Campbell, 1961).

It can be asked if this assumption underlying the development of the CHEM Study curriculum or others, such as, does the student attain an understanding of the concepts included in this curriculum using the recommended procedures, are correct. Since the acceptance of the new curricular materials, there has been much criticism of the content of the courses and some research has been done in an attempt to evaluate the courses.

Pode (1966) finds both CBA and CHEMS guilty of introducing ideas without adequate discussion.

> The first example of this occurs in their treatments of equilibrium, for which both courses produce brilliant analogies combined with an otherwise excellent discussion. The state of equilibrium is introduced as a compromise between minimum energy and maximum randomness, yet the implication in this, that the potential energy of a system tends toward a minimum, is in direct contradiction of the Law of Energy Conservation on which much stress has been laid. It would not have been difficult to explain that all other forms of energy tend to degrade to thermal, since this is energy in a more "disorderly" form.

Pode also finds that the courses are too long.

> Very few of the hundreds of teachers whom I have asked have ever managed to finish either course, even though CBA is now shortened by a whole section of descriptive work than was originally intended. It is easy to say that it is better to be too long than too short, and that in any case most teachers manage just to reach the descriptive chapter; but surely it is precisely here that the students get the most value when they see that the principles that they have developed so laboriously are very widely applicable in unforseen situations. The weakest part of both courses is the section on energy, where they stray into physics; the obvious solution is an integrated two year course (Pode, 1966).

Morgan and Koelsche (1966) investigated and compared the vocabularies, principles and objectives of text books in high school chemistry. High school chemistry tests that were published between 1934 and 1964 were analyzed to determine the objectives and principles included in these. Their data supports the following conclusions.

1. The basic principles of chemistry have undergone little change in the last thirty years and these principles were generally found in all texts reviewed.

2. The methods of presentation utilized in the new curriculum texts differed from the traditional primarily in the emphasis placed on laboratory data and theoretical and mathematical considerations.

3. Although principles appeared equally in the traditional and new curriculum texts, words and terms found in science articles from popular literature were contained to a greater extent in the traditional text. Furthermore, it is concluded that the new curriculum texts and the modern traditional texts represent a re-emphasis and implementation of methods, techniques, and organization proposed by other curriculum study groups beginning in 1920.

It is the hypothesis of Uricheck (1967) that the new curricular projects, CBA and CHEMS, are not more successful than the traditional courses in chemistry. He calls for more research to determine if they attain the following objectives:

1. To impart understanding for basic chemical concepts.
2. To foster creativity.
3. To better prepare the student for college chemistry.
4. To motivate the student into considering chemistry as a career.

Heath and Stickell (1963) conducted a study to determine the relative effectiveness of the CBA, CHEM and traditional courses utilizing a procedure in which teachers of the course were carefully matched. The groups using CBA and CHEM were further divided into sub-groups on the basis of geography, community size and sex of teacher. It was noted that geographic region, community size and sex of the teacher were not significant factors with respect to student achievement.

Ferris (1962) warns that studies to evaluate the new curriculum may not be valid. He warns that the use of test scores in the evaluation of the new curriculum is "fraught with the dangers of misinterpretation." Ferris continues:

> Once student learning has been reduced to numbers, there is a tendency to forget what the test itself is designed to measure and to consider the resulting numbers as precise, or even exact, numerical indices of the extent to which a student has mastered a given course.
>
> Because numbers in the form of test scores become amenable to all sorts of mathematical manipulation, attention becomes focused solely on statistics as the criterion of success.

The most important use of the achievement tests in the new curricula is, according to Ferris, to answer this question: Is the science embodied in the new courses effectively teachable to the average high-school student of physics, chemistry, or biology? First it is of the "utmost importance to determine the extent to which the new course materials communicate to that segment of the student population for which the course was developed." According to Ferris most students selecting high school chemistry are estimated to rank above the fiftieth percentile of a national norms group of U.S. high school students.

If the tests have content validity, and if the students taking the new course materials are representative of the group of students who take the particular science, one can conclude that the course materials are staisfactory. According to these criteria Ferris concludes that in the first year of testing CHEM Study and BSCS are satisfactory.

> . . . all indications are that the new courses--even in their preliminary form--are far from being advanced-placement courses appropriate only for the gifted student. Indeed in these two projects, assuming that the achievement test in their preliminary form can serve as any sort of reasonable barometer of teachability, one can make the generalization that students can cope with the kinds of learning built into the courses (Ferris, 1962).

III

PROCEDURE

Although high school chemistry courses are somewhat selective by virtue of their reputation, there are many enrolled students who fail the courses. It is acknowledged that student failures may be due to lack of academic ability, lack of interest, lack of prerequisite knowledge and/or lack of mathematical and reading skills. Although these deficiencies are generally accepted they do little to help understand what causes the student to fail. In this study, the concern is with the presence or absence of certain concepts and/or skills and student failure on tests in CHEM Study chemistry. It is recognized that these deficiencies may be traced back to ability, interest, or other causes. However, their cause is not of concern; of concern is the consequence.

Identification of Concepts and Skills

In the CHEMS program the pass or fail status of a student is determined in part by the scores he earns on the prepared examinations. Therefore, these tests were analyzed to determine what concepts and what skills were required for success. The Achievement Tests, 63-64 edition, prepared by the Chemical Education Material Study were used.

The specific tests utilized were those designed to be administered at the completion of Chapters 4, 7, 10 and 13 in Chemistry, An Experimental Science.

Each item on each test was analyzed to determine the concepts and/or skills necessary to give the desired response to that item. The skills identified as necessary for the pupil to give an acceptable answer to the questions on the CHEM Study examinations were two types, mathematical and stoichiometric.

1. Mathematical skills consisted of the following:
    - A. Arithmetic skills such as the manipulation of numbers in addition, subtraction, etc.
    - B. Algebraic skills such as the solution of simple equations.
    - C. The use of scientific notation and significant numbers.
    - D. Pictorial skills involved in the reading and interpretation of graphs, charts and tables.
2. The stoichiometric skills consisted of the following:
    - A. Writing and reading formulas.
    - B. Writing and balancing chemical equations.
    - C. Correctly setting up and solving chemical problems.

In the analysis of the test items, it was assumed that the student possessed adequate ability in reading and would be able to correctly comprehend such qualifier words as what, when, how, more, etc. In the list of concepts and skills needed to provide the acceptable responses were included those needed to reject the distractors as well as to select the correct foil in each test question.

The lists of the concepts and skills identified as necessary for successful completion of each examination and the frequency of occurrence of each are found in the Appendix, Tables 1-4.

Development of the Interview

The step following the identification of the needed concepts and skills for each question was that of determining whether the student who failed to respond acceptably to a test item possessed the needed concept or skill. It was decided that a clinical approach would be most effective, so a sequence of interviews was planned.

The interview questions evolved directly from the lists of concepts and skills which had resulted from the analysis of the test questions. The sequence was planned so that each concept as well as each skill identified as needed became an important part of at least one question in an interview. An attempt was made to confine each question to one concept or skill in order to obtain as much information as possible about that concept or skill. If this were not possible, more than one question was developed for a concept. The interviews were planned to encourage the development of pupil confidence by including "easy" items as well as those that were more difficult.

Four interviews related to the four tests were developed for use with students having difficulty on any of the four tests used, and a fifth interview was developed for use with those students whose test scores were classified as within the upper 20 percent of the class in School A or the upper 30 percent of the class in School B. This fifth interview included the use of previously prepared interview questions selected from those that were answered incorrectly during the previous interview by 50 percent or more of the students in either of the two participating schools. The five interviews and the results of analysis are found in Chapter IV, Tables VIII, IX, X, XI and XII.

The interview procedure consisted of three steps: The identification of the students to be interviewed, the interview and the analysis of the interview.

Selection of Subjects

A list of high schools in central Wisconsin including the CHEM Study program as a part of their curriculum was obtained from the Wisconsin Department of Public Instruction and three school districts were identified within commuting distance of Madison, Wisconsin. One district was eliminated because of a small enrollment in chemistry. The other two school districts were contacted and both agreed to participate in the study.

The indicator of the level of academic ability of the students in both groups was taken as the IQ. The Watson-Glaser Critical Thinking Appraisal was administered to obtain a measure of critical thinking ability.

The CHEM Study examinations were analyzed to determine the mathematical skills needed to solve the problems included. A review of several elementary algebra texts (listed in the Appendix, Table 5) revealed that the required mathematical skills and procedures were a part of the course represented by those texts. The level of student proficiency in mathematics was therefore judged on the basis of student course grades in ninth grade algebra.

Subjects were selected for participation in these interviews on the basis of scores earned on the separate examinations. Originally the students to be interviewed were to include those whose CHEMS test scores made up the lowest 20 percent of the distribution within each school; however, upon examination of the first sample it was noted that the scores earned by the students in School A were appreciably higher than those from School B. It was then decided to interview the 20 percent of the students studying chemistry who earned the lowest grades on the test in School A and the 30 percent in School B who earned the lowest grades on the test in order to include students from both schools with approximately the same range of scores.

Students included in these groups were contacted as soon as possible after each examination and arrangements were made for the interview during a convenient study period. In some cases students refused to take part in the interview or were unable to take part because of prolonged or frequent absence from school. When this occurred the student with the next highest sequential score was contacted. Each test thus produced a new group of students for interviews since the same students did not always earn the low grades.

The subjects to participate in Interview 5, those who had been successful on the tests, had earned test scores in the top 20 percent for School A and in the top 30 percent for School B on at least two of the first three examinations.

The Interview

At the beginning of each interview a short period was set aside to become acquainted with the student and explain the project. This was followed by a sequence of questions related to the test questions. Each student was asked the same questions in the same order during the interviews concerned with a given test. At no time was an indication given that a response was acceptable or not acceptable; therefore the answers to successive questions would not be affected by information which might be obtained in this manner. Each interview session was recorded on tape for later playback and analysis so that possible unfavorable reaction by the subject to the tabulation of data during the session could be avoided.

Interview Analysis

The response to each question given by each student was classified as a no answer, an answer not acceptable, an answer partially acceptable, or an answer acceptable. The correctness of the answer was determined by its agreement or disagreement with the information in the CHEM Study curriculum. An answer was judged as partially acceptable if the student demonstrated some knowledge of the concept but had phrased the response incorrectly in some way. An answer was judged as unacceptable if it was completely wrong. The response was classified as a no answer if the subject said he did not know or merely remained silent. The frequency of the responses to each question were tabulated as percentages based upon the total number of students responding.

Test Statistics

The CHEM Study examinations are designed with an intended mean score of 60 percent (CHEM Study Newsletter, 1966). To determine if this population attained this score the four CHEMS examinations were analyzed using the Generalized Item and Test Analysis Program (GITAP) prepared by Baker (1966) for use on a CDC 1604 computer. This program provided the following information:

1. Group Mean.
2. Hoyt reliability.
3. Standard Deviation.
4. Standard Error.
5. Individual Item Analysis.

The Hoyt reliability is a measure of the internal consistency of the test using Hoyt's Analysis of Variance Method. The Item Analysis revealed the difficulty of each question. According to Wood (1961), "Opinions of test theorists still differ as to whether in general the items should all be of about 50 percent difficulty or whether a fairly wide range of difficulty values with an average of fifty is preferable." Both criteria were applied to the examinations used with this group.

IV

RESULTS

The population involved in this study was enrolled in one of two high schools in central Wisconsin: School A, a large urban school, with an enrollment of 118 in four classes in chemistry (1 ninth, 29 tenth, 46 eleventh and 42 twelfth graders), and School B, a rural school with 44 enrolled in chemistry (39 tenth and 5 twelfth graders).

In offering the CHEMS program the teachers followed the suggestions included in the associated Teacher's Guide. However, it was not possible to follow the same time schedule in both schools; School A completed Chapter 17 and School B completed Chapter 14 during the year.

Description of the Population

The scholastic ability of the students making up the total population enrolled in chemistry in these schools was slightly above average as indicated by the mean IQ of the two groups: School A--114.59, S.D.--9.97 and School B--114.78, S.D.--6.58. Examination of the distribution of IQs for the students interviewed (Table I) indicates that the majority of them were average or above.

It is noted from Table II that the majority of the students of this population completed successfully an algebra course in which

Table I

Distribution of IQ Among Students Interviewed

IQ	School A Interview					School B Interview				
	1*	2**	3**	4	5	1	2	3	4	5
146-150	0	0	0	0	1	0	0	0	0	0
141-145	0	0	0	0	0	0	0	0	0	0
136-140	0	0	0	0	2	0	0	0	0	0
131-135	0	0	1	0	2	0	0	0	0	0
126-130	0	0	1	0	1	0	1	1	1	2
121-125	1	0	1	1	2	0	0	2	2	2
116-120	4	4	2	2	2	1	1	1	1	4
111-115	2	8	4	4	1	6	6	4	5	2
106-110	6	6	5	9	1	3	5	5	5	1
101-105	6	6	5	5	0	1	1	1	0	0
96-100	2	0	2	1	1	0	0	0	0	0
91-95	0	0	0	0	0	0	0	0	0	0
86-90	0	0	1	0	0	0	0	0	0	0

* Two scores not available.
** One score not available.

Table II

Frequency of Academic Grades Earned

in 9th Grade Algebra

Grade	School A*	School B**
A	38	9
B	40	14
C	29	13
D	10	6
E	0	1

* Two grades were not available.

** Grades have been converted from percentages to letter grades using the criteria of the participating school. One grade is missing.

they should have acquired the necessary mathematics skills required to adequately solve the problems involved in the CHEM Study program. Sixteen ninth-grade algebra books were examined and all were found to contain the skills needed.

Based upon the stanine scores, listed in Table III, earned on the Watson-Glaser Critical Thinking Appraisal, Form ZM, the majority of the students from both schools may be considered to be of average or above in critical thinking ability.

The CHEM Study Examinations

The CHEM Study examinations used in this study were submitted to analysis using the computer program, GITAP, by Baker (1966). It is noted from Table IV that the mean raw score of 60 percent (18 correct) for which the examination is designed was obtained on Test 63-64-1 and exceeded on Test 63-64-3 by the students in School A. The mean in School B did not exceed 15.6 on any test.

It is also noted from Table IV that the group mean scores on the CHEMS tests in School B were consistently lower than in School A. This fact led to recognition of the need to increase the number of students to be involved in interviews from School B noted in Chapter III.

Also to be noted from Table IV is that the reliabilities of these tests exceed .68 for this population. According to Kelly (1927) the minimal requirement for reliability is .50 "for determining the status of a group in some subject or group of subjects." According to Davis (1964), "Experience has shown that for measuring characteristics of

Table III

Distribution of Stanine Scores on

Watson-Glaser Critical Thinking Appraisal

Stanine Score	School A	School B
9	14	3
8	16	7
7	33	10
6	22	10
5	14	9
4	6	2
3	11	2
2	0	0
1	0	0

7, 8 and 9--above average
4, 5 and 6--average
1, 2 and 3--below average

Table IV

Test Statistics--CHEM Study Examinations

	CHEM Study Norm Group		School A				School B			
	Group $\overline{X}$	S.D.	Group $\overline{X}$	R	S.D.	S.E.	Group $\overline{X}$	R	S.D.	S.E.
Test 63-64-1	17.1	5.8	18.3	.78	5.4	2.3	12.9	.72	4.6	2.4
Test 64-64-2	15.1	5.4	15.9	.72	4.5	2.3	11.8	.69	4.2	2.3
Test 63-64-3	17.8	6.1	19.2	.76	4.8	2.3	15.6	.74	4.8	2.4
Test 63-64-5	15.9	5.7	15.4	.77	5.0	2.3	14.7	.68	4.4	2.4

individuals, scores with reliability coefficients below .75 are rather inefficient. For measuring the average characteristics of groups of the size of many classes, scores with reliability coefficients as low as .50 may often be highly serviceable."

When the item difficulty is calculated in terms of percent of the population providing an acceptable response to each item (Table V) it is noted that the difficulty of certain items appears to be school associated, and from Table VI this observation becomes more apparent. The students in School B consistently found the tests to be more difficult than those in School A.

If the approach to the interpretation of the item difficulty statistics is the use of average test item difficulty rather than individual item difficulty (Table VII), the indication is similar; the tests again are more difficult for students in School B than School A.

Learning Difficulties

The information accumulated on tapes during each interview was tabulated as each item was related to the interview question, Table VIII. For the first interview, 21 students in School A and 13 students in School B were used.

Table V

Difficulty of Test Items Expressed as Percent of Students

in Each School Giving an Acceptable Response for Each Item

	Test 63-64-1		Test 63-64-2		Test 63-64-3		Test 63-64-5	
Item	School A	School B	School A	School B	School A	School B	School A	School B
1	81.3	45.4	59.8	43.2	71.4	48.8	53.6	40.5
2	49.1	34.1	65.0	29.5	74.1	73.2	58.0	83.3
3	94.0	54.5	63.2	45.4	79.5	85.4	77.7	64.3
4	88.1	54.5	51.3	52.3	67.0	53.7	91.1	83.3
5	66.9	45.4	44.4	27.3	50.0	34.1	25.0	23.8
6	81.4	63.6	46.1	15.9	59.8	51.2	49.1	38.1
7	77.1	56.8	65.8	61.4	80.4	65.8	37.5	35.7
8	57.6	40.9	47.9	47.7	49.1	48.8	76.8	61.9
9	73.7	47.7	82.0	63.6	79.5	58.5	60.7	47.6
10	57.6	13.6	67.5	34.1	71.4	61.0	78.6	45.2
11	44.9	25.0	77.8	52.3	85.7	65.8	82.1	76.2
12	36.4	36.4	60.7	38.6	66.1	53.7	52.7	52.4

(Cont.)

	Test 63-64-1		Test 63-64-2		Test 63-64-3		Test 63-64-5	
Item	School A	School B	School A	School B	School A	School B	School A	School B
13	34.7	15.9	29.9	4.5	71.4	48.8	47.3	38.1
14	64.4	45.4	37.6	31.8	77.7	43.9	83.9	76.2
15	66.9	43.2	40.2	25.0	34.8	26.8	50.9	40.5
16	49.1	34.1	64.1	45.4	75.0	70.7	37.5	40.5
17	92.4	6.8	89.7	68.2	58.0	56.1	19.6	21.4
18	58.5	47.7	94.0	77.3	43.7	29.3	64.3	64.3
19	50.8	43.2	57.3	50.0	70.5	56.1	22.3	26.2
20	58.4	31.8	67.5	18.2	71.4	78.0	49.1	61.9
21	56.8	38.6	27.3	6.8	97.3	85.4	64.3	71.4
22	79.7	77.3	32.5	13.6	69.6	41.5	49.1	50.0
23	63.6	61.4	21.4	34.1	56.2	56.1	39.3	30.9
24	7.6	6.8	41.9	36.4	66.1	39.0	42.0	47.6
25	77.1	75.0	29.1	43.2	10.7	12.2	47.3	33.3

(Cont.)

	Test 63-64-1		Test 63-64-2		Test 63-64-3		Test 63-64-5	
Item	School A	School B	School A	School B	School A	School B	School A	School B
26	59.3	40.9	87.8	84.1	76.8	61.0	48.2	50.0
27	32.2	22.7	25.6	15.9	58.0	53.7	33.9	45.2
28	70.3	50.0	26.5	15.9	58.9	53.7	26.8	38.1
29	48.3	34.1	54.7	68.2	50.9	26.8	40.2	42.9
30	51.7	36.4	36.7	31.8	45.5	17.1	31.2	42.9

Table VI

Number of Items Given Unacceptable Responses

by 50 Percent or More of the Students

	Test 63-64-1	Test 63-64-2	Test 63-64-3	Test 63-64-5
School A	8	14	5	17
School B	23	22	12	19

Table VII

Average Percent of Difficulty

	Test 63-64-1	Test 63-64-2	Test 63-64-3	Test 63-64-5
School A	60.97	53.18	64.22	51.34
School B	40.97	39.39	54.02	49.42

Table VIII

Questions: Interview No. I

1. What is meant by the word mole?

2. How much does one mole of carbon weigh? If the answer is correct, proceed to question 3. If the answer is incorrect, proceed to question 4.

3. What do you have to know to answer the preceding question?

4. Show the student a periodic table of the elements. Ask the student to find carbon on the table.

5. What is the atomic number of carbon?

6. What is the atomic weight of carbon?

7. Which of these, the atomic weight or the atomic number, is important in determining the weight of one mole of carbon?

8. Tell the student the answer to the proceding question. What is the weight of one mole of carbon?

9. What is Avogadro's number? If answer is correct, proceed to question 11. If answer is incorrect, proceed to question 10.

10. What is the number 6.02×10^{23}?

11. Show the student a picture of two closed flasks. One flask contains oxygen and the other contains chlorine. How many particles are there in the flask containing oxygen?

12. How many particles are there in the flask containing chlorine?

13. Are there more, the same, or fewer particles in the flask of oxygen compared to the flask of chlorine?

14. Show the student a picture of two flasks, one filled with oxygen and the other with an unknown gas. The two flasks have the same volume and the gases are at the same temperature and pressure. If you knew the weights of both of these samples, could you calculate the molecular weight of the unknown gas?

15. If the answer to question 14 is yes, ask how?

16. Suppose that the oxygen gas weighed .32 g, and the unknown gas weighed .64 g, how many times heavier is the unknown gas?

17. If the molecular weight of oxygen is 32 g, what is the molecular weight of the unknown gas?

18. What is meant by the term solid? If the answer is correct, proceed to question 20. If the answer is incorrect, proceed to question 19.

(Cont.)

19. Name some materials that are solid at room temperature?

20. What picture or model do you have for a solid?

21. What is a gas? If the answer is correct, proceed to question 23. If the answer is incorrect, proceed to question 24.

22. What are some examples of materials that are gases at room temperature?

23. What picture or model do you have for a gas?

24. What is a liquid?

25. What is the difference between a solid and a liquid?

26. What is the difference between a liquid and a gas?

27. Show the student a beaker with some ice cubes in it and another with some liquid water in it. What is the difference between the water particles in these two beakers?

28. Figure I is a graph which shows the cooling of steam to ice. What does this graph represent? Explain it.

29. Point to line AB. What does this portion of the curve represent?

30. On what portion of the curve do the particles have the greatest energy?

31. Why do you choose that portion?

32. Point to BC. What does this portion of the curve represent?

33. What is a calorie?

34. What is a calorimeter?

35. What is represented by the formula of a chemical compound?

36. The formula for the compound benzene is C_6H_6. Explain what is meant by this formula?

37. What is molecular weight?

38. How do you calculate the molecular weight of benzene, C_6H_6? If the answer is correct, proceed to question 41. If the answer is incorrect, proceed to question 39.

39. The atomic weight of carbon is 12 and the atomic weight of hydrogen is 1, with this information can you calculate the molecular weight of benzene?

40. What is the molecular weight?

41. What is a chemical change? If the answer is correct, proceed to question 44. If the answer is incorrect, proceed to question 42.

42. What is an example of a chemical change?

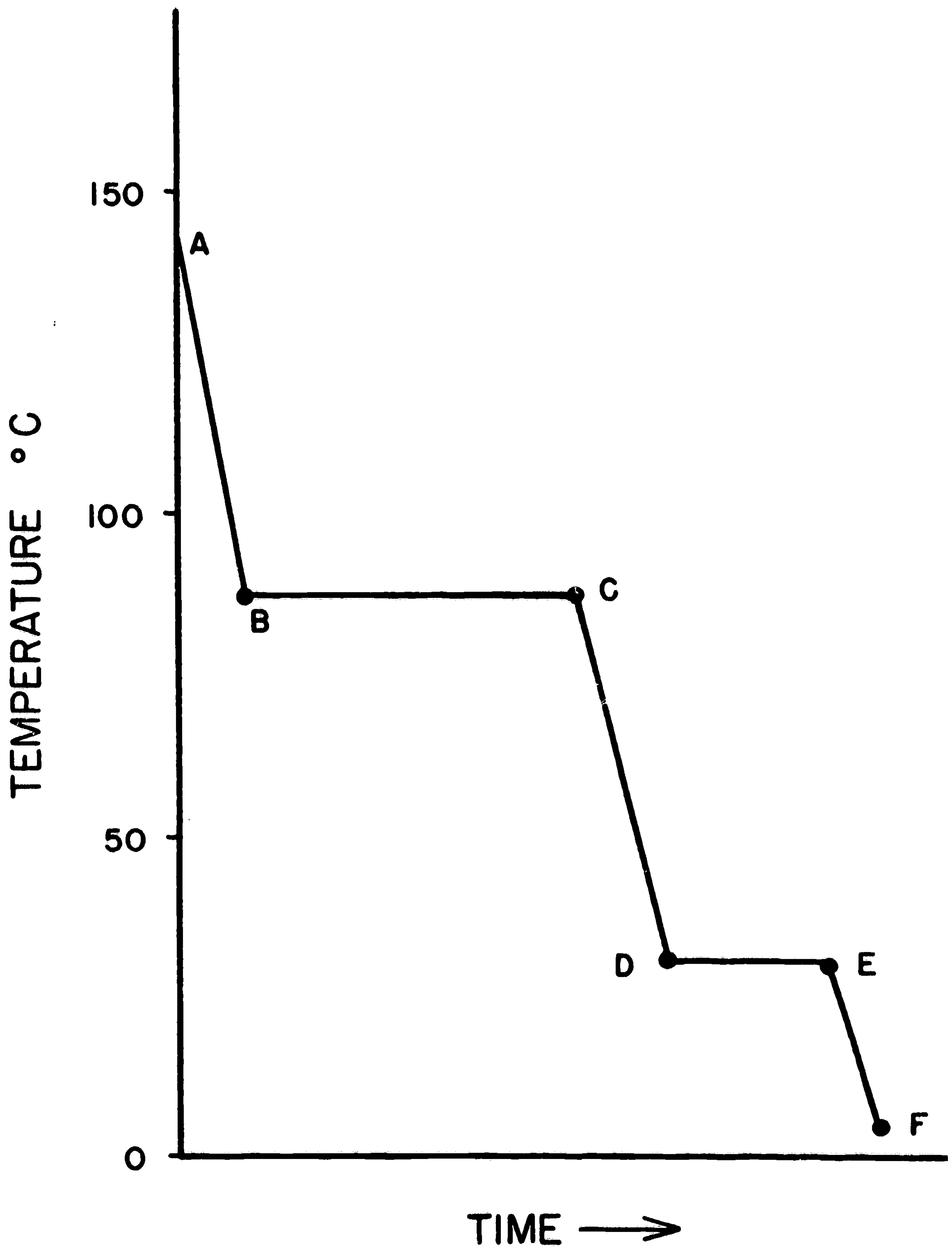

Figure 1. Graph Showing Cooling of Steam to Ice

(Cont.)

43. Why is that a chemical change?

44. What is a physical change? If the answer is correct, proceed to question 47. If the answer is incorrect, proceed to question 45.

45. What is an example of a physical change?

46. Why is that a physical change?

47. Which change, the physical change or the chemical change, would usually require more energy?

48. Why do you think so?

49. In an experiment in the laboratory you measured the heat of combustion of wax and the heat of solidification of wax. Which was a chemical change, the burning of the candle or the melting of the candle wax?

50. What does a chemical equation represent?

51. What does this equation represent?
$C_{(coal)} + O_2 \longrightarrow CO_2$

52. What terms are used for the substance on the right side of the equation and for those on the left?

53. Is the following equation correct?
$H_2 + O_2 \longrightarrow H_2O$

54. What is the meaning of conservation of matter?

55. What is the meaning of conservation of atoms?

56. If you started with a total mixture of 18 g of hydrogen and oxygen, what is the most water that could be formed?

57. Why?

58. Please read the following equation out loud.
$2H_2 + O_2 \longrightarrow {}_2O$

59. Which numbers in that equation are the coefficients?

60. What do the coefficients in the equation represent? Or what do the numbers in front of the formulas represent?

61. Using that equation, how much more hydrogen must react than oxygen?

62. If the answer to question 61 is correct, how do you know that?

63. Please balance this equation.
$Na + Cl_2 \longrightarrow NaCl$

64. What is meant by the word heat?

65. What is temperature?

66. What is the difference between heat and temperature?

67. Suppose that a bathtub is filled with hot water and you scoop out a cup of that water, which container has more heat?

(Cont.)

68. Consider the same situation as described in the last question. Which has the higher temperature?

69. What is absolute zero?

70. What is meant by Kelvin or absolute temperature?

71. What is meant by centigrade or Celcius temperature?

72. Is it possible to convert from the centigrade scale to Kelvin?

73. How?

74. What is pressure?

75. Show the student an open flask. How does the pressure in this room compare with the pressure in this flask?

76. Close the flask. If the flask is heated, how does the pressure in the flask compare with the pressure in this room?

77. What is the relationship between pressure and temperature?

78. Show the student an inflated balloon. If this balloon is heated, what will happen to it?

79. Why?

80. What is the relationship between temperature and volume?

81. Show the student a picture of two flasks containing two different gases at the same temperature. Which has the greater kinetic energy?

82. How does the kinetic energy of particles compare at the same temperature?

83. Is there any relationship between a mole of a gas and its volume? If answer is correct, proceed to question 86. If answer is incorrect, proceed to question 84.

84. What is the volume of one mole of any gas at 0° C and 1 atm.?

85. What is the volume of one mole of any gas at 25° C and 1 atm.?

86. If a gas is in an expandable container and the temperature is raised from zero to 25° C, what will happen to the volume?

87. What does an equation tell you about the rate of a chemical reaction?

88. Does an equation tell you how fast a reaction takes place?

89. If you have two different gases in a container, what is the total pressure in the container?

90. If there is a container with two gases in it and the pressure due to one is 20mm, the total pressure is 50mm, what is the pressure of the second gas?

(Cont.)

91. Consider the following data.
Weight of empty beaker 20g.
Weight of beaker+$AgNO_3$ 25g.

How much does the $AgNO_3$ weigh?

92. How did you figure that out?

93. Consider the following data averaged from the data collected by ten students.
Weight of empty beaker
$20.45 \pm .02$ g
Weight of empty beaker+$AgNO_3$
$25.95 \pm .02$ g
How much does the $AgNO_3$ weigh?

94. What does the .02 stand for?

95. If one mole of copper will react with 2 moles of silver nitrate, how much will two moles of copper react with?

96. Write out an equation to represent the situation discussed in question 95.

Solve the following equations.

97. $\frac{1}{2} = \frac{2}{x}$

98. $\frac{3}{2} = \frac{2}{x}$

99. $\frac{3}{2} = \frac{1}{x}$

100. $\frac{2}{x} = \frac{3}{1}$

101. If 3 is to 9 as x is to 50, what number is x?

Note.--Quality of responses expressed in percentages may be found in Swartney (1968).

Item statistics gathered indicate that in response to questions asked at this interview 50 percent or more of the 34 students interviewed, irrespective of schools, did not:

A. Possess the following concepts:

1. The definition of a solid.
2. The definition of a liquid.
3. The definition of a gas.
4. The definition of heat.
5. The definition of temperature.
6. The definition of a calorie.
7. The definition of molecular weight.
8. The definition of a chemical change.
9. The definition of a physical change.
10. The definition of pressure.
11. The definition of absolute zero.
12. The definition of Avagadro's number.
13. Recognition of 6.02×10^{23}.
14. The basis of the Kelvin temperature scale.
15. The basis of the centigrade temperature scale.
16. The volume occupied by one mole of a gas at STP or 25^{o} and 1 atm.
17. Particles at a higher temperature have greater kinetic energy.
18. Energy is required for a change of state.
19. Equal volumes of gases under the same conditions of temperature and pressure contain equal numbers of particles.

20. The particle nature of matter to explain a gas, liquid and solid.
21. The meaning of a chemical formula.
22. The difference between a chemical change and a physical change.
23. Relationship between chemical changes, phase changes, and energy.
24. The meaning of numerical coefficients in a chemical equation.
25. Law of conservation of matter.
26. Law of conservation of atoms.
27. Relationship between the Kelvin and centigrade temperature scale.
28. Rate of reaction.
29. Uncertainty in measurement.
30. Difference between a solid and a liquid.
31. Difference between a liquid and a gas.
32. The meaning of a chemical equation.
33. The difference between the heat of a substance, the temperature of a substance.

B. Possess the following skills:

1. The ability to determine the molecular weight of an unknown gas using Avogadro's Hypothesis.
2. The ability to explain and interpret a cooling curve.
3. The ability to balance an equation.
4. The ability to write equations.

5. The ability to convert centigrade temperature to Kelvin.
6. The ability to manipulate numbers with an uncertainty.
7. The ability to solve simple algebraic equations.

For the second interview, 24 students in School A and 15 students in School B were interviewed.

Table IX

Questions: Interview No. II

1. What does the atomic weight of an element represent?
2. Find chlorine on the periodic table. It is circled in red. What is the atomic weight of chlorine?
3. What does the atomic number of an element represent?
4. Find sodium on the periodic table. It is circled in red. What is the atomic number of sodium?
5. What is an atom?
6. What are the basic parts of an atom?
7. What are the characteristics of the electron?
8. What are the characteristics of the proton?
9. What are the characteristics of the neutron?
10. How much does the neutron weigh?
11. What is meant by nuclear charge?
12. What kind of charge does the nucleus have?
13. How does the nucleus of the atom compare to the size of the entire atom?
14. How large do you think an atom is?
15. Can you compare the size of an atom with something you know?
16. How many particles of sodium would weigh 23.0 g.?
17. What is the difference between the terms atomic weight and mass number?
18. What is a nucleon?
19. How many nucleons would be present in a uranium nucleus of mass number 235?
20. How do you know?
21. What is a nuclear reaction?
22. How does energy change in a nuclear reaction compared to the energy change in a chemical reaction?
23. If the answer to the above question is greater, ask the following. How much greater is it?
24. What is an isotope?
25. How do the physical properties of two isotopes of the same element compare?
26. How do the chemical properties of two isotopes of the same element compare?
27. What is an ion?

(Cont.)

28. The formula for calcium oxide is CaO and the formula for calcium chloride is $CaCl_2$. How is the calcium ion charged? Is it positive or negative?

29. How many electrons are there in a calcium ion?

30. How do you know the answer to the last question?

31. How many electrons are there in a neutral calcium atom?

32. What element on the periodic table would have the same number of electrons as the Ca ion?

33. Among the following compounds, which one would you expect not to exist under normal laboratory conditions?
NaCl BaO KCl_2

34. Why did you pick that one?

35. What is a phase change?

36. What is an example of a phase change?

37. Define boiling.

38. What is the boiling point of water at standard pressure?

39. What is a boiling point?

40. How is the boiling point of water affected if a substance like NaCl is added to the water?

41. What is vapor pressure?

42. What effect will raising the temperature have on the vapor pressure of a liquid?

43. What is equilibrium?

44. What is an example of equilibrium?

45. What is an example of a gas at room temperature?

46. What characteristics does that gas have that you would choose it as an example of a gas?

47. What mental model do you have for a gas? (If the student does not understand mental model, ask what picture the student has for a gas.)

48. What is an example of a liquid at room temperature?

49. What characteristics does that liquid have that you would choose it as an example of a liquid?

50. What mental model do you have for a liquid? (See question 47.)

51. What is an example of a solid at room temperature?

52. What characteristics does that solid have that you would pick it as an example of a solid?

(Cont.)

53. What mental model do you have for a solid? (See question 47.)

54. Define homogeneous.

55. What is an example of a homogeneous substance?

56. Why is that homogeneous?

57. Define heterogeneous.

58. What is an example of a heterogeneous substance?

59. Why is that heterogeneous?

60. What is a solution?

61. How does the chemist measure the concentration of a solution?

62. What is molarity?

63. If 11.9 g of KBr were dissolved in enough water to make 1000 ml or 1 liter of solution, what would you have to do to calculate the molarity?

64. If one mole of KBr weighs 119 g, what is the molarity of the solution?

65. What factor or factors affect the amount of solute that can be dissolved in a solvent?

66. If you wanted to dissolve some sugar in a glass of water, what can you do to make the sugar dissolve.

67. What is a chemical reaction?

68. What are two observations that you can make in the laboratory that indicate that a chemical change has taken place?

69. What is an exothermic reaction?

70. What is an endothermic reaction?

71. What is meant by the symbol Δ H?

72. What is represented by the Greek letter delta?

73. Z + X ——> G + H + 10kcal
Rewrite this equation using the Δ H notation.

74. Which of the following represent an endothermic reaction?
a) $H_2 + 1/2\ O_2 \longrightarrow H_2O \quad \Delta H = -57.8kcal.$
b) $1/2\ N_2 + 1/2\ O_2 \longrightarrow NO \quad \Delta H = -57.8kcal.$
c) $NH_3 + 11.0kcal. \longrightarrow 1/2\ N_2 + 3/2\ H_2$

75. What is energy?

76. What is an example of energy?

77. What is potential energy?

78. What is an example of potential energy?

79. What is kinetic energy?

80. What is an example of kinetic energy?

(Cont.)

81. Which of the following will require more energy?
a) changing a mole of liquid water into gaseous water, or
b) the decomposition of one mole of water by electrolysis.

82. Explain your answer to the last question.

83. What is the Law of Additivity of Reaction of Heats?

84. If you have the following information,
1) $A + B \longrightarrow C \quad \Delta H = -20kcal/mole$
2) $E \longrightarrow B + D \quad \Delta H = -5kcal/mole$
How would you calculate H for this reaction?
(Equation 3)
3) $A + E \longrightarrow C + D \quad \Delta H =$ ___

85. What would the answer be?

86. Is the above reaction exothermic or endothermic?

87. There are these consecutive elements on the periodic table, X, Y, and Z.
X will form the ion X^+
Y will form the ion Y^+
and Z has one less electron than X. What group of three elements on the periodic could these be?

88. Are these three elements in the same family?

89. Can element X react with chlorine?

90. (If the answer to question 89 was yes ask this question.) What is the formula of the compound formed?

91. Pick an element that is a metallic solid.

92. Can you define metallic solid?

93. Pick an element that is a molecular solid.

94. Define molecular solid.

95. Pick and element that is a network solid.

96. Define network solid.

97. Pick an element on the periodic table that is a gas?

98. What is meant by the chemical family on the periodic table?

99. Point out a family on the chart.

100. Here is a chart lising some properties of the alkali elements. Show the students Table 6-V, Some Properties of the Alkali Metals on p. 94 in Chemistry, An Experimental Science. Which is a solid at the boiling temperature of water?

101. Which has the smallest molecules?

102. Which has the smallest number of electrons in the neutral atom?

103. How is partial pressure defined?

104. If you have two gases in a container what is the total pressure in that container?

(Cont.)

105. If you knew that the total pressure exerted by a mixture of gases was 100 mm and the pressure due to gas A was 20 mm, and that due to gas B was 50 mm, what would be the pressure of gas C? Total Pressure - 100 mm, Gas A - 20 mm, Gas B -50 mm, Gas C - ?

106. What element would be formed in the following nuclear reaction?
$_7N^{13} + {}_{-1}e^{o} \longrightarrow$ ______

107. How would you write the symbol of that substance?

108. What is a precipitation reaction?

109. What is a precipitate?

110. If .1 M solutions of the following substances were mixed in all possible combinations the results would be those listed on this chart. Show the student Figure II. Pick two substances in which a precipitation reaction will occur.

111. If A and B' were mixed together in a test tube, would a reaction occur?

112. If B and B' were mixed together in a test tube, would a reaction occur?

113. Write a balanced equation for the net ionic reaction which occurs when B and B' react.

Note.--Quality of responses expressed in percentages may be found in Swartney (1968).

		A'	B'	C'	D'
		Sodium nitrate solution $Na^{+}(aq)+NO_3^{-}(aq)$	Sodium sulfate solution $2Na^{+}(aq)+SO_4^{-2}(aq)$	Lead acetate solution $Pb^{+2}(aq)+2CH_3COO^{-}(aq)$	Lead nitrate solution $Pb^{+2}(aq)+2NO_3^{-}(aq)$
A	Sodium chloride solution $Na^{+}(aq)+Cl^{-}(aq)$	none	none	ppt.	ppt.
B	Lead nitrate solution $Pb^{+2}(aq)+2NO_3^{-}(aq)$	none	ppt.	none	
C	Lead acetate solution $Pb^{+2}(aq)+2CH_3COO(aq)$	none none	ppt. ppt.		
D	Sodium sulfate solution $2Na^{+}(aq)+SO_4^{-2}(aq)$	none			

Figure II. Results of .1 M Solutions, Adapted from Achievement Test 63-64-2, Chapters 5-7, p. 5.

From data gathered at the second interview, it is noted that 50 percent or more of the 39 students interviewed, irrespective of schools, did not:

A. Possess the following concepts:

1. The definition of atomic weight.
2. The definition of an atom.
3. The definition of a nucleon.
4. The definition of a nuclear reaction.
5. The definition of nuclear charge.
6. The definition of an isotope.
7. The definition of an ion.
8. The definition of boiling and boiling point.
9. The definition of equilibrium.
10. The definition of vapor pressure.
11. The definition of homogeneous.
12. The definition of heterogeneous.
13. The definition of a solution.
14. The definition of molarity.
15. The definition of chemical reaction.
16. The meaning of Δ H.
17. The meaning of the Greek symbol delta.
18. The definition of energy.
19. The definition of potential energy.
20. The law of additivity of reaction heats.
21. The meaning of chemical family.
22. The definition of metallic solid.

23. The definition of molecular solid.

24. The definition of network solid.

25. The definition of partial pressure.

26. The definition of a precipitation reaction.

27. The definition of a precipitate.

28. The particle nature of matter to explain a gas, liquid, and solid.

29. The difference between atomic weight and mass number.

30. The meaning of nuclear charge.

31. Comparison of the size of the nucleus to the size of the entire atom.

32. Relationship between chemical change, phase change, and energy.

33. Relationship between chemical change, nuclear change, and energy.

34. The formation of ions.

35. Differentiation between heterogeneous and homogeneous substances.

36. Recognition of exothermic and endothermic reactions.

37. Application of the laws of periodicity.

38. The meaning of atomic weight.

39. The weight of a neutron.

40. Comparison of the physical properties of two isotopes of the same element.

41. The comparison of the chemical properties of isotopes of the same element.

42. Recognition of correct formulas.

43. Ability to cite an example of equilibrium.

44. Factors which affect solubility.

45. Ability to cite an example of energy.

46. Ability to cite an example of potential energy.

47. Relationship of exothermic, endothermic reaction and the size of Δ H.

B. Possess the following skills:

1. The ability to determine the number of nucleons in an atom.

2. The ability to determine the number of electrons in an ion.

3. The ability to recognize correct chemical formulas.

4. The ability to write correct ionic formulas.

5. The ability to calculate the concentration of a solution.

6. The ability to write an equation using the Δ H notation.

7. The ability to calculate Δ H using the law of additivity of reaction heats.

8. The ability to calculate partial pressure.

9. The ability to write net ionic equations.

10. The ability to write nuclear equations.

11. The ability to write nuclear formulas.

12. The ability to use the law of periodicity to determine the identity of elements.

13. The ability to write chemical formulas.

14. The ability to use a chart of physical properties to identify elements in a family.

In the third interview, 22 students from School A and 15 students from School B were interviewed.

Table X

Questions: Interview No. III

1. What is energy?

2. What is an example of energy?

3. What is potential energy?

4. What is an example of potential energy?

5. What is kinetic energy?

6. What is an example of kinetic energy?

Show the student Figure III. This is a potential energy diagram for the reaction between carbon monoxide and nitrogen dioxide to form carbon dioxide and nitric oxide.

7. What does A represent on this diagram?

8. What does D represent on this diagram?

9. What does B represent on this diagram?

10. Is this reaction exothermic or endothermic?

11. How do you know?

12. What is the definition of an exothermic reaction?

13. In this reaction are the products at a lower or a higher energy level than the reactants?

14. What is the definition of activation energy?

15. What is the activation energy of this reaction?

16. Which line on the diagram represents the activation energy?

17. What is an activated complex?

18. Where is the activated complex on this?

19. After the formation of the activated complex what will happen to it?

20. If the above question is incomplete, ask this question. Could anything else happen to it?

21. Define heat of reaction.

22. What is the numerical value for the heat of this reaction?

23. Which line represents the heat of this reaction?

24. What is a catalyst?

25. How would the addition of a catalyst affect the shape of the curve?

26. What is an equilibrium reaction?

27. What is the difference between steady state and equilibrium?

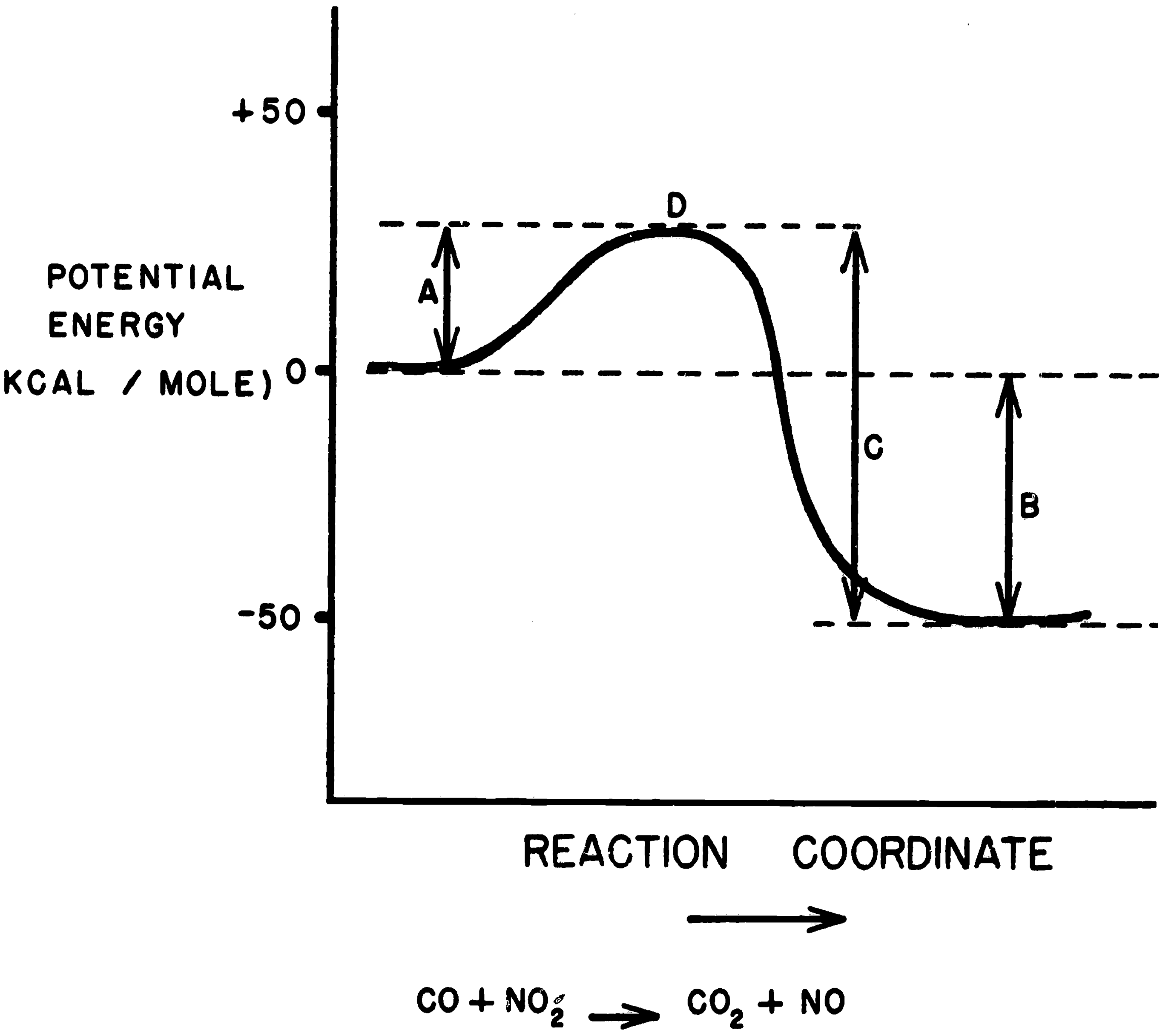

Figure III. Potential Energy Reaction

(Cont.)

28. If there is no answer to question 27, ask this question. What is an example of steady state or equilibrium?

29. Explain the following statement. Equilibrium tends to favor maximum randomness and minimum energy. Show the student the following equation.

$$CO_{(g)} + NO_{2(g)} \rightleftarrows CO_{2(g)} + NO_{(g)} + \text{heat}$$

30. Does this equation represent an equilibrium reaction?

31. How do you know that?

32. After the reaction has come to equilibrium the concentration of CO_2 is increased. What effect, if any, will this have on the concentration of NO?

33. Explain your answer.

34. If the concentration of CO_2 is decreased what will happen to the concentration of NO_2?

35. Explain your answer.

36. If the temperature is increased what will happen to the concentration of CO?

37. How will the addition of a catalyst affect the rate of the forward reaction?

38. How does the catalyst affect this change?

39. How will the catalyst affect the rate of the reverse reaction?

40. How will the addition of a catalyst affect the equilibrium concentration?

41. How will an increase in pressure affect the concentration of CO?

42. Why will that happen?

43. What is Le Chatlier's principle? Can you explain in your own words what it means?

44. What is calorimetry?

45. What is a calorimeter? Show the student the following equation.

$$A + B \rightleftarrows C + D$$

46. Does this equation represent an equilibrium reaction?

47. How do you know?

48. Write the equation for the equilibrium constant for that reaction.

49. This is the correct expression for the equilibrium constant.

$$K = \frac{[C]\,[D]}{[A]\,[B]}$$

What does the bracket represent?

TlCl	1.9×10^{-4}
CuCl	3.2×10^{-7}
AgCl	1.7×10^{-10}
TlBr	3.6×10^{-6}
CuBr	5.9×10^{-9}
AgBr	5.0×10^{-13}
TlI	8.9×10^{-8}
CuI	1.1×10^{-12}
AgI	8.5×10^{-17}

Figure IV. Some Solubility Products at Room Temperature

Adapted from original. Pimentel, George O. (Ed.) 1963. In Chemistry: An Experimental Science. W. H. Freeman and Company, San Francisco, p. 174.

50. If the equilibrium constant is a small number, what can you say about the tendency of the reaction to take place.

51. What is meant by solubility product?

52. What symbol is used to represent the solubility product constant?

53. Show the student the following equation.

$$BaSO_{4(s)} \rightleftarrows Ba^{+2}_{(aq)} + SO_{4(aq)}^{-2}$$

What is the K_{sp} expression for this reaction?

54. If the answer is correct, ask why there is no term in the denominator. If correct ask why there is a term in the denominator.

55. What does the size of the solubility product constant at a specific temperature tell you about the solubility of a solid?

56. If the solubility is high will the K_{sp} be a large number or a small number?

57. Show the student Figure IV. This is a table of solubilities of some common substances. On this table, which of the chlorides is most soluble?

58. Why do you say that?

59. If a car can travel the 80 miles between Madison and Milwaukee in one hour, at what rate does the car travel?

60. What is meant by rate?

61. Suppose that this car can travel 80 miles/hr. but you have to stop and get gas every ten miles. Can you reach Milwaukee in one hour?

62. Why not?

63. What determines the rate at which the car travels?

64. What factors affect the rate of a chemical reaction.

65. Show the student Figure V. A and B represent containers of the same volume at the same temperature and pressure. The black dots represent one substance and the white dots another. In which container will the rate of reaction between the black and white be greater?

66. Why?

67. If the pressure in A were increased, how would the rate be affected? Show the student a vial containing a saturated sugar solution. Tell him it is saturated and have some solid sugar at the bottom of the vial.

68. Is this an example of equilibrium?

69. Explain what is happening in the bottle.

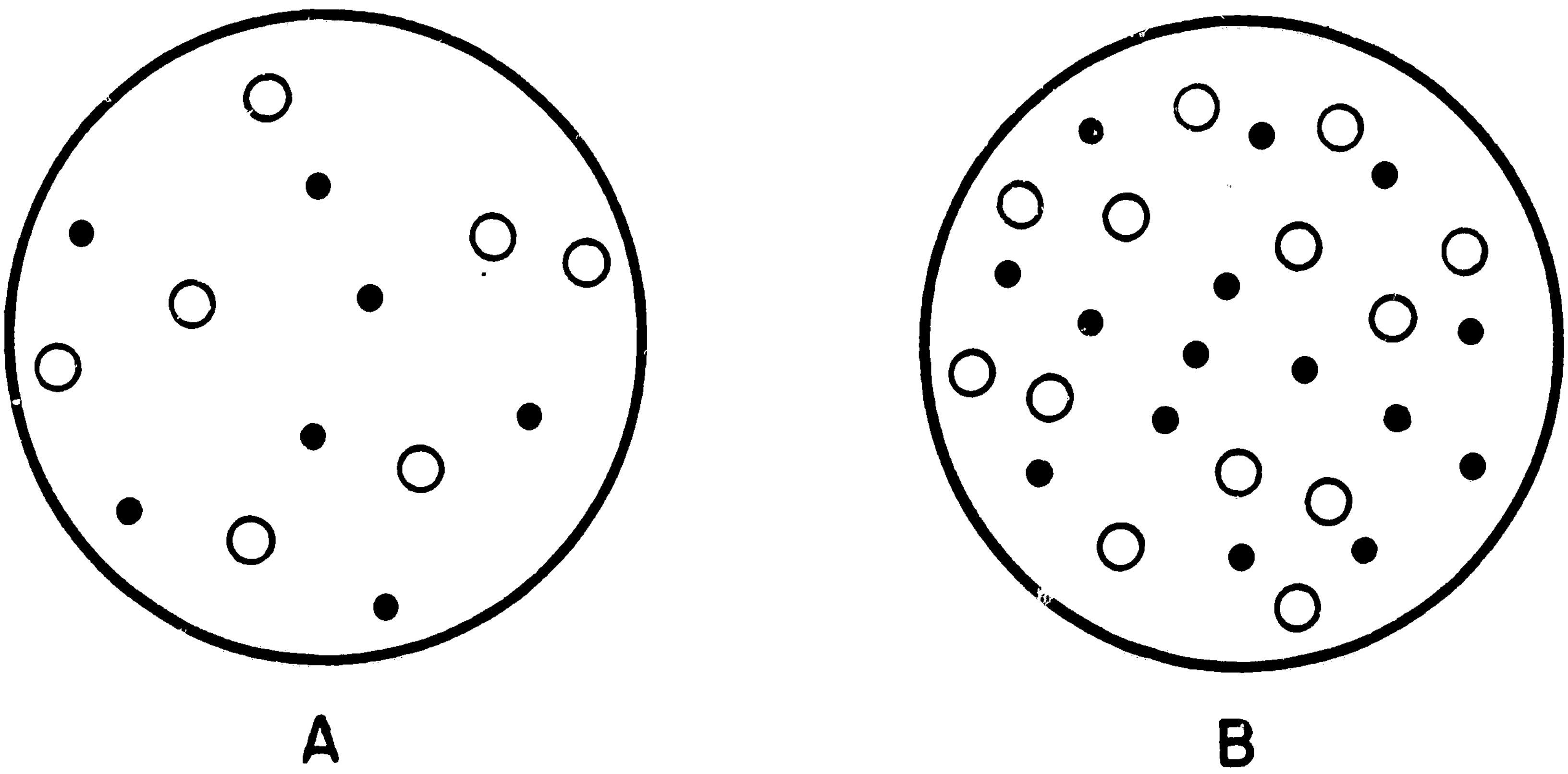

Figure V. Container Representations of Two Substances

(Cont.)

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70. Is any sugar dissolving?

71. Is any sugar precipitating?

72. How does the rate of dissolving compare to the rate of precipitating?

73. How many equilibria are there in this bottle?

74. What are they?

75. What is a solution?

76. In this example of the sugar and the water, which is the solute?

77. Which is the solvent?

78. What is the definition of a solvent?

79. What is the definition of a solute?

80. What is the process of dissolving? Can you explain the process of dissolving using an example or a model?

81. What is precipitation? Would you explain precipitation using an example of a model?

82. What factors affect the rate of dissolving?

83. What factors affect the rate of precipitation?

84. If I take three sugar cubes and leave one whole, crumble one up and grind one up, which will dissolve faster?

85. Why?

86. What factors affect the solubility of a solid in a liquid?

87. What factors affect the solubility of a gas in a liquid?

88. How will an increase in temperature affect the solubility of sugar in water?

89. How will an increase in temperature affect the solubility of carbon dioxide in water?

90. How will an increase in pressure affect the solubility of carbon dioxide in water?

91. What is an ion?

92. How is an ion formed?

93. What is a cation?

94. What is an anion? Show the student the following list.

1. Ca^{+2}	6. K^{+1}
2. Cl^{-1}	7. SO_4^{-2}
3. Na	8. Fe
4. NaCl	9. OH^-
5. Ba^{+2}	10. I

95. Which of these are ions?

96. Which are cations?

97. Which are anions?

98. What is an electrolyte?

99. Is a solution of NaCl an electrolyte?

100. How do you know?

(Cont.)

101. How could you test to determine if NaCl was an electrolyte?

102. Show the student Figure VI. Would a precipitate form if .1 M NaCl is added to an equal volume of .1 M $AgNO_3$?

103. Which of the following is the best equation for that reaction?
A. $NaCl + AgNO_3 \rightarrow AgCl + NaNO_3$

B. $Na^+{}_{(aq)} + Cl^-{}_{(aq)} + Ag^+{}_{(aq)} + NO_3{}^-{}_{(aq)} \rightarrow AgCl_{(s)} + Na^+{}_{(aq)} + Cl^-{}_{(aq)}$

C. $Ag^+{}_{(aq)} + Cl^-{}_{(aq)} \rightarrow AgCl_{(s)}$

104. Why did you pick that one?

105. Hydrogen and oxygen will react according to the following equation.
$2H_{2(g)} + O_{2(g)} \rightarrow 2H_2O_{(g)} +$ 115.6Kcal
If 16 grams of hydrogen react completely, how would you calculate how many moles of water would be formed?

106. How many moles of water would be formed?

107. If .2 moles of water were formed, how much heat would be released?

108. If 20 liters of hydrogen were used, how many liters of oxygen would be used?

109. If the equilibrium concentration are the ones in the Figure VII, how would you determine the equilibrium constant?

110. What is the equilibrium constant?

Note. Quality of responses expressed in percentages may be found in Swartney (1968).

Negative Ions (Anions)	+ Positive Ions (Cations)	Form	Compounds with Solubility:
All	Alkali ions Li^+, Na^+, K^+, Rb^+, Cs^+, Fr^+		Soluble
All	Hydrogen ion, $H^+_{(aq)}$		Soluble
All	Ammonium ion, NH_4^+		Soluble
Nitrate, NO_3^-	All		Soluble
Acetate, CH_3COO^-	All		Soluble
Chloride, Cl^- Bromide, Br^- Iodide, I^-	Ag^+, Pb^{+2}, Hg_2^{+2}, Cu^+		Low Solubility
	All others		Soluble
Sulfate, SO_4^{-2}	Ba^{+2}, Sr^{+2}, Pb^{+2}		Low Solubility
	All others		Soluble

Figure VI. Solubility of Common Compounds in Water

Adapted from original. Pimentel, George O. (Ed.) 1963. In Chemistry: An Experimental Science. W. H. Freeman and Company, San Francisco, p. 174.

$$2H_{2(g)} + O_{2(g)} \rightleftharpoons 2H_2O_{(g)} + 115.6 \text{ Kcal}$$

Atomic weights

H = 1
O = 16

Eq. Concentration

H_2 = 2 moles/l

O_2 = 1 mole/l

H_2O = 1 mole/l

Figure VII. Equilibrium Concentration

From data gathered at the third interview, it is noted that 50 percent or more of the 37 students interviewed, irrespective of school, did not:

A. Possess the following concepts:

1. The definition of energy.
2. The definition of potential energy.
3. The definition of activation energy.
4. The definition of activated complex.
5. The definition of heat of reaction.
6. The definition of equilibrium.
7. Le Chatlier's Principle.
8. The definition of calorimetry.
9. The definition of K_{sp}.
10. The definition of rate.
11. The definition of a solution.
12. The definition of a solute.
13. The definition of a solvent.
14. The definition of an ion.
15. The definition of a cation.
16. The definition of an anion.
17. The definition of an electrolyte.
18. The meaning of the brackets in an equilibrium expression.
19. The meaning of activated complex.
20. The difference between equilibrium and steady state.
21. Rate of a reaction depends upon the slowest step.

22. The formation of ions.

23. The identification of an electrolyte.

24. The basis for the use of net ionic equations.

25. The effect of a catalyst.

26. The effect of changes in concentration in an equilibrium reaction.

27. The meaning of the equilibrium constant, K_{eq}.

28. The ability to identify the solute.

29. The ability to identify the solvent.

30. Knowledge of the factors which affect the solubility of a substance.

31. The ability to cite an example of potential energy.

32. The ability to cite an example of steady state of equilibrium.

33. The ability to explain a potential energy diagram.

34. The effect of an increase in concentration on the rate of a reaction.

35. The ability to recognize an equilibrium situation.

36. The factors which affect the rate of precipitation.

37. The factors which affect the rate of dissolving.

38. The ability to explain a solid-liquid equilibrium.

39. Equilibrium favors maximum randomness and minimum energy.

40. Explanation of the process of dissolving using the particle nature of matter.

41. Explanation of the process of precipitation using the particle nature of matter.

42. Explanation of Le Chatlier's Principle.

43. Explanation of equilibrium.

B. Possess the following skills:

1. The ability to interpret a potential energy diagram.

2. The ability to predict the effect of a catalyst on the potential energy curve.

3. The ability to predict the effect of changes of concentration on an equilibrium reaction.

4. The ability to calculate the equilibrium constant.

5. The ability to predict the effect of concentration on the rate of a reaction.

6. The ability to interpret a solubility table.

7. The ability to identify the best equation to represent a net ionic equation.

8. The ability to solve chemical problems involving the determinations of moles, grams or liters of a substance formed, given any of the three.

9. The ability to determine K_{sp}.

10. The ability to calculate the heat of reaction from potential energy diagrams.

Participating in interview number four were 22 students from School A and 14 students from School B.

Table XI

Questions: Interview No. IV

1. What is an acid?

2. What is an example of an acid?

3. Name two properties of an acid.

4. What is a base?

5. What is an example of a base?

6. Name two properties of a base.

7. What is the symbol of the hydrogen ion?

8. What is the symbol of the hydronium ion?

9. What is the symbol of the hydroxyl ion?

10. Which of the following do you associate with an acid?
    A. H^+
    B. H_3O^+
    C. OH^-

11. If the student picks either A or B only ask the following question. What do you associate H^+ (H_3O^+) with?

12. Which of those do you associate with a base?

13. How do acids react with metals?

14. What is an acid base indicator?

15. What is an example of an acid base indicator?

16. What color will litmus turn in acid solution?

17. What is a neutralization reaction?

18. Which of the two following equations represents a neutralization reaction?
    A. $2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + H_2O$
    B. $Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2$

19. What does the symbol K_w stand for?

20. What does K_w equal?

21. What numerical value does it have?

22. Which of the underlined substances is an acid? (If the student only picks one ask if there are any others.)
    A. $\underline{HCO_3^-} + H_2O \rightarrow CO_3^{-2} + H_3O^+$
    B. $\underline{HCl} \rightarrow H^+ + Cl^-$
    C. $\underline{NaOH} \rightarrow Na^+ + OH^-$
    D. $\underline{CH_3COOH} \rightarrow CH_3COO^- + H^+$
    E. $\underline{HCO_3^-} + H_2O \rightarrow H_2CO_3 + OH^-$

23. Why did you pick those?

24. Which are bases?

25. How do you measure the strength of an acid or a base?

(Cont.)

26. What does K_a represent?

27. Would the K_a of a strong acid be large or small number?

28. If the acid HB dissociates to form H^+ and B^- ions, what is the equation for the reaction?

29. Write the K_a for the reaction in question 28.

30. If HB is a strong acid with concentration of .01 M what would the concentration of the hydrogen ion be?

31. What is the concentration of B^-?

32. Here is a chart of the relative strength of acids. (Student is given a copy of Appendix C in _Chemistry, An Experimental Science_.)

33. Equal volumes of benzoic acid and carbonic acid are mixed together. Using the chart of relative strengths of acids, which will act as an acid?

34. The equilibrium constant for an acid, HA is 5 x 10^{-5}.

$$K_a = \frac{(H^+)\quad(A^-)}{(HA)} = 5 \times 10^{-5}$$

Is this a weak acid or a strong acid?

35. If the equilibrium concentration of HA is .5 M how would you calculate the concentration of H^+?

36. What is the concentration?

37. If this same solution is altered by the addition of a .5 M solution of a salt KA, so that at equilibrium the concentration of HA is .5 M and A^- is .5 M, what is the hydrogen ion concentration?

38. Is an acid a proton donor or proton acceptor?

39. Explain what is meant by that statement, i.e., whatever answer the student made.

40. In the pair of substances labeled A, which is the acid?

$$\underbrace{NH_4 + OH^-}_{A} \rightarrow \underbrace{NH_3 + HOH}_{B}$$

41. Why did you pick that one?

42. What is oxidation?

43. What is reduction?

44. Does the following equation represent an oxidation or a reduction reaction?

$Li \rightarrow Li^+ + e^-$

45. Show the student a table of standard oxidation potentials for half reactions. (The student is given a copy of Appendix 3 in _Chemistry: An Experimental Science_.) How do you use this table? What information does it give you?

46. Will a substance at the top of the table reduce a substance below it?

(Cont.)

47. Will a substance at the bottom of the chart oxidize a substance above it?

48. Which of the following will spontaneously oxidize Fe to Fe^{+2}?

Half Reaction	E^{o} (volts)
$Zn \rightarrow 2e^{-} = Zn^{+2}$	0.76
$Cr \rightarrow 3e^{-} + Cr^{+3}$	0.74
$Fe \rightarrow 2e^{-} + Fe^{+2}$	0.44
$Cr^{+2} \rightarrow e^{-} + Cr^{+3}$	0.41

49. How is the strength of an oxidizing agent measured?

50. If a substance has a strong tendency to give up electrons, is it a reducing agent or an oxidizing agent?

51. What is an electrochemical cell?

52. Show the student Figure VIII. Explain what is happening in this electrochemical cell.

53. What is a half cell?

54. What is the anode in a chemical cell?

55. What reaction takes place at the anode?

56. What is the cathode?

57. What reaction takes place at the cathode?

Questions 58-61 are based upon Figure IX.

58. In the diagram is a reaction taking place?

59. How do you know?

60. What is the purpose of the U tube in picture A?

61. The equation for the reaction taking place in the second diagram is
$Ag^{+} + Cu \rightarrow Cu^{+2} + Ag$
How would this equation be balanced correctly?

Questions 62-71 refer to Figure X.

62. In which of the two pictures is copper being oxidized?

63. In the bottom picture which is the cathode?

64. Are there both positive and negative ions in the bottom picture?

65. In which direction do the electrons move?

66. If NaCl is added to the left beaker at the top, what will happen?

67. Would a precipitate form?

68. Would electrons continue to flow?

69. Why?

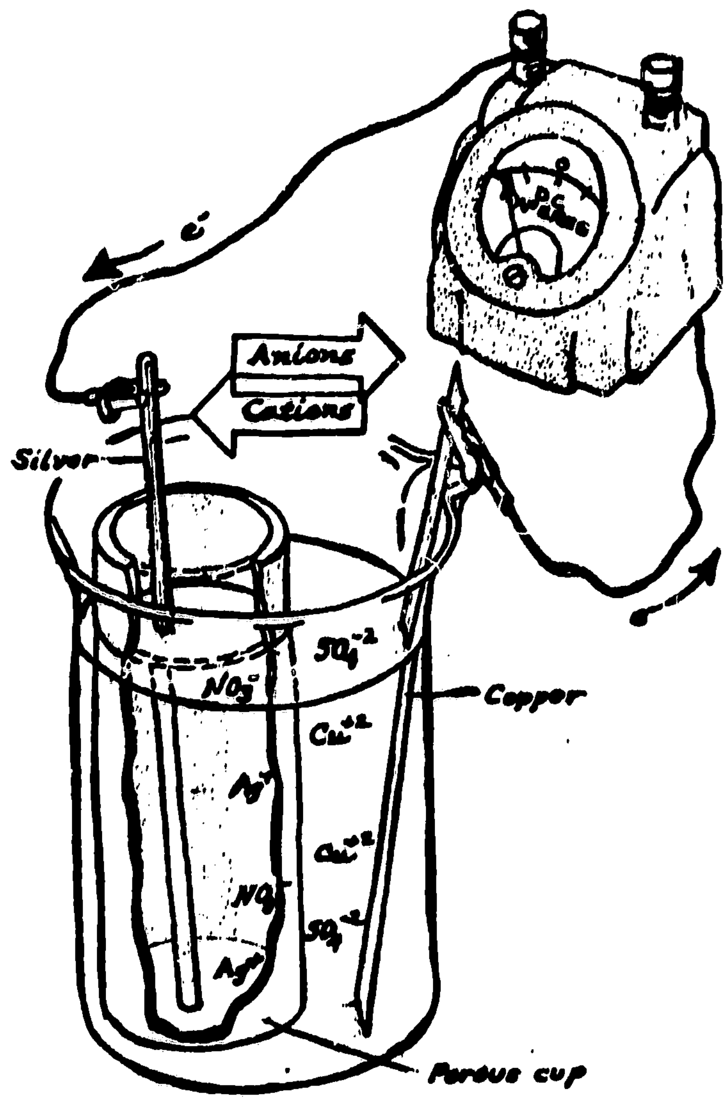

Figure VIII. Electrochemical Cell

Adapted from Fig. 12-5, p. 206, in Chemistry: An Experimental Science. 1963. W. H. Freeman and Co. San Francisco.

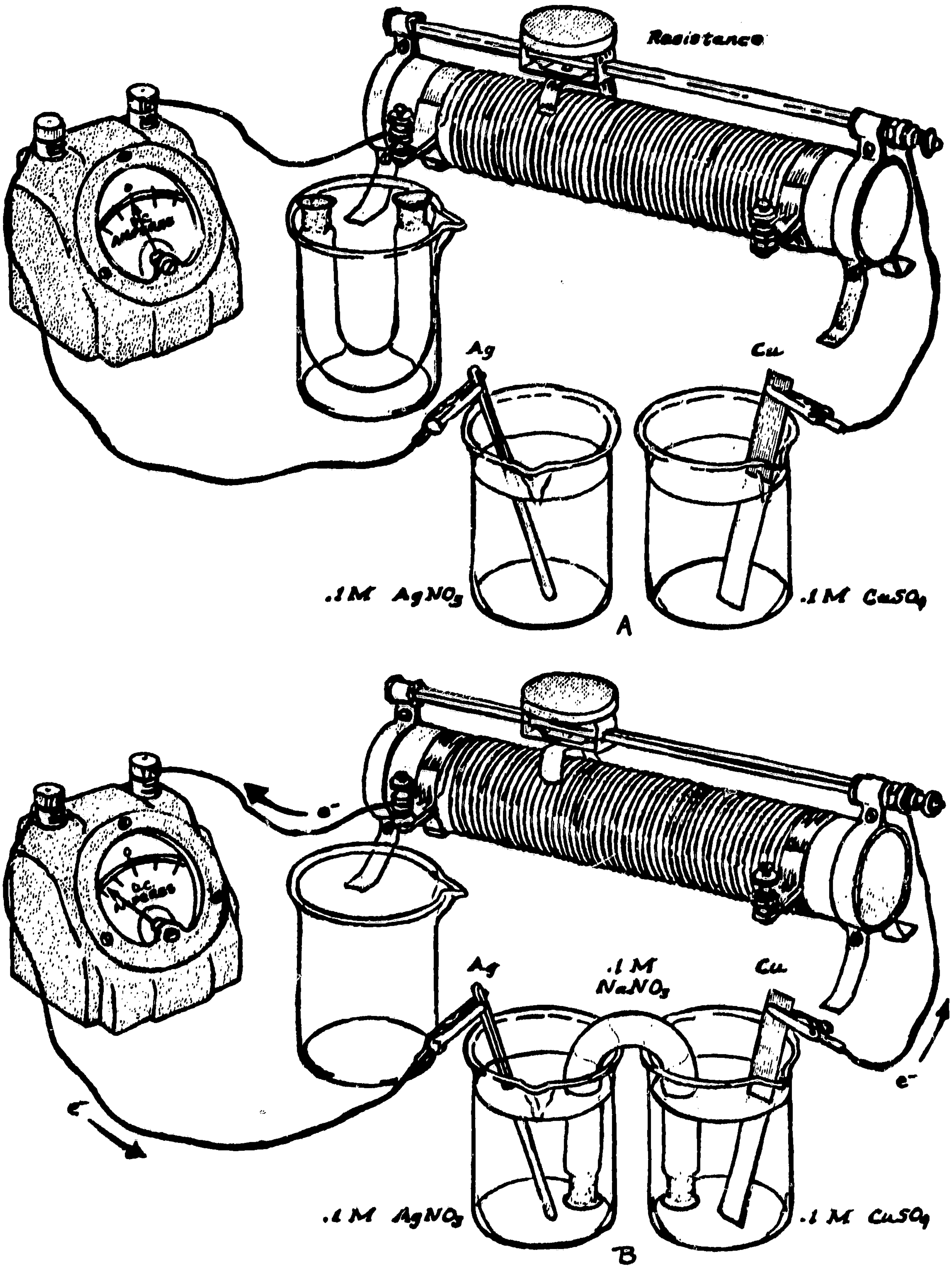

Figure IX. Diagramed Reaction

Adapted from Fig. 12-1, p. 200, in Chemistry: An Experimental Science. 1963. W. H. Freeman and Co. San Francisco.

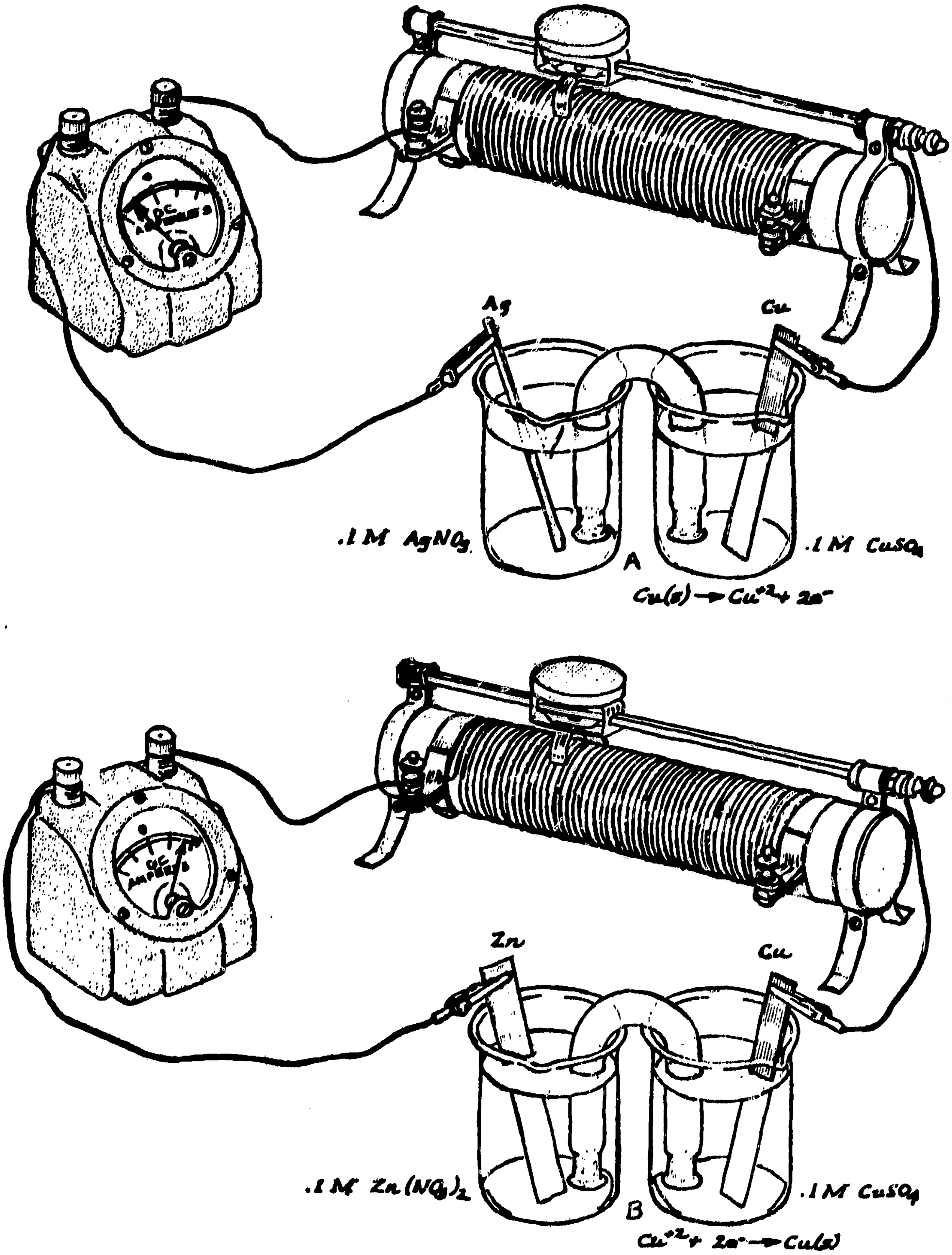

Figure X. Oxidized Copper

Adapted from Fig. 12-4, p. 204, in Chemistry: An Experimental Science. 1963. W. H. Freeman and Co. San Francisco.

(Cont.)

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70. Would the reading on the voltmeter change?

71. What would happen to the concentration of silver ions?

72. What is electrolysis?

73. What is oxidation number?

74. How do you calculate oxidation number?

75. Pick one of the compounds on the following list and calculate the oxidation number of S.
H_2S, SO_2, SO_3, S, H_2SO_4

76. How would you balance the following equation using the oxidation number method? $S + O_2 \rightarrow SO_3$

77. Which substance is reduced in the above reaction?

Show the student Figure **XI**.

Questions 78-83 refer to Figure XI.

78. After .01 moles of electrons pass through the voltmeter in diagram A, what will be the change in the mass of the Ni electrode? That is, will it be more or less?

79. If the atomic weight of Ni is 58.7 how would you calculate the change?

80. How would you calculate what the voltmeter would read?

81. What will it read?

82. In diagram B current is allowed to flow until the mass of the Zn electrode has changed by 6.54 g. How much would the silver electrode change?

83. In which of the following pairs would a reaction take place spontaneously?

    A. $Ag_{(s)}$, Ni^{+2}

    B. $Ag_{(s)}$, Zn^{+2}

    C. $Zn_{(s)}$, Ag^{+1}

    D. $Ni_{(s)}$, Ag^{+1}

84. When sugar is metabolized in the body it reacts with oxygen to form carbon dioxide and water. If you were asked to work a problem using this reaction, what is the first step you would have to make?

85. How would you balance this equation for the reaction just described?

    $C_{12}H_{22}O_{11} + O_2 \rightarrow CO_2 + H_2O$

    If the student does not balance the equation correctly show them the correct equation to use with the following questions.

86. How many moles of sugar would be needed to produce 6 moles of carbon dioxide?

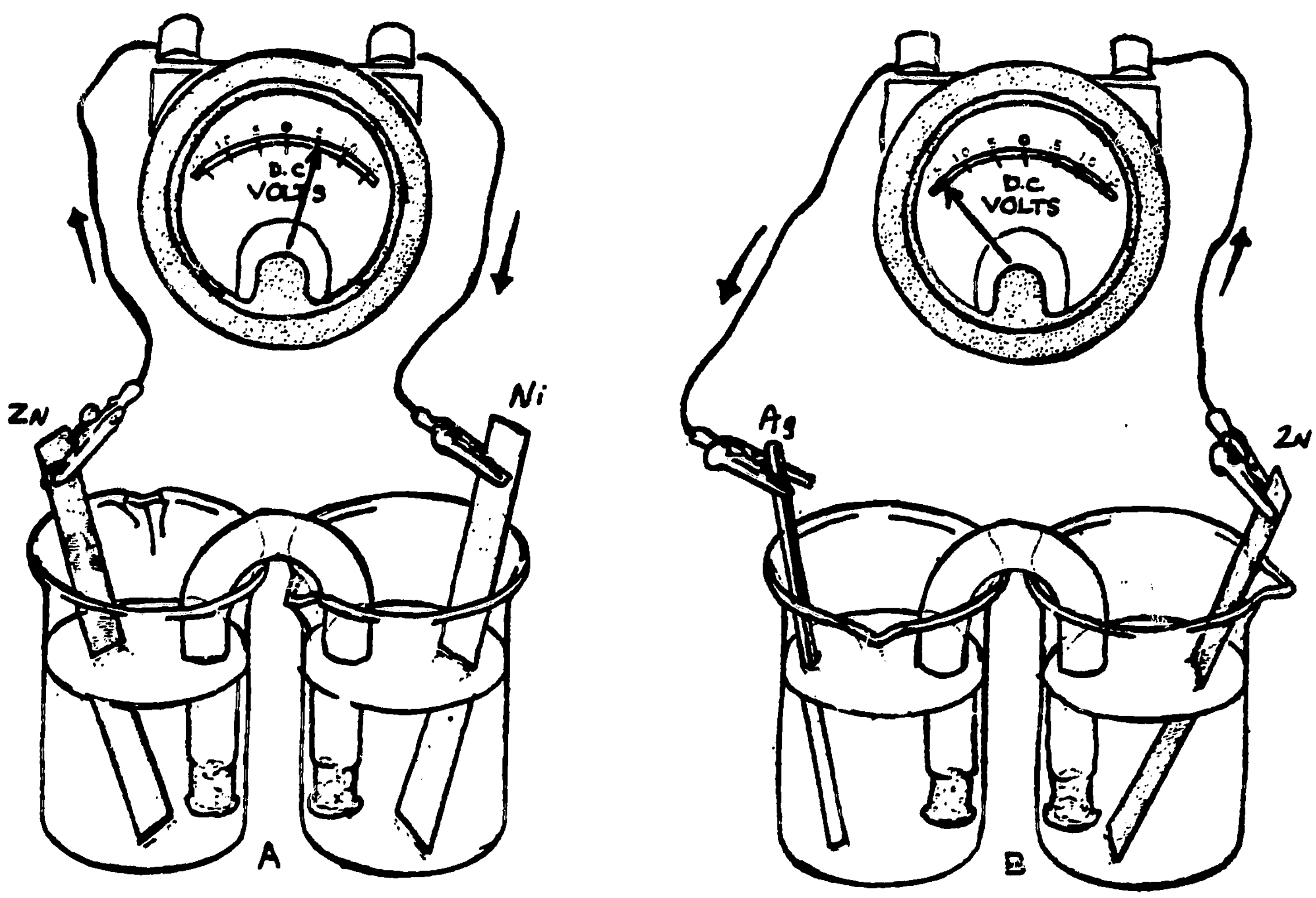

Figure XI. Voltmeter

Adapted from Fig. 12-6, p. 208, in Chemistry: An Experimental Science. 1963. W. H. Freeman and Co. San Francisco.

(Cont.)

87. If 32 grams of oxygen reacted, how would you calculate how many moles of carbon dioxide would be formed?

88. How many moles would be formed?

89. How many liters of carbon dioxide would be produced from 10 liters of oxygen?

Note.--Quality of responses expressed in percentages may be found in Swartney (1968).

Interview data shows that 50 percent or more of the 36 students interviewed, irrespective of school, did not:

A. Possess the following concepts:

1. The definition of an acid.
2. The definition of a base.
3. Recognition of the H_3O^+ ion.
4. Recognition of the H^+ ion.
5. The definition of a neutralization reaction.
6. The definition of K_w.
7. The definition of K_a.
8. The definition of oxidation.
9. The definition of an electrochemical cell.
10. The definition of a half cell.
11. The definition of the anode.
12. The definition of a precipitate.
13. The definition of electrolysis.
14. The definition of oxidation number.
15. The properties of an acid.
16. The properties of a base.
17. The meaning of K_w.
18. The recognition of an acid or a base as either a proton donor or proton acceptor.
19. Measurement of the strength of an oxidizing agent.
20. Description of the mechanism of an electrochemical cell.
21. The necessity of the U tube in an electrochemical cell.
22. Recognition of the cathode and anode in an electrochemical cell.

23. Recognition of an acid by its ability to form H_3O^+ or H^+ ions.

24. The meaning of K_a.

25. Identification of the substance being reduced in a chemical reaction.

B. Possess the following skills:

1. The ability to write an equilibrium expression for the ionization of an acid.

2. The ability to determine the hydrogen ion concentration given the equilibrium constant and the concentration of a weak acid.

3. The ability to use a table of oxidation potentials.

4. The ability to balance an equation using the oxidation number method.

5. The ability to balance an equation of an electrochemical reaction.

6. The ability to solve problems dealing with half cell reactions.

    a. Determination of the reading of the voltmeter.

    b. Calculation of the weight change of an electrode.

    c. To determine if a reaction will take place between two substances.

7. The ability to determine the oxidation number of an element in a compound.

8. The ability to balance a chemical equation.

9. The ability to write an equation to determine K_a.

10. The ability to solve problems involving the determination of moles, grams or liters of a substance formed given any of the three.

Thirteen students from School A and 11 students from School B participated in the fifth interview.

Table XII

Questions: Interview No. V

1. If you have two flasks of equal volume at the same temperature and pressure, and one is filled with oxygen and the other with chlorine, how does the amount of chlorine compare to the amount of oxygen?

2. If one of these two flasks was filled with oxygen and the other with an unknown gas and you knew the weight of each and the molecular weight of oxygen, how would you calculate the molecular weight of the unknown gas?

3. How would you define a solid?

4. How would you define a gas?

5. How would you define a liquid?

6. What is a calorie?

7. What is a calorimeter?

8. What is calorimetry?

9. What is molecular weight?

10. How do you calculate molecular weight?

11. What is chemical change?

12. What is a physical change? Phase change?

13. Which change would require more energy, a chemical change or a physical change?

14. Why?

15. What does a chemical equation represent?

16. What does a chemical equation tell you about the rate of a reaction?

17. What do the coefficients in an equation represent?

18. What is meant by the word heat?

19. What is temperature?

20. If you dip a cup of hot water out of a bath tub, which will have more heat, the tub or the cup?

21. Which will have the higher temperature?

22. What is absolute zero?

23. What is the centigrade temperature scale based on?

24. How is the Kelvin temperature scale related to the centigrade scale?

25. What is pressure?

26. What is the relationship of a mole of gas to its volume?

27. Consider the following data:
    Weight of beaker + $AgNO_3$
    $25.95 \pm .02$ g
    Weight of empty beaker
    $20.45 \pm .02$ g
    How much does the $AgNO_3$ weigh?

(Cont.)

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28. What is an atom?

29. What does the atomic weight of an element represent?

30. What particles are in the nucleus of an atom?

31. How much does a neutron weigh?

32. What kind of a charge does the nucleus have?

33. How large is an atom? Can you compare it to something you know?

34. What is a nuclear reaction?

35. How does the energy change in a nuclear reaction compare to the energy change in a chemical reaction?

36. What is an isotope?

37. What is an ion?

38. How is an ion formed?

39. Define boiling.

40. What is vapor pressure?

41. What is equilibrium?

42. Define homogeneous.

43. Define heterogeneous.

44. What is a solution?

45. What is the solute?

46. What is the solvent?

47. How does the chemist measure the concentration of a solution?

48. If 11.9 g of KBr were dissolved in enough water to make 1000 ml or 1 liter of solution, how would you calculate the molarity?

49. What factors affect the amount of solute that can be dissolved in a solvent?

50. What is represented by the symbol delta H?

51. What does the Greek letter delta represent?

52. What is the law of additivity of reaction heat?

53. If you have the following information, how would you calculate delta H for the third reaction?
$A + B \rightarrow C \quad \Delta H = -20$ kcal/mole
$E \rightarrow B + D \quad \Delta H = -5$ kcal/mole
$A + E \rightarrow C + D \quad \Delta H = ?$

54. There are three consecutive elements on the periodic table, X, Y, and Z.
X will form the ion X^+
Y will form the ion Y^+
Z has one less electron than X.
What group of three elements might these be?

55. What is meant by a family on the periodic table?

(Cont.)

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56. Define metallic solid.

57. Define molecular solid.

58. Define network solid.

59. What is partial pressure?

60. Complete the following nuclear reaction.

$_7N^{13} + _{-1}e^{\bullet} \rightarrow$ ________

61. What is a precipitation reaction?

62. What is energy?

63. What is kinetic energy?

64. What is potential energy?

Questions 65-71 refer to Figure III, Interview III.

65. What does A represent on this diagram?

66. What does D represent on this diagram?

67. What does B represent on this diagram?

68. What is activation energy?

69. What is activated complex?

70. What is heat of reaction?

71. How would the addition of a catalyst affect the shape of the curve?

$$CO_{(g)} + NO_{2(g)} \rightleftarrows CO_{2(g)} + NO_{(g)}$$

Questions 72 to 74 refer to the above equation.

72. If the concentration of CO_2 is increased, what effect will this have on the concentration of NO?

73. Why? Explain.

74. How would you write the equilibrium constant for this reaction?

75. What is K_{sp}?

76. What does the size of the K_{sp} tell you about the solubility of a substance?

77. What is meant by rate?

78. Show the student Figure V, Interview III. A and B represent containers of the same volume at the same temperature and pressure. The black dots represent one substance and the white dots another. In which container will the rate of reaction be greater?

79. Why?

80. Explain dissolving using a model or example.

81. What factors affect the rate of dissolving?

(Cont.)

82. A precipitate forms when sodium chloride is added to silver nitrate. Which is the best equation to represent that reaction?

A. $NaCl + AgNO_3 \rightarrow NaNO_3 + AgCl$

B. $Na^+_{(aq)} + Cl^-_{(aq)} + Ag^+_{(aq)} + NO_3^-{}_{(aq)} \rightarrow NA^+_{(aq)} + NO_3^-{}_{(aq)} + AgCl_{(s)}$

C. $Ag^+_{(aq)} + Cl^-_{(aq)} \rightarrow AgCl_{(s)}$

83. Why?

84. What is an acid?

85. What is a base?

86. What is the symbol of the hydronium ion?

87. How do acids react with metals?

88. What is a neutralization reaction?

89. What does the symbol K_w stand for?

90. What is the numerical value of K_w?

91. How do you measure the strength of an acid?

92. What does K_a represent?

93. Would the K_a of a strong acid be large or small?

94. If the concentration of HA is 0.5 M how would you calculate the concentration of H^+?

$$HA \rightarrow H^+ + A^- \quad K_a = 5 \times 10^{-5} = \frac{[H^+]\ [A^-]}{[HA]}$$

95. The solution is altered by the addition of a .5 M solution of a salt so that the equilibrium concentrations are HA = .5 M and A^- = .5 M. What is the hydrogen ion concentration?

96. What is oxidation?

97. What is reduction?

The student is given a copy of a table of standard oxidation potentials for half reactions. (Appendix 3 in _Chemistry: An Experimental Science._)

98. Here is a table of standard oxidation potentials for half reactions. How do you use this table? What information does it give you?

99. There are four equations underlined on this table.

Half Reaction	E° (volts)
$Zn \rightarrow 2e^- + Zn^{+2}$	0.76
$Cr \rightarrow 3e^- + Cr^{+3}$	0.74
$Fe \rightarrow 2e^- + Fe^{+2}$	0.44
$Cr^{+2} \rightarrow e^- + Cr^{+3}$	0.41

Which of the other three will spontaneously oxidize Fe to Fe^{+2}?

(Cont.)

100. What is an electrochemical cell?

101. What is a half cell?

102. What is electrolysis?

103. What is oxidation number?

104. How do you calculate oxidation number?

105. How would you balance the following equation using the oxidation number method? $S + O_2 \rightarrow SO_3$

Show the student Figure XI, Picture A.

106. If the atomic weight of Ni is 58.7 and the equation for the reaction at the nickel electrode is

$Ni \rightarrow Ni^{+2} + 2e^-$

calculate the change in weight of the nickel electrode if .01 moles of electrons pass through the cell.

107. When sugar is metabolized in the body it reacts with oxygen to form carbon dioxide and water. If you were asked to work a problem using this reaction, what is the first step you would take?

108. How would you balance the following equation?

$$C_{12}H_{22}O_{11} + O_2 \rightarrow CO_2 + H_2O$$

109. How many moles of sugar would be needed to produce 6 moles of carbon dioxide?

110. If 32 grams of oxygen reacts, how would you calculate how many moles of carbon dioxide would be formed?

111. How many moles would be formed?

112. How many liters of carbon dioxide would be produced from 10 liters of oxygen?

Note. Quality of responses expressed in percentages may be found in Swartney (1968).

From the results of the fifth interview which was based upon the questions answered incorrectly in the first four interviews, it is noted that 50 percent or more of the better students interviewed, irrespective of school, did not:

A. Possess the following concepts:

1. The definition of heat.
2. The definition of isotope.
3. The definition of boiling.
4. The definition of metallic solid.
5. The definition of molecular solid.
6. The definition of network solid.
7. The law of additivity of reaction heats.
8. The definition of energy.
9. The definition of K_{sp}.
10. The recognition of the H_3O^+ ion.
11. The definition of K_w.
12. The definition of K_a.
13. The definition of oxidation number.
14. Recognition of the factors which affect the rate of dissolving.
15. The reaction between acids and metals.
16. Comprehension of the meaning of heat.
17. The meaning of activated complex.
18. Affect of the addition of a catalyst on an equilibrium reaction.
19. The measurement of the strength of an acid.

B. Possess the following skills:

1. The ability to manipulate numbers with uncertainty.
2. The ability to calculate the heat of reaction using the law of additivity of reaction heats.
3. The ability to balance a nuclear reaction.
4. The ability to write an equilibrium constant expression.
5. The ability to determine the hydrogen ion concentration given the equilibrium constant and the concentration of a weak acid.
6. The ability to balance an oxidation-reduction equation using the oxidation number method.
7. The ability to solve problems dealing with half cell reactions, including determination of the weight change of an electrode and determining if a reaction will take place.

V

SUMMARY AND IMPLICATIONS

Based upon the findings within the limited population involved in this study, it may be stated that:

I. More than half of the students earning low scores on the CHEMS examinations:

A. Did not enter the chemistry course with the prerequisite knowledge of or conviction to the particle nature of matter.

B. Were unable to define the following terms:

atomic weight, atom, nucleon, nuclear charge, nuclear reaction, isotope, gas, liquid, solid, chemical change, phase change, molecular weight, solution, homogeneous, heterogeneous, molarity, ion, solute, solvent, cation, anion, electrolyte, precipitate, precipitation reaction, heat, temperature, calorie, calorimetry, absolute zero, potential energy, energy, equilibrium, Le Chatlier's Principle, K_{sp}, K_w, K_{eq}, electrochemical cell, half cell, anode, electrolysis, oxidation number, chemical family, metallic solid, molecular solid, network solid, acid, base, H_3O^+, neutralization, Δ, ΔH, activation energy, activated complex, heat of reaction, rate, pressure, boiling, boiling point, vapor pressure, Avogadro's number, Kelvin temperature scale, centigrade temperature scale, molar volume,and partial pressure.

C. Were unable to verbalize and/or use the concepts of:

phases of matter, ionization, equilibrium, temperature, pressure, vapor pressure, electrochemistry, oxidation-reduction, acid-base theory, chemical change, physical change, chemical equations, theoretical models, numerical constants, precipitation, dissolving, chemical formulas, Law of Conservation of Matter, Law of Conservation of Atoms, Law of Additivity of Reaction Heats, periodicity, atomic theory, solubility, isotopes, Kelvin vs. centigrade temperature scale, rate of reaction, Avogadro's hypothesis, relationship of chemical change, physical change, nuclear change and energy, Le Chatlier's Principle, catalyst, relationship between exothermic, endothermic and ΔH, and energy.

D. Were not able to carry out the arithmetic process of long division, solve simple algebraic equations of one unknown, solve problems involving ratio and proportion, or manipulate numbers involving uncertainty.

E. Were not able to interpret graphs and tables.

F. Were not able to solve problems of a stoichiometric nature dealing with:

writing ionic, molecular and nuclear formulas, writing and balancing equations, equilibria, half cell reactions, oxidation reduction, and determination of moles, grams or liters of a substance formed given any of the three, and determination of hydrogen ion concentration.

II. When asked questions dealing with the areas listed above, more than half of the students earning high scores on the CHEMS examination:

A. Were unable to define the following terms:

heat, isotope, boiling, metallic solid, molecular solid, network solid, energy, K_{sp}, H_3O^+, K_w, K_a, oxidation number.

B. Were unable to verbalize and/or use the concepts of:

Law of Additivity of Reaction Heats, energy, dissolving, heat, catalyst, acid reactions.

C. Were not able to manipulate numbers with uncertainty.

D. Were not able to solve problems of a stoichiometric nature dealing with:

writing an equilibrium constant expression, calculation of heat of reaction, determination of hydrogen ion concentration, balancing oxidation reduction equations, half cell reaction.

III. Apparently the definitions, concepts and mathematical skills listed above (II) were not essential for the student to earn high scores on the CHEMS examinations.

IMPLICATIONS

1. It does not seem reasonable for the teachers of chemistry to assume that the common definitions used by students for common words as rate and boiling are the same as technical definitions when the terms are used in chemistry.

2. In planning curricula in chemistry it does not seem reasonable to assume that all students have a common background of scientific knowledge.

3. The manipulation of numbers should be stressed to a greater extent if students are to competently solve chemistry problems.

4. Some concepts such as equilibrium and oxidation-reduction may be too rigorous for the high school student.

5. Teachers of chemistry should include instruction in the use and interpretation of charts and graphs.

6. Teachers of chemistry should give special attention to concepts which deal with abstractions.

7. Teachers of chemistry should consider more drill in skills such as equation writing and balancing, and formula writing.

APPENDIX A

FREQUENCY OF CONCEPTS AND SKILLS IDENTIFIED IN CHEM STUDY ACHIEVEMENT TESTS

TEST 63-64-1

Concept	Frequency
Definition of molecular weight	3
Definition of mole	4
Definition of solid	3
Definition of liquid	3
Definition of gas	4
Definition of heat	3
Definition of temperature	4
Definition of kinetic energy	1
Definition of molecular formula	2
Definition of calorie	3
Definition of chemical change	1
Definition of phase change	1
Definition of pressure	3
Definition of absolute zero	1
Definition of partial pressure	1
Relationship of chemical change, phase change, and energy	3
Relationship of kinetic energy and temperature	1
Meaning of coefficient in a chemical equation	4
Basis of the Kelvin temperature scale	2
Basis of the centigrade temperature scale	1
Relationship of temperature and pressure	2
Relationship of temperature and kinetic energy	1

(Cont.)

Concept	Frequency
Avogadro's Hypothesis	5
Relationship of pressure and volume	1
Rate of reactions	1
Law of Conservation of Mass	2
Law of Conservation of Atoms	1
Particle nature of matter	4

Skills	Frequency
Manipulation of numbers with uncertainty	2
Conversion of grams to moles	4
Interpretation of a graph	4
Calculation of molecular weight using Avogadro's Hyp.	3
Balancing equations	1
Calculation of molecular weight	1
Writing equations	3
Conversion from centigrade to Kelvin temperature	1
Calculation of partial pressure	1
Chemical problems involving the determination of moles, grams or liters of a substance formed given any of the three	4
Solving simple algebraic equations	4

Test 63-64-2

Concepts	Frequency
Definition of atomic number	5
Definition of mass number	2
Definition of nucleus	4
Definition of atom	6
Definition of proton	1
Definition of nuclear charge	1
Definition of atomic weight	2
Definition of isotope	5
Definition of molecule	1
Definition of electron	3
Definition of neutron	2
Definition of ionic solid	1
Definition of molecular solid	1
Definition of metallic solid	1
Definition of network solid	1
Definition of gas	5
Definition of solid	4
Definition of liquid	5
Definition of ion	3
Definition of molarity	2
Definition of solution	2
Definition of equilibrium	4
Definition of heterogeneous	1
Definition of homogeneous	1
Definition of phase	1
Definition of vapor pressure	1
Definition of boiling point	1
Definition of pressure	1
Definition of boiling	2
Definition of chemical family	1
Definition of element	6
Definition of compound	3
Definition of exothermic	1
Definition of solute	1
Definition of kinetic energy	2
Definition of potential energy	2
Definition of calorie	1
Definition of precipitation reaction	2
Definition of precipitate	2
Definition of partial pressure	1
Definition of pressure	1
Definition of nuclear reaction	1
Definition of nucleon	1
Definition of ΔH	1
Definition of Greek symbol Δ	1

(Cont.)

Concepts	Frequency
Meaning of chemical formula	2
Meaning of the concentration of a solution	1
Law of Additivity of Reaction Heats	3
Effect of solute on the boiling point	1
Relationship of chemical change, physical change, and energy	1
Particle nature of matter	1
Relationship of pressure and temperature	2
Relationship of chemical reaction, nuclear reaction, and energy	1
Difference between atomic weight and mass number	1
Size of the nucleus compared to the atom	2

Skills	Frequency
Recognition of a correct chemical formula	1
Calculation of molarity	1
Conversion from grams to moles	1
Ability to use the periodic table	3
Ability to use the Law of Additivity of Reaction Heat	2
Solution of chemical problems involving the determination of moles, grams or liters of a substance formed given any of the other three	1
Writing and recognition of correct ionic equations	2
Ability to use a table to predict precipitation	1
Identification of a precipitate	2
Calculation of partial pressure	1
Writing nuclear equations	2
Writing nuclear formulas	1
Writing chemical formulas	1
Ability to use a chart to identify elements	4

Test 63-64-3

Concept	Frequency
Definition of energy	4
Definition of potential energy	4
Definition of kinetic energy	4
Definition of heat of reaction	1
Definition of activation energy	1
Definition of activated complex	1
Definition of equilibrium	8
Definition of a catalyst	6
Definition of calorimetry	1
Definition of exothermic	2
Definition of endothermic	2
Definition of mole	1
Definition of K_{sp}	1
Definition of electrolyte	1
Definition of ion	1
Definition of cation	1
Definition of anion	1
Definition of electrolysis	1
Definition of vapor pressure	1
Definition of rate	5
Definition of solution	4
Definition of solute	4
Definition of solvent	4
Le Chatlier's Principle	7
Effect of a catalyst	2
Effect of temperature on equilibrium	1
Meaning of brackets in an equilibrium expression	4
Equilibrium favors maximum randomness and minimum energy	1
Particle nature of matter	1
Effect of temperature on the rate of a reaction	1
Explanation of process of dissolving	1
Explanation of process of precipitation	1

Skill	Frequency
Ability to interpret a potential energy diagram	3
Use Le Chatlier's Principle	5
Convert grams to moles	1
Calculate equilibrium constant K	2
Interpret Solubility chart	3

(Cont.)

Skill	Frequency
Use a table of solubility product constants	2
Calculate K_{sp}	2
Recognize a correct net ionic equation	1
Recognize correct equilibrium expressions	1
Solve problems, chemical problems involving the determination of moles, grams or liters of a substance formed given any of the other three	5

Test 63-64-5

Concept	Frequency
Definition of an acid	2
Definition of a strong acid	1
Definition of a weak acid	1
Definition of K_a	1
Definition of a base	1
Definition of oxidation	1
Definition of reduction	1
Definition of a half cell	4
Definition of the anode	1
Definition of the cathode	1
Definition of oxidation number	1
Definition of electrolysis	1
Definition of neutralization	1
Definition of an acid-base indicator	1
Definition of K_w	1
Definition of a precipitate	1
Recognition of the H_3O^+ ion	1
Recognition of the H^+ ion	1
Recognition of the OH^- ion	1
Acid as proton donor	1
Base as proton acceptor	1
Meaning of a chart of oxidation potentials	2
Meaning of a chart of relative acid strength	1
Explanation of the electrochemical cell	5
a) parts	
b) reaction at the electrodes	
c) flow of electrons	
d) U tube	
Reaction between a metal and an acid	1
Volume occupied by one mole of a gas	1

Skills	Frequency
Ability to recognize acids in an equation	1
Calculation of hydrogen ion concentration of a strong acid	1
Interpretation of a chart of relative acid strength	1
Convert grams to moles	1
Calculation of the hydrogen ion concentration of a weak acid	1
Ability to interpret a chart of oxidation potentials	5

(Cont.)

Skills	Frequency
Balance equations of reactions in an electrochemical cell	2
Calculate the voltage of a cell	3
Determine the change in an electrode in a cell	2
Predict which electrochemical reactions will take place spontaneously	2
Determine the oxidation number of an element in a compound	1
Chemical problems involving the determination of moles, grams or liters of a substance formed given any of the three	8

APPENDIX B

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