DETERMINATION OF THE FEASIBILITY OF IMPROVING
THE TEACHING OF INTRODUCTORY COLLEGE CHEMISTRY
THROUGH A CASE-STUDY APPROACH

DISSERTATION

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By

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CHAPTER I

INTRODUCTION

Statement of Problem and Its Limitations

The purpose of this study is to determine the feasibility of improving the teaching of chemistry by presenting it through a "case-study" type of approach analogous to that currently being used in business education in the Harvard Business College. The study is based upon the hypothesis that, since chemistry is an experimental science, it can be understood better if presented in a way more nearly consistent with the methods of an experimental science. This approach is to involve extensive use of experimental procedures and data as a basis for the formulating of concepts basic to the science of chemistry. These are to be presented in a wide variety of ways, and, through discussion the student is to be led to formulate and apply the generalizations chosen for study.

It is proposed that by selecting a group of topics from general chemistry and developing them by means of such an approach, it may be shown that this is a feasible method for making the teaching of chemistry more effective than the commonly used lecture-laboratory procedures. By way of evaluation, it is planned to submit the prepared topics to a selected group of chemistry teachers who have shown an interest in the area of general chemistry. This group of teachers will
be asked to evaluate the topics in light of specific points to be designated in a questionnaire. Their judgment, based upon their experience and understanding relative to the problems of teaching introductory chemistry, is assumed to be an appropriate criterion for evaluation.

The success of such an approach depends greatly upon the skill and degree to which the individual student becomes involved in the solution of each problem. For this reason, each problem is to be stated in such a way as to arouse curiosity and stimulate interest in its solution. Since much of the evidence, which has been accumulated to substantiate current scientific theories, is far beyond the availability of beginning laboratory work, such evidence is brought under consideration through various graphic means. This wide variety of experimental evidence is then woven together into the cloth of theory by posing provocative questions leading to generalizations and a subsequent summary of ideas.

Since each topic is intended solely as an introductory phase of work, textual materials, reference work and further experimental work would need to be added at the discretion of the individual instructor. In many instances side issues may arise and can readily be developed from discussion and additional laboratory or reference work. The rigor with which each problem is developed will, of necessity, be dependent upon the nature and interests of the individual class and instructor.

This study is directed specifically to the needs of the non-science student who approaches a course in chemistry with no intention of further study in the field. His predominant interests are those of one who looks upon the study of chemistry as a contribution to his own
personal growth. Often he is motivated by curiosity, and generally he
chooses chemistry as an elective from a possible selection of other
sciences. Since his motivation for study and his needs with respect
to skills and details are different from those of the potential spe­
cialist, it is here suggested that intellectual achievement and satis­
faction might best be obtained through a different approach to the
subject matter. The principal objective to be sought is that of bridg­
ing the gap resulting from the "intellectual isolation" described in
the Pursuit of Excellence as follows:

Just as we must insist that every scientist be broadly edu­
cated, so we must see to it that every educated person is literate
in science. In the short run this may contribute to our survival.
In the long run it is essential to our integrity as a society. We
cannot afford having our most highly educated people live in intel­
lectual isolation from one another, without even an elementary
understanding of one another's intellectual concerns. Such frag­
mentation must lead to loss of purpose.¹

¹Pursuit of Excellence: Education and the Future of America,
Rockefeller Brothers' Fund, Panel report v of the special studies pro­

Under the premise that the teaching which is most effective is
that which involves the greatest variation in techniques, there is no
specific limit placed on the method of presentation of the materials
developed herein. The use of the lecture, however, is minimized by the
need for emphasis on discussion in such an approach. It is feasible
that all material might be presented by a discussion-demonstration
method, but, where facilities and equipment are adequate, much may be
gained by some use of laboratory in combination with discussion and
demonstration. In any instance, those topics which arise from the
development of this introductory material may well serve as bases for study through projects, laboratory study, library research, or other means which might prove to be appropriate in light of the situation in question.

This is not intended to be a simpler approach to the problem of teaching introductory chemistry, but, rather, a more effective approach. It makes no claim to be a means for "covering more ground" in less time, but, rather, it is intended to promote better understanding of the ground that is covered as well as to develop some insight into the purposes, nature, and limitations of scientific study in the field of chemistry. To insure greater effectiveness, the material is developed in consideration of recent advances in the theories of learning and their implications for classroom practices.

In the programs of most colleges, chemistry appears to be taught through some combination of lecture, discussion, and laboratory work. In most of these situations it would be possible to use a portion of the allotted time for the developmental discussions as proposed here. It is suggested that such an approach might better serve the needs of the general education student than do the existing types of programs.

**Importance of the Problem**

The need for public interest and literacy in science. The importance of this study is best found in the multiplicity of needs relating to science and technology which arise in the lives of modern men. Never before in history has there been such a great opportunity to use, to the advantage of all, the great literature of science together
with the vast accumulation of information. Similarly, there has never been such horrendous danger as exists today from the potential misuse of such knowledge. Only if the responsibility for mutual understanding is assumed by scientist and nonscientist alike, can these dangers be alleviated and the greatest good from these potential benefits ensue. Since the leadership of future generations must rest on the shoulders of the current group of college students, it is to them that attention must be directed.

In a social order where all decisions are in the hands of a relatively few persons, there may be little to be gained from a highly literate people. On the other hand, in a democracy, where the ballot is a more important means of making decisions, the contemporary situation requires a highly literate public capable of interpreting all available facts in a question and foreseeing the consequences of imprudent action in making such decisions. A few of the major areas for which public attention is crucial may be categorized as (1) the need for prudent support for basic research and the development of talent, (2) the use of intelligence in the solving of major problems arising from community living, (3) a rational response to the problems of the consumer, and (4) the development of sufficient interest in science to encourage continued attention to the literary works growing out of its achievements. Perhaps nowhere is the lack of the public's understanding more detrimental than in its attitudes toward basic research and its support. A highly materialistic outlook on the part of the general population has provided approximately five billion dollars a year for research and
development with only 5-10 per cent of the total budget allocated for basic research.\(^2\)

\(^2\)Seaborg, Glenn T., "The University and Basic Science" (Chemical and Engineering News, 35:58, March 4, 1957).

As experimental results accumulate at ever increasing rates, more and more consideration must be given to their correlation and interpretation. Since this is a time-consuming task for well-trained, basic scientists, there is an ever increasing need for such persons. In fact, it has been said that at present "our population is increasing so that it is doubling every fifty years, the need for skilled workers is doubling every twenty years, and the need for highly trained scientists and engineers is doubling every ten years."\(^3\)


To those most familiar with the situation, this portends a serious problem. Advances in technology govern, to a great degree, national economic growth. Because growth in technology depends upon advances in basic knowledge, it can be anticipated that applied science may overtake basic science under the present trends in support. The resulting stagnation in technological growth can only be avoided if basic research is permitted to grow at a rate commensurate with its needs.

That the public, who now furnishes a major portion of the support for all research through its various governmental agencies, is unaware of the distinction between basic and applied research is obvious.
Evidences for this misunderstanding are common in "public utterances which commonly confuse science with technology, . . . the wholesale identification of science with highly specialized or even vocational courses, . . . the strange ideas that one gets either scientific or liberal education, but somehow cannot have both, . . . the public images of the scientific egghead and the mad scientist" as are so successfully portrayed in comicbook fashion. The need to rectify this situation in favor of a more rational attitude was well expressed by Hans Selye as follows:

The basic research of today produces both the lifesaving drugs and the destructive weapons of tomorrow. Its outcome will affect everybody, and, in a democracy whose people decide how wealth shall be distributed, everybody shares the responsibility of developing the nation's scientific potential. But how can anybody vote intelligently without some grasp of the problems bearing upon that development?

Bridging the gap between the scientist and the general public will not be easy. The former will have to learn to translate his problems into a language meaningful to the layman; the latter will have to realize that, however simplified, the essence of basic research cannot be assimilated without mental effort.

Such attitudes have not only served to limit support for the basic sciences, but have also served to discourage talented youth from entering this area where their special capabilities may well serve to
make the difference between survival in a prosperous world at peace or destruction at the hands of unreasoned use of power.

Because the chemical industry is now the largest in the world, and it has an ever growing periphery of new developments, the need for identification and encouragement of talented youth bears special significance for chemistry. Out of basic chemical research will come much of the necessary knowledge to advance our understanding of the prevention of disease and malnutrition, to increase efficiency in the use of arable lands, and to provide for the production of a wide variety of materials to replace those now dependent upon dwindling natural resources. At a time when basic research in these problems is delayed for want of fertile young minds, we find the number of freshmen students enrolled in chemistry dropping from 41.3 per cent in 1951 to 34.9 per cent in 1954. In addition, only 4 per cent of the total enrollees are potential chemists or chemical engineers.6


Failure to interest young students in chemistry in sufficient numbers to support continued growth in the field has been attributed to an adverse public attitude toward science in general. In his study of manpower needs in relation to supply Killian observed:

We note today evidence of a surprising amount of fear of science and of a misreading of what science really is.

Some of this adverse reaction arises from antiintellectualism from the disdain and distrust toward the learned man and realm of reason which defaces the surface of our mid-century period like the tropical fungus which blemishes the polished surface of optical glass. Some of the aversion has grown out of the part
which science has been called upon to play in the development of weapons.

Antagonism towards science and engineering has also been engendered by a feeling that they are wholly materialistic and anti-humanistic. Even in this age of science we have residual legacies from the conflicts which swirled about great innovators like Roger Bacon, Galileo, and Darwin, and other discoverers. In fact, there is some evidence that we are in a period of fresh reaction against science. Underlying this reaction is one of our great educational failures, the failure to find effective ways of communicating the meaning, the method, and the spirit of science to the nonscientist - a failure for which responsibility must be shared by both the humanist and the scientist. Valiant efforts to take the nonscientist into the arcana of science have been made, such as Conant's program at Harvard and Hildebrand's at Berkeley, but the problem is still unsolved and is still receiving inadequate attention and creative effort.7

7Killian, J. R., Jr., "The Shortage Re-Examined" (American Scientist, 44:124, April, 1956).

In addition to such important areas as basic research and the encouragement of talent, the public must be in a position to use an intelligent approach to problems of community living. Of these problems most directly allied to chemistry are those involving (1) pollution of air and water resources; (2) conservation of timber, soil, and mineral resources; (3) the increasing use and need for regulation of man made chemical products in the production and processing of food, textiles, and other fibers; and (4) the control, reclamation and disposal of radioactive waste products. Restrictive legislation, written by uninformed political bodies and promoted by irrational public sentiment or vested interests can be equally as damaging as the laissez faire attitudes of the past which have helped to create these problems.

The public must be encouraged to participate actively in the solution of these problems. To do so intelligently requires some un-
derstanding of science and a capacity for the objective consideration of facts. Most important, the scientists themselves must accept the civic responsibility of applying their specific talents to rational action and foster sufficient public confidence to encourage its support in the direction of the best possible solution to such problems.

Further needs for public understanding of science arise from the efforts of overzealous peddlers to promote the sale of their products by pseudo-scientific appeal. High on the list of such promotion is the problem of consumption of products of questionable benefit such as alcohol and tobacco. A better understanding of the methods of science and their relationship to objective behavior might well serve to counter wild claims with intelligent study and interpretation of facts. Closely allied to this problem is the ever increasing promotion of chemicals for the control of such diverse annoyances as weeds, insects, the common cold, malnutrition, and even the simple headache. Indiscriminate use of any and all of these products is of dubious benefit and their wide acceptance suggests a need for public appreciation of their merit and limitations.

Finally, if we are to expect the nonscientist to find a use for scientific methods and to learn to approach a problem with a scientific attitude, it is important that he understand the nature of the scientific enterprise and the limitations under which it may be applied. Because fear and distrust can arise through a misunderstanding of the results of science, it is necessary to provide an understanding of the goals and methods of science. To avoid disillusionment resulting from unfounded faith in the capacity of science to solve all problems, it
is necessary to acknowledge the limitations under which science functions.

In its infancy, science had an ally in the form of contemporary literary works to assist in developing an understanding of its efforts. No distinction was drawn between literature dealing with the great ideas of science and that treating the major concepts of other disciplines. In fact, science had its initial impetus through the thoughts and teachings of philosophy. As a result, scientific literature was commonly included among the readings of most educated men. As it grew in complexity, however, it grew ever more specialized, and increasingly less available to persons not interested in specialization. The resulting chasm which developed between the humanities and science is a major factor in the problems of scientific education today.

The extent of this fissure is evidenced in the "Combined Book Exhibit" of the National Council of Teachers of English, in 1955. Whereas the American Association for the Advancement of Science found high school students interested in 112 of the 200 selected books in their travelling science library, only 22 of the 900 books in the above exhibit were directed to science above the ninth grade level. In the category of "Seeking to Understand the Universe," science was not regarded as having any relevancy. In the category "Seeking to Understand the World Around Us," no biological concepts were included and all physical science was directed to materials, things and inventions. In the category "Conquest of Space and Ocean Depths," the reading involved
wartime use of torpedoes and engineering fantasies. In speaking of


the obvious neglect, on the part of the humanities, of the literature from the sciences, Gallant has said:

It is almost as though the English teacher's association had planned to misdirect student attention; to guide it into arid and narrow channels dealing with gadgetry, pet-care and the trivial curiosities of science; to divert student attention from the breath-taking vistas presented by literally hundreds of contemporary expository works for the layman. A sinister group, determined to inhibit the growth of an interest in science reading among high-school youth and to forestall development of a passion for scientific studies, could hardly have planned better.

All of this is not to say that masterful literary works in science are not available for the layman. Rather, it suggests that one of the major problems in the education of our youth lies in the impregnation of a seed of interest which will survive and grow with the individual. For the nonscience major this interest has profound significance for satisfying his need to understand the problems he will encounter. Perhaps nowhere else can it be developed better than through the introduction and promotion of the literary works of such men as Sarton, Hoyle, Gamow, Shapley, and others, or through the creation of a habit in reading the science oriented articles in Life, Harper's, or such magazines as The Scientific American. It cannot be denied that some responsibility for the promotion of these interests
must be assumed by the science educators who provide the nonscience student with his limited contacts in the fields of science.

**Significance of the problem for teacher education.** This study has special significance in satisfying the needs of the teachers in nonscience areas for a more functional understanding of science. Although this is a problem common to all sciences, each individual area must take its specific share of responsibility. This is most especially true where these persons take a single course to meet graduation requirements in their training program. This problem has two major facets which are best considered independently, the elementary teacher in the self-contained classroom of the modern school, and the junior and senior high school teachers in areas of history, English and other nonscience related fields.

For the elementary level, the responsibility for identification and encouragement of talent is of major importance. Young children show a natural curiosity and interest very closely allied to those of vital importance to the scientist. In some respects, if left to their own devices, they may be seen to exercise many of the methods and attitudes inherent in scientific study. Through proper encouragement, these early attitudes may well be nurtured and directed to create an enduring interest in the sciences. Dubins, however, found that children's interests and curiosity tended to be discouraged by adults in many situations.10 Furthermore, Todd found that the influence of middle-class

mores led women teachers to look upon science as a man's activity, and, by avoiding it, these "attitudes determined to a considerable extent her effectiveness in teaching science." 11

11 Todd, V. E., "Women Teachers' Attitudes Toward Science in the Classroom" (Elementary School Journal, 58:385-8, April, 1958).

Another problem facing the elementary teacher is that of understanding the dynamic nature of scientific knowledge. It has been estimated that over fifty per cent of all research published in chemistry has been published within the last twenty years. 12 It might be postu-


lated that this is probably equally true in the areas of medical science, physics, mathematics, astronautics, meteorology, and many other fields of science. For one who leaves school secure in the feeling of having the right answers, confusion and discouragement leading to insecurity are likely to result as new findings continuously contradict previous learnings. What, then, can a person in the position of teaching all things to all types of children at a given grade level possible gain from ten to fifteen hours in college science? The principal gains to expect from such a course are (1) some insight into the methods of science, (2) actual experience in problem-solving to develop confidence in ability to attack a problem relating to science, and (3) an aroused interest which will lead to a willingness to study further as the need arises. Such objectives can be achieved only if the course is directed
to these specific ends and instruction appropriate to their development is used.

At the high school level, the desirability for the correlation of work between fields has been accepted as an important step in making learning effective. This is especially true in areas of the social sciences where misconceptions relative to science can develop. The ever-present problems relating to advancing technology versus unemployment is an important case in point. Currently, other social problems leading to possible misconceptions include (1) nuclear testing and development in relation to fallout and waste hazards and (2) the relative importance of financial support for research needs in space exploration and the prevention and cure of disease as contrasted to expenditures in the welfare fields. A proper perspective relative to these problems can only be gained through better understanding of science and its impact on human progress.

A second important reason for nonscience teachers to be appreciative of science and its needs is an outgrowth of the administrative practices in most high schools. Whereas guidance services are available for discipline problems and irregular cases, responsibility for most educational guidance falls on the shoulders of the homeroom teacher. In consequence, it is essential that all teachers be in a position to give assistance in educational planning in all areas. For this reason any disinterest or antagonism toward science can be detrimental to the interests of the students seeking counsel. The adverse effects of poor counsel, as well as other influences, was shown in a study by Finkel. He found that interest in science for a significant
A portion of high school students is dampened at some point in their careers in school and that many of those interested in science were taking insufficient work in science and/or mathematics as background for a career in this field. The needs for manpower in all fields can only be met through a mutual cooperation growing out of basic understanding on the part of the science oriented personnel and the non-science oriented personnel. Nothing can be gained by misunderstandings on the part of either group.

Definition of Terms

Throughout this study certain terms are used in a somewhat restrictive manner. To clarify this usage it is necessary to establish this restriction through a definition of these terms.

Case method and case-study approach. In frequent use throughout this study are the terms case method and case-study approach. As a means of distinguishing between these, the term case method is restricted for use to refer to the method of cooperative problem solving as developed in the business education program at Harvard University. The case-study approach is restricted to use in reference to the adaptation of the case method to the presentation of the material selected for use in this study.

Judges and the evaluation committee. The procedure for evaluation of this study required the cooperation of a group of chemistry
teachers. This group is collectively referred to as the evaluation committee. Individually the members are referred to as judges or as committee members. These latter two terms are used interchangeably throughout the study.

Units. To implement this study it was necessary to prepare materials illustrative of the application of the case-study approach. For these examples, ten topics were selected and developed into study outlines. Throughout the study, these ten study outlines are referred to as units.
CHAPTER II

HISTORICAL ASPECTS OF THE PROBLEM

Science in the Role of General Education

The efforts which have been made to provide for the science needs of the general education group may be viewed from the point of view of modifications in a single course or the integration of the work of many related areas into a unified course. For an adequate understanding of the present status of these efforts, it is necessary to examine recent developments in all of the sciences as well as those which are specifically directed to the field of chemistry.

In general, the provisions which have been made fall into three main categories: (1) the use of orthodox courses for all students, with the inclusion of some emphasis on special needs of the individual member of the group; (2) the establishment of special courses in the single subject areas; and (3) the development of survey courses covering broad areas of interrelated sciences. Each of these schemes has had extensive trials and, under special conditions, has been shown to satisfy the needs of the non-specialist with varying degrees of success. Each presents its problems, however, and these have been instrumental in limiting the general acceptance of any one of these methods to solve the problem in question.
By orthodox courses is meant those courses designed as the beginning of professional scientific training. In general, they are found to be courses in a single science and of relatively standardized content.\(^1\)

\(^1\)McGrath, E. J. (ed.), *Science in General Education* (Dubuque, Iowa, Wm. C. Brown Company, 1948), p. 2.

These courses hold special favor for the small schools where enrollments make multiplicity in course work prohibitive of staff time and overtax facilities. That they are not completely satisfactory in meeting the needs of the general education group may be evident in a variety of studies, among them being *Science in General Education* which reported that

... conventional instruction in science has given scant consideration to the relation of the work of the scientist to the social order of which it is such an important feature. In fact, scientists, like their fellow men in other walks of life, have only recently become conscious of the fact that ours is a science-centered culture, a civilization in which a technology based on science has shaped our lives and our thinking often in subtle and unobserved ways. It is increasingly apparent that unless the proper social controls can be exercised the latest work of scientists may nullify all the benefits to human kind that have flowed from the activities of their fellow workers in earlier days. Hence courses for those who will not be scientists or physicians or engineers, but who nevertheless in a democracy determine social policy which may wreck modern culture, or destroy the scientific enterprise itself, must, a growing number of scientists are agreed, instruct students in the social implications and consequences of scientific work.\(^2\)

\(^2\)Ibid., p. 389.

The adoption of single courses to the needs of the general student, like the use of orthodox courses, depends somewhat on school
size and staffing problems. Although it is somewhat uncertain as to when such a practice originated, it usually consists of separate courses designed to fulfill special needs for nurses, medical and pharmacology students, engineers, or other areas where the course may have special significance. In many schools these may scarcely be considered as general education courses, because they are specifically directed to the vocational needs of a selected few. However, they are available for election on the part of students in the general studies curriculum. Here again it would seem that they predominantly serve the specific needs of a few and may, in the same way as orthodox courses, be weighted in detail rather than directed to the cultivation of the intellectual skills and concepts desired in a good general education program.

The survey courses were first proposed in his inaugural address (1909) by President Lawrence Lowell of Harvard as "general courses to give men not intending further work to comprehend underlying principles and methods of thought."\(^3\) This idea was accepted slowly (the first science course was offered at Dartmouth in 1919-1920), but 124 courses were being presented throughout the United States by 1935.\(^4\)


\(^4\)Ibid., p. 7.
the same time allotted to any one of the single subjects, they proved to be unavoidably superficial and led to extensive rote learning of an array of facts of the "quiz show" type of information. By 1940, they began to lose favor with many institutions, and a shift in emphasis evolved, producing courses centered around the understanding of a selected few laws or principles of general application.\(^5\) These courses, known by a variety of names most common of which is "block-and-gap" courses, form a large portion of the science programs for general education in the colleges today.

Such courses present major problems among which are found three of a rather critical nature: (1) the lack of textual material suited to the course; (2) the problem of articulation between high school and college or at the college level when a student becomes inspired to change his course of study; and (3) a paucity of teachers with sufficiently great breadth of interest and training to teach in such a course.

The problem of textual material can be solved in part by the cooperative efforts of the teachers involved. In some schools, outlines or syllabi have been developed to include discussion of the major problems to be presented, provocative questions have been assembled for further study, and supplementary reading lists are provided. Entriken suggests that the teaching of such a course requires at least

50 per cent more time than is necessary with the conventional type of presentation. Perhaps a failure to recognize and provide for such time is a basic cause for the limited development of such courses.

The problem of articulation is soluble in a variety of ways, dependent upon its nature. For the student who enters college with a substantial background in high school science, the hazard of repetitious work in an introductory course may be avoided through advanced placement. For those whose qualifications permit, the general education course requirements may be waived. As for the student who desires to change courses, he may be asked to take a beginning course in his major area. He may avoid this penalty by an arrangement, such as that offered at the University of Florida, whereby he may enter an advanced course with auxiliary class sessions, extra reading assignments, or tutoring.

Of the difficulties arising from the educational background of the faculty, McGrath has said:

... The education of college teachers is so narrow that few have the breadth of knowledge needed in teaching a course which includes more than one science, and the attitudes cultivated in the graduate schools militate against their studying more widely in later life. For these reasons courses in science for the non-major student in many institutions must be a series of lectures by specialists.
The problem of faculty personnel remains to be solved, and a few institutions are now setting up programs with this in mind. Through the auspices of the National Science Foundation, and industrial grants, teachers are able to return to school and strengthen their background in the way most suited to the needs of their respective positions. There remains, however, the problem of interesting more teachers in partaking of these opportunities. Promotion policies and faculty-status consciousness tend to militate against such a move.

A modification of this survey-type course has very recently been adopted by three of the liberal arts colleges of the Midwest (Wabash, Beloit, and Carlton). Since nearly 30 per cent of introductory chemistry is repeated in a first year physics course, and the two courses are mutually interdependent in other respects, this seems a promising move in the direction of improved teaching in these two sciences. On the other hand, it might prove equally unsatisfactory for the nonscience major if the reorganization does not involve an emphasis directed to his specific needs.

In criticizing the status quo, attention must be given to the fact that individual differences undoubtedly exist between the teachers of any of these courses. With a basic interest in the problem, it is possible for a capable teacher to make use of library, laboratory facilities, and discussion to provide for the varied needs of a heterogeneous class. Unfortunately, these master teachers are in greater demand than are available, and the future supply will have keen competition for filling the needs of shortages which exist now and are on an increase in the conventional courses.
The Role of Chemistry in Science Education

Since special courses have not, as yet, proved completely adequate in meeting the needs of the general education student, it may be helpful to examine the existing situation in the field of chemistry.

The teaching of chemical information predated the establishment of chemistry as a science by many years. The alchemists of most early civilizations perpetuated their art through apprenticeship programs of a highly secret nature. Out of some of these practices grew an empirical knowledge of the application of chemistry to medicine. It was from this position that the teaching of chemistry was introduced into the early universities of Europe.

Such teaching consisted entirely of incidental lectures in chemistry as it was known to be applicable to medicine. Essentially, no provision for the education of those interested in chemistry as a science was provided. In consequence, those men, now looked upon as the founders of chemistry, found it necessary to pursue their studies completely independent of the universities.  


As a result of dissipating wars on the continent, England assumed a commanding lead in the industrial revolution. This initiated a popularization of science for the tradesman, but resistance on the part of classical faculties of the universities prevented acceptance of science as a legitimate pursuit of the scholar. It remained for
France to recognize the importance of organized scientific research and promote its study. Under the leadership of the Paris Academy and the schools associated with it, scientific research successfully defeated the resistance of the traditional university faculties and gained its rightful place in the university family.

The lecture remained the predominant method of teaching chemistry until Rouelle, and later Gay Lussac and Thenard, introduced the use of demonstrations as illustrative material for their lectures. In general, little experimental work was included in the teaching program. The laboratory was first introduced as a part of the training program of chemists by Thomas Thomas of Edinburgh University (1800-1807) and, from his example, it soon spread to general use.¹⁰


This early laboratory work was predominantly miscellaneous experimentation until Liebig (1824), at the University of Geissen, initiated a program built around the preparation of gases, qualitative and quantitative analysis. In 1846, Professor Will published an outline of the qualitative analysis portion of the course and this became generally adopted as the basis for elementary laboratory instruction. As late as 1902, Alexander Smith writes of this outline:

Even at the present day the tradition still retains its influence, and the importance of fuller preliminary instruction in general chemistry is still fighting its way to recognition in some quarters. The one-sided and distorted view of chemistry
which the standpoint of elementary qualitative analysis gives is still unfortunately the only one offered to many beginners.¹¹


On the American educational scene, chemistry had its first recognition with the founding of a chair at Princeton University (1795), and it remained predominantly a college course until Harvard College (1888) accepted it for admission credit. From that date many notable contributions have been directed to the improvement of the teaching of science in general and chemistry in particular, but the large majority of these are directed to the secondary school program. The literature directed to the college level work deals principally with what to teach, and shows limited concern for the problem of teaching methods in college chemistry. As a result, the principal sources of information relative to the problems of teaching college chemistry are the textbooks in use, the catalogue descriptions of courses and the articles published in journals such as the Journal of Chemical Education.

Over a period of the past fifty years, textbooks have shown an extensive degree of conformity in presenting the conventional content relating to the occurrence, preparation and properties of selected elements and common compounds. Along with this there has been a varied degree of emphasis on industrial processes, applications of chemistry to the home, to medicine, or in specialized areas such as agriculture, and an ever increasing degree of inclusion of theory basic to the understanding of the principles involved. The major variations exist in the
extent to which applied chemistry is included, the relative emphasis on organic or inorganic chemistry, the emphasis placed upon recent theoretical developments, and the rigor with which the quantitative material is developed. The extent to which this conformity is a reflection of consensus of opinion relative to content or a reflection of the dictates of publishing practices is uncertain. The trend away from excessive use of factual detail and toward an approach emphasizing major basic concepts, indicates an improvement of significance in the direction of an essential goal in effective teaching.

Examination of school catalogues likewise shows a rather uniform pattern relative to the administration of instruction in the introductory courses. Predominantly, the teaching is done through a lecturing program accompanied with a laboratory session in which the factual details of the lecture are confirmed. In general, laboratory manuals are written with precise instructions which may be followed in "cookbook" fashion to produce results already known to the student who has read the assignment and attended the lecture. Admittedly, the exact method of presentation of any one instructor cannot be justifiably deduced from above sources, but little evidence is available otherwise, as is suggested by Miss Raushenbush, who points out:

There has been a long standing tradition in America, and a rather strange one when all the circumstances are considered, that college teaching is something you do, but something you do not talk about. Anyone who has spent twenty years on college faculties knows that most of the time he has been informed little about what his colleagues do in their classes, how they use their knowledge and insight in teaching. What he does know he often
learns accidentally and in a fragmentary way from students, who seem to care about teaching, if no one else does.12


That the existing program has met with reasonable success for potential chemists may be evidenced by the fact that chemistry leads in the number of doctoral degrees granted in the total educational program. That it has met with some dissatisfaction may be evidenced by the numerous plans for reorganizing the instructional program in many colleges. Among these plans are found those of Brown University, Earlham College, Harvey Mudd College, and the consolidation of physics and chemistry at Wabash, Beloit and Carleton Colleges. Although these programs are directed to the acceleration of the total chemistry program to enable the major to cover the ever increasing scope of the field with greater speed and increasing independence, success in these plans may eventually serve to benefit the non-major courses.

The one concession to discussion of methodology has been in the realm of the use of demonstrations. In an effort to encourage greater use of this teaching device, the Division of Chemical Education of the American Chemical Society has promoted the publication of demonstration materials throughout its history. Of most recent interest are the review, summary and revision of much of the past published materials by
In this work, new demonstrations relating to recent advances in the field have been added. Examination of these and the publications of Arthur, Fowles, and similar works reveal extensive reliance on the conventional approach to the teaching of chemistry. The influence of this work is reflected in the results of a survey of two hundred colleges approved by the American Chemical Society for the training of chemists. In this survey, J. A. Campbell found that "less than half of the responding schools do any lecture demonstrations at all; less than a quarter do any appreciable number; and only 5-10 percent do as many as 100-200 during a full year."

From this overview, it may be safe to conclude that for the most part, the methods by which chemistry is taught in the colleges today is much the same as that of fifty years ago, when the proponents of faculty psychology were strongly supported. Undoubtedly, the problem is highly individualized and is said to reflect the way in which the teachers themselves were taught. Similarly, the extent to which course work
is subject-centered would imply a general lack of attention to modern theories of learning as they apply to the college classroom. The degree to which this reflects the traditional policy of classroom autonomy is indisputable, but the degree to which it can be tolerated at the expense of efficient learning is another matter. It would seem that the most logical recourse is to convince the instructors that other methods are possible and encourage their efforts to experiment with them. The past few years have seen a few studies directed to this problem. Some of these will be discussed subsequently in the development of the problem.
CHAPTER III

IMPLICATIONS OF RECENT EDUCATIONAL THEORY
FOR COLLEGE TEACHING

A major reason for undertaking a study such as this lies in the failure of college instructors to consider recent advances in the understanding of the learning process as it applies to their instructional programs. As a result, the effectiveness with which current science courses are presented is limited by reliance on practices still reflecting much faith in faculty psychology as it was understood fifty years ago. Although research relating to general education in science is becoming more evident in the literature, it still deals primarily with what subject-matter emphasis is desirable. Such research generally is based upon surveys of textbooks and periodical literature or on the opinion of committees of experts. "The impact of recent developments in the behavioral sciences, educational psychology, and philosophy has not been reflected to any considerable extent in science education research" at the college level.¹

¹Weaver, E. K., "Survey of Research in College Level General Education in Science" (School Science and Mathematics, 56:529-34, November, 1956).

Faced with the problems of exploding enrollments and astronomical costs, much research is directed to efficient use of faculty time
through the development of films, television programming, the effects of class size on learning, and similar studies. The evaluations of most of these studies are based solely upon the accumulation of facts, and, therefore, are invalid for judging other outcomes of learning such as understanding, development of attitudes, and the ability to apply a scientific method in problem solving. Meaningful learning is most economical by virtue of the fact that it is more permanent, its effects are accumulative in facilitating further learning, and it fosters the habit of expecting to understand.\(^2\) Consequently, it might be that such trends in instructional practices may prove to have less merit than would appear to be true on the present basis of evaluation. Much more and varied research is needed before conclusive evidence will be forthcoming in this matter.

It has been shown that the lecture is superior in conveying factual information,\(^3\),\(^4\) and some go so far as to show that reading is


even more efficient than the lecture. If, however, we are to accept
the aim of education to be "the development of the art of the utiliza-
tion of knowledge," then the lecture method has been shown to be the
poorest approach to this objective. Furthermore, Brinkley found that
students recognized this fact when asked to rate ten learning processes
on the basis of effectiveness. They rated the lecture eighth while
rating group discussion second out of the ten possible choices.
Ideally, it would seem that some combination of a variety of methods
would be most suitable.

If the needs for more effective teaching in the sciences are
to be met, the problems of teaching science must be considered in light
of successful educational experiments to this end. Although much of
this experimentation has been done at elementary and secondary levels,
it is here assumed that the learning processes and products may be
extrapolated for application at the college level. The added problems
of unlearning conditioned responses to classroom activity may be

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5 Greene, E. B., "The Relative Effectiveness of Lecture and
Individual Reading as Methods of College Teaching" (Genetic Psychology

6 Corey, S. M., "Learning from Lectures versus Learning from
Readings" (Journal of Educational Psychology, 26:188-94, 1935).

7 Whitehead, A. N., The Aims of Education and Other Essays

8 Bloom, op. cit.

9 Brinkley, S. G., "Mental Activity in College Classes: Student
Estimate of Relative Value of Ten Learning Situations" (Journal of
multiplied, but the added maturity of the individual student should function to counter this effect.

Also, because of their voluntary choice of being in college, the students should be somewhat more favorably inclined toward learning than many of their younger counterparts. Such an inclination cannot be taken for granted, however, but must be encouraged through deliberate teacher efforts toward promotion of interest in the work at hand. The desire to learn is a crucial factor in effective learning, and good teaching necessitates consideration of this fact. Attention was directed to this matter by Tead when he said:

Any assumption at the college level that this desire to learn is spontaneously general and dominant is surely a supposition contrary to fact. And the teacher who ignores the critical problem of creating a situation in which the student is eager to learn has simply failed to take account of the primary hurdle in carrying learning on to completion.10

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For teaching in any field to be effective, it must have some degree of permanence, and educational experiments show that retention is greatest where material is meaningful and well organized. If one applies this fact to the classroom situation, retention is least for that material acquired by rote memory, more permanent for that material acquired as meaningful concepts, and most permanent for that material for which
meaningful generalizations may be made by the student individually.\textsuperscript{11,12}


\textsuperscript{12}Brownell, W. A., \textit{op. cit.}

Emphasis here upon the term \textit{meaningful} is a deliberate effort to stress the fact that memorization of verbal associations makes no guarantee of understanding and hence provides no assurance of permanent, useful knowledge. Evidence points to the fact that "that kind of learning that takes place is the result of the kind of experiences which we have."\textsuperscript{13} Therefore, the learning situation in the classroom must be altered to provide for learning processes other than rote memory if the desired results are to be attained.

Brownell and Sims point out that successful learning largely depends upon the methods employed by the teacher. They emphasize that (1) understanding depends upon the degree of initial motivation and recognition of need; (2) to develop understanding, a background of relevant experience sufficient to meet these needs is essential; (3) attention must be focused on details which hold the key to understanding in order to acquire understanding; (4) understanding increases when a student formulates the results of learning in his own words and in a variety of ways; (5) to get understanding requires an active, aggressive approach which is best encouraged by leading the student to "discover"
things, processes and the relations of which understanding is sought;
(6) understanding is most complete when the learner himself has had an
opportunity to make a choice and come to a conclusion that such and such
is the important thing to do; (7) the kind and degree of a student's
understanding may be inferred from observing what he says and does with
respect to his needs.\textsuperscript{14} Hilgard\textsuperscript{15} cites other studies which support
these conclusions.

\textsuperscript{14}Brownell, W. A., and M. S. Sims, "The Nature of Understanding"
(Chapter III, Forty-fifth Yearbook of the National Society for the Study

\textsuperscript{15}Hilgard, E. R., \textit{op. cit.}

These observations suggest that the task of the teacher is first
to provide the initial motivation for the student by presenting a wide
variety of experiences in as varied a number of ways as possible to
serve as background material. If attention is then focused on details
which provide the key to understanding, the student may be led through
questions and discussion to formulate and articulate the appropriate
generalizations. To insure a degree of permanence of this learning he
must then be given opportunities to apply these generalizations to re-
lated situations and ultimately be led to see their import in situations
more commonly encountered in non-school experiences. The degree to
which this last step is taken provides the guarantee of transfer value
in the teaching process.

What has been discussed thus far pertains to factual learning
as well as learning relative to other objectives in the teaching of the
sciences. A study of these objectives shows that in addition to factual
information, teachers of chemistry aim to develop (1) an understanding of or predisposition toward a scientific attitude toward issues and problems as they arise; (2) an ability to think critically in relation to the solution of all problems; (3) an insight into the methods and limitations of the field, with special attention to applicability of these methods in relation to other areas; (4) an appreciation of the unity of goals in science with special emphasis on the uniqueness of approach in chemistry; and (5) an appreciation of the role of chemistry in society and its importance in everyday living. There are many studies to show that these objectives are attainable. Such studies give evidence of the fact that objectives of this nature are not automatically an outgrowth of the accumulation of factual information. Rather, it has been shown that, unless teaching is directed to these ends, such objectives cannot be successfully realized.

Glaser,16 Fawcett,17 Downing,18 and Noll19 showed that critical thinking could not be developed as a by-product of the study of science. These studies show it to be essential for students to have extensive experience in thinking critically about issues if this ability


18Downing, E. R., "Does Science Teach Scientific Thinking?" (Science Education, 17:87-9, April, 1933).

19Noll, V. H., "Teaching the Habit of Scientific Thinking" (Teachers College Record, 35:202-212, 1933).
is to be developed. Glaser's study demonstrated that, through the appropriate development of study units, students showed growth in their ability to think critically. Furthermore, he showed that such an ability was retained as evidenced by retest and observable behavior six months after completion of the study.

The Committee on the Function of Science in General Education supports these studies by affirming:

Cultivation of reflective thinking requires repeated and varied experience in critical analysis of manageable materials, in the formulation of appropriate inferences, in the interpretation of data, in the application of principles, and in the testing of hypotheses.

... It calls for an emphasis upon the problem approach. ... It means continuous opportunity to arrive at understandings through thinking, rather than through memory, and opportunity and encouragement to apply such understandings to new situations. ... .

These considerations suggest that through his science experience the student may come to appreciate the value of reflective thinking, to see how the method has enabled man to banish many unreasonable fears and superstitions, better to control his life and better to attain his ideals. It is hoped that through the development of such understandings the student may develop both ability and determination to apply reflective thinking to his problems in every pertinent area. 20

Laton and Powers, 21 Curtis, 22 Barnard, 23 and Peters 24 showed that desirable attitudes such as the habit of weighing evidence, a tendency to delay judgment, open-mindedness, active curiosity, and similar traits could be cultivated, if experiences were provided to help the students realize the desirability of such attitudes. One of the major

23 Barnard, J. D., "Lecture Demonstration versus Problem Solving Method of Teaching a College Science Course" (Science Education, 26:121-34, October, 1942).

difficulties requiring persistent efforts and encouragement to overcome has been sighted by Harris. He points out that previously established habits are not readily reconstructed and continue to color new learnings. 25 This necessitates continuous effort and attention to succeed in the establishment of the desirable attitudes.

alizations may be made meaningful, it becomes necessary to develop an ability to achieve in this area. Thorndike has shown this to be a highly individualistic process, which can be seriously hampered by too formal a pattern of procedure. Hilgard, Wertheimer and others point out that the establishment of an habitual pattern of procedure actually inhibits productive thinking. For effective results, Patrick suggests that it is the teacher's responsibility to lead students to approach a problem by viewing it from as many different angles as possible, then help them to decide upon a proper orientation.

Admittedly, all of these deliberate efforts to achieve goals other than the accumulation of facts, necessitate an infinite amount of patience and much more time than the conventional procedures consume. In all of these studies, however, it has been shown that emphasis in favor of these objectives has not been detrimental to achievement in the accumulation of information. On the contrary, by reinforcing the usual memory work with more basic understanding, retention of informa-

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26 Brownell, W. A., op. cit.


tion has been enhanced, and increased interest has led to more independent study. Under these circumstances, it seems reasonable that more attention could be given to the attainment of such goals and it is justified to take time for emphasis in this effort.
CHAPTER IV

THE CASE METHOD

In this study it is proposed that the case-study approach can result in more effective learning. In order to further clarify the nature of this study, it becomes necessary to define what is meant by a case-study approach and how this may be adapted to use in the presentation of introductory college chemistry.

The case method was first introduced in 1869 by C. C. Langdell of the law school of Harvard University. It has subsequently been adopted and expanded for use in business education as well as such areas of study as human relations, sociology and psychology. The case method was primarily designed to use problems as a means of helping the students to discover ways of thinking productively.

As pointed out in Chapter III, psychological studies have shown that the cultivation of ability to think is a result of practice. It also is known that achievement of positive results depends upon the degree to which the problem situations are significant to the student.*


To be effective, then, the proposed method requires the selection of problems which can be made interesting to the student and permit some degree of freedom in the mental activity necessary for solution. The
extent to which this thinking process will lead to generalization of knowledge is known to be proportional to the range of context within which practice in thinking is encouraged.²


The original purpose in designing the case method was to change the student's role from that of a passive absorber of accepted facts to one of an active participant in the formulation of a solution to each problem. A change in emphasis in the instructor's role was required if this was to be achieved. No longer could he serve as an authority, doing the thinking and reasoning to help students avoid error. Instead, it was necessary for him to provide the sympathetic coercion needed to give a student confidence and encourage self-evaluation in relation to his solution. Since each problem was of a nature not to have a "best" answer, each student was expected to arrive at an individual conclusion consistent with factual information related to the situation being studied. It was necessary that the student be prepared to defend his position as reasonable in light of all available evidence.

Modifications of the case method have been adapted, with a limited degree of success, in the teaching of science. The Harvard Case Histories³ were one of the earlier adaptations. Unfortunately, these

studies are limited to the early historical growth of the sciences, and tend not to develop a completely satisfactory picture of the proper perspective relative to modern scientific developments. Furthermore, by emphasis on the reading of original documents and controversial issues, much time is spent in traversing a long and circuitous route at the expense of progress. Although it is desirable for students to realize that scientific progress is not a sequence of simple successes, it may be of questionable merit to belabor this point at the exclusion of other important factors.

A second modification, which is similar to the case method, is seen in the "problems approach" developed as an outgrowth of survey courses at Colgate University. This approach is very similar to the "block-and-gap" approach developed by Eric M. Rogers at Princeton University. Both of these methods serve much the same purpose, that of general education in science, and each is based upon the selection of a few topics which are treated thoroughly by a combined discussion-lecture method accompanied by varying degrees of application of demonstration and laboratory techniques. In reading of the type of material included, it is difficult to distinguish between these methods as described.

The case method, as originally conceived, is not always applicable to the presentation of scientific materials. One of the diffi-

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5Ibid., Chapter X.
culties in adapting it for use arises from the dissimilar nature of the factual material being discussed in the development of the case. In most problems arising in the social sciences, a degree of familiarity exists in the experiential background of the students. This enables the student to use references with some assurance of achievement in the solution of the problems in question. This familiarity is not always existent in the area of science. Moreover, the tendency of some students to avoid the mastery of necessary quantitative skills makes reference work especially difficult for these students. For this reason the mode of presentation of the factual material in science is of the utmost importance if a satisfying degree of success is to be forthcoming.

A second difficulty arises from the type of solution derived through the development of a problem. In its initial form, the problems selected for study by the case method were chosen from the social science areas. Each problem was so chosen as to have many possible solutions of relatively equal merit, and the solution derived by a particular student would reflect the personal interpretation read into the problem situation by that student. Although the proposed solution as submitted by each student had to withstand the test of logic, there was no need for it to be in accord with other solutions in the class. As a result a variety of solutions were possible, as is often true in the decision of court cases and similar problems.

Such is not the situation in relation to many problems from the sciences. The very nature by which scientific knowledge has evolved restricts, to some degree, the freedom of choice in interpretation of
results. For this reason, there will be a degree of uniformity in the solution which serves as the most adequate response in light of all known data. This is not to say it is a final solution, for subsequent experimental evidence may change the interpretation, but it implies a "best" answer in view of the existing knowledge relating to the problem. In such a situation, the instructor's role as discussion leader requires considerable emphasis in tying the loose ends of the students' thinking together into a unifying concept. His ability to do so without being dogmatic is a key to the effective use of the proposed method.

A third difference between the application of the case method to the natural sciences or to the social sciences lies in the difference in the use of the solution of each specific problem. As the case method was originally conceived, each case was independent of all preceding or succeeding cases, and its subsequent use was very limited. Although this might be possible in the natural sciences, such a practice would not be desirable. Important concepts relative to the unity inherent in a science and the way in which that science has evolved can best be developed by using the generalizations derived in one problem as a basis for the interpretation of other problems. Wherever possible, it is desirable to show how a generalization must be modified to provide for the interpretation of new experimental evidence. The care with which problems are selected, arranged in sequence, and developed will be critical in the growth of understanding relative to the evolution of scientific knowledge.

With these points in mind, it is possible to develop the individual units to be studied in such a way as to promote their use to
achieve the goals of the case-study approach, while making provision for the achievement of the basic objectives of the course. Of necessity, each unit is to be presented as an interesting problem, relevant data and experimental observations are to be introduced in a logical sequence as needed, questions relating to these observations and their correlation will be used to derive generalizations appropriate to the problem. This constitutes the essence of the case method as it is to be adapted for use in introductory chemistry in this study.
CHAPTER V

SELECTION AND DEVELOPMENT OF THE CASE-STUDY UNITS

Selection of the Case-Study Units

In order to determine the effectiveness of the case method in the teaching of chemistry, it is proposed to select a group of problems and develop them as case-studies. As in the selection of teaching units in any course, some basis must be established as a guide for choice. Since this study is directed to the presentation of chemistry for the nonscience majors, the needs of this group provide the frame of reference from which this study proceeds. These needs have been discussed in Chapter I, and the objectives which arise from them form the basis for selection of problems for such a course.

In Chapter II, reference was made to the programs established by those schools which have sought to provide science courses for general education. A study of these programs shows remarkable agreement as to the major objectives for such courses. Minor objectives, which arise as a result of the unique problems in any one institution, serve predominantly to adapt the course to the local situation and cannot be considered outside the context of a specific situation.

The major objectives most commonly expressed in these studies include (1) a meaningful acquaintance with a representative selection of basic principles and laws, with emphasis upon concepts relating to the
nature and limitations of scientific knowledge; (2) the development of an appreciation for the attitudes and methods which have contributed to the success of the scientific enterprise in advancing man's understanding of himself and his environment; (3) the development of a predisposition toward the application of scientific attitudes and methods to the solution of problems arising from community and personal living situations; and (4) an acquaintance with the historical aspects of the growth of science as a means of revealing how cooperative efforts of succeeding generations of scientists have been responsible for the present day level of understanding of the universe and its components.

These objectives form the basis of selection for instructional materials for a course in chemistry for general education students.

The discussion in Chapter III relative to learning theories stressed the fact that objectives such as those listed above are not obtained as by-products of the transmission of information. Instead, informational material must be used in such a way as to provide for the achievement of such objectives. The selection of problems appropriate to this use is an important factor in the successful achievement of the desired objectives.

Since any course must be built around the subject matter of the field, selection of problems begins with this content. For the student to achieve a meaningful acquaintance with a representative selection of basic principles, some provision must be made for the student to derive the basic generalizations appropriate to these principles. This requires a careful selection of problems, the solution to which will lead to the desired generalizations. That some principles, by virtue of
their complexity, demand a more mature background than is expected of beginners should be obvious. Problems relating to these principles must be delayed until that background is developed. The initial selection of problems will include, therefore, any which contribute to a basic understanding necessary to subsequent work, those which provide an opportunity for the student to develop fundamental generalizations, and those which will be of a level of difficulty to challenge the student yet permit a degree of success as a result of an application of honest effort.

In planning for the development of an understanding of scientific method and the essential attitudes accompanying its use, it might be assumed that all available problems in a science course would be suited to this purpose. It can be expected, however, that some will be more easily adapted for use with beginners. In order to appreciate the scientific method, it seems necessary for the student to struggle with the processes by which experimental evidence is obtained, sorted out, interpreted, and tested. This requires a wide variety of data associated with a single generalization. A problem which is based upon a broad experimental background is more applicable to the achievement of this objective than one supported by limited experimental evidence.

A problem of transfer is involved in developing a predisposition toward the application of scientific attitudes and methods to the solution of problems arising outside the classroom. It was shown by Laton and Powers that this transfer is possible if it is planned for and
opportunities for repeated use are made available. If transfer is to occur, the student must be made to realize the merit in the scientific approach to a problem and be given sufficient opportunity to make use of it in practice. Any problem which has undergone long years of evolutionary development from a crude and often misleading interpretation to a refined still incomplete development, is ideal for establishing the value of such an approach. Practice in its application to community problems similar to those suggested in Chapter I will assist in providing for transfer of the approach to subsequently encountered problems.

Closely related to the development of an appreciation for scientific method is a familiarity with the historical growth of science. The true achievement of science cannot be evident without some appreciation of the slow and often devious route which has led to the present level of progress. Similarly, the resulting concepts which develop relative to the present degree of uncertainty of scientific knowledge can serve to reveal the limitations of such knowledge as it applies to modern problems. The selection of problems which can be developed with the inclusion of historical aspects of their evolution can readily serve to provide opportunities for growth in perspective in relation to the nature and limitations of scientific knowledge.

By way of summary, it may be said that any problem appropriate for use in this approach to the teaching of chemistry must provide for the achievement of one or more of the major objectives discussed here.
To do so requires problems which permit the student an opportunity to observe and interpret extensive varieties of experimental evidence with a degree of freedom of choice in such interpretation. Each problem must provide for intellectual challenge yet be capable of solution with a facility commensurate with the students' abilities. The greater the opportunity available for critical examination of factors related to the problem, the greater will be the growth which can ensue in respect to the understanding and habituation to use of scientific attitudes and methods. Problems rich in historical background are important in the development of an appreciation for the power of scientific method for the acquisition of knowledge and an understanding of the nature and limitations of such knowledge.

Large numbers of problems can be found which meet the above criteria. Because all cannot be included in any single course, further selection is necessary. In this, minor objectives are involved, and the relative importance given to them will depend upon the local situation. It must be said, however, that a major factor in the effectiveness of any teaching rests in the interests the students develop for participating in learning. If the problems are selected with attention to local factors influencing these interests, the resulting enthusiasm will be a major motivating force in the learning situation.

In this study, attention was given to the selection of problems which could provide background for the development of the major objectives discussed above. In addition, special attention was given to the interest value in the problem. In deference to the committee volunteering to assist in the evaluation of this study, the number of topics
selected was held to the minimum judged essential to illustrate the proposed method. As the study progressed, ten units were selected and assumed adequate for fulfilling this requirement.

That some problems might lend themselves better to the type of development proposed is acknowledged. For this reason less apt topics were rejected. As a further consideration, it was judged wise to select those topics least commonly supported by experimental work in common usage. The intent in this respect was that of providing some suggestion of the possibility for greater use of demonstrations or laboratory work in these areas. In general, chemistry has a fabulously rich resource of spectacular, demonstrable phenomena available for such use. Efforts to promote their use have resulted in publications such as *Lecture Demonstrations in General Chemistry*\(^2\) and *Tested Demonstrations in General Chemistry*.\(^3\) Despite these efforts, there are areas in beginning chemistry where very little has been done to stimulate interest through demonstrable phenomena. Emphasis upon this area is favored in the development of this study.

Since a principal concern in the case method is for the stimulation of student participation in formulating the basic generalizations appropriate to the course, each topic selected must be of a nature that lends itself to this procedure. Of specific interest in selecting problems were (1) the potential which the topic held for arousing curiosity and stimulating interest, (2) the adaptability of the problem in con-

\(^2\)Arthur, Paul, *op. cit.*

\(^3\)Alyea, H. N. (ed.), *op. cit.*
veying an understanding of the scope of interests and the limitations in the field of study in chemistry, and (3) the possibilities inherent in the topic for developing concepts relative to the evolution of chemical theories.

In the process of selection, many topics were considered and discarded as inadequate in light of the above criteria. In addition, other topics were explored and abandoned as unsuited to this study by virtue of the fact that they were (1) too narrowly defined to demand adequate development to illustrate the desired method, (2) too diffuse a problem to be resolved within the limits of a single unit, (3) too similar to conventional units to permit creativity in their development, and (4) too demanding of complex background information to serve as introductory units. Some topics in the latter category might be developed after appropriate background is provided for the student. Among these might be such topics as photosynthesis and its importance to man, energy resources and their conservation, metabolic processes and their relation to man's health, equilibrium systems, and dyes and the relation of color to molecular structure.

Consultation with the committee supervising this study served to support the selection and development of the units. Final approval was sought before they were submitted for evaluation.

**Development of the Case-Study Units**

Having selected the problems, the next step is to develop each one in accordance with the proposed method of presentation. Initial emphasis must be placed upon the statement of the problem. The degree
to which its phrasing serves to stimulate interest toward a solution is a key factor in providing the impetus under which the class will delve into the work of solving the problem. In specific instances (Units I, III, IV, IX, and X) the statement of the problem is supplemented by a set of preliminary questions designed to arouse curiosity regarding the problem and to provide background for its interpretation. Wherever feasible, these questions are selected with the intent of relating the topic to the experiential background of the student, and they could conceivably vary with the teaching situation as used. Many of these questions, especially in Unit I, are of a type designed to give direction to subsequent thinking or to indicate the scope of the problem. Most of these are not of a nature to require answering. In fact, some have no known answer and, thereby, serve only to direct attention to the pattern of work as it might develop for future chemists. Such questions might also serve to stimulate creativity for those sufficiently interested in their solution.

The discussion in Chapter III, relative to learning theories, indicated the need for greater opportunity for students to derive the generalizations associated with the information presented in the teaching process. This suggests that the presentation of each problem should be accompanied by as great a variety of experimental evidence as is feasible. If experimental materials are to be effective in promoting inductive processes in the formulation of generalizations, certain factors must be considered in choosing these materials.

It seems evident that any experimental work selected must be illustrative of the basic ideas inherent in the solution of the problem.
A careful analysis of the implications of the problem directs attention to the type of evidence which must be included. Moreover, if such materials can serve to sustain or enhance the interest initially stimulated by the preliminary discussion, much will be gained by way of a favorable learning atmosphere.

Since the effectiveness of learning is enhanced in proportion to the degree of reality it bears for the student, concrete experiences are given preferential selection over abstractions. Still further consideration must be given to the ability of the student to observe and develop ideas from the selected experimental work. Because learning takes place through a stepwise accumulation of concepts, too gross a leap from one level to another must be avoided to prevent confusion and discouragement. It may be helpful in this respect to relate the experimental work to the thermodynamic concept relating to work. The maximum work which can be achieved is that done under reversible conditions. Unless the experimental work is successful in nucleating the students' thoughts, it might serve no purpose, or, even worse, it could serve as a deterrent to further learning.

For this method or presentation to be effective, the generalizations developed in each problem must be applied to succeeding learning situations. The facility of transfer is directly related to the variety of background of information associated with each generalization.4

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4Hilgard, E. R., op. cit.
phenomena as is possible. Where expensive equipment is required, this variety is introduced through the use of visual aids, such as the projection of graphic material, construction of charts as needed, and the presentation of models where appropriate. As another criterion for selection, recent developments in experimental methods, unknown to early theoreticians, are emphasized wherever such are applicable and understandable. This is deemed desirable to give the student an appreciation of the developmental aspects of theory and some idea as to the dependence of the sciences upon technological advances resulting from previous theoretical studies.

In the conventional textual material used in teaching courses in science, emphasis is placed upon what the scientist believes to be true. This is subsequently supported by selected bits of evidence. Few students realize how these beliefs came into being, and the beginner is often led to the fallacious belief in factual certainties which do not exist from the point of view of most scientists. To correct such misconceptions, efforts are made throughout these units to evolve an understanding of why a certain explanation is accepted and how, through the accumulation of new evidence, it may readily be altered or rejected as inadequate.

Finally, to insure a wider use of the developed materials, experimental work is deemed appropriate only if equipment is likely to be available in the average teaching situation. This restricts the use of elaborate and expensive equipment available only at the larger or better endowed institutions.
In the assembling of the experimental material, leading questions are inserted at appropriate intervals to demonstrate the way in which such materials might be presented. All such questions are intended to provoke thought and focus attention on a solution to the problem. They are organized, as nearly as possible, in a logical sequence to assist the student in the organization of his thinking. In some specific instances questions are inserted to stimulate discussion and aggravate students to ask further questions which might be helpful in the development of the problem.

As information is accumulated, the questions are increasingly directed to the correlation of the various observations made. In many instances, it is possible that the question, as stated, might not solicit a useful response relative to the issue at hand. In such a situation, a rephrasing of the question would be essential, and other questions might need to be inserted. On the basis of ten years experience with students in chemistry, this investigator has made every effort to phrase questions in the most probably way to stimulate an adequate response. As a result of such experience, however, it is acknowledged that no two classes are alike, and students may be most unpredictable in relation to such experiences. In all probability, the effectiveness of such an approach will depend upon a teacher's sensitivity to these differences and adaptability in providing for them.

As the units were initially developed, it seemed evident that they must contain a great deal more detail than was desirable if they were to convey all the possible implications of such a presentation to the evaluating committee. Since too specific detail tends to limit the
flexibility with which student participation may enter into a progres-
sive development of the projected generalizations, some alternate means
of conveying the intent of each unit was sought. To be satisfactory,
such a means must avoid an excessive burden in reading on the part of
the evaluating committee.

This alternate means was found in the insertion of an abstract
immediately following the statement of the problem. This abstract was
so written as to convey the point of view to be emphasized in the sub-
sequent development as well as to give a general overview of the pro-
posed content. This abstract could well serve as a summary at the
completion of the presentation of the unit in a classroom situation.

To further simplify the work of the evaluation committee, a
brief outline showing the general nature and sequence of the selected
experimental work was inserted following this abstract. The abstract
and outline together were intended to give a preview of the develop-
mental material as it might be used by the instructor.

Assuming the statement of the problem, abstract, and outline to
be adequate in expressing the intent of the unit, they were followed by
the proposed approach to the presentation of the unit. This material
was written for use by the instructor as a type of lesson plan to serve
as a guide in developing the problem. Since, in any sequence, subse-
quent questions often are "give-away" clues to previous questions, many
of the questions would need to be phrased orally as experimental work
was being presented.

The resulting outlines of the ten selected problems as developed
are shown in Appendix C, page 114. As presented, they give a skeletal
framework from which each problem might be approached through the case-study method. The procedure for use and the limitations are discussed in the succeeding chapter.
CHAPTER VI

USE OF THE CASE-STUDY UNITS

If these case studies are to serve the purpose for which they were designed, there are certain pedagogical considerations which must be taken into account. Foremost among these is a clarification of the limitations of the units as presented. They are planned to be purely introductory in nature, and no claim for comprehensive coverage of the subject matter is made. As such, they are of a design that would permit their insertion into the conventional sequence of work where appropriate. As they are presented, they would be accompanied by various reference materials and additional laboratory work, as time would permit. On occasion, it might be necessary to include a limited lecture to provide information concerning those topics which arise and need more extensive teacher direction for clarification. As students gain in background and self assurance, it should be possible to increase the degree of independence in study and arrange for work on projects or other self-directed study.

In the proposed development of each problem, it was planned to provide patterns illustrative of the scientific method. By so doing, it is intended that the students gain experience in observation, organization, and interpretation of data. By using as varied a type of experimental work as possible, the students can be led to realize the
importance of approaching a problem from many directions in order to establish trends in basic facts and to verify hypotheses which might be posed in drawing conclusions from such observations.

Class time and experimental facilities limit the degree of sampling which is possible. For this reason, such devices as graphs, charts, displays, models, and slides can be used to supplement where direct observation is not feasible. As in all teaching situations, these should be used in accordance with pedagogically sound practices if they are to be effective.

In order to practice critical thinking, the student must not be required to follow the precise development of a problem as seen through the eyes of the teacher. Instead, he should be able to proceed at his own risk, yet be helped over the hurdles by other students' ideas and constructive criticism from the instructor. A major gain in the learning process results from the immediacy with which erroneous ideas are corrected. Whereas, in a lecture system there is only occasional experience in correcting erroneous concepts, in the approach here suggested, such errors can be recognized as they are formulated. By rectifying them before they become established learning, the student should find much less need for unlearning and the inefficiency it implies.

The degree to which such an approach can achieve the objectives established for general education students does not lie solely with the organization of materials. A great deal of its success rests upon the attitude and efforts of the instructor. Of significance in this respect
are the findings resulting from a study made at Hope College. The conclusions of this study showed that

1) the stimulation to thinking and development of thinking abilities and habits are more hoped-for by-products than consciously aimed-at objectives of teaching.

2) the faculty are handicapped in teaching for these objectives by the inadequacy of their understanding of what actually is happening to students in their courses.

3) although faculty members themselves engage effectively in thinking through questions and problems in their discipline, there is a general lack of clear-cut, conscious understanding among the faculty of the principles of sound reasoning and the processes for attacking the problems and questions in their own field, . . . . This inadequacy is a major reason why faculty members do not teach more effectively and why students frequently remain inept in their own thinking.

4) not enough attention is being given to devising questions, problems and projects which will stimulate and even on occasion compel each student to do independent critical or creative thinking.

5) there is too strong a tendency toward authoritarianism in our treatment of students in relation to the academic program.¹


These findings point to a need on the part of the instructor to re-examine his planning and direct attention to a conscious effort toward those objectives other than the transmission of information.

Of vital importance in the use of this approach is the emphasis required on the discussion as it predominates the learning situation. Andrews directs attention to the need for patience in initiating such a
If students are habituated to rote-type learning, their initial responses reflect confusion and frustration. With persistence, encouragement, and understanding direction, however, abilities to think are developed and mature in proportion as they are exercised. The ultimate achievements of good discussion techniques have been summarized by Axelrod. They include

1) making students aware of a given problem and its significance.

2) making students aware of the considerations which must be made in order to arrive at a solution to the problem.

3) requiring students to think through the problems and work out a solution which they will be prepared to present and defend.

4) giving students the opportunity to present the solution which they have worked out, to argue in its support and to answer objections to it, and to encourage them to modify their original solutions in light of those objections and in light of other proposed solutions.

5) enabling students to see, through the modifications they find themselves forced to make, how their original thinking on the issue has been inadequate and where the inadequacies lie.

6) teaching students, through actual practice, the art of discussing an issue with others on a rational basis; to give them practice in interpreting accurately another person's position and in evaluating that position soundly; to inculcate in them the attitude that the best solution (even if it is an opponent's) is a greater end than victory in an argument.

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The skill with which the instructor can keep the discussion to the point yet avoid dominating it to the exclusion of student participation is critical to the success of this method. Of prime importance in this respect is the teacher's confidence in the students' abilities to think. The realization that a contribution of ideas, correct only to a limited degree, may be helpful in promoting discussion can be of assistance in developing this skill. Since initial efforts are apt to be slow, some time lag between question and answer may be essential to permit ideas to germinate. This could be arranged by posing more complex questions at the end of a session, thereby giving the student time for study and contemplation before discussion. The artistry with which students may be provoked into constructive response must be cultivated by the instructor and undoubtedly will vary from class to class.

Because most students are habituated to the acceptance of the authority of the instructor or text, the instructor must avoid a presentation of a predigested thought sequence or divulgence of the accepted responses. This is not to say that erroneous concepts should be accepted. Rather, it implies a technique whereby the habit of questioning ideas is fostered to the eventuality of achieving adequate understanding and a satisfactory solution to the problem. To guide and elicit thought processes while encouraging students to question their results is the essence of skillful discussion leadership.

Needless to say, wherever discussion techniques are used, the instructor must avoid negation, derogatory comment, and similar practices which serve to discourage student participation. Instead, emphasis must be directed to the encouragement of communication to give
the student practice in framing his ideas in his own language and transmitting them for critical examination to others. Such is the only technique by which students can learn to judge their own achievements in comparison with those of others. Moreover, by so doing, they may be led to realize the need for more thorough preparation and more critical examination of resources in solving problems.

An often overlooked factor of prime importance to the learning a student may take with him from any study is that resulting from the techniques of evaluation.

Children soon discover the wisdom of learning what they will be tested on. For this reason the kind of evaluation employed affects children's learning procedures and determines their actual learning objectives, regardless of the objectives that may be set in theory. Few intelligent children continue long to tease out relationships and to understand principles and processes when their learning is evaluated according to other criteria. And we accomplish nothing at all by exhorting children to understand what they learn if we do not measure their understanding.4


It has been expressed repeatedly that the objectives of general education in science include the understanding of the nature and methods of science. To the degree we think this to be important, it is necessary to include such objectives in the evaluation program. There is little doubt that this is a task not well understood by most instructors. Moreover, it is of a nature to demand more effort in preparation than evaluation of absorbed information. For these reasons, testing of
a student's abilities in thinking and understanding tends to be neglected in many instances.

Since tests requiring extensive grading are almost humanly impossible in large classes, some adaptation of the short-answer, objective-type test must be developed. Otherwise, the emphasis of the above mentioned objectives in the evaluation program will continue to be subject to evasion. Heil, Kambly and Mainardi point out that understanding may be indicated by the ability with which the student can

1) cite specific illustrations of factual generalizations and concepts of science;

2) use factual generalizations for the purpose of making predictions in new problems;

3) use factual generalizations for the purpose of explaining a given phenomenon or judging the validity of a given prediction, conclusion, or course of action;

4) use factual generalizations in formulating hypotheses;

5) use factual generalizations as one basis for judging the validity of sources of information.5

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Furthermore, they state that comprehension of method is evident in the student's ability to

1) make proper qualifications when interpreting data;

2) identify necessary and unstated assumptions involved in a conclusion, prediction, course of action, or practice;

3) recognize and use defensible arguments or reasons when justifying a prediction, conclusion, etc.;
4) identify a valid cause and effect relationship when interpreting a given phenomenon.\textsuperscript{6}

\textsuperscript{6}Ibid.

Evaluation of the above mentioned abilities may be done through a variety of means. Observation of student behavior in discussion, laboratory, or during conference can be of help in a partial evaluation of growth. The objective-type test questions, if they are so directed, can also serve this purpose. As an example, the student might be asked

1) to predict the results of an entirely new (to him) combination of materials in view of his generalized knowledge;

2) to correlate a variety of data and from them formulate generalizations not previously encountered in the course of study;

3) to pose a hypothesis relative to a demonstrated phenomenon;

4) to recognize assumptions basic to a given interpretation;

5) to state the limitations under which a specific interpretation would be valid.

Examples of the type of questions which might serve the above and other purposes can found in the literature. One such article suggests the use of the following:

1) A descriptive type question followed by a statement to be classified as

a. statement true plus an expected observation.

b. statement true plus an expected conclusion.

c. statement true but not related to experiment.

d. statement contradicted by established facts or principles.
2) An assertion followed by reasons and classified as

   a. assertion and reasons both true and related as
      cause and effect.
   b. assertion and reasons both true and not related.
   c. assertion true and reasons false.
   d. assertion and reasons false.  

7Gifford, D. W., "Trends in High School Chemistry" (Journal of

Other types of questions of value in this respect might be
phrased as follows:

1) Assume you chose to prepare chlorine by the reaction of manganese
dioxide, sodium chloride, and concentrated sulfuric acid.

   a. What would result if you were to omit the manganese dioxide?
   b. Would this happen if you were using a similar method for
      preparing iodine? Explain your answer.
   c. What purpose does the manganese dioxide serve in the reaction?
   d. Could something else be used in its place? If so, what
      would you suggest?
   e. Would it be possible to substitute potassium chlorate or
      potassium perchlorate for the sodium chloride in the reac-
      tion? Explain your answer.

2) How does the atomic structure of chlorine serve to account for
   a. the diatomic structure of the free element?
   b. the oxidizing activity of the element?
   c. the formation of compounds such as chlorates and perchlorates?
   d. the fact that hydrogen chloride forms an acid in water?
   e. the reactivity of chlorine with most metals?
3) How might you devise an experiment to demonstrate some given principle?

A great number of variations can be developed similar to those shown above which would require the emphasis in evaluation to be directed toward thought processes rather than memory and regurgitation. Although they may require some originality on the part of the instructor, and initial efforts may be confusing to the students, the ultimate goal to be achieved should merit their use.

This study implies that through the use of the proposed approach the students will gain some insight into the nature of a scientific problem and the way in which it might be approached by the scientist. Through proper use it is expected that students will grow in their ability to select and weigh important factors from a tangle of facts, in the ability to place ideas and facts into new combinations appropriate to the solution of a specific problem, in their skill in assimilating facts and a flexibility in revision of their significance as learning progresses, in their ability to create a coherent structure of generalized propositions and to make inferences, and in their ability to approach new problems directly and simply without the waste of "trial and error" techniques so commonly used.

Finally, by exposure to experiences similar to those met under the proposed method, it is expected that the student may better appreciate the work of the scientist and the contribution he makes to the advancement of knowledge. He should also gain in understanding of the nature of such knowledge as it is conceived by the scientist.
CHAPTER VII

PROPOSED METHOD OF EVALUATION

AND SELECTION OF COMMITTEE

The most rigorous method by which a study such as this might be evaluated is to test its application under properly controlled classroom conditions. Such a method would require the solution of many administrative problems dealing with the selection of class members and a parallel control group, assignment of teaching personnel, provision for testing procedures, and some assurance that the experimental and control groups might continue throughout the course of study. This assurance would be greatly dependent upon a voluntary status of the participants.

Since it is common practice for students to compare notes relative to parallel sections of the same course some provision would need to be made to avoid individual concern for future deficiencies in background. Such concern, which may well have an inhibiting effect on learning, could be avoided if the membership were to be restricted to students who have expressed no intention of further study in chemistry, and were willing to continue throughout the entire course in the same section. Because administrative problems made such planning impossible, this study could not be evaluated under actual classroom conditions and an alternate plan was proposed.

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The plan considered most feasible was to solicit the assistance of persons familiar with the problems of teaching introductory chemistry and willing to serve as members of an evaluation committee. It was proposed to submit the unit plans, as outlined, to such a committee to seek their judgment in regard to the merits of the approach and to factors pertinent to the success of such a presentation.

In selecting the judges, it was considered essential that each one be interested in the problem, be familiar with the conventional work in beginning chemistry, and be willing to serve on the committee. Qualifications of potential judges were determined on the basis of current classroom activities, recent publication of articles relevant to problems in teaching general chemistry, and activities associated with publication of textbooks or participation on American Chemical Society committees studying problems related to the area.

An initial group of approximately fifty persons was chosen to be considered for committee membership. With the assistance of members of the advisory committee under which the study was made, the group was reduced to thirty-three persons. To each one of these an introductory letter was sent explaining the study and requesting assistance in its culmination. Sent with this letter was a brief questionnaire dealing with background information concerning the persons who were to participate in the evaluation. As is shown in Table I, page 73, eighteen of this group expressed their willingness to participate, and three of the group transferred the letter to alternates who agreed to assist in the evaluation. This gave a total of twenty-one persons who were to serve as members of the evaluation committee. From this group, twelve
TABLE I

SELECTION OF JUDGES

<table>
<thead>
<tr>
<th>Type of Institution</th>
<th>Private College</th>
<th>State College</th>
<th>State University</th>
<th>Junior College</th>
<th>Other*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number Asked to Participate</td>
<td>8</td>
<td>8 + 1A**</td>
<td>12 + 2A**</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Number Accepting</td>
<td>4</td>
<td>5 + 1A</td>
<td>7 + 2A</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>Number Completed</td>
<td>L*** + 1</td>
<td>L*** + 2</td>
<td>7</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>

* Administrator in Science Education.

** Alternates suggested by initially selected party.

*** Letter returned. Evaluation forms not included.
questionnaires were returned in usable form, two letters were returned without the questionnaires and requesting to be withdrawn from the committee, and no response was forthcoming from seven of the twenty-one persons. On the basis of the expressed judgment of the twelve members who completed and returned the questionnaires, interpretations relative to the merits of the proposed approach were drawn.

Tables II, page 75, and III, page 76, give a summary of the teaching background from which the participants view the material for evaluation. Table II shows that nine of the twelve members of the committee are teaching general chemistry at present. Two of the remaining three are known to have taught such courses within the past two years. The majority of the judges shows a degree of dissatisfaction with the existing course work. All students were enrolled on the basis of some selection, with the majority being placed in accordance with their major field of study. This would suggest the possibility of some special emphasis for non-science students if such were considered desirable.

From Table III, it may be observed that the teaching backgrounds of the committee fall into two general classifications; those having classes over 100, and those having classes below fifty in enrollment. In the former group, classes are composed of students selected on the basis of major fields of study, with approximately 30 per cent of the students' class time devoted to lectures by a senior professor. The remaining 70 per cent of the course work is done by assistants who supervise laboratory and discussion sessions. For this
<table>
<thead>
<tr>
<th></th>
<th>YES</th>
<th>NO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Now Teaching General Chemistry</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>2. Present Course Seems Adequate</td>
<td>4</td>
<td>7</td>
</tr>
<tr>
<td>3. Students are Selected</td>
<td>1*</td>
<td>1**</td>
</tr>
<tr>
<td>4. Basis for Selection Admissions Policy</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Background in Mathematics</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>Major Field of Study</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>High School Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>5. Proportional Division of Teaching Time Lecture</td>
<td>25-50</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Discussion</td>
<td>12-25</td>
</tr>
<tr>
<td></td>
<td>Laboratory</td>
<td>33-57</td>
</tr>
<tr>
<td>6. Use of Demonstrations Extensively</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Occasionally</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>No Response</td>
<td>1</td>
</tr>
<tr>
<td>7. Average Class Size (125-200)</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(25-50)</td>
<td>5</td>
</tr>
<tr>
<td>8. Percentage of Students Continuing to Major in the Field of Chemistry</td>
<td>0-5</td>
<td></td>
</tr>
<tr>
<td>9. Percentage of Students Taking No Further Work in Chemistry</td>
<td>60-85</td>
<td></td>
</tr>
</tbody>
</table>

* Committee Member teaching at a selective private institution.

** Selection by major field of interest.
TABLE III

Administrative Problems Related to Background of Judges*

<table>
<thead>
<tr>
<th>Judge</th>
<th>Class Size</th>
<th>Class time (%)</th>
<th>% of Students taking no more chemistry</th>
<th>% of Students majoring in chemistry</th>
<th>Student Selection Policies</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Distribution Use of Demon.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Lect.</td>
<td>Lab.</td>
<td>Disc.</td>
<td></td>
</tr>
<tr>
<td>A</td>
<td></td>
<td>Not teaching chemistry at present</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>200</td>
<td>30</td>
<td>57</td>
<td>14</td>
<td>Occas.</td>
</tr>
<tr>
<td>C</td>
<td>200</td>
<td>50</td>
<td>38</td>
<td>12</td>
<td>Occas.</td>
</tr>
<tr>
<td>D</td>
<td>125</td>
<td>33</td>
<td>50</td>
<td>17</td>
<td>Occas.</td>
</tr>
<tr>
<td>F</td>
<td>125</td>
<td>30</td>
<td>57</td>
<td>14</td>
<td>Ext.</td>
</tr>
<tr>
<td>I</td>
<td>25</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>Occas.</td>
</tr>
<tr>
<td>J</td>
<td>140</td>
<td>50</td>
<td>33</td>
<td>16</td>
<td>Ext.</td>
</tr>
<tr>
<td>L</td>
<td>125</td>
<td>33</td>
<td>50</td>
<td>17</td>
<td>Ext.</td>
</tr>
<tr>
<td>M</td>
<td>45</td>
<td>23</td>
<td>54</td>
<td>23</td>
<td>Occas.</td>
</tr>
<tr>
<td>N</td>
<td>125</td>
<td>30</td>
<td>57</td>
<td>14</td>
<td>Ext.</td>
</tr>
<tr>
<td>R</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>20</td>
<td>Occas.</td>
</tr>
<tr>
<td>S</td>
<td>50</td>
<td>25</td>
<td>50</td>
<td>25</td>
<td>Occas.</td>
</tr>
</tbody>
</table>

* See questionnaire, Appendix B, page 111, for specific questions.
group adaptation of the proposed method of approach might entail problems of major importance.

In the latter group (those with classes below fifty) classes generally are composed of students selected on the basis of admissions and or background, with approximately 60 per cent of the class time devoted to lecture-discussion work conducted by the senior professor. In each of these situations, laboratory work is supervised by senior staff but not necessarily the same person as the lecturer. In such a situation, adaptation of the proposed method of presentation would be feasible and entail no serious disruption in administrative procedure.
CHAPTER VIII

PROCEDURE FOR EVALUATION AND SUMMARY OF RETURNS

With no way available for making a direct measure of the effectiveness of the proposed approach, some indirect method of obtaining information which might indicate the feasibility and effectiveness of the presentation was needed. The questionnaire which accompanied the unit plans was designed to provide this information.

Because specific topics to be included in any course sequence are selected from the point of view of local objectives as well as generally accepted major objectives, it was considered unnecessary to have the choice of topics judged as appropriate or inappropriate to the course. Instead, care was exercised to select topics assumed to be generally agreed upon as important concepts to be developed in introductory chemistry, and the evaluation was initiated from this point of departure. The wisdom of this assumption was evidenced by the fact that only one committee member made comment regarding the appropriateness of a single topic. His criticism was directed to the merit of including Unit X at the exclusion of other possible topics. Since the ten units were selected to present an approach rather than to represent a complete outline of the course, no such exclusion can be assumed.

In order to develop a case-study effectively, provision must be made for the selection of appropriate experimental work; a logical
arrangement of that work; and suggested discussion questions which could serve to provoke thought, stimulate interest or assist in organizing group thinking toward an appropriate solution of the problem. In this study, units are developed as illustrative of ways to provide for these factors. If these are judged to be adequate in the development of the concepts involved in the view of the members of the evaluation committee, then it is assumed feasible for chemistry to be taught in this way.

As was shown in the discussion relative to the theories of learning, the effectiveness of learning is dependent upon the degree to which the learning is meaningful to the student. Similarly it was shown that meaningful learning is the result of active participation on the part of the student in the formulation of concepts and generalizations basic to that learning. The units are developed to provide background, arouse interest, give organizational assistance, and provoke thought for such participation. If it is the judgment of the committee members that the unit plans meet these demands, then it is assumed that the proposed method might well be more effective than the present practices common in the lecture-laboratory presentation of chemistry.

On the basis of these two assumptions, a questionnaire was designed to determine the degree to which the proposed units met the desired qualifications. The questionnaire, as shown on page 112 of Appendix B, provided the committee members with an opportunity to express their judgment in regard to these factors. Provision was made for positive, negative, or uncertain responses in the expression of decisions with respect to the merit of the individual units, the accompanying experimental work, and the questions incorporated in its development.
In addition to judgments relative to individual units, it was considered desirable to seek judgment concerning a general response to the method of approach. This was done through a second questionnaire shown on page 113 of Appendix B. Here each judge was asked to express his judgment relative to any limitations which might restrict the use of the proposed approach. In regard to these limitations, specific questions were directed to class size, time allowance for the course, selectivity of the students, and availability of equipment. In addition, each committee member was asked to express his judgment as to the use of the approach in his own teaching situation or in the use of the method in teaching via television.

In the interpretation of the responses to this study, it was assumed that a predominance of positive answers to the factors listed above would be indicative of the feasibility of using a case-study approach to teaching introductory chemistry.

The responses of "uncertain" were looked upon as a possible failure resulting from the manner of presentation of the material to convey the implied meaning intended by the investigator. Such a response could also represent the reservation with which any conservative group may view proposals which deviate from a generally accepted pattern. Provision was made to identify reasons for this doubt by requesting an expression of the specific criticism. Unfortunately, only one committee member completed this portion of the questionnaire by commenting on specific responses.

Since the number of committee members was so small and so highly selected, no conclusions could be considered in terms of statistically
valid results. Instead, it was assumed that favorable responses could only serve to indicate that such an approach can be developed, and, on the basis of similar studies in the learning processes, it might be more effective than conventional methods if properly used.

Results in Relation to Individual Questions

The results of the evaluations as submitted by the judges have been tabulated on Tables IV, V, VI, VII. Table IV, page 82, gives an overall view of the responses received. From this it may be seen that, with the exception of one judge, the individual committee members recorded better than 75 per cent favorable responses to the proposed plan. Moreover, only two committee members, C and R, expressed greater than 10 per cent negative responses to the units. Dividing the group into two parts on the basis of class size in their present teaching positions, it can be seen that such a division bears no relation to the relative portion of positive, negative, or uncertain responses. Nor is the teaching situation influential in decisions relating to such factors as the influence of available time on the use of the approach, the desirable class size for effective use, and an expression of usefulness of the approach in the individual's own classroom. Concern for the availability of equipment appears to be the only factor directly related to the class size in the teaching situations of the individual judges. Perhaps this is a reflection of the problems involved in providing adequate equipment in many of the small schools. From these observations, it may be safe to assume that each committee member did not
**TABLE IV**

Summary of Individual Judge's Responses to Questionnaires

<table>
<thead>
<tr>
<th>Class Size</th>
<th>Judge</th>
<th>Responses (%)</th>
<th>Factors Related to Potential Use**</th>
<th>Personal Use</th>
<th>Class Limit</th>
<th>Use on T.V.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Student Selection</td>
<td>Course time</td>
<td>Equipment</td>
<td></td>
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<tr>
<td>Over 125 Students</td>
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<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>100</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>46 33 20</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>78 5 17</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
</tr>
<tr>
<td></td>
<td>F</td>
<td>91 2 7</td>
<td>N</td>
<td>N</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>J</td>
<td>92 2 6</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>L</td>
<td>75 4 21</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
</tr>
<tr>
<td>Under 50 Students</td>
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<td>88 1 11</td>
<td>U</td>
<td>U</td>
<td>Y</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>I</td>
<td>100</td>
<td>Y</td>
<td>Y</td>
<td>N</td>
<td>Y</td>
</tr>
<tr>
<td></td>
<td>M</td>
<td>88 12</td>
<td>Y</td>
<td>U</td>
<td>Y</td>
<td>N</td>
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<td></td>
<td>R</td>
<td>77 14 19</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
<td>U</td>
</tr>
<tr>
<td></td>
<td>S</td>
<td>80 20</td>
<td>Y</td>
<td>Y</td>
<td>Y</td>
<td>U</td>
</tr>
</tbody>
</table>

*Return incomplete - Data based on seven units

**See Questionnaire, Appendix B, page 113, for questions used.
permit his own teaching problems to influence unduly the decisions expressed in responses to the questionnaire.

From Table IV, it may also be seen that, with one exception, it was agreed that such an approach would be of use only in small classes (less than forty students). The majority expressed the judgment that there should be some selection of the students, preferably on the basis of adequate background in mathematics and above average ability, if such a presentation is to be successful. With the exception of three judges, it was agreed that the time available for a course would limit the use of such an approach. However, five of these judges felt it better to limit the material covered than to exclude use of a more effective method if such a choice must be made.

Table V, page 84, gives a summary of all responses to the questionnaire dealing with the individual unit plans. To assist in the interpretation of these data, Tables VI, page 85, VII, page 87, and VIII, page 88, show an analysis of the negative and uncertain responses given by the individual judges. These three tables identify the degree of dissatisfaction with respect to each item being investigated and in reference to each specific unit.

As may be seen from Table VI, only one item (question 2, dealing with the sequence of the experimental work) received more than 8 per cent negation. Sixty-two per cent of the negative responses on this item (2) were submitted by judge C, who commented in reference to his decisions as follows:

A most difficult assignment to evaluate without knowledge of the teacher, class, etc. Obviously a teacher in the field who has his own text, which he feels has an order of presentation,
### Tabulation of Responses

<table>
<thead>
<tr>
<th>UNITS Responses</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
</tr>
</thead>
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<td>Item*</td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
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<td>-</td>
<td>11</td>
<td>-</td>
<td>1</td>
</tr>
<tr>
<td>1b</td>
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<td>1</td>
<td>4</td>
<td>10</td>
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<tr>
<td>3</td>
<td>8</td>
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<td>2</td>
<td>10</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
<td>11</td>
<td>-</td>
<td>1</td>
<td>9</td>
<td>-</td>
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<td>6</td>
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<td>9</td>
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<td>6</td>
<td>7</td>
<td>3</td>
<td>2</td>
<td>10</td>
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<tr>
<td>% Total</td>
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<td>19</td>
<td>83</td>
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* See questionnaire, Appendix B, page 112, for specific items.

** Judge D failed to complete these three units.
### Proposed Unit Plans

<table>
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<tr>
<th>VI</th>
<th>VII</th>
<th>VIII**</th>
<th>IX</th>
<th>X</th>
<th>% Total</th>
</tr>
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<tbody>
<tr>
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<td>-</td>
<td>-</td>
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<td>-</td>
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</tr>
<tr>
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<tr>
<td>2</td>
<td>1</td>
<td>6</td>
<td>92</td>
<td>2</td>
<td>6</td>
</tr>
</tbody>
</table>

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None.
TABLE VI

Unit Distribution of Negative Responses to Proposed Plan

<table>
<thead>
<tr>
<th>UNITS</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>(%) Total Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Item</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>la*</td>
<td></td>
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<td></td>
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<tr>
<td>ld</td>
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<td>C</td>
<td></td>
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</tr>
<tr>
<td>2</td>
<td>C,R</td>
<td>C,D</td>
<td>C</td>
<td>J</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>C</td>
<td>R</td>
<td>R</td>
</tr>
<tr>
<td>3</td>
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<td>C</td>
<td>C</td>
<td>J</td>
<td></td>
<td>C</td>
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<td></td>
<td></td>
<td>R,L</td>
<td>7</td>
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<tr>
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<td>C</td>
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</tr>
<tr>
<td>% Total</td>
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<td>7</td>
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<td>8</td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>4</td>
<td>6</td>
<td></td>
</tr>
</tbody>
</table>

* See Questionnaire, Appendix B, page 112, for identification of specific items.

** All letters are code identify of individual judge.
based upon long years of experience, best suited to the first year student, will be somewhat skeptical of changes from that order. . . . to do real justice to your plan one would have to devote far more time than is available.

Since no further comments were made relative to specific responses, the negative responses from C were assumed to be explained wholly by the above comment. These constituted 55 per cent of all negative responses, as may be seen in Table VIII, page 88. C also submitted 19 per cent of all of the uncertain responses received.

Responses relative to the presentation of background (item 1b), grouping of experimental work (item 3), ability of students to respond to questions (item 5), and adequacy of the development of proposed concepts, each showed a 7 to 8 per cent negation. Here again the responses from C predominate and are assumed to be explained by the above statement. Among these negative responses, however, is a liberal sprinkling of no's from judge R. In fact, 24 per cent of all negations were submitted by R. Together, R and C submitted a total of 79 per cent of all negative responses. Only five other committee members submitted any negative responses. Since comments relating to the decisions submitted by R were made for specific units, they will be incorporated in the discussion dealing with the analysis of these individual units.

Examination of Table VII, page 87, shows the responses of uncertainty to fluctuate about 10 per cent for each item on the questionnaire. Since any interpretation of such responses could only be judged on the basis of proffered explanations, and the few such explanations were submitted in reference to specific units, they will be discussed subsequently. In general, however, they appear to be an
TABLE VII

Unit Distribution of Uncertain Responses to Proposed Plan

<table>
<thead>
<tr>
<th>Item</th>
<th>I</th>
<th>II</th>
<th>III</th>
<th>IV</th>
<th>V</th>
<th>VI</th>
<th>VII</th>
<th>VIII</th>
<th>IX</th>
<th>X</th>
<th>(% Total Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>1a</td>
<td>L</td>
<td>C</td>
<td>M</td>
<td>S, L</td>
<td>J,M</td>
<td>C,N</td>
<td>C,L</td>
<td>M</td>
<td></td>
<td></td>
<td>10</td>
</tr>
<tr>
<td>1b</td>
<td>C,D</td>
<td>M,S</td>
<td>S</td>
<td>R</td>
<td>D,L</td>
<td>R</td>
<td>C</td>
<td>S</td>
<td>L,M</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>1c</td>
<td>C,D</td>
<td>N,S</td>
<td>C</td>
<td>S</td>
<td>L</td>
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<td>S,C</td>
<td>C</td>
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<td>8</td>
</tr>
<tr>
<td>1d</td>
<td>D,S</td>
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<td>R</td>
<td>J</td>
<td>R,N</td>
<td>L</td>
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<td>C,L</td>
<td>L,F</td>
<td></td>
<td>11</td>
</tr>
<tr>
<td>2</td>
<td>J,L</td>
<td>S,R</td>
<td>S,L</td>
<td>M</td>
<td>S</td>
<td>S</td>
<td></td>
<td>C,L</td>
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<td>C</td>
<td>C</td>
<td>S,N</td>
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<td>C,F</td>
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<td>4</td>
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<td>C,R</td>
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<td>C</td>
<td>C</td>
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<td>L,N</td>
<td>F</td>
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<tr>
<td>6</td>
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<td>D</td>
<td>D</td>
<td>D</td>
<td>M</td>
<td>M</td>
<td>C,N</td>
<td>S</td>
<td>F</td>
<td></td>
<td>10</td>
</tr>
</tbody>
</table>

* See Questionnaire, Appendix B, page 112, for identification of specific items.

** All Letters are code identity of individual judges.
TABLE VIII

Percentage of Total Negative and Uncertain Responses

by Individual Judges

<table>
<thead>
<tr>
<th>Judge</th>
<th>(% Total Responses) Negative</th>
<th>Uncertain</th>
</tr>
</thead>
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<td>0</td>
</tr>
<tr>
<td>B</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>54.6</td>
<td>18</td>
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<tr>
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expression of reservation which might readily arise as a result of the limited and introductory nature of the proposed materials. The degree to which they reflect a tendency of college teachers to be conservative with respect to teaching practices is uncertain.

The greatest degree of uncertainty (12%) seemed to lie in doubts concerning the ability of students to respond to the questions (item 5) posed to develop thought processes. As was anticipated in the discussion pertaining to the use of the units, this difficulty may demand a rephrasing of the question or the addition of necessary clues to the desired response. Such highly specific details had to be excluded from the textual materials submitted for examination and evaluation.

**Results in Relation to Individual Units**

If responses are studied on the basis of individual units, by far the greatest degree of doubt was shown concerning Unit I. The judges expressed 10 per cent negation and 19 per cent uncertainty for a total of 29 per cent of the possible responses on this unit. Moreover, this was the only unit in which more than 50 per cent (67%) of the committee expressed some degree of doubt as to its use. In the submitted explanations relating to their positions in such decisions, two specific criticisms predominate. The first centered about dissatisfaction with the questions posed in the unit. The comments included objections to using questions which (1) had no known answers, (2) were very general and encouraged diffuse answers, and (3) were so complex as to require extensive help or outside reading. The second criticism suggested that the preparation and use of charts and other demonstration
materials required too much time and effort, or such materials would be either too superficial or too involved for students to understand.

These criticisms reflect a failure on the part of the investigator to communicate the intended function of this introductory unit. The abstract was presented in anticipation of such misunderstanding to assist in the interpretation of the function the unit was to serve. It appears to have been inadequate in this respect. As explained, this introductory unit was designed as illustrative of (1) the type of problem the chemist might study, (2) the extent to which applied chemistry influences daily living, (3) the type of problem the chemist seeks to answer in his efforts to advance the frontiers of knowledge, and (4) a sampling of the observations which might serve to initiate a chemical investigation. In anticipation of doubts arising from the posing of unanswerable questions, it was specifically stated in the abstract that, "New problems are continuously evolving. . . . The nature of these problems and the direction toward which chemistry may develop in the future may be evident in the diversity of questions which the chemist seeks to answer." The above criticisms appear to indicate that the judges neglected to read the abstract intoto before proceeding to subsequent material.

The selection of materials for the development of these four objectives of an introductory unit is, undoubtedly, a highly individualized matter. The extent of balance between the use of simple questions which serve to develop a student's confidence or more complex questions to encourage adventure into the unknown is one which must be made in light of the students' and instructor's interests. It is this investi-
gator's judgment that questions demanding immediate response are of greatest value in the discussion of the background materials proposed here as displays and charts. Moreover, it seems that such a unit is an ideal place for the introduction of the puzzles which, through future work and study, are to evolve continuously throughout the course into understandable concepts. The fascination which such mystery may hold for an active mind can be a highly motivating force.

In considering the use of unanswerable questions, one is only facing the reality of science as it exists. To limit any selection to the problems already solved, on the assumption that there are such problems, would convey a concept of the status quo which is untenable. Furthermore, it seems reasonable that, in order to convey the concept of "frontiers to conquer," such questions are necessary. The way in which such questions are used is probably a most vital factor in their effectiveness. They can serve to stimulate curiosity, to guide a student to the literature in search of a background relating to what has been achieved in the direction of a solution, and to encourage expressions of originality. It is difficult to conceive of a better technique for stimulating creativity, for, in any group, the selection of answered problems will inevitably touch upon questions introduced in previous study. Furthermore, a satisfaction with half-answers is all too common in preventing the effective use of creative thinking by many students.

In reference to the diffuse nature of the responses which such questions might call forth, this can readily be restricted by the teacher who is willing to say, "Are you sure?" "How might one proceed to find out?" and similar leading probes. A limited use of such a
discussion procedure can serve a useful purpose in developing an understanding of "problem-solving" techniques.

In regard to the time-consuming efforts required to prepare and use the proposed visual aids, it might be said that time and effort are required in all phases of good teaching. The question then arises as to the portion of time which can be spent in preparation and presentation of any single phase of a course. There is little doubt that the lecture is much more easily prepared than any other classroom procedure, especially if the course has been taught previously. The question, then, resolves itself into the relative degree of emphasis to be made on selected materials. The use of visual aids serves as emphasis by providing multisensory stimuli, and, by so doing, serves to impress upon the student the importance of the learning involved.

The use of the suggested displays, charts, and models need not be so time consuming as presumed. Collections can be assembled and rotary displays developed which can serve a most useful purpose in the stimulation of interest throughout the course. Moreover, they serve a most important function in continuously calling attention to the impact of the field upon the student's life and environment. If these materials are made available for browsing and accompanied by suggested readings, those students who wish to gain from them can do so with limited encouragement. Skillful teaching can provide that encouragement through discussion in class or extra-class conversations. Learning so motivated is essentially what is needed if it is to be functional in the solutions of problems arising from daily living in post-school years.
Unit X proved to be second in the degree of doubt which it evoked. Out of the total responses on this unit, there was 6 per cent negation and 15 per cent uncertainty as expressed by 50 per cent of the judges. Few comments were made relative to the reasons for such decisions, but seven of the twenty-one doubtful responses were given by a single participant who commented, "I fail to see the basic importance of this topic in contrast to the others." One other judge considered the unit too long.

The expressed doubt may be due to the novelty of the approach as presented. Although the actual content is generally presented in beginning chemistry with varying degrees of complexity, and point of view of the approach is unique. As presented, it is intended to tie together a fund of ideas into a unifying interpretation of the behavior of the materials of the universe. The uncertainties evoked may well be due to the conservatism of the committee members or may be the result of satisfaction with existing procedures. The approach does add to the conventional material dealing with energy concepts in relation to the behavior of matter and could involve more lengthy study in comparison with the other units. The degree to which the material is expanded into a more comprehensive unit would be an individual problem which must be solved in relation to the ability of the students and the interest with which they seek to pursue the problem further.

No other units were singled out for specific criticism by the judges. Some comments were forthcoming as to alternate experimental work or correction of typographical errors, but nothing was said relating to the approach. Especially favorable comments were made
concerning the development of Units III, VIII, and X. Unit III received more favorable comment than other units, with four of the twelve judges choosing to make special note of its merit.

Since the Units II through IX showed more than 80 per cent affirmative responses, it was assumed that their development was in accord with the intended purposes as emphasized in the questionnaire. Some general comments were made by a few of the judges, however. Two questioned the length of time to be allowed for the work as outlined. Another asked if laboratory work was to be used in conjunction with the presentation. Some felt that certain questions were beyond the "realm of reason" without extensive outside reading and help from the instructor. A final comment suggested that the effectiveness of any method of teaching rested heavily upon the instructor's interpretation of his responsibilities.

No specific answers are possible for these questions, but it may be possible to propose an interpretation as an answer. First, the time required for the presentation of these units will greatly depend upon the detail with which they are developed and the direction in which they lead the class toward more extensive study. Since they are designed to be introductory, they should be developed in such a way as to lead the student beyond the limited material presented and on to questions of a more profound nature. Because they are predominantly the type of work presented early in any chemistry course, they, of necessity, must serve to lead into more advanced work as the course objectives and class interests may dictate.
The use of laboratory work in conjunction with this material will depend upon the facilities available. It is conceivable that Unit III, for example, might be presented entirely through individual laboratory work. On the other hand, units such as IV, requiring more elaborate equipment, could not be presented in this way. Perhaps a more important function of the laboratory, when used with such an approach, would be through its use for the development of individual projects by the student. In this way, each student could follow in greater detail those interests aroused as a result of the introductory work. Moreover, the material to be studied subsequent to the completion of these units, undoubtedly, will involve extensive use of the laboratory.

The criticism regarding the need for outside reading and assistance is puzzling. In the discussion on the importance of this study in general education, emphasis was made on the need for nonscience majors to develop confidence and ability to study independently. If they are never required to do so, it is difficult to see how such a development can evolve. Of course, reference materials must be made available, and textual resources must accompany the presentation. These were omitted solely because of the individualistic character of such materials in any specific library. It was felt that such material would be of limited use beyond any specific situation and would serve only to add to the already heavy burden of the evaluation committee.

Finally, there can be little doubt concerning the degree to which the individual instructor is responsible for the effectiveness of any method of teaching. It seems wise to make a distinction, here, however, between thought stimulation and its ultimate effectiveness, and
entertainment with its limited interest stimulation. Properly used audio-visual materials of all types have a direct influence upon the effectiveness of learning. Little value results from the extremes found in use where they are never used or where they are introduced solely for the purpose of entertainment. It is also questionable whether any method can serve to enhance the effectiveness of the man who doesn't want to teach. By the same token, it is conceivable that any method can be made effective in the hands of the really inspiring teacher.

This investigator is most appreciative of the burden added to the already crowded schedule of responsibilities of the cooperating judges. Their frank and concise suggestions were most helpful in providing a basis upon which the merit of the proposed approach might be evaluated. The predominance of favorable responses serves to indicate the potentiality the plan holds for enhancing the effectiveness with which introductory chemistry may be presented. From this response it may be tentatively concluded that the proposed approach represents a feasible way to approach the presentation of general chemistry for the general education student.
CHAPTER IX

SUMMARY AND CONCLUSIONS

The purpose of this study was to determine the applicability of a case-study approach to the teaching of introductory chemistry for the non-science major in a general education program. It is believed that such an approach can be made more effective for this group of students than is the conventional expository lecture method.

The importance of this study is an outgrowth of the multiplicity of needs relating to science and technology which arise as a result of the problems of community living encountered by modern man. The demands made upon democratic citizenry dictate a need for greater interest and understanding relative to the rapidly expanding body of knowledge resulting from the scientific enterprise.

Historically, science is a young discipline and its message has not been effectively communicated to the vast portion of the literate populace. In its infancy it held no place in the classical university programs. Moreover, there is evidence to show that, whereas it shared

1Ashby, Sir Eric, op. cit.

an important place in the literary achievements of the eighteenth and nineteenth century, it has gradually lost its status in the literary
programs of the modern educational curricula. If the needs for a scientifically literate citizenry are to be met, such a trend cannot continue unchecked.

\[ \text{Gallant, J., op. cit.} \]

The approach to this problem as presented in this study is directed specifically to the area of chemistry. There is nothing inherent in this approach, however, which would limit its use to this field. In fact, much of the material selected for use is common to the field of physics, and additional units could be developed which are related to mathematics and the biological sciences.

Recent advances in understanding of the learning process provide the basis for the proposed approach. The case method of approach, as adapted herein, places emphasis upon an inductive development of the concepts basic to the selected learning. A study of the learning processes has shown learning to be more effective when it enables the student to develop the desired concepts and derive the related generalization. It is proposed in this study that this approach is feasible and may be found to be more effective than the conventional lecture-laboratory approach.

To implement this study, ten topics commonly presented in introductory general chemistry were selected and developed as illustrative of the proposed approach. Each topic was developed, as nearly as possible, from the experimental point of view. This provided the student with an opportunity for observing, sorting out, and organizing the appropriate experimental evidence required to solve the selected problem.
through the use of leading questions he was then assisted in correlating the evidence and drawing conclusions appropriate to its interpretation.

Because administrative problems prevented a direct measure of the effectiveness of such an approach, an evaluation of the study was made through the cooperation of a group of chemistry teachers volunteering to serve in the capacity of judges for the purpose of the evaluation. These individuals were selected from persons having an active interest in the problems of the general chemistry program as it is currently in use in the colleges today. To assist the evaluation committee, each unit plan was accompanied by an abstract designed as a preview of the concepts to be developed in the unit and an outline of the experimental work to be discussed. This abstract could serve as a summarizing statement in using the unit plans.

Effective learning has been shown to be proportional to the extent to which a student participates in the evolution of the concepts involved. An evaluation of the proposed approach must serve to establish the degree to which such participation is required of the student. For this reason, the judges were asked to evaluate the function of the proposed material in (1) arousing interest in the problem, (2) provoking thought directed toward a solution of the problem, and (3) providing a logical sequence which could assist in organizing evidence in such a way as to lead to the development of the desired concepts. Affirmative response from the judges concerning these functions was considered to be

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3Brownell, W. A., op. cit. Also E. R. Hilgard, op. cit.
indicative of the adequacy of the proposed approach in providing for this participation.

From the summary of results, it may be seen that an overall affirmative response of 85 per cent and an average negative response of 5 per cent were received. From such results, it may be tentatively concluded that the approach, as outlined, is a feasible one. The affirmative judgments point to the fact that experimental work can be selected, arranged in logical sequence and presented by the proposed method. Moreover, such experimental work may be accompanied by questions which are effective in provoking thought and providing a framework upon which the students may develop the basic understanding essential to effective learning.

In the light of present knowledge relative to learning processes, it may reasonably be concluded that the proposed method provides an approach which should, with continued refinement, prove to be more effective than the conventional procedures in common use. As with any teaching method, however, the ultimate effectiveness does not rest solely with the mechanics of selection, organization, and presentation of materials. Much depends upon the sensitivity of the instructor to the total teaching-learning situation. This sensitivity has its basis in an understanding of the way in which a student learns and a knowledge of the factors which can encourage or inhibit this learning. Furthermore, it requires a predisposition on the part of the instructor to make use of such knowledge in all aspects of the teaching situation from the initial presentation through to the final evaluation of the learning products desired.
The lack of a conscious understanding of the factors basic to the learning processes was shown in the Hope College study to be the underlying cause for ineffective teaching and the failure to affect competence in thinking on the part of the students.\textsuperscript{4} The potential this approach holds for effective teaching depends greatly upon the effort of the instructor to acquire and make use of this understanding.

In addition to their evaluation of specific factors related to the individual units, the judges indicated some limiting factors which may serve as proper cautions to those wishing to pursue experimental teaching along the general lines of the case-study approach. Among these limiting factors are found (1) the need to limit class size in using discussion techniques, (2) the desirability of selecting student members on the basis of ability and background, (3) the need to limit the amount of material to be studied in order to permit time for more comprehensive study of the selected material, and (4) the need to provide adequate reference materials and essential equipment for the work. From the preceding discussion, it may also be said that the selection of instructors who can and will apply the techniques essential to the success of the case method is a critical factor in its effectiveness.

In many ways, this has been a pioneer study in relation to the area considered. In the course of its progress, it became evident that all too frequently there were serious limitations to the information available relative to the various aspects of teaching college chemistry considered herein. Those problems requiring further study might be

\textsuperscript{4}Hollenbach, John, and C. DeGraef, \textit{op. cit.}
classed in three categories: those related to the extension of the present study, those related to the improvement of college teaching in general, and those related to the student.

Of those concerned with the extension of this study, the most obvious is the need to put the proposed method to a test under actual classroom conditions. This most probably would need to be done in an institution large enough to have multiple sections in beginning chemistry, but some cooperating plan might be worked out between two or more institutions interested in the problem.

Two other areas of study arise from the dearth of supplementary materials available in most schools for adaptation to use in the proposed approach. One of the areas might develop around a study of available reference materials and sources which could accompany the case-study approach. The second area of study is related to the laboratory work which might be developed to provide the best possible experiences necessary to fulfill the objectives for the general education students. In all probability the best possible laboratory experiences might result from the selection and development of appropriate projects.

In the area of improving college teaching there is only limited information available as to the actual practices and needs. Because the teacher is the focal point about which effective teaching radiates, this should be a most fruitful place from which to initiate a study directed to more effective teaching practices. It may be of help to discover the degree to which specific practices are inherent in the classroom activities of the more effective instructors and lacking in the procedures involved in less effective teaching. Because one tends to teach as one
has been taught, perhaps a study should be made on the influences of existing graduate school practices in using teaching assistants on their subsequent effectiveness in the classroom. Above all, it seems evident that in order to improve some change must be made and to encourage instructors to experiment with teaching practices is an important step toward that change.

More effective teaching also requires a greater receptivity on the part of the student. The reticence with which many approach the sciences seems to have a deep-seated foundation. It may be well to explore the source of this attitude and make efforts to correct the situation if possible. Just what influences have served to develop this reticence? How much of it is the result of the reputation science has for being a difficult course? To what extent does the discriminatory cost of a scientific course cause some students to evade such courses? These and many other questions must be answered before a program to develop public literacy in science can be truly effective.
APPENDIX A

CORRESPONDENCE
List of Judges

1. Clarence H. Boeck, University of Minnesota, Minneapolis, Minnesota.
2. James F. Bonk, The Ohio State University, Columbus, Ohio.
3. Robert Brasted, University of Minnesota, Minneapolis, Minnesota.
4. Daryl H. Busch, The Ohio State University, Columbus, Ohio.
5. Jack G. Calvert, The Ohio State University, Columbus, Ohio.
* 6. J. Arthur Campbell, Harvey Mudd College, Claremont, California.
8. Frank M. Dudley, West Palm Beach Junior College, West Palm Beach, Florida.
11. Robert L. Shirley, The Ohio State University, Columbus, Ohio.
14. Wilmer J. Stratton, Ohio Wesleyan University, Delaware, Ohio.
15. Donald B. Summers, New Jersey State College, Glassboro, New Jersey.

* Only letters returned. Questionnaires not included.

** Questionnaire incomplete and returned too late to be included in study.

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Letter of Solicitation for Assistance

Dear 

By way of introduction, I am a graduate student at Ohio State University and am working on a dissertation problem relating to the teaching of general college chemistry. It is my thesis that the teaching of chemistry could be made more effective if it were to be approached with more emphasis on the experimental methods by which it has been developed.

I propose to select ten topics which might be included in a conventional sequence of general chemistry and develop them with two goals in mind, (a) to lead the student to develop some basic concepts through more extensive emphasis on experimental work and the interrelating of data from a variety of experimental sources, and (b) to use a case-study type of approach utilizing both recent developments and historical bases for the interpretation of each problem.

Ideally, such a study should be evaluated over a period of years under controlled classroom conditions not available to me at this time. As a result, it is my proposal to submit this material to a number of teachers who are recognized among their colleagues as being successful teachers of chemistry, and who are known to be active or interested in the problems of teaching introductory chemistry. Your name has been suggested to me by Dr. A. B. Garrett as one who fulfills these requirements. It is with this in mind that I am writing to inquire as to whether you are able to give me the benefit of your judgment pertaining to this study. I am aware of the demands upon your time and will do my best to keep further demands to a bare minimum.

If you can help in this project, copies of the suggested topics, as I have proposed to develop them, will be submitted to you in the near future accompanied by a checklist to serve as your guide in judging the material. If you are able to assist, please complete and return the enclosed information form. This will serve as a basis for the interpretation of the checklist which is to accompany the unit plans.

Your time and efforts on behalf of this study directed to the improvement of the teaching of chemistry are greatly appreciated.

Respectfully yours,
Letter of Transmittal of Proposed Unit Plans

Dear ________:

Your expressed willingness to assist in the evaluation of the enclosed material is greatly appreciated. Perhaps a brief summary of intent and plan will save you time in this task.

In this evaluation, please keep in mind that this study aims at an inductive approach to the teaching of several selected topics from general chemistry. It is an approach to the teaching of an experimental science through extensive use of experimental evidence. The units are chosen and planned in the hope that they will give the student some insight into the way problems might be approached in the experimental sciences. Each unit, as presented here, is not intended to be comprehensive but, instead, to serve as introductory material. Each unit would be accompanied by selected references from the text as well as from supplementary sources as suggested in Unit I, and in all instances further discussion would depend upon the abilities and needs of the students.

Each unit is organized in four major divisions as follows:
1. Statement of Problem as it would be presented to the students.
2 and 3. Abstract and Outline of Approach to give the evaluation committee a preview of the point of view from which the problem is to be studied.
4. Proposed Approach which varies with units but consists generally of
   a. Preliminary questions designed to direct the students' thinking in relation to the problem and not always of a nature to require answering.
   b. Experimental material presented in a variety of ways such as (1) displays, graphs, charts and tables prepared in advance and presented in such a way as to assist the student in observing necessary correlations as well as to give him an appreciation of the wide variety of information available for the formulation and validation of theories

(2) experimental material presented as demonstrations or laboratory work as facilities permit.
c. Questions interspersed throughout the experimental work to stimulate thinking toward a solution to the problem. In practice, it may prove necessary to rephrase some questions or to pose others as a clue to the responses sought.

It will probably save you time if, before you read the plans, you study the two evaluation forms and formulate ideas relative to the type of judgment to be made.

Let me again express my thanks for your cooperation in this matter. Your objective and irank evaluation will be greatly appreciated.

Respectfully yours,
Follow-up Letter to Judges

Dear __________:

In accordance with our previous exchange of letters, a set of materials dealing with an inductive approach to the teaching of general education courses in introductory college chemistry were mailed to you on March 21, 1959.

Realizing that you may have been enroute to the Boston meeting at the time of their arrival, I am sending this letter to inquire as to their reception. In the event that they have not been received, it would be appreciated if you could notify me of this fact by returning the enclosed postcard. I will send a duplicate set for your consideration, if you so indicate.

In the event that the evaluation forms have been returned recently, please ignore this follow-up and accept my most sincere expression of appreciation for your generous cooperation on behalf of this study.

Respectfully yours,
APPENDIX B

QUESTIONNAIRES
I (will, will not) be able to assist in an evaluation of materials relating to the teaching of general chemistry.

BACKGROUND INFORMATION

To be completed by those who will assist in the evaluation. Please answer in consideration of your own institution only. Answer by underscoring correct response or completing blanks.

1. I (am, am not) now teaching in the area of general chemistry.

2. The average general chemistry class has ____ (number) students.

3. These students are (selected, not selected) on the basis of (admission policies, ability, major fields of study, high school background in chemistry, other means such as ______________________

4. In teaching general chemistry, the portion of time is divided approximately as follows: lecture ____%, laboratory ____%, discussion ____%.

5. Demonstrations are used (extensively, occasionally, rarely, never).

6. The present general course seems (to be, not to be) quite adequate in serving the needs of all the students enrolled.

7. Approximately ____% of the students take no further work in chemistry.

8. In general ____% of the students continue as majors in chemistry.

9. The text(s) used in general chemistry (is, are) __________________

Signed __________________________
PART I

(Please answer by marking in the appropriate space for reply. Y = Yes, N = No, U = Uncertain. For each No or Uncertain answer, your comments explaining criticism would be helpful. A blank page for this purpose is attached hereto.)

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1. Selected experimental work is effective in
   a. arousing interest in the problem.
   b. presenting proper background to the solution of the problem.
   c. presenting the problem.
   d. provoking thought directed to a solution of the problem.

2. Experimental work is in appropriate sequence for presentation.

3. Grouping and interrelating of experimental work is consistent with the development of the principles involved.

4. Questions are effective in provoking and directing thought.

5. Anticipated answers are within the "realm of reason" in respect to the abilities of first-year students.

6. Concepts are adequately developed to provide a basic understanding for more detailed study to follow in an elementary course.
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PART II

(Please express your opinion in relation to the merits of this approach as proposed in the unit plans presented.)

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1. Procedure as developed would be limited in effectiveness to a selected group of students.

2. If students should be selected (yes on 1 above), how would you make the selection? (i.e., ability, non-science major, etc.)

3. A class size of ____ (number) students would be the limit for effective use of method suggested.

4. Time allowed for course would limit use of approach.

5. Presentation may have special significance in teaching by television.

6. Would you find such an approach useful in your teaching situation?

7. Are the material and equipment required for selected experimental work generally available in your department?

8. Please express below any further criticism or suggestions which you think might be helpful.
APPENDIX C

UNIT PLANS
Unit I

What is Chemistry All About?

Problem:

The objective of chemistry is an identification and interpretation of the behavior of all the materials in the universe from the tiniest, sub-atomic particle to the components of the most distant galaxies. In order to achieve this objective, what are some of the problems which the chemist seeks to solve through his studies?

Abstract:

The chemist studies the structure, composition and reactions of the materials in the universe in order to establish a basis for its interpretation. Among the great successes of his work has been his ability to analyze, duplicate and improve upon natural products. Such success has given him confidence in his theories about the behavior of matter, but he does not limit his work solely to this area of applied chemistry. New problems are continuously evolving as a result of current laboratory studies. The nature of these problems and the direction toward which chemistry may develop in the future may be evident in the diversity of questions which the chemist seeks to answer.

Outline of Approach to the Problem:

The nature of chemistry may best be understood through a realization of the extent to which it reaches into all aspects of life and its environment. This may be emphasized through the use of

A. preliminary questions of a wide variety to illustrate the types of problems a chemist might study.

B. displays of the products of applied chemistry to convey its influence on daily living.

C. charts or models to introduce areas in which the theories of chemistry play a major role.

D. selected, common, everyday phenomena to illustrate the variety
of observations which might initiate a chemical investigation.

**Proposed Plan of Approach:**

A. Preliminary questions posed for the purpose of arousing interest and stimulating thought

1. Interpretation of the Universe

   (a) How do we know the nature of gases on the sun and other stars?

   (b) What evidence leads us to believe that life, as we conceive it on earth, does not exist on most other planets in our solar system?

   (c) How have we determined that the atmospheres on other planets differ from that of the earth?

   (d) How should the knowledge of materials found on the moon aid us in understanding more fully the origin and age of the universe?

2. Understanding of Life Processes

   (a) Why does man, a purposeful being, thus far remain totally dependent upon the chemical "factories" of green plants for his source of food and energy?

   (b) Why can a cow (or other ruminant) consume hay, convert it to meat or milk and provide us with food constituents (such as complete protein) without which we cannot live, yet man cannot, himself, digest hay to produce these essential food constituents?

   (c) How does the body select just those materials it needs from our food, rearrange them into materials of which body tissue is composed, and eliminate all other food constituents not essential to our growth and general health?

   (d) How have the facts accumulated from the chemists' research served to provide us with better health, longer life expectancy, more comfortable and convenient living? Have these advances resulted in any detriment to man?

   (e) How do the senses of taste and smell function?
(f) Are the processes of mental activity, such as thinking, memorization, and learning of a chemical nature or controlled by body chemistry?

3. Miscellaneous

(a) Why are some trees deciduous and others not? Why do leaves change color in the fall?

(b) What is color? How do our senses respond to it? Why are there no blue roses or jet black tulips?

(c) Why does the addition of Epsom salts to the soil change the color of the blossoms on a hydrangea plant?

(d) What are the essential differences between chemistry and alchemy?

(e) How does it happen that hydrogen (a gas used for high temperature welding) and oxygen (a gas essential to combustion as commonly known) combine to form water (a material used extensively for extinguishing fires)?

(f) We say that our principal source of energy is from the sun. Why then does the atmosphere get progressively colder as we move out toward the sun into rarified air?

(g) How may we develop a lighter weight, easier to handle, high-energy fuel to enable us to increase the pay-load of rockets?

(h) Why does salt taste salty, sugar taste sweet, and a lemon taste sour?

B. Displays

Prepare a series of displays dealing with applied chemistry and showing a wide variety of materials in common use, i.e., the products of chemistry used in the home, in agriculture, in medicine, and in industry. These may be assembled and continuously revised as a means of impressing upon the students the importance of chemistry in their lives.

C. Some problems under study: the advancement of knowledge through chemistry

1. CHART - Understanding the Universe

   Its Composition    Its Age    Its Origin
2. MODELS - Structure of Matter and Its Relation to Properties
   a) Crystalline materials
   b) The structure of textiles
   c) The structure of proteins, fats, and carbohydrates

3. CHART - Understanding the Nature of Life
   a) The processes of growth - chemistry of metabolism
   b) The body catalysts - vitamins, minerals and enzymes
   c) The body regulators - hormones
   d) The nature of heredity - genes and their function
   e) Needs and uses for trace elements in body metabolism
   f) How do drugs perform specific and irresistible actions on the human body?
   g) Why can't man live forever? - the chemistry of aging

4. CHART - Other Questions Being Studied
   a) Radioactivity - transmutation of the elements
   b) Solar Energy - our dependence upon it and more efficient use of it
   c) Photosynthesis - can man duplicate the synthesis of chemicals in plants?

D. Some common observations to be explained

1. Why does a cake rise?

   Place a few teaspoonfuls of baking soda in the bottom of a flask. Insert (upright) a vial containing sour milk or vinegar. Cover flask mouth with a balloon. Invert to mix acid and soda and watch balloon inflate.

2. What makes ice cream freeze in an old-fashioned freezer?

   Prepare a beaker of salt-ice mixture and a beaker of plain ice water. Insert a test tube containing koolade mixture and a wood splint into each bath.
Questions:
(a) From which beaker is a popsicle obtained?
(b) How must the two ice baths differ?

3. Electrical energy from chemistry

Show a variety of cells which might be of use. Using a voltmeter, show the difference in potential in these cells.

Questions:
(a) Where might such electrical energy be used in daily living?

4. Other selected observations

a) Corrosion - Show any rusted object. Compare with steel wool moistened in acidic water and exposed to air.

b) Demonstrate combustion and explosions.

c) Observation of chemical changes occurring in the laboratory.

\[
\begin{align*}
\text{CuSO}_4 & \rightarrow (\text{blue}) \quad \text{NH}_3 & \rightarrow (\text{blue}) \quad \text{Pb} & \rightarrow (\downarrow) \quad \text{Zn} & \rightarrow (\downarrow) \quad \text{colorless} \\
& \quad \text{(green)} \quad \text{HCl} & \rightarrow \quad \text{Pb} & \rightarrow (\downarrow) \quad \text{Zn} & \rightarrow (\downarrow) \quad \text{colorless}
\end{align*}
\]

5. The river delta

Prepare two cylinders of a clay-mud suspension. To the first add 25 ml of distilled water and mix. To the second add 25 ml of sea water or a salt solution containing Mg\(^{++}\), Na\(^+\), Al\(^{+++}\). Compare the settling rates.

Questions:
(a) How have such areas as New Orleans and Lower California been formed?

(b) How might you proceed to "discover" an explanation for each of the above observations? What would you need to know? How would you use this knowledge to "prove" your explanation valid?

(c) How would you define chemistry?
References to supplement conventional textual material


UNIT II

Simplification Through Classification

Problem:

The interpretation of the universe is an enormous task involving a vast number of materials and facts about them. By what means might a sense of order be developed which will serve to simplify the study of these materials and facts?

Abstract:

Although the science of chemistry is less than 200 years old, enormous numbers of facts have been accumulated through the work of a few generations of scientists. Early in the development of the field of chemistry, it became evident that some means must be devised whereby a sense of order might be established from these facts. This has been achieved and a most effective method of solving many complex problems has evolved through classifying these facts and thereby greatly simplifying their use. Since methods of classification are arbitrary and selected in light of the specific purpose they are to serve, the chemist has developed a number of ways for classifying the facts he has accumulated.

Outline of Approach to the Problem:

In order to develop an understanding of the needs and uses of classification, a variety of ways in which materials may be classified are to be illustrated.

A. Display a wide variety of items of common acquaintance. Show how these may be grouped in a variety of ways depending upon the common properties considered. (See figure 1, page 122.)

1. Animal, vegetable, mineral - source of origin
2. Liquid, solid, gas - state of natural occurrence
3. Metal, non-metal - chemical properties
4. Element, compound, mixture - state of aggregation
CLASSIFICATION: A TOOL FOR ORGANIZING FACTS

A Variety of Common Things
Textiles Metals Household Chemicals Minerals
Soils Crystalline Materials
Vials containing solids, liquids, gases

- Animal
  - Vegetable
  - Mineral

- Metals
  - Non-metals

- Gas
  - Liquid
  - Solid

- Element
  - Compound
  - Mixture

Figure 1
B. Classification of elements - periodic relationships

1. The inadequacy of atomic weight as a basis for classification

2. Recurring ratios in formulae

3. Atomic number versus selected periodic properties

4. X-ray spectra versus atomic numbers

C. CHART - Divisions of Chemistry

Organic Chemistry  Inorganic Chemistry

D. CHART - The "Functional Groups" of Organic Chemistry

Proposed Plan of Approach:

A. Display a wide variety of items selected to illustrate the fact that chemicals are common in all of life and not just laboratory curiosities.

1. Salt, pepper, sugar, sand, vinegar, soda, ammonia, iodine, alcohol, tooth paste, etc.

2. Various textiles

3. A variety of metals in all forms (powder, pellets, rods, wires, etc.)

4. Sealed tubes containing gases, liquids, or solids

5. Soils, rocks, minerals

6. Various crystalline materials

Questions:

(a) These materials may all be classified into what single classification?

Regroup all items in (A) according to classification of animal, vegetable, or mineral, selecting a few to withhold temporarily.

(b) What do the members of each group have in common?

(c) Where would each of the withheld items belong?

(d) How does one know where to place each item?
Regroup the sealed tubes into three classifications (solid, liquid, or gas). Withhold a few temporarily.

(e) What do the members of each group have in common?

(f) Where would each of the withheld tubes belong?

(g) How does one know where to place each tube of material?

Regroup all items in (A) as metals or non-metals.

(h) What do the members of each group have in common?

(i) Where would such items (show samples) as mercury, fool's gold, etc. belong in such a grouping?

(j) Is it possible from observation alone to be certain where each item must be classified?

Regroup all items in (A) as elements, compounds, or mixtures.

(k) What do the members of these groups have in common?

(l) Where would each of a selected few items (withheld from above) fit into these groups?

(m) Can one be certain by observation alone where all of these belong?

(n) What is necessary to make a positive placement of each item? (Show a few tests which might be used.)

Further Discussion:

(a) How are each of these methods of classification limited in use?

(b) How might the knowledge of the classification to which a substance belongs serve to give one an idea of how that substance might behave?

B. Organization of the Elements:

From nearly 750,000 known compounds, the chemist has isolated fewer than 100 naturally occurring elements. How might these be organized to facilitate their study and use?
1. Observation of the atomic weights

a) If the elements were to be arranged in increasing order by atomic weights, would such an arrangement be consistent with that of the periodic chart?

b) Is there any evident reason for making the rows of different length on this chart?

2. Have the students rearrange a random group of formulae, such as LiCl, BeCl₂, AlCl₃, CCl₄, NaCl, MgCl₂, GaCl₃, SiCl₄, Li₂O, BeO, Al₂O₃, CO₂, Na₂O, MgO, Ga₂O₃, SiO₂, N₂O₅, AsO₅, in accordance with similarity of atom ratios.

Questions:

(a) Does this arrangement correspond to that of the periodic chart?

(b) How might one expect formulae of compounds of Cs or Rb with Cl to appear?

(c) Postulate what one might expect binary formulae of compounds of F, Br, or I to appear with Na, Li, Be, Mg, etc.

3. Plot atomic number versus selected properties, such as first ionization potential, melting points, etc., of the elements. (See page 126.)

Questions:

(a) Select from these plots elements which you might expect to behave similarly.

(b) Does this selection show any relationship to the periodic chart?

(c) Does it show any reason for the length of rows in the chart?

(d) What might be meant by the term "periodic property"?

(e) Are there examples of periodic relationships in other natural phenomena?

4. Show X-ray spectra for a series of adjacent elements in successive periods. (See page 127.)
Plot of Ionization Potentials versus Atomic Number

Plot of Melting Point versus Atomic Number
### Principal X-ray Emission Lines for a Series of Elements

<table>
<thead>
<tr>
<th>Atomic No.</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>X-ray Tube</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Principal Line (A)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Target Material</td>
<td>Al</td>
<td>Si</td>
<td>P</td>
<td>S</td>
<td>Cl</td>
<td>A</td>
<td>K</td>
<td>Ca</td>
<td>Sc</td>
<td>Ti</td>
</tr>
<tr>
<td>Target Material</td>
<td>Cr</td>
<td>Mn</td>
<td>Fe</td>
<td>Co</td>
<td>Ni</td>
<td>Cu</td>
<td>Zn</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The Source of X-ray Emission Spectra
THE MAJOR SUBDIVISIONS OF CHEMISTRY

750,000 Known Compounds

Organic Chemistry
700,000 Compounds
of Carbon in Combination
with Relatively Few other Elements
Classified in Nine "Functional Groups"

Inorganic Chemistry
50,000 Compounds
of about 90 Elements other than Carbon
Classified in Eighteen Family Groups
Question:

(a) How might these be used as a basis for arranging the elements systematically?

C. Other Useful Classifications in Chemistry.

1. CHART - (See page 128.)

   Of approximately 750,000 known compounds identified by the chemists, about 50,000 are found to contain varying numbers of 91 elements. The remaining 700,000 are permutations of carbon in combination with relatively few other elements. To simplify the study of these compounds, chemistry has been divided into two major subdivisions of ORGANIC and INORGANIC chemistry with approximately 32 subdivisions of these two.

2. "Functional Groups" - an organization to simplify the study of organic chemistry. (See chart, page 130.)

   The unique properties of the many organic compounds result from the reactivity of a few specific groups. These groups, called "functional groups", include such major classes as alcohols, ketones, aldehydes, ethers, esters, acids, amines, and amides. More complex compounds may contain a variety of these groups and react specifically at each functional center.
THE FUNCTIONAL GROUPS OF ORGANIC CHEMISTRY

The Hydrocarbons

\[ \text{NH}_3 \rightarrow \text{Amines} \]

\[ (0) \]

\[ \downarrow \]

Alcohols

\[ (0) \]

Ketones

\[ \downarrow (\text{-H}_2\text{O}) \]

Ethers

\[ \text{Acids} \]

\[ \text{NH}_3 \rightarrow \text{Amides} \]

\[ \downarrow (\text{-H}_2\text{O}) \]

Esters
UNIT III

The Work of the Chemist

Problem:

In the solution of any problem, scientific or otherwise, it is necessary to accumulate sufficient related information and correlate it in such a way as to formulate hypotheses which will lead to a satisfactory interpretation or solution. What does the chemist do in his work? What are some of the types of information or data that he might need, and what means are available for him to gather this information?

Abstract:

The materials of the universe are most often found as a complex mixture of a variety of substances: so complex that the chemist finds it a difficult problem to gather pertinent data needed to identify these materials. He is successful in gathering some information by simple, direct observation, but this is often inadequate because of the limitations of his sense perception. Consequently, the chemist must find ways of extending his senses to advance his study.

Through the application of his general observations and particularly with the help of cleverly devised instruments for extending his senses, the chemist has gained extensive knowledge of the physical and chemical properties of many substances. From this knowledge he has developed processes for separation and purification of materials and discovered specific tests for their identification. Knowledge of these tests and processes is indispensable in implementing the work of the chemist and forms an important basis for the study of chemistry.

Outline of Approach to the Problem:

Selected illustrations of the types of information the chemist might seek, and a few of the more common means available to him for gathering such information.

A. Preliminary observations as a clue to the nature of the material being studied, including color, density, odor, crystalline
form, melting and boiling points, conductivity of solutions, taste and pH of solutions with emphasis on the limitations of such observations used independently

B. Selected tests available for more specific identification of materials

1. Effects of heat on a substance
2. Solubility of a substance in a variety of solvents
3. Selected precipitation reactions from qualitative analysis
4. Charcoal reduction of CuO
5. Illustrations of relative reactivities

C. Separation of complex mixtures as a means of simplifying the study of materials

1. Solvent separation - filtration
2. Magnetic separations
3. Distillation
4. Sublimation and fusion
5. Other methods as desired - i.e., electrolysis, ion exchange, instrumental techniques

Proposed Approach to the Problem:

A. Develop, through discussion, an awareness of the various types of observations which might be made by proper use of the senses. Illustrate the proper way in which to taste, smell, etc., an unknown substance, and emphasize the caution with which each must be used.

1. Prepare a sequence of nine "stations" around the room designed in such a way as to assist the student in "discovering" observable differences for which one might look in studying materials.

   a) In uniform-bore tubes, place equal volumes of colored solutions such K$_2$Cr$_2$O$_7$, KMnO$_4$, NaCl, CuSO$_4$, FeCl$_3$.

   b) Prepare a series of objects of uniform size, shape and color but filled with materials of varying density, i.e. Al powder, Hg, Fe filings, etc. (children's plastic
blocks may be suitable). Have one duplicate in the
group. Ask the students to "discover" differences.
Test them to see if each can select the matching	pair from the group.

c) Prepare a series of covered vials containing odorous
materials, i.e. NH$_3$, CH$_3$OH, CH$_2$O, esters, camphor,
etc. Include a duplicate sample among the group.
If vials are numbered and arranged in order of in-
creasing pungency, they may be differentiated. Have
each student select a matching pair from the group.

d) Display a series of macro crystals of various sym-
metries. (This may be done by placing several seed
 crystals on the same microscope slide. Such crystals
as NaCl, Na$_2$S$_2$O$_3$, KAl(SO$_4$)$_2$·$n$H$_2$O, are suitable. Have
students identify the differences.

e) Prepare four temperature baths, i.e. ice-salt, water
at room temperature, hot water, oil bath. Insert a
thermometer in each bath. Select materials suitable
to show wide ranges of transition temperatures, such
as acetic acid, water, alcohol, salt. Have students
identify differences.

f) Prepare solutions of sodium chloride, acetic acid,
water, sugar, alcohol and provide an apparatus for
observing conductivity. Provide instructions for
washing apparatus before transfer from one solution
to another. If a meter is used, differences become
more evident.

g) Prepare solutions to be identified by taste. CAUTION
students against indiscriminate use of this test.
Illustrate salty, bitter, sour and sweet taste. If a
duplicate is included students may be instructed to
select a matching pair from the group.

h) Show solutions of acids, bases, salts with pH paper
inserted in each. Have students select a matching pair
from the group.

i) Select a group of materials uniform in each of the
above properties in order to illustrate the limitations
of this procedure for identifying materials. (A series
of halide salt solutions might suffice.)

Questions:

(a) How many different ways of distinguishing materials
have been shown above? What are they?
(b) Are these characteristic observations unique to the area of chemistry? Where might they apply in daily living?

(c) Check "matching" pairs to see if all of the students agree on the selection of pairs. How reliable are the senses in detecting differences in materials?

(d) How might one proceed to treat the group of items in (i) for positive identification?

(e) Can one positively identify any substance by use of the characteristics in (a through h) alone or in combination with each other?

B. Selected tests of use in more specific identification of materials

1. Use of heat

   a) In separate test tubes, place some CuSO₄ 5H₂O, and Na₂CO₃ 10H₂O, and insert litmus paper and cobalt chloride test paper into the mouth of each.

Questions:

   (a) Is the change the same in each tube?

   Add water to the anhydrous CuSO₄.

   (b) To what might the color of CuSO₄ 5H₂O be attributed?

2. Solubility of substances in various solvents

   a) Select a variety of solvents such as water, alcohol, acetone, etc. Show how selected materials will dissolve in one solvent or another yet be insoluble in still other solvents.

Questions:

   (a) Could water soluble materials be classified in a specific category?

   (b) Could water insoluble materials be so classified?

   (c) How might solubility be used to aid in identifying a substance?

   (d) Could positive identification be made in this way?
3. Selected precipitation reactions by which identity might be established.

a) Show the reaction between CrO$_4^{2-}$, and such ions as Pb$^{++}$, Ag$^+$, Ba$^{++}$.

Questions:

(a) Would you expect such precipitation reactions to give positive identification of a substance?

(b) Is there a test shown in part 2 above which might be used with this precipitation to distinguish these three substances?

Show the reaction of Cl$^-$ with Pb$^{++}$, Ag$^+$, Hg$^{2+}$. To each of these precipitates add NH$_3$(aq).

4. Using a charcoal block and blow pipe, show how the reduction of CuO, and SnO$_2$ may be used to distinguish some materials.

Questions:

(a) What evidence shows that a change has occurred?

(b) What do the products appear to be?

5. Insert iron wire into solutions of a variety of substances, i.e., NaCl, HCl, SnCl$_2$, ZnCl$_2$, KCl, AgNO$_3$, CuSO$_4$.

Questions:

(a) What evidence is there to show that a change has occurred?

(b) Is the evidence the same in all instances?

(c) Postulate an explanation for any observed differences.

(d) Why is it necessary for the chemist to be aware of a wide variety of facts relating to the behavior of substances, when studying unknown materials?

C. Separation of complex mixtures as a means of simplifying the study of matter

1. Preliminary discussion

(a) How is sugar extracted from cane or beets?
(b) How is iron ore processed to avoid shipping large quantities of impurities with the ore?

(c) How is petroleum processed to provide the variety of products in commercial use?

2. Solvent separations

a) Mix salt, sand and sugar. Dissolve in water, filter and partially evaporate.

 Questions:

(a) What is the residue in the filter?

(b) What is the crystalline material formed on evaporation?

(c) What has happened to the sugar? Could it be recovered in its original form?

Dissolve out the pigments from green leaves in 82% hot alcohol. Add equal volumes of petroleum ether to the solution and mix thoroughly.

(d) What appears to be true of the pigments in green leaves?

(e) Might this have any bearing on the color changes seen in leaves from early spring to fall?

3. Separation by use of magnetic properties

a) Separate a mixture of iron filings, sand, etc., by use of a magnet.

4. Distillation

a) Separate a mixture of colored salt, water and alcohol by fractional distillation.

 Questions:

(a) Is this separation complete? (Show water content of the alcohol.)

5. Sublimation and fusion

a) Separate a mixture of Hg, Bi, Fe by fusing the mixture. Collect Hg on a cold finger. Allow Bi to fuse and separate out Fe by flotation.
C. Demonstrate any further examples of separation techniques as desired, i.e., ion exchange, electrolytic deposition, dialysis, chromatography, etc.

Discussion:

(a) Upon what specific property does each of the above processes (1-5) depend?

(b) How does a cement worker separate out coarse particles in preparing sand for finish work? Which process above is analogous to this?

(c) Many seashore areas are in need of potable water. Which process above could make sea water usable? Why is it not used in Los Angeles, North Africa, and similar places?

(d) Which one of these processes is in use for softening water in homes and certain industries? Could this be used to provide water to sea coast areas?
UNIT IV

The Particle Nature of Matter

Problem:

History records extensive discussions as to whether matter is continuous or composed of discrete particles. Which point of view is most useful in the explanation of phenomena commonly observed in the study of matter?

Abstract:

In order to explain the phenomenon of diffusion, the scientist assumes that all matter is composed of tiny, discrete units which are in constant motion. This assumption is also basic in explaining such effects as the Brownian movement, the Tyndall beam, the radiometer, and those effects observed in the Wilson cloud chamber and the Geiger counter. So effective has this assumption (working hypothesis) been in explaining such a wide variety of observations that the scientist has come to accept the existence of these particles to be a fact. The nature of these particles will be studied in greater detail in subsequent units.

Outline of Approach to the Problem:

Most students accept, without question, the "atomistic" nature of matter, yet this concept was not readily accepted by early scientists. An awareness of the many evidences for these particles can serve to convey the source of "faith" in the atomic theory as well as to develop ideas relating to the evolution of a theory or hypothesis in science.

A. Preliminary discussion

B. Evidences of the particle nature of matter

1. Diffusion of solids, liquids, and gases

2. Brownian movement

3. Tyndall light effects

4. The radiometer
5. The Geiger Counter

6. The Wilson cloud chamber

7. Crystalline structure

**Proposed Plan of Approach:**

A. Preliminary discussion designed to lead into the observations of diffusion and other phenomena illustrating the particle nature of matter.

1. How can a teaspoonful of flavoring be detected throughout an entire cake?

2. How can a small drop of perfume be detected throughout a large room even after its wearer has departed?

3. What is wind? How does a windmill work? Is this similar to a water wheel?

4. What is fallout? How is it detected? How can a few ounces of material from a bomb be spread over such a wide area of the earth and detected thousands of miles away?

B. Evidences of the particle nature of matter

1. Diffusion

   a) **Odors** - Select a solid, liquid, and gas, each of which might be detected by odor in a brief period of time. Expose each individually, allowing persons farthest from the demonstration to indicate observation by show of hands. (*Sample materials:* camphor, ammonia, oil of wintergreen.)

   **Question:** How might the material be dispersed across the room?

   b) **Color** - With a minimum of agitation insert a drop of colored liquid such as $\text{KMnO}_4$ into a beaker of cold water. Repeat with warm water. (*Crystalline material may be used.*)

   **Questions:**

   (a) How are the observations in (b) different from each other?

   (b) What causes this material to be dispersed?
(c) What effect does the heat appear to have?

(d) How might dispersion be accelerated?

1. c) Show "smoke" ring of NH₃ + HCl reaction. (See figure 1, page 141.)

Place, simultaneously, at opposite ends of a 4' X 1" glass tube, wads of cotton which have been saturated with NH₃(aq). Observe the location of the ring.

Questions:
(a) What evidence is there to show that something has happened?

(b) What makes this observation possible?

(c) Why is the "ring" not centered between the two ends of the tube?

1. d) Prepare apparatus as shown in figure 2, page 141. Close B, open A, observe time of diffusion of Br₂.

Close A, sweep out system and evacuate from A to B. Repeat initial operations, observing the time for diffusion.

Questions:
(a) What evidence is there to show that something has occurred?

(b) Why might the time for diffusion be different during the second trial than it was the first time?

(c) How might this be likened to the time for travelling across town and the relative density of traffic?

1. e) Inflate a rubber balloon. Observe the odor upon deflation.

Reinflate and suspend over a solution of odorous material as shown in figure 4, page 141. Note odor upon deflation after a brief period of time.
Figure 1

Ring

NH₃

HCl

Br₂

Stopcocks

A

B

Figure 2

Red and Blue Litmus paper

Filter paper

NH₃(aq)

CS₂

Figure 3

Figure 4
Question: Account for the difference between successive observations.

1. f) Assemble apparatus as shown in figure 3, page 141, and allow it to stand three to five minutes. Observe the change in litmus paper. Show how this change occurs if litmus is dipped into NH₃(aq).

Question: How has the ammonia been dispersed through the filter paper to change the litmus paper color?

1. g) Set a piece of dry ice on the desk. Observe its disappearance.

Question: How has the dry ice dispersed?

Further Discussion:

(a) Is there a common explanation for the observation above?

(b) Assuming that matter is composed of tiny particles, what must be true of these particles in order for them to behave as has been observed?

(c) Assuming that we temporarily abandon the theory that matter is composed of small particles, how might one explain the observations that have been made above?

(d) How might these observations be related to evaporation?

B. 2. Brownian movement

Using a microscope (or microprojector), observe the agitation in a smoke cell or other colloidal dispersion.

Question: To what might this movement be attributed?

3. Tyndall beam and other colloidal light effects

a) Show the Tyndall effect and compare it with the transmission of light in a true solution.

Questions:

(a) What is necessary to cause light to be reflected?

(b) Why is light reflected in the colloidal sol and not in a solution?
(c) Have the particles disappeared in the solution?

3. b) Using a projection lantern, pass a beam of light through 500 ml of water, 20 - 30°C., and contained in a tank having parallel sides five inches apart. Add 10 ml of concentrated "hypo" and 3-8 ml of 5N HCl, and mix thoroughly. Observe the change in light effects on the screen as the particle size increases.

**Question:** Observations in a and b are the result of the same phenomenon. How would you explain them?

4. The radiometer

   a) Expose a radiometer to strong light. Observe its motion.

   **Question:** How might this effect be analogous to the windmill?

5. Crystalline form

   a) Display several crystalline forms of solids. Demonstrate the building of a crystal by projecting the reaction of copper wire inserted in a dilute solution of AgNO₃ on a screen.

   **Questions:**

   (a) How might the building of a crystal be compared to the stacking of fruit in a display?

   (b) What happens to the order in a pile of balls if larger or smaller ones are interspersed in the stack? (Use a variety of balls to show effect, i.e., billiard, ping-pong, golf, tennis, etc.)

   (c) How might crystalline forms be related to the relative size of the particles from which a crystal is built?

6. The Geiger counter

   a) Show how radioactivity is detected. How is this related to fallout?

7. The Wilson cloud chamber

   Glue black felt on the inside bottom of a large crystallizing dish (3-4" deep and 3" radius). Glue black felt on a metal sheet suitable for a cover for the dish. Saturate both felts with methanol and set metal on dry ice, with the
dish inverted over the felt pad. After thermal equilibrium is reached (about 15 min.) direct a beam of light diagonally through the dish from top to bottom. Cloud tracks from cosmic rays will be observed. Using a radioactive source taped inside the dish, more tracks will be visible.

Further Discussion:

(a) In all of the above observations, similar explanations are given for each phenomenon. For the most part, each is explained by assuming that matter is composed of very small particles which undergo constant motion. Do any of these observations prove the existence of a particle nature of matter?

(b) In consideration of (1) above, what do you presume to be meant by a "working hypothesis"?

(c) Try to propose an entirely different "working hypothesis" that will serve to explain the phenomena observed above.

(d) Why do you suppose that scientists accept the particle theory of matter without having seen or isolated a single particle?
UNIT V

The Building Blocks of Matter

Problem:

Approximately 750,000 different compounds have been isolated and identified, yet, upon analysis, fewer than 100 unique, elementary components (building blocks) of these compounds are found. What are these building blocks from which compounds appear to be formed?

Abstract:

Just as most naturally occurring substances are shown to be more or less mixtures of a variety of compounds, so, careful study reveals that the 750,000 isolated and identifiable compounds are aggregations of varying complexity. It is possible to identify the elementary substances, of which these aggregations (compounds) are composed, by studying the various changes they undergo when attacked by chemical agents, or energy such as heat or electricity. Fewer than 100 such elementary substances (elements) have been found to occur naturally.

Furthermore, in order to interpret the behavior of these elements, the scientists have found it convenient to assume that they are composed of tiny particles called atoms. This assumption has proved to be most useful in explaining the behavior of matter, and these atoms are considered to be the building blocks from which matter is composed.

Outline of Approach to the Problem:

The existence of relatively few building blocks, from which a wide variety of materials are made, can be inferred from such phenomena as

A. The same product derived from several sources

B. The same product from a single substance treated in a variety of ways

C. Photographic evidence: X-ray diffraction, electron microscope
D. Laws of chemical combination

Proposed Plan of Approach:

A. The same product derived from several sources

1. To samples of sugar, flour, paper, wood, etc. add a few milliliters of concentrated $\text{H}_2\text{SO}_4$. With duplicate samples heat until decomposition occurs.

Questions:

(a) What evidence is there that a change has occurred?

(b) Is there a similarity in the products from each sample?

(c) Is the product from the acid application similar to that of the heating experiment?

(d) Does this suggest a conclusion which might be drawn relative to each of the above samples?

(e) How could you be sure that the products are not the same substances as those with which the experiment was initiated?

B. The same product from various treatments of a single compound

1. Treat $\text{Hg(NO}_3\text{)}$ by several means, i.e., heating, electrolysis, insertion of an active metal into a solution of the salt.

Questions:

(a) What is observed in comparing the products?

(b) Might this observation suggest anything pertaining to the nature of the particles produced in these reactions?

(c) Is there any proof that the products cannot be further subdivided? How can one determine whether a new product is elemental or just another compound?

C. Photographic evidences

1. Show a variety of X-ray diffraction patterns.

Questions:

(a) What do these photographs suggest concerning the nature of matter?

(b) Are these photographs picture of actual atoms?

D. The laws of chemical combination

1. The Law of Definite Composition

a) Display reaction portions of a substance. Label to indicate quantity. Repeat with other examples as needed.

5.585 gms Fe + 3.207 gms S \rightarrow 8.792 gms FeS.

5.585 gms Fe + 4 gms S \rightarrow 8.792 gms FeS + 0.793 gms S.

Questions:

(a) Why do you presume that analysis of many compounds shows a fixed ratio of reactants as shown above?

(b) If 5.585 gms of Fe were to react with 3 gms of S, which would be in excess? What would this excess be?

(c) If the masses of reactants should be subdivided to single particles, what ratio would exist between a particle of iron and one of sulfur?

2. The Law of Multiple Proportions

a) 12 gms of carbon react with 11.2 liters of oxygen to form carbon monoxide.

12 gms of carbon react with 22.4 liters of oxygen to form carbon dioxide.

Questions:

(a) What relationship exists between the quantities of oxygen reacting in (a) above?

(b) What does this suggest as to the relationship between the number of oxygen particles in combination with a single carbon particle in each instance?

(c) If the reacting masses were repeatedly subdivided into single particles, what ratio would exist between the carbon particle and the oxygen particle?
(d) How do the ratios of iron to sulfur and carbon to oxygen compare with the atomic weight ratios of these elements?

Further Discussion:

Reality is a term to be defined in the area of metaphysics and not in the realm of science, however, the scientist looks upon reality in terms of observable phenomena and the "working hypotheses" which best serve to explain them. In view of this, what observations have you made here to substantiate the scientists' confidence in the reality of atoms?
Problem:

The lack of suitable instruments for observation and the failure to understand electricity doomed to failure all efforts of the early scientists to subdivide the atom. As a consequence it was considered indivisible until the late nineteenth century when workers found evidence to the contrary. What type of evidence was found, and what does it suggest about the composition and structure of the atom?

Abstract:

As new detection devices were developed, careful observations revealed an increasing amount of evidence to indicate that atoms are not simple particles but rather are composed of three stable particles. Similarly such observations as spectral phenomena, radioactive decay, Rutherford's bombardment experiments, and the identification of isotopes coupled with early knowledge relating to the periodicity of properties and reactivity of elements provided a foundation upon which hypotheses concerning the structure of atoms might be built. The present day concept of the atom is one of a compact, positively charged nuclear mass, surrounded by an atmosphere of electrons behaving as though they were distributed in progressively higher energy levels from the nucleus to the outer periphery of the atom. Most commonly observed chemical phenomena are now explained in relation to this concept of atomic structure.

Outline of Approach to the Problem:

A. Evidence for subatomic particles

   1. The electrical nature of matter

      a) static charge
      b) ion migration
      c) conductivity
2. Why is matter affected by electricity?
   a) identification of the electron
   b) identification of positively charged particles

3. Arrangement of subatomic particles
   a) the nucleus
      (1) Rutherford's experiment
      (2) the Geiger counter - 3 types of particles
   b) the electrons
      (1) spectral data
      (2) ionization potential data
      (3) molecular formulae - periodicity
      (4) X-ray spectra - atomic numbers

4. Discussion and summary
   a) questions leading to correlation of facts
   b) MODEL - orbital distribution of electrons
   c) isotopes

Proposed Plan of Approach:

A. Evidence for subatomic particles

1. The electrical nature of matter
   a) Using an electroscope, glass and rubber rods, fur and silk, show how the electroscope may be charged and discharged. Repeat with pith balls, paper, etc.

Questions:

(a) What phenomena in daily experience are related to your observations here?

(b) What do you presume to be occurring when, by scuffing your feet across carpeting, you are able to "shock" another person?
1. b) The effect of electrical energy on solutions

Fill a U-tube two-thirds full of a solution of 1% NaCl, 4% gelatin and a few drops of litmus, and allow the gel to set. Place dilute NaOH in one arm and dilute HCl in the other. Insert electrodes and observe the migration of H and OH⁻ through the gel.

1. c) Show conductivity with a variety of solutions, i.e., concentrated and diluted acids, bases, salts, sugar, alcohol.

2. Why is matter affected by electricity?

a) Identification of the electron

Using a Crooke's tube, demonstrate an electron beam, deflection of the beam by a magnet, interference as with the Maltese Cross, and paddle wheel.

Questions:

(a) Why are cathode rays affected by a magnet?

(b) Account for direction of deflection.

(c) What name is given to the subatomic particles which cause the effects observed?

(d) What natural phenomenon is similar to that shown?

(e) If matter is electrically neutral, what further observation must be possible?

3. b) Detection of the proton and other positive particles.

(1) Illustrate the principle of canal rays.

(2) Radioactivity as affected by a magnetic field

(See figure below.)
4. Rutherford's experiment - the bombardment of metal foils

a) Explain observation by interpretation of diagram below.

Questions:

(a) How does sand pass through a sieve or water through cloth?

(b) Why, then, might it be possible for alpha particles to pass through foil?

(c) Relatively few of these particles are deviated from a straight line from source through foil to screen. To what might this deviation be due?

(d) Why might a few particles be "reflected" back toward the source?

5. The Geiger counter - Show evidence for a variety of particles by illustrating how tissue paper, metal foils, etc., serve to filter out particles from radiation sources.

6. Spectral data

a) Fill shakers with salts such as NaCl, CaCl₂, BaCl₂, SrCl₂, and LiCl.
Light burner and shake small amounts of these salts across the flame.
Relate color variations to energy spectra. $E = \frac{h}{\lambda}$
b) The spectroscope - Show flames above as viewed with the spectroscope (color slides may be used). Relate energy and color phenomena through the introduction of the scale of electromagnetic vibrations. (See page 154.)

c) A qualitative illustration of color phenomena

Have the students wrap rubber band around their fingers. By pulling band progressively farther out, the release results in increasingly more sting (higher energy). By moving one finger out toward the stretched band the sting will be reduced.

d) Using a diagram of the Bohr model (page 155), relate spectral energies to the orbital arrangement of the electrons in the atom.

7. Ionization potentials

a) Recall discussion of periodicity of ionization potentials.

b) Using a Hg-vapor discharge tube, show how the ionization potentials of gaseous ions may be measured.

c) From a table of ionization potentials (i.e., Moeller, T. Inorganic Chemistry, p. 156, N.Y., Wiley and Sons), have the students select the position of "inconsistent" increases as shown in Table I, page 156. Block out configuration initially.

Questions:

(a) Is there a relationship between these "breaks" in the ionization potentials and the "family" classification as shown on the periodic chart?

(b) Discuss potentials in relation to Coulomb's law.

\[ F = \frac{e_1 e_2}{r^2} \]

Since force of attraction varies with the distance and charge, relate ionization potentials to reactivity in light of the size and nuclear charge on the atom.

8. X-ray spectra

a) Recall the discussion of X-ray spectra from Unit II. Illustrate the continuous increase of principal
Energy Spectrum - Electromagnetic Vibrations

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<th>Wave Length (Å)</th>
<th>Uses</th>
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<td>10^-8</td>
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<td>10^-9</td>
<td>Television</td>
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<td>10^-10</td>
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<td>10^-11</td>
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<tr>
<td>10^-21</td>
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vibrational, rotational energies
bonding energies
Lyman Series

Balmer Series

Paschen Series

Bracket Series

Pfund Series

γ-rays

X-rays

Infra-red

Ultra Violet

visible

Wave Length - A

Bohr Orbital - Spectral Energies
# TABLE I

Ionization Potentials of the Elements\(^1\)

<table>
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<tr>
<th>Atomic Number</th>
<th>Symbol</th>
<th>Configuration</th>
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<th>3rd</th>
<th>4th</th>
<th>5th</th>
<th>6th</th>
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<td>120.</td>
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<td>140.8</td>
</tr>
</tbody>
</table>

lines in the spectrum. (Be sure to emphasize the simplification of spectra as shown here.) Relate these spectra to the determination of atomic numbers.

9. Recall lists of selected formulae from Unit II. Correlate these with ionization potential data.

Question: In bonding, what relationship appears to exist between the number of alkali metal atoms (or halogen atoms) with which an atom reacts and the consistent increases in the ionization potentials?

Discussion:

1. Early concepts of the atom pictured it as a hard, spherical particle which could not be altered in any way. Compounds formed from these atoms were simply a regrouping of atoms, held together by forces of unknown nature.

   (a) How is this theory unsatisfactory in explaining

   (1) Rutherford's experiment?
   (2) electrical conductivity?
   (3) the laws of chemical combination?

   (b) How has early theory been modified to satisfy these experimental conditions?

2. Rutherford's experiments showed the atom to be a small, heavy, positive core surrounded by large open spaces. To be so, this implies that the mass of the atom must be localized in a compact nucleus. If so, what must be the chief constituents of the nucleus?

3. In view of the fact that atoms do not appreciably change their mass as a result of a chemical reaction, what portion of the atom must be effected in a chemical reaction resulting in the formation of binary compounds?

   a) Continuous change in X-ray spectra with atomic number?

   b) The uniqueness of spectral patterns for each atom?

   c) Ionization potential changes in relation to Coulomb's law and changes seemingly unrelated to electrostatic forces.

5. What is the meaning of the statement "for the most part chemistry deals principally with effects relating to the extra-nuclear structure of the atom?"
6. What evidence do ionization potentials and spectral data give to suggest that the electron configuration of an atom might consist of varying energy levels often referred to as shells and orbitals?

7. The arrangement of "fundamental" particles in the atom.

   a) Correlate data discussed to show nuclear structure and the orbital arrangement of electrons.

   For this purpose, a device shown on page 159 might be of use. It consists of concentric discs which may be used individually or as a composite group to illustrate the "building up" of atoms from H to U.

   Each disc represents a shell and may be superimposed above the other discs to show a composite wheel as illustrated.

   In each disc, provision is made for orbitals of that particular shell and colored thumb tacks may be inserted to show the electron arrangements and limitations in the orbitals.

   The area under each disc might be painted to show completed inner shells when smaller discs are removed.

   If made with suitable surface, orbitals could be placed geometrically as desired by use of felt, and moved as desired to indicate directional bonding or ease with which orbitals in very close energy levels might "interchange" positions.

   With such a device it would be especially simple to show "available orbitals" for a reaction and to illustrate the rearrangement of electrons in "similar" energy levels to provide orbitals for bonding.

   In using this device, it will be necessary to show the relationship between the representation of electron configuration on the wheel and the conventional notation used in writing or in print.
Orbital Distribution - Atomic Structure
UNIT VII

Why and How Elements Combine Forming a Wide Variety of Compounds

Problem:

It is observed that some elements react so violently that they are difficult to obtain in a free state, yet others are apparently inert. These differences provide an interesting test of the validity of the theory of atomic structure. How may this theory be applied to explain these differences in reactivity, and does the theory provide for an explanation of the differences in the properties of compounds formed by reactions between atoms?

Abstract:

Because the inert gases are unreactive, it is assumed that their electron configuration is unusually stable, hence such a configuration serves as a model for the configuration of other stable particles. All elements may acquire this stable configuration by losing, gaining or sharing the necessary electrons, thereby acquiring the configuration of the nearest inert gas. Bonding then results, either from electrostatic forces between oppositely charged particles (ionic bonding), or from the sharing of paired electrons in overlapping orbitals from both bonding atoms (covalent or coordinate bonding).

The tendency of an atom to assume this stable configuration is dependent upon many factors, among them being (a) the availability of empty or partially filled orbitals which can receive electrons in bond formation, (b) a source of electrons which can be paired to form a bond, (c) the radius and nuclear charge of an atom which governs the ionization potential and electron affinity of the atom and the spatial limitations restricting bond formation.

Outline of Approach to the Problem:

A. Types of Bonds

1. Electron configuration of the inert gases
2. Ionic bonding
   a) Configuration of the alkali metals, halogens, alkaline earths, etc.
   b) Reaction - change in configuration as compared to that of the inert gases
   c) Conductivity - flow of charged particles
   d) Bonding - electrostatic attraction between ions

3. Covalent and Polar-covalent bonds
   a) Molecular structures of \( \text{H}_2, \text{N}_2, \text{O}_2 \), etc.
   b) Non-conductivity of \( \text{C}_n\text{H}_{2n+2}, \text{C}_n(\text{H}_2\text{O})_n, \text{ROH}, \text{H}_2\text{O}, \) etc.
   c) Bonding - the electron pair bond and overlapping orbitals
   d) Electronegativity - the polar bond

4. The Coordinate bond
   a) Available (empty) orbitals and the formation of complexes

5. The Metallic bond

6. Summary - bond types and compound properties
   a) Bond types and properties
   b) The hydrogen bond and the unusual properties of water

Proposed Plan of Approach:

A. Types of Bonds

1. Using discs (Unit VI) show the electron configuration of the inert gases.

Questions:

(a) How are the "inner shells" of \( \text{Rn}, \text{Xe}, \text{Ar}, \text{Kr}, \) etc. similar to those of the next lighter inert element?

(b) What does this suggest concerning the "capacity" of the K, L, M, N, etc. shells?
(c) Since chemical reaction is assumed to occur by the formation of a more stable configuration, what can be assumed to be a stable configuration in light of the inert nature of these gases?

2. The ionic bond

a) Show the electron configuration of the alkali metals and the halogens (using discs).

Questions:

(a) What is the configuration of the nearest inert gas in each instance?

(b) How could each of the above atoms acquire the "stable" electron configuration of its nearest inert neighbor?

(c) What would the resulting charge balance between positive nucleus and electrons be if such (2) should occur?

(d) How would such particles (ions) be held together in compounds?

(e) Would these be strong or weak bonds (energy-wise)?

2. b) Repeat (questions a to e) for alkaline earths and oxygen-sulfur families.

(c) Assuming that all atoms tend to acquire the electronic configuration of the nearest inert gas, what would you expect to occur in family III, family IV, and family V?

Note: In family IV would you expect atoms to lose or gain electrons? What influence might control the direction taken?

(d) If sodium (structure?) and chlorine (structure?) were to be mixed, what might one expect to observe?

Repeat (d) with several other binary combinations.

e) Conductivity and structure. Using two tubes joined by a short length of rubber tubing and filled with solutions of salts from (d), insert an electrode into each arm and observe the conductivity. By pinching off the rubber connection, conductivity ceases.
Questions:
(a) What might be the cause of conductivity in these solutions?

(b) Why is conductivity stopped by closing off the tube?

(c) Can the same phenomenon be demonstrated by pinching an electric cord? Why?

3. Covalent and polar-covalent bonds

(a) Show the molecular structures of oxygen, nitrogen, hydrogen, etc., using stick models.

Questions:
(a) In each of these elements, what change in atomic configuration becomes necessary in order to form a bond?

(b) In ionic bonding we observed one atom acquiring an electron while a second atom released an electron. How can this occur between two atoms of the same element? If they do not lose or gain electrons in bond formation, what other alternative is possible?

(c) If no ions are formed and hence no electrostatic charge, what holds the atoms together?

(d) Would you expect such material to conduct electricity? Test a few samples.

(e) Discuss the electron-pair bond.

3. b) The polar bond

Questions:

(f) Hydrogen and carbon each lie halfway between the extremes of their respective periods. In what way does this make them similar in the way in which their configuration might change in reaction? Which one would be more apt to "gain" electrons in bond formation? How might one determine this?

(g) What would you need to know in order to tell whether an atom would lose, gain or share electrons with another atom? (Which would win the "tug of war" or would it be a draw?)
Discuss electronegativity and its effect on bond strength. (See Table II, page 165.)

(h) Would you expect polar-covalent compounds to conduct electricity? Test a few samples.

(i) How is conductivity related to bond type?

(j) In bonds between carbon and oxygen, carbon and hydrogen, hydrogen and oxygen, etc., which element is apt to have the strongest pull on the electron pair forming the bond?

(k) What effect would this uneven pull have upon the polarity of the bond?

(l) How would you define the polar-covalent bond?

4. The coordinate bond

   a) Observe the available orbitals in the structure of the transition elements. (Use discs from Unit VI.)

Questions:

(a) How might these orbitals be filled to form the electronic configuration of the next higher inert gas?

(b) Observe complexes of these elements. How do the metal atoms appear to have reacted? Pt(NH₃)₄Cl₂, Co(NH₃)₆Cl₃, etc.

(c) What two types of bonds are apparently formed simultaneously?

(d) What must be true of a "central" atom before it can form a coordinate bond?

(e) What must be true of the coordinating atoms or groups of atoms, before they may form a bond with the central atom?

(f) How would you define a coordinate bond?

(g) What type of bond would you expect in such species as SO₄²⁻, NO₃⁻, ClO₄⁻, ClO₃⁻, ClO⁻, from observation of the electron configuration of oxygen, nitrogen, chlorine and sulfur, and the available orbitals in each of the "central" atoms (S, N, Cl).
TABLE II

The Electronegativity Scale\(^1\)

(The power of attraction for electrons in a covalent bond)

<table>
<thead>
<tr>
<th></th>
<th>H</th>
<th>Li</th>
<th>Be</th>
<th>B</th>
<th>C</th>
<th>N</th>
<th>O</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2.1</td>
<td>1.0</td>
<td>1.5</td>
<td>2.0</td>
<td>2.5</td>
<td>3.0</td>
<td>3.5</td>
</tr>
<tr>
<td>Na</td>
<td>Mg</td>
<td>Al</td>
<td>Si</td>
<td>S</td>
<td>Cl</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>1.2</td>
<td>1.5</td>
<td>1.8</td>
<td>2.5</td>
<td>3.0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Ca</td>
<td>Sc</td>
<td>Ti</td>
<td>Ge</td>
<td>As</td>
<td>Se</td>
<td>Br</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>1.0</td>
<td>1.3</td>
<td>1.6</td>
<td>1.7</td>
<td>2.0</td>
<td>2.4</td>
<td>2.8</td>
</tr>
<tr>
<td>Rb</td>
<td>Sr</td>
<td>Y</td>
<td>Zr</td>
<td>Sn</td>
<td>Sb</td>
<td>Te</td>
<td>I</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>1.0</td>
<td>1.3</td>
<td>1.6</td>
<td>1.7</td>
<td>1.8</td>
<td>2.1</td>
<td>2.4</td>
</tr>
<tr>
<td>Ca</td>
<td>Ba</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>0.7</td>
<td>0.9</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4. b) The geometry of the coordinate bond

This would be discussed only with an exceptional group, but might be suggested as a point for study by the better students.

5. The metallic bond

Briefly discuss the need for explaining such properties as ductility, malleability, conductivity, etc. and show the need for the formulation of this fifth bond type to serve this purpose. Further discussion is probably too difficult at this point.

B. Bond types in relation to properties of compounds

1. Show a table listing a variety of compounds and such properties as melting points, boiling points, conductance, solubility, etc. (See Table III, page 166.)

Questions:

(a) What type of bonds would you expect in each of these compounds?

(b) Compare the properties of all of the ionic-bond types selected against the properties of other bond types.

(c) What appears to be the difference in each of the following properties in respect to bond type: melting point, boiling point, conductance, solubility in water, etc.

(d) What would you consider to be the typical properties of compounds having ionic bonds?

(e) Why might this be true?

(f) What would you expect to be the properties of each of the following compounds? NaBr, CaBr₂, CBr₄, HBr (selected as intermediate between those given on the table).

(g) Postulate a reason for the abnormal properties of water, i.e., the unusual transition temperatures, the long liquid range, high specific heat, etc.

Discuss the hydrogen bond.
### TABLE III

Some Properties of Selected Compounds

<table>
<thead>
<tr>
<th>Substance</th>
<th>Melting Point (°C)</th>
<th>Boiling Point (°C)</th>
<th>Conductivity</th>
<th>Solubility</th>
<th>Bond Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>O₂</td>
<td>-218.9</td>
<td>-182.96</td>
<td>non-conductors</td>
<td>in pure state</td>
<td></td>
</tr>
<tr>
<td>H₂</td>
<td>-259.08</td>
<td>-252.62</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CH₄</td>
<td>-182.5</td>
<td>-161.5</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N₂</td>
<td>-210.0</td>
<td>-195.8</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCl</td>
<td>-114.0</td>
<td>-85.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HI</td>
<td>-50.7</td>
<td>-35.4</td>
<td>conductors</td>
<td>soluble in water</td>
<td></td>
</tr>
<tr>
<td>H₂S</td>
<td>-85.49</td>
<td>-60.33</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NH₃</td>
<td>-77.74</td>
<td>-33.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>H₂O</td>
<td>0.00</td>
<td>100.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CCl₄</td>
<td>-22.9</td>
<td>76.4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CO₂</td>
<td>-56.6</td>
<td>78.5 (5 atm)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂Cl₆</td>
<td>192.6 press.</td>
<td>180.0 subl.</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Al₂I₆</td>
<td>179.5</td>
<td>381</td>
<td>good conductors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaCl</td>
<td>992.0</td>
<td>1705.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>NaI</td>
<td>651.0</td>
<td>1300.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CaCl₂</td>
<td>575.0</td>
<td>718.0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SiC</td>
<td>2200 (?</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C (diamond)</td>
<td>3570</td>
<td>3470 (subl.)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Problem:

It is said that there are as many atoms in a single red blood cell as there are blood cells in the human body \((10^{13})\). Since an atom has never been seen, and it would take a man counting as rapidly as possible more than 500,000 years to count this high, how has this conclusion been reached?

Abstract:

Since chemical reactions involve the rearrangement and recombination of individual particles to form new compounds, it is expedient for the chemist to have a means whereby he may measure out numbers of particles in proportion to the desired reaction ratios. Because these particles are too small to be observed directly, it becomes necessary to arrange experiments by which the number of atoms in a specific quantity of material may be determined by a means more feasible than direct counting. This is achieved by allowing some measurable change to occur and then relating this change to the number of particles. Early methods used an interdependence between mass and numbers for counting particles, and these will be discussed with material relating to weighing atoms. Independent of these, very exact methods applicable under special conditions, have been developed and are presented here. These methods depend upon (1) radioactive decay, (2) electrodeposition, and (3) X-ray diffraction patterns.

Outline of Approach to the Problem:

Since counting and weighing of atoms are interdependent many of the means by which counting is done are deferred to the unit on weighing of atoms. These units may be interchanged in sequence.

A. Counting by radioactivity

1. The spinthariscope

2. Geometry of sampling to count decay particles
3. Sample problem - radium decay

B. Counting by electrolysis

1. Faraday's laws

2. Electrolytic deposition - amount of electricity in relation to the number of electrons

   The relative amounts (mass) deposited in relation to the number of electrons

3. Sample problem

C. Counting by X-ray diffraction techniques

1. Sample photographs

2. The unit cell - volume

3. Density

4. Sample problem

Proposed Approach to the Problem:

A. Counting particles by radioactivity

1. Show that a sample of radioactive ore shows activity in all directions.

2. Using something such as a "sparkler", show how the particles are emitted into a spherical space with equal activity in all directions.

3. Using a flint and steel, show how contact between certain materials can cause a spark on collision.

4. Show the phenomenon of (3) in the spinthariscope.

   a) This may be shown on a larger scale by etching the inside of a test tube with CaF₂ paste and acid; coating the etched surface with ZnS paste and inserting a radioactive source. The tube will fluoresce in subdued light.

Question:

(a) Since emissions as shown in 1 and 4 above are much too numerous to be singled out and counted, how might it be
possible to sample these emissions and count the sample?

5. Show a radioactive source shielded in such a way as to give a minute sampling of particles being emitted. Assume this to be a point source, emitting in all directions and screened except for a pinhole in the shield.

Questions:

(a) If a detecting device such as a square centimeter of film were placed at a distance R from the point source, what portion of the emitted radiation would be picked up by the detector?

\[
\text{Portion of Counts recorded} = \frac{\text{Area of detector}}{\text{Area of sphere of radius } R}
\]

(b) If the portion of actual count is known, how may the total emission be calculated?


a) Observed - at a distance of 1 meter (R) a film of area = .1mm² recorded 2.705 X 10³ particles per gram per second.

(1) What fraction of all emissions were counted?
(2) What is the total number of particles emitted?

b) Observed - radium produces helium (S.T.P.) at a rate of 1.07 X 10⁻⁴ ml per gram per day.

(3) How many particles are contained in one milliliter of helium?

(note: The interrelationship between volume and molecular weights might be introduced here or delayed until weight relationships have been developed.)

B. Counting particles by electrolytic deposition

1. Faraday's laws

a) Prepare an apparatus by which several electrolytic processes may be arranged in series so that the same current may be applied simultaneously to all units. (See figure, page 170.) Close circuit and show the formation of deposits or gas along the system.
Demonstration of Faraday's Laws

any other electrolyte as desired

CuSO₄

Ag(NO₃)

H₂O with H₂SO₄
Questions:

(a) Note that the amount of gas accumulating is directly proportional to the time of flow of the current. Would you expect this to be true of all of the deposits?

(b) What would you expect to observe if the current were to be increased? (Show this effect.)

(c) What two ways might the quantity of electricity used be changed?

(d) What relationship exists between the quantity of electricity and the amount of material deposited?

1. b) If the apparatus is operated sufficiently long enough, each product may be weighed. The resulting weights are found to be in the proportion Ag: Cu: H₂: O₂: as 108: 31.5: 1: 8.

Question: Do these ratios bear any similarity to those of the atomic weights of these elements?

2. How are electrolytic deposits related to number of particles?

Questions:

(a) How many electrons would be required to neutralize each of the following ions? Ag⁺, Cu²⁺, H⁺, Al³⁺, Ca²⁺.

(b) What might these charges have to do with the structure and family grouping of these ions?

3. Discuss Faraday's laws and the numerical relationships established by his studies.

4. Sample problem

(a) The charge on an electron = 1.602 X 10⁻¹⁹ coulombs. In the electrolysis of water, 96,496 coulombs of charge released 1.0076 grams of hydrogen. How many atoms of hydrogen were released.

(b) How many particles of Ag would be released by the same current? What would these weigh?
(c) How many particles of Cu would be released by the same current? What would these weigh?

(d) If there were as many particles of Cu as there were of Ag, what would they weigh?

(e) Is there any similarity between the weights of a, b, and d and the atomic weights of these substances?

(f) From this data, how might one define atomic weights?

C. Counting atoms by X-ray

1. Display samples of X-ray diffraction patterns of crystalline materials. (Projection might be effective.)

2. What information would be necessary to enable one to count the number of particles in a gram of material from such a photograph?
   a) Dimensions of a unit cell - (repeating units)
   b) Volume of unit cell
   c) Density of material

\[
\text{Number of Particles} \times \frac{\text{Unit cell}}{\text{cm}^3} \times \frac{\text{cm}^3}{\text{gms}} = \text{Atoms}\]

3. Sample problem

(a) The unit cube of tungsten contains 2 atoms, and X-rays show it to be \(3.160 \times 10^{-8}\) cm on an edge. Its density is 19.34 gms/cm\(^3\). How many atoms are there in a gram of material?

(b) If you had as many grams as the atomic weight as given on the periodic chart, how many particles would there be? How does this compare with the numbers in B. 3. a, b, and d?

D. Summarize the unit by relating Avogadro's number to atomic weights.
UNIT IX

Weighing Atoms

Problem:

The assumption of the existence of the atom has been a most useful concept in explaining the behavior of substances, but these tiny particles are much too small to be seen or to be handled individually. How, then, can they be weighed and their "weights" determined so accurately?

Abstract:

In any measurement, an appropriate standard must be established, and some suitable means must be devised for its use. In the determination of atomic weights, the standard adopted is that of one-sixteenth of the mass of the oxygen atom. Since this is much too small to be detected by any available instruments, the scientists have developed ways of comparing equal numbers of atoms of the different elements. By this comparison, they have established a scale of weights relative to the weight of the same number of oxygen atoms. These relative weights are the "atomic weights" which form the basis of any quantitative study of materials.

Outline of Approach to the Problem:

Since individual particles cannot be isolated, relative weights must be obtained through indirect means. This can be approached through comparison of the weights of equal numbers of particles.

A. Preliminary discussion - the establishment of standard units of measure suited to the task at hand

B. Student exercise - the determination of the weight of a single shot with a balance insensitive to such a weight and the shot only relatively uniform

C. Methods of obtaining equal numbers of particles for the comparison of their weights

1. Gay Lussac's law and Avogadro's hypotheses as presented by Cannizzaro
a) Relative weights from vapor density experiments

2. The laws of chemical combination - comparison of combining weights

3. Raoult's law - as applied to non-volatile, molecular materials

D. More complex and precise methods of determining relative weights

1. The mass spectrograph

2. X-ray diffraction patterns of pure elements

Proposed Plan of Approach:

A. Preliminary discussion

1. What criteria are given consideration in the selection of standard units by which measurements are made?

(a) What units are used for measuring (1) heavy-industrial products, (2) retail foods, (3) lumber, (4) electricity as consumed in the home, (5) drugs, (6) jewels, (7) precious metals?

Why are the same units not used in all instances above?

How were these standards selected?

(b) What system of units have been adopted by science as a basis for all measurement? Are there any special advantages in such a system?

(c) In the metric system, the meter is a standard unit of length, and the kilogram is the standard unit of mass. The hydrogen atom has a diameter of $2.08 \times 10^{-11}$ meters and a mass of $1.66 \times 10^{-27}$ kilograms. Other atoms are similar in magnitude. Why might a new set of units be desirable for measuring such particles? How might such a set be chosen? What are these new units now being used?

B. The problem of weighing very small objects

1. Issue to several groups of students boxes of uniform shot (each group a different material, i.e., Pb, Cu, Al, etc.) and instruct them to determine the mass of a single shot on a trip balance.
176

a) Problems to be solved

(1) balance insensitive to a single shot

(2) all shot not identical - hence an average mass must be considered as the mass of one pellet

b) Using the same particles and small cubic cells, have each group determine the diameter of a single particle.

c) Compare weights of equal numbers of shot having the same gauge but of different materials. Why will these ratios not be the same as those of the atomic weights of these materials?

Under what circumstances might these ratios be the same as those of the atomic weights?

2. In order to compare weights of individual atoms, it is essential to compare weights of equal numbers of atoms. The three methods we have examined for counting particles are among the best we have and are a reliable means of checking less accurate data, but they are extremely complex to apply in many instances. How, then, is it possible to obtain samples of equal numbers of particles without such complexity?

a) Gay-Lussac's law and Avogadro's hypothesis

(1) The following type of data were shown by Gay-Lussac to hold true in gaseous reactions.

(a) 2 vol. hydrogen + 1 vol. oxygen = 2 vol. water (as gas)
(b) 1 vol. nitrogen + 1 vol. oxygen = 2 vol. nitric oxide
(c) 2 vol. nitrogen + 1 vol. oxygen = 2 vol. nitrous oxide
(d) 1 vol. hydrogen + 1 vol. chlorine = 2 vol. hydrogen chloride
(e) 3 vol. hydrogen + 1 vol. nitrogen = 2 vol. ammonia
(f) 2 vol. oxygen + 1 vol. nitrogen = 2 vol. nitrogen dioxide

Questions:

(a) Why do you presume that these combinations, and many others like them, are never observed to have fractional coefficients? (Gay-Lussac's law.) (This may be further illustrated by "reacting" a bag of bolts with a bag of nuts such that they come out even.)

(b) Assuming Gay-Lussac's law to hold, it was suggested by Avogadro that equal volumes of all gases, under identical conditions of temperature and pressure, would have the same number of particles. If this is true,
what must be true of the particles of oxygen in (a),
chlorine and hydrogen in (d), or nitrogen in (b), (e),
or (f) in order to obtain the products? (See figure 1,
page 177.)

2. b) Application of Gay-Lussac's law and Avogadro's hypo-
thesis as interpreted by Cannizzaro for the approximate
determination of atomic weights

(1) Prepare a table of a series of compounds con-
taining an element in common.

<table>
<thead>
<tr>
<th>Substance</th>
<th>Molecular Weight</th>
<th>Per Cent Hydrogen</th>
<th>Weight of Hydrogen</th>
<th>No. of Atoms of Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen</td>
<td>2.02</td>
<td>100.</td>
<td>2.02</td>
<td></td>
</tr>
<tr>
<td>Methane</td>
<td>16.04</td>
<td>25.05</td>
<td>4.04</td>
<td></td>
</tr>
<tr>
<td>Hydrogen chloride</td>
<td>36.5</td>
<td>2.75</td>
<td>1.01</td>
<td></td>
</tr>
<tr>
<td>Ethanol</td>
<td>46.08</td>
<td>13.10</td>
<td>6.06</td>
<td></td>
</tr>
<tr>
<td>Methyl chloride</td>
<td>50.53</td>
<td>5.95</td>
<td>3.03</td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td>17.02</td>
<td>17.60</td>
<td>3.03</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Substance</th>
<th>Molecular Weight</th>
<th>Per Cent Hydrogen</th>
<th>Weight of Hydrogen</th>
<th>No. of Atoms of Hydrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>28.02</td>
<td>100.</td>
<td>28.02</td>
<td></td>
</tr>
<tr>
<td>Nitrous oxide</td>
<td>44.02</td>
<td>63.8</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>Nitric oxide</td>
<td>30.01</td>
<td>46.9</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>Nitrogen trioxide</td>
<td>76.02</td>
<td>36.9</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>Nitrogen dioxide</td>
<td>46.01</td>
<td>30.6</td>
<td>14.0</td>
<td></td>
</tr>
<tr>
<td>Nitrogen pentoxide</td>
<td>108.02</td>
<td>25.9</td>
<td>28.0</td>
<td></td>
</tr>
<tr>
<td>Ammonia</td>
<td>17.02</td>
<td>82.4</td>
<td>14.0</td>
<td></td>
</tr>
</tbody>
</table>

Questions:

(a) Since atoms are believed to react as integral species,
the above compounds must contain one or more atoms of
hydrogen or nitrogen. Which one would seem most
likely to contain only one atom? How many atoms must
be contained in each of the other compounds? What is
the approximate atomic weight of hydrogen? of nitro-
gen?

(b) How many atoms must be contained in a molecule of
hydrogen? of nitrogen?
Volume Relationship in Gaseous Reactions

2 vol. hydrogen + 1 vol. oxygen = 2 vol. water (as gas)

3 vol. nitrogen + 1 vol. oxygen = 2 vol. ammonia

Figure 1
2. c) **Vapor density as a means of obtaining relative weights.**

   (1) Prepare 250 ml bulbs filled with gases (i.e., O₂, N₂, Cl₂, etc.) or volatile materials in vapor form (i.e., Br₂, I₂, etc.) by allowing them to stand in a constant temperature bath until all materials volatilize. Seal bulbs while still in bath. 
   
   \[ T = T_{bath}, \quad V = V_{bulb}, \quad P = P_{atms} \]
   
   Be careful to obtain uniform volumes and determine the correction factor for the glass as in the Dumas vapor density procedure. Bulbs may be stored for repeated use.

   (2) Using a pan balance, weigh each bulb and compensate for the weight of glass.

**Questions:**

(a) What are the ratios of weights of each bulb to that of the other bulbs?

(b) How do these ratios compare with those taken from the periodic chart?

(c) What would you expect the ratios \( \frac{H₂}{O₂} \), \( \frac{H₂}{N₂} \), etc. to be? (Select some not available for weighing.) How might you check these ratios?

(d) Would this method be applicable for the determination of the relative weights of such materials as C, Pb, Fe, Cu, etc.? Explain how it might apply or suggest an alternate procedure for relating these weights.

3. **Use of the laws of chemical combination**

   a) Weigh a group of spherical balls, similar to those found in molecular model kits, in such a way that their weights are proportional to those of a selected group of atoms. Color for identification.

   b) Using a demonstration model pan balance, counterbalance one of these atoms (such as Mg) against a weight. "React" the Mg atom with another atom such as O and restore balance by use of added weights.

   c) Use repeated combinations as models will allow being sure to use the proper numbers of atoms in each compound.
d) Follow the demonstration, if possible, by a similar experiment in the laboratory, with each student assigned to different compounds.

Questions:
(a) What "weight" of magnesium was used initially?
(b) With what weight of oxygen did it combine?
(c) Repeat (a and b) with calcium combining with oxygen.
(d) What are the relative weights of Mg and Ca?
(e) How do these compare in ratio with the atomic weights on the periodic chart?
(f) Using carbon, repeat questions a and b forming both possible products.
(g) From the information obtained by "reacting" carbon and oxygen, how would you determine the weight of carbon relative to that of Mg or Ca?
(h) Magnesium "reacted" with only one unit of oxygen, yet it "reacted" with two units of chlorine. Referring back to the study of structure, how might one know how many units must be combined to form a specific product?
(i) Is the procedure involving combining ratios alone suitable in determining atomic weights, or must additional information be obtained? (Recall the "reaction" of carbon with oxygen.) Explain your answer.

4. Use of Raoult's law in comparing weights of equal numbers of particles.

a) CHART - Using figure 2, page 180, discuss the vapor pressure of water and its relationship to temperature. By use of a colored string against the chart, show what effect addition of solute will have on the vapor pressure of water.

Questions:
(a) From "new" vapor pressure curve (string), what is the effect of added solute upon the freezing point of water?
Water Vapor Pressure versus Temperature

218 atm.

4.579 mm.

1 atm.

0.01°C triple point

100°C standard boiling point

374°C critical temperature

pure water

solid

liquid

vapor

salt solution

Figure 2

Separation of Mass Differences as in a Mass Spectrograph

Figure 3
(b) What is the effect of added solute upon the boiling point of water?

(c) As an increasing amount of solute is added to the solutions, what might be expected to happen to the freezing and boiling points of the solution?

(d) Could this effect be continued indefinitely? Explain.

(e) How does salt cause the ice on the streets to thaw, even at below freezing temperatures? Could the temperature be low enough to prevent this effect?

4. b) This change in vapor pressure of a solvent upon the addition of solute has been shown by Raoult to follow a specific law $P_v = P_0 N_S$, where $P_v$ = vapor pressure of the solution, $P_0$ = vapor pressure of pure solvent, and $N_S$ = the mole fraction of solvent (a value inversely proportional to the amount of solute added).

Questions:

(a) Assuming that the amount of solute added is proportional to the number of particles added, how might this method be used to obtain equal numbers of particles of different materials? (non-electrolytes)

(b) Could this method be applied to determine the molecular weights of materials?

(c) If this vapor pressure change is due to the number of particles of solute added, what would you expect to be the effect of the addition of ionic compounds such as NaCl or CaCl$_2$ which form ions in solution?

(d) How many ions would be formed from NaCl? Would you expect the effect to be twice as great? How could you test your answer?

(e) How many ions are formed from CaCl$_2$? What would you expect the total effect to be from this salt? How could you test your answer?

(f) Could this method be used for a substance which is insoluble in water? Explain.

5. Weight determination by mass spectrography.

a) Using glass walled box as shown in figure 3, page 180, show how ping pong balls, filled to have variable weights are influenced by a deflecting force in inverse
Questions:

(a) Here the deflecting force is due to an air jet. If the deflection were to result from magnetic or electrostatic forces, what would have to be true of the particles being deflected?

(b) If the charges on two equal masses were in the ratio of 2 to 1, where would you expect the resulting separation of particles to be observed? (Which would be most highly deflected?)

(c) In the mass spectrograph, the results indicate a charge to mass ratio (ne/m). Might not a variety of materials from a mixture be found recorded at the same spot? How could such a problem be avoided?

5. b) Most of the weights now recorded for atoms have been determined by use of the mass spectrograph. How was this instrument helpful in identifying isotopes?

6. X-ray methods in the determination of atomic weights

a) X-ray diffraction patterns give information dealing with the dimensions of a unit cell and the number of atoms in it.

b) The density of a material is easily determined. How?

c) The number of particles in a gram atomic weight is known. (What is this number called?)

d) How may the atomic weight be determined from a, b, and c?

\[
\frac{\text{cm}^3}{\text{unit cell}} \times \frac{\text{gms}}{\text{no. atoms}} \times \frac{\text{atoms}}{\text{cm}^3} \times \frac{\text{gms}}{\text{atomic weight}} = \frac{\text{gms}}{\text{atomic weight}}
\]

e) Sample problem

The unit cube of carbon (diamond) contains 8 atoms and X-rays show it to be 3.57 X 10^-8 cm on an edge. The density is 3.51 gms/cm^3. If Avogadro's number is taken to be 0.6024 X 10^24, what is the atomic weight of carbon?
C. Extra problems in summary

Select problems for each of the methods discussed.
UNIT X

The Temperature Scale of the Universe

Problem:

Our interpretation of the universe should include some explanation of what happens to the particles of matter over the wide range of temperatures believed to exist (0°K to $5 \times 10^9°K$). If, as has been postulated, matter is composed of tiny particles in constant motion, how is a change in temperature related to the motion of these particles?

Abstract:

The absorption of energy by matter has resulted in a tremendously broad range of temperatures in the universe, and man's thermal environment constitutes only a very narrow portion of the total range. Interpretation of this broad temperature range must be made in consideration of the effects of energy on the particles of matter. Among the variety of effects are found (a) increased vibrational activity of molecules, atoms, or ions in solids, (b) translational motion as shown by the behavior of liquids and gases, (c) rotational and vibrational motion resulting in dissociation of molecules or ion-pairs as in free radical formation or ionization, (d) excitation of electrons to higher energy levels or the stripping of electrons from atoms, and (e) nuclear effects as shown by fission or fusion.

Since equal quantities of matter show different temperature changes when exposed to equal quantities of heat (energy), temperature is not a direct measure of quantity of heat, but is rather more correctly thought of as associated with the kinetic energy of the particles of matter.

Outline of Approach to the Problem:

A. Preliminary questions

B. The Temperature Scale of the Universe

C. What effects does heat have upon matter?
   1. Expansion
2. Change in state

3. Molecular changes
   a) association - dissociation
   b) decomposition

4. Atomic changes
   a) electron excitation - as observed in flame tests
   b) ionization

5. Nuclear changes
   a) fission
   b) fusion

D. How might these changes be detected?

1. Temperature change upon heating a variety of materials

2. Tracing the temperature change over ranges of transitions in state: ice to water to steam - "Cooling" curves

E. How are these changes explained by theory?

1. What change is believed to be occurring as energy is added to a substance?

2. Do these changes follow any constant pattern? (laws)
   a) the ideal gas law

3. The kinetic-molecular theory

4. Application of the kinetic-molecular theory in interpretation of cooling curves

5. The history of water from 0°K to 5 X 10^6°K

**Proposed Plan of Approach:**

A. Preliminary questions

1. How is heat produced or released in car brakes? in the ordinary home furnace? in an electric blanket? in a steam radiator? in a nuclear reactor?
2. How are temperature and quantity of heat different? How are they the same?

3. Why does steam (100°C) cause a more serious burn than boiling water (100°C)?

B. The Temperature Scale of the Universe

1. Construct a logarithmic graph (see page 187). In use unroll as a scroll across the room. Indicate such things as (a) the narrow range of life processes, (b) the normal range of chemical studies, (i.e., aqueous systems, non-aqueous systems, metallurgical systems, ceramic systems), (c) low temperature phenomena, (d) nuclear reaction temperatures, and (e) stellar temperatures.

Questions:

(a) Why do you presume the human body cannot survive if its temperature varies much beyond the limits of 70 - 110°F?

(b) What are the normal temperature extremes in which man lives? Why is this possible if the human body is so sensitive to temperature variations?

(c) Could you postulate a similarity between the critical limits of man's body temperature and the cause for distinction between deciduous and coniferous plant life?

C. What are the effects of heat upon matter?

1. Expansion

a) Wire a circuit in such a way as to include a source of current, a bell, and a metal rod which is free at one end in order to break the circuit. Warm the rod and observe it expanding, closing the circuit and ringing the bell. (See figure 1, page 188.)

b) Fill a volumetric flask with cold water to the base of the neck. Heat and observe the expansion into the neck.

c) Place solid CO₂ in a container as shown in figure 2, page 188. Close the stopcock and warm. The cork is ejected as the solid changes to gas and expands.

Question: In considering matter as composed of minute particles, what appears to be happening to these
The Temperature Scale of the Universe

He freezes at $10^6$°K

He boils at $4 \times 10^6$°K

$H_2O_2$ Flame

Surface - Type M Stars

Limit of Chemistry

Total Molecular Dissociation

Limit - Elementary Liquids

Electrons Boil Off (ionization)

1. A-bomb
2. Energy of Stars
3. H-bomb
4. Lighter Elements Form from Fusion
5. Inelastic Collisions
Water freezes

Limit of Life Processes

Water boils

Fusion Process of Elements
(Coulombic forces too weak to repel particles of high energy.)

Atoms Dissociate
( Electrons Nuclei)

Protons, Neutrons, Electrons,
Only Stable Particles
Figure 1

Metal rod

Open circuit

Stopcock

Cork

Dry-ice

Bell

Figure 2

Figure 3

I$_2$ crystals

Figure 4

Spring Balance

Compressed air
particles as they are heated? In light of this, how would you define expansion?

2. Changes in state

a) Assemble a distillation flask, condenser, and receiving flask in such a way as to show the change of ice to water to steam and back to water, then ice.

b) Heat iodine crystals in a container as shown in figure 3, page 188. Violet vapors appear in the upper bulb and will disappear if crystals are cooled. If upper bulb is cooled the crystals will collect there.

Questions:

(a) What happens to the particles of matter as it changes from solid to liquid to gas?

(b) Would you expect this to be true (possible) of all substances?

(c) What appears to be the essential difference between the solid state, liquid state and gaseous state? (What is necessary to make these changes occur?)

(d) Postulate a reason for I\(_2\) and CO\(_2\) not forming a liquid state under the conditions of the experiment. Are there other materials familiar to you which behave similarly?

3. Molecular changes

a) Dissociation or association and rearrangement

Warm flowers of sulfur slowly. Observe changes to a pale, thin liquid; then a dark, thick tar; and finally a thin, dark liquid.

\[ S_8(\text{cyclic}) \rightarrow S_6(\text{polymer chains}) \rightarrow S_6(\text{chains}) \]

Questions:

(a) What evidence is there to show that this reaction differs from that of expansion or change of state?

(b) How might this phenomenon be related to the thermosetting of plastics?

(c) Why might heat be required for this type of change?
3. b) Decomposition

(1) Test a sample of KClO$_3$ for Cl$^-$. Fuse the salt and repeat the test.

Questions:

(a) What evidence is there that a change has occurred?

(b) How does this change differ from that in 3.(a).

Repeat 3.(b) with HgO, heavy metal nitrates, etc. as desired.

(c) What evidence is there in each of these instances of a change?

(d) How might one proceed to prove the changes in 3.(b) to be different from those in 3.(a)?

4. Atomic changes

a) Excitation of electrons as shown in flame tests

The effects shown here may be illustrated by running a heavy cord through a tube, tying a large weight to the bottom end and a much smaller weight to the top end. By twirling the small weight, the larger one may be seen to be lifted, and, as the small acquires energy, its radius of rotation increases. A slowing of the motion causes the small weight to "drop" back into its initial position. The loss of energy causes the larger weight to be lowered.

Question: The energy provided by the flame here is used in what way in this experiment?

b) Ionization

Questions:

(a) What could happen to the electron in (a) if the energy were to be increased beyond that of the ionization potential? (the cord broke)

(b) If this is true, what might be expected of matter as the heat energy added to it became very large?
5. Nuclear changes

Discuss a comparison between the energies required to hold the nucleus together and those required to hold the electrons in the atom.

a) Radioactive decay - the emission of alpha and beta particles to form a new element

b) Fission - the division of an unstable nucleus into two fragments with the emission of neutrons and large quantities of energy

c) Fusion - nuclear particles at very high velocity, collide and combine to form a new nucleus

\[ 4 \, ^1H = ^4He + \text{energy} = mc^2 \]

D. How may the heat effects on matter be studied?

1. Select a series of substances having widely different specific heats (i.e., water, ethyl bromide, etc.). Heat simultaneously on the same hot plate, observing the differences in rate of change of temperature.

Question: Since equal amounts of energy were added to each of the substances, what appears to be true of the relationship between quantity of heat and the temperature of a substance?

2. Beginning with ice at \( T \) \( 0 \)°C, gradually warm the ice observing the change in temperature as the energy input is increased. Plot a curve to show these changes. (This will be the inverse of a cooling curve. See figure at top of page 193.)
Questions:

(a) As the ice is warmed, what appears to be happening initially?

(b) What is observed at 0°C? Since energy continues to be added, how could you explain this? Might the additional energy be serving some other function than that of changing temperature?

(c) What is observed at 100°C? How is this similar to the observation at 0°C?

(d) Would you expect the same sort of observation from all materials?

(e) From these observations, what must be necessary to change the state in which matter is found?

(f) There appear to be two uses for energy in these observations. What use does it serve in the vertical range of the curve? What use does it serve on the plateau of the curve?

(g) The energy required to change the temperature of a substance is referred to as specific heat. Examine specific heat data for several materials, and show how the curve for a material such as alcohol might differ from that of water.
E. How are these differences in matter explained by theory?

1. What change is believed to be occurring as energy is added to a substance? A qualitative discussion.

   Partially fill a large glass column with ping-pong balls or pith balls, one or two of which are colored. Force compressed air up through the balls, observing the gradually increasing activity of the balls. This may be shown to be representative of the effects of energy on the particles of matter. (See figure 4, page 189.)

2. Do these changes follow any constant pattern (law)?

   a) The ideal gas law

   (1) Pressure vs. volume - Insert a sensitive spring balance above the ping-pong balls in (1). Notice the increase in pressure (decrease in readings on balance) as the balance is lowered into the cylinder and the air is admitted at a constant rate.

   Question: How do pressure and volume of gases appear to be related? How does one express this inverse ratio mathematically?

   (Test the relationship between P and V by use of the Boyles' law apparatus commonly used in the laboratory.)

   (2) Pressure vs. temperature - Demonstrate by use of a constant volume gas thermometer, the relationship between temperature and pressure. This may be shown by use of the apparatus in (1) by holding the balance in constant position and increasing the flow of air being admitted.

   Question: How do temperature and pressure appear to be related? How does one express this direct ratio mathematically?

   (3) Volume vs. temperature - Demonstrate by use of a constant pressure gas thermometer, the relationship between volume and temperature. This may be shown by a gradual increase in the volume of the balls in the apparatus of (1) as the air pressure is increased.

   Question: How do volume and temperature appear to be related? How does one express this direct relationship mathematically?
(4) Summary - Express each of the relationships above mathematically and show how they may be combined into one law. \( PV = nRT \)

3. Discuss the kinetic-molecular theory.

The rigor with which this is presented depends upon the class in question, but it is suggested here that it be so developed to derive the interrelationship between energy and the velocity of particles.

\[ v = \frac{3RT}{\sqrt{M}} \]

4. Application of the kinetic-molecular theory in the interpretation of the energy versus temperature curve.

a) Relate the temperature changes to particle motion (velocity).

b) Refer back to the problem of absorption of heat without temperature change, and discuss what might be happening to the material as a result of the added energy.

Questions:

(a) In light of the discussion relating to energy and temperature, how might temperature be defined in terms of energy effects on particles of matter?

(b) Is this definition consistent with the relationship between temperature and velocity of matter?

(c) In light of this definition, what might be a few reasons for the differences in specific heat found in the study of a variety of materials?
4. c) The History of Water - \(0^\circ\text{K} \text{ to } 5 \times 10^6^\circ\text{K}\)

- \(0^\circ\text{K}\)  | Vibration of molecules in solid
- \(273^\circ\text{K}\)  | Translational motion of molecules in liquid
- \(373^\circ\text{K}\)  | Electron transitions
  - Rotation of molecules
  - Vibration of atoms in molecules
- \(2000^\circ\text{K}\)  | Translation motion
- \(6000^\circ\text{K}\)  | Molecules all dissociated into ions and electrons

- \(1 \times 10^6^\circ\text{K}\)  | Violent translational energy - atoms stripped of all electrons

- \(10 \times 10^6^\circ\text{K}\)  | Thermonuclear reactions
  - Fusion of nuclei - formation of new elements
- \(5 \times 10^9^\circ\text{K}\)  | Violent collisions - complex nuclei unstable
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