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ABSTRACT

Designed for college-bound students, their parents, and high school teachers, counselors, and administrators in California, this statement sets forth recommendations concerning the skills, attitudes, and qualities that should be imparted by high school science programs and the curriculum and courses to impart them. Prefactory material provides background to the project and a summary of its major recommendations, including that: (1) college, university, and secondary school science teachers work together closely to review the content of the high school science curriculum; (2) college-bound high school students take 1 year each of biology, chemistry, and physics; (3) the content of the courses be at an accessible and masterable level; (4) a laboratory component in which students carry out projects and experiments be an integral part of these courses; and (5) the California State University and Colleges and the University of California implement an admission requirement of 3 years of science. Part I provides quotes reflecting the debate over the state of science education. Part II presents recommendations concerning the intellectual attitudes, skills, and qualities that contribute to success in college curricula; secondary school science curriculum requirements; and admissions requirements to baccalaureate programs. Section III focuses on the recommended core biology, chemistry, and physics courses, specifying content and providing sample questions, problems, and laboratory exercises. (LAL)

STATEMENT ON PREPARATION IN NATURAL SCIENCE EXPECTED OF ENTERING COLLEGE FRESHMEN

The Academic Senates of
The California Community Colleges,
The California State University,
and The University of California

STATEMENT ON PREPARATION IN NATURAL SCIENCE EXPECTED OF ENTERING COLLEGE FRESHMEN

Table of Contents

Preface

In November of 1982, the Academic Senates of the California Community Colleges, California State University and Colleges, and University of California jointly developed and published a Statement on Competencies in English and Mathematics Expected of Entering Freshmen. In that statement the Senates indicated that statements of expected competencies in other academic disciplines would be forthcoming. This Statement on Preparation in Natural Science Expected of Entering College Freshmen is the first of those. Preparation in natural science was selected for immediate attention because of the growing concern among educators and business and political leaders that there is an increasing shortage of scientists, technicians, science teachers, and scientifically-literate college graduates.

This statement differs from its predicessor because of the nature of the subject matter. The statement on English and mathematics addressed skills and competencies without which a student has little chance of success. For example, the English skills learned in high school (and earlier) are needed for all courses taken in college. In contrast, the specific content of a high school science course, like chemistry, might not be needed for any of the courses a student might take in college. Even if a student were required to take a college-level physical science course, he or she might not select chemistry but might elect another course in which the skills previously learned, while helpful, are not prerequisite for the course. Therefore, we believe a student's high school science courses must be considered to complement his or her college experience as well as to prepare for it.

This statement, like the previous one, is addressed to students preparing for college, their parents, high school teachers, counselors, and administrators. The Academic Senates urge that it be widely distributed to all of these interested parties, so that they have a clear understanding of the expectations of college and university faculty. Further, the Academic Senates urge that secondary and postsecondary educators take measures to implement the recommendations contained in this statement as educational policy in California.

The Intersegmental Committee to
Prepare a Statement on Preparation in
Natural Science for College

EXECUTIVE SUMMARY

In October 1982, the Intersegmental Committee of the Academic Senate formed a committee to prepare a statement on preparation in natural science for college-bound students. This project was the second of a series intended to reexamine college prepatory studies. The previous, and first, project was a statement of competencies in English and mathematics expected of entering freshmen[1].

The quality of California's public education system has been a matter of public debate for some time. Recent recognition of the need for change and secondary schools by the state and the reimposition of state-mandated, minimum high school graduation requirements. An example of the latter is the state minimum requirement in science, set at two years for all students. This constitutes an increase from the previous recommendation of just one year. The increase is a reflection of a nationwide trend to institute greater science requirements. The trend, in turn, reflects the increasing technical and scientific knowledge required of citizens to be full participants in modern society.

We recognize that our recommendations, if implemented, will require adjustments, some quite extensive, at both the high school and college levels. We therefore intend any change to be at a measured pace. The important recommendations in this summary highlight our deliberations. The body of the statement contains other recommendations which further clarify our deliberations or which highlight ancillary matters.

We call upon college, university, and secondary school science teachers to work ever more closely together on the local level to review the content of the high school science curriculum and to guide instruction.

Faculty in both segments must recognize their collegial responsibilities to one another.

We recommend that all high school students planning a baccalaureate education take one year of biology, one year of chemistry, and one year of physics.

A major concern was that these courses be taken in a sequence which matches the maturing mathematical skills of the students. Hence the most likely pattern would be biology in the sophomore year, chemistry in the junior year, and physics in the senior year. A common alternative pattern of biology in the freshman year, chemistry in the sophomore year, physics in the junior year with the senior year open for electives would be acceptable if the student's mathematical development coincided with this alternative pattern.

Our reocmmendation considers not only preparation for college but also recognizes that high school science courses are in important component of a student's general education. Non-science majors in

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[1] Statement of Competencies in English and Mathematics Expected of Entering Freshmen, November 1982 by The Academic Senates of the California Community Colleges, California State University, and University of California.

college take few science courses and, in some cases, can graduate without taking any physics, chemistry, or biology. Even college science students sometimes specialize so much that they do not take science courses outside of their discipline. Consequently we recommend that students in high school take advanced courses only after they have completed the three core courses. Furthermore, we recommend against segregating intended science and non-science majors by creating special high school courses for each group.

We strongly recommend that all college-bound students (prospective science and non-science majors alike) take the same three core courses, not substituting more specialized or more simplified courses.

Because the science courses are expected to serve students with a broad range of interests, we specify a level of sophistication for these courses.

We believe that the content of the recommended courses should be at a level that is accessible and masterable by all college-bound students.

We also specify in more detail the content and level expected in each course. Lists of topics to be covered and sample problems are included. We also include a section on the laboratory portions of the courses.

We recommend that a laboratory component in which the students carry out experiments and projects, not just simulations, be an integral part of these courses.

The experimental nature of these disciplines is the basis for our recommendation of a strong laboratory component in these courses. Experimentation is integral to the sciences.

Recognizing that universities accept and educate nominally prepared students while the community colleges educate students who chose not to enter the university or who are not nominally prepared, we also make a recommendation addressing the minimal preparation for students entering the universities.

We recommend that the California State University and Colleges and the University of California implement an admission requirement of three years of science, including one-year long, laboratory courses in two of the three disciplines of biology, chemistry, and physics.

All high school students in the state will be required to complete two years of science to graduate under recently passed legislation. The expectation that college bound students take an additional year is not excessive. Moreover, most students in the state take some type of combined introductory science course, usually in the freshman year, and this course would count towards the admission requirement of three. The other two courses would come from courses of one year length in physics or biology or chemistry. We feel this is a crucial recommendation because university admission requirements are of paramount importance in setting and maintaining educational expectations.

I Introduction

The state of science education has been the subject of public debate for many years but recently the volume of debate has reached avalanche proportions. Most of the comment is negative. The following are typical.

> "The science programs developed for the 60's are not appropriate for teaching science today. We can see now that science and technology impact upon a wide range of our economic, social, and political policies and decisions. A basic understanding of science is becoming a requirement for more jobs. Our quality of life, perhaps even our national security, depends on the quality and amount of science education offered by our schools. Today's science education must recognize the role that science and technology play in resolving the problems of our age. The problem of low enrollment in science is central to the issues discussed here."
>
> Edward T. Walford
> Cheyenne Mountain High School
> in December 1983 Journal of Chemical Education.

> "Only 25% of American high school students take three years of science, compared to approximately 98% of high school students in Japan, West Germany, and the Soviet Union. Only 37% of our students take chemistry and 22% take physics."
>
> From a 1980 Survey by the
> Carnegie Foundation--reported
> in September 1983 Physics Today

The level at which science courses are taught is also under attack.

> "I sometimes think that the high schools have made the science courses so difficult that they have reduced the population of students who will take these courses. If you take a look at a typical high school textbook, my belief is that it asks too much. I'd prefer to see them taught at a less demanding level, but ensuring that a much large proportion of the students will take them."
>
> Richard Atkinson on his
> retirement as Director of the
> National Science Foundation,
> 1980

Recommendations from individuals, groups, and governmental agencies seeking to ameliorate the problem have been numerous, as can be seen from the following excerpts.

"We recommend that state and local high school graduation requirements be strengthened and that, at a minimum, all students seeking a diploma be required to lay the foundations in the Five New Basics by taking the following curriculum during their four years of high school: (a) four years of English; (b) three years of mathematics; (c) three years of science; (d) three years of social studies; and (e) one-half year of computer science. For the college-bound, two years of foreign language are strongly recommended . . ."

The National Commission on Excellence in Education in _A Nation of Risk: Imperative for Educational Reform_

"The trend in the 1960's toward reduced high school graduation requirements in many school systems and reduced admissions criteria in many college systems is frequently blamed for producing a decreased emphasis on academic standards and achievement in secondary schools." "Lessening rigor in secondary schools directly affects priorities in elementary schools. The Commission believes that high school graduation requirements in mathematics and science . . . should be significantly increased and this should be done forthwith." "Thus the Commission recommends: all secondary school students should be required to take at least three years of high school mathematics . . ., and at least three years of science and technology including one semester of computer science, . . ." "Steps should be taken to phase in higher mathematics and science entrance requirements for all colleges and universities . . . . Such college requirements should include four years each of high school science, including physics, chemistry, and one semester of computer science, four years of mathematics, including a second year of algebra and coursework covering probability and statistics."

The National Science Board Commission on Precollege Education in Math, Science, and Technology in _Educating Americans for the 21st Century_

In early December 1983, Secretary of Education Terrell H. Bell established "four performance goals for the next five years for American Education." including the goal that, by 1989, all high school graduates in all 50 states will be required to study English for four years and math, science, and social studies for three years.

Reported in December 14, 1983 _Chronicle of Higher Education_

A consensus clearly has developed that substantial experience in science is needed for college-bound students. The real problem lies in summoning the will and establishing the mechanism to provide this experience. Moreover this mechanism must provide a system to maintain the curricular integrity of those high school science courses which provide the scientific experience. In order to foster quality and provide for continuous progress in this area, we make what we feel is one of our most important recommendations:

*We call upon college, university, and secondary school science teachers to work ever more closely together on the local level to review the content of the high school science curriculum and to guide instruction.

The task of precisely defining the minimum level of understanding or competency in science required for students entering college is somewhat more difficult than the same task for mathematics (covered by the previous statement). Science is unlike mathematics, in which the topics in high school and beginning college courses are generally sequential and there is a generally recognized division between baccalaureate and high school work. Science is divided along the lines of scientific disciplines, e.g. physics, chemistry, biology, and geology. Within those disciplines various topics are taught at many levels with the depth of coverage increasing as students progress from primary to secondary to college levels. The same topic may be covered a number of times but with increasing level of abstraction, complexity of language, and standards of performance. This practice has arisen because of the many interrelationships between the branches of science and the nonsequential nature of some topics.

Ideally, to define competence in science we need to consider both the breadth of a student's exposure and the depth of a student's comprehension. We address breadth in this statement in the form of a recommended curriculum and by course content lists and sample laboratory exercises, which we hope will provide adequate guidance for further discussion and course development by our high school and college colleagues. We address depth by providing a statement of skills and attitudes that should be acquired or developed by high school students, as well as by appending sample questions and problems.

We regard the specific recommendations and suggestions that follow to be only a starting point of a continuous dialogue.

II. Recommendations

A. Skills, Attitudes, and Qualities that Should be Imparted by a High School Science Program

A broad background in science is necessary for every college-bound student. Regardless of the fields students enter, literacy in science is necessary to understand our present culture, the prevailing philosophy of the western world, and western history over at least the last five hundred years. It is also needed to be a productive participant in a technological workplace. Moreover high school science courses provide certain intellectual attitudes, skills, and concepts that contribute to success in college curricula.

The skills and attitudes listed below are important because they represent a major part of what a student needs in order to be successful in higher education, scientific and technical professions, business, and other careers that require intellectual effort. A student with these skills will be able to learn when faced with new problems and adapt when faced with new situations. However, these skills and attitudes do not define a high school curriculum or the content of a course, and therefore some high school teachers may initially be puzzled at how to apply this list to their own courses. There is surprisingly little in the educational literature that guides the teaching of "defining a scientific problem," "analysis," or "generalization," let alone "objectivity." We believe that the answer lies, in part, in the types of projects a teacher assigns and in the standards he or she sets for student performance. The rest of the answer lies in the teachers themselves. We know that there are teachers in California schools who have devised excellent ways of teaching these skills and attitudes, and we are convinced that it is a responsibility of the science education community, parents, and school boards to identify these teachers and to encourage and extend their methods.

*<u>We recommend that secondary school science teachers foster the traits of inquisitiveness, objectivity, open-mindedness, skepticism, and perseverance.</u>

-- <u>Inquisitiveness</u>: asking well-defined questions about nature.

-- <u>Objectivity</u>: viewing and describing events and phenomena without personal bias and with as few preconceptions as possible; being aware of personal choices and alternatives in deciding what to emphasize; appreciating the value of accuracy and honesty in making and reporting observations, i.e., appreciating why it is better to be accurate than to support a dogma or authority.

-- <u>Open-mindedness</u>: seeking and accepting alternative models and hypotheses.

-- <u>Skepticism</u>: challenging dogmatic contentions and focussing on evidence.

-- Perseverance: continuing to ask and answer questions until one reaches a satisfactory level of understanding.

*We recommend that the language skills, mathematical skills, and general mental skills needed for scientific work or study (listed below) be sharpened and refined in secondary school science courses.

-- Reading comprehension: the ability to read and comprehend scientific materials; the ability to distinguish facts from hypotheses and from opinions.

-- Writing and speaking: the ability to communicate observations and ideas clearly.

-- Memory: the ability to recall enough facts and scientific principles to progress to more complex problem-solving activities, such as generalization or application.

-- Mathematics: the ability to handle quantitative relationships; the ability to reason symbolically; the ability to translate symbolic statements into English, and vice-versa; the ability to display and interpret data in tables and graphs and to prepare graphs from tables.

-- Analysis: the ability to separate a theory or observation into component parts.

-- Reasoning: the ability to draw correct inferences from a set of statements or observations; the ability to marshal relevant arguments to defend or refute a proposition.

-- Generalization: the ability to find patterns in isolated facts and to describe those patterns in a clear and concise way.

-- Classification: the ability to organize objects, concepts, and observations in a way that promotes understanding of their relationships; the ability to recognize and use different levels of abstraction.

-- Application: the ability to use scientific principles and laws to explain familiar and unfamiliar observations; the ability to devise and apply analogies in a scientific setting.

*We recommend that students be provided with some exposure to the processes of scientific investigation that are listed below. Though these are simple to list, their use is complex, and a scientist is constantly relearning and refining his or her ability to apply them. High school science courses, with their multiple responsibilities, cannot and should not provide exhaustive training in these activities. Nevertheless, each science course can, through description and practice, provide some experience with them.

-- Defining a scientific problem: listing questions about the observable nature of objects and forces, materials, and organisms; recognizing which questions are answerable and which are not.

-- Proposing a scientific hypothesis: suggesting reasonable alternative solutions to the problem in question; distinguishing relevant from irrelevant models.

-- Making predictions that are designed to test an hypothesis: deciding what measurements will distinguish one hypothesis from another; recognizing the necessary controls.

-- Making measurements and other observations needed to confirm or refute a prediction (see next recommendation).

-- Deciding whether evidence confirms or refutes a given prediction; applying simple statistics (mean and estimate of error) to decisions.

*We recommend that each high school student should receive practical instruction in laboratory procedures. Laboratory instructors provide perspective to the study of science, since science cannot be divorced from the basic activities involved in making descriptive and quantitative observations. Laboratory activity also provides a basis for further college laboratory work. It is a firm belief of college instructors that students with previous laboratory experience are better able to set up, perform, and evaluate experiments in their classes than those with backgrounds in lecture-only courses. The following general skills should be taught in each laboratory course.

-- Laboratory safety: awareness of common dangers, techniques for dealing with dangerous instruments, materials, and situations.

-- Measurement: accuracy and precision; use of standard units; scientific notation; significant figures.

-- Use of Statistics: calculation and meaning of mean, mode, and median; calculation and meaning of variation; estimation of errors and interpretation of their significance.

-- Reporting: accuracy and completeness; selection and communication of cogent information.

B. Curriculum Recommendations

In order to address the question of what constitutes a proper science curriculum for college-bound students, we divided the question into three parts. The first is, "Which courses should be taken by the college-bound student and what should be the content of those courses?" The second is, "Should students who are prospective majors in the sciences or engineering take the same number and level of courses as students who are not prospective science or engineering majors?" The third is, "To what extent should the computer be utilized in secondary science instruction and what form should such use take?" This section of the statement addresses these three questions.

*We recommend that all high school students planning a baccalaureate education take one year of biology, one year of chemistry, and one year of physics.

The preferred sequence would be biology in the tenth grade, chemistry in the eleventh grade, and physics in the twelfth grade. The recommended contents of these three courses are provided in Section III. We presume that ninth grade instruction in science, where available, is a basic course of some substance that presents fundamentals needed to study science in general, particularly the physical sciences. We recognize that in some four-year high schools, students can take biology in the ninth grade, chemistry in the tenth grade, and physics in the eleventh grade; however, we do not recommend such an **accelerated** program, unless it is combined with accelerated mathematics courses, so that a student's mathematics background supports the demands of his/her science courses. The preferred timing and sequence is recommended specifically because it does correspond well with the maturing math skills of the students, which are needed in chemistry and, especially in physics.

*We believe that the content of the recommended courses should be at a level that is accessible and masterable by all college-bound students.

These courses are not meant to be in-depth studies of some aspect of the disciplines, nor are they meant to mimic introductory college courses. They should be sound introductions to the disciplines and should address, in addition, the scientific endeavor in general, the relationship between science and society, and the responsibilities of citizens in a technological society.

All three recommended disciplines are experimentally based, consequently;

*We recommend that a laboratory component in which the students carry out experiments and projects, not just simulations, be an integral part of these courses.

Without laboratory work, the disciplines cannot be taught well. The ability to gather and evaluate experimental data properly is essential to all three disciplines. Without laboratory studies, the question of "How do we know?" cannot be fully addressed. The importance of the experimental component of these disciplines cannot be overemphasized, yet it is frequently the least understood component of the science curriculum. The public often does not fully appreciate that all science is based on experiment, not on authority, and many school systems deemphasize laboratory courses in favor of lecture courses, because of the cost and logistics problems associated with laboratory instruction. A greater commitment to provide laboratory instruction in secondary schools is needed.

*We strongly recommend that all college-bound students (prospective science and non-science majors alike) take the same three core courses, not substituting more specialized or more simplified courses.

In particular, courses like "Ecology" or "Human Anatomy" are inappropriate as basic science courses. Students who intend college majors in non-technical fields often take few science courses in high school because they feel such courses are "inappropriate" to their careers. This practice is undesirable because these students almost certainly are inclined to study little science in college and consequently have the greatest need for an introduction to basic science offered by the high school courses. Students who intend majors in scientific and technical fields would also be served by getting a broad exposure to science that complements their more focused studies in college.

For students greatly interested in science, or science-related careers, it is suitable to provide honors or Advanced Placement (AP) courses in high school. But such courses should encompass, or require the prior knowledge of, the content courses we describe. Acceleration of a student's program should not involve the omission of elementary material to make room for more advanced material. Specifically, AP courses are intended to be equivalent to college-level courses and, as such, require the content of the high school courses as prerequisites. It does not seem possible to cover the contents of the high school course and the college course simultaneously.

*We recognize that many high schools offer prospective science majors Advanced Placement science courses, but, since these are intended to be equivalent to college courses, they should not substitute for the courses recommended above.

For students interested in advanced placement, and who have suitable preparation in English, mathematics, and science from grade school, a program in which biology is taken in the ninth grade, chemistry in the tenth, and physics in the eleventh grade would allow the taking of AP courses in the twelfth grade.

The three courses that are recommended, though complementary, present unique methodologies and viewpoints within the overall structure of scientific thought. Secondary school students who take these three courses will receive a broad exposure to scientific disciplines. Furthermore, a common curricular experience for pre-college students provides students with more options for collegiate study and assists colleges and universities in doing their jobs more effectively and economically. By focussing their resources on these few courses, school districts should be able to deliver quality instruction more economically. These curricular and financial benefits should not be minimized.

We would like to point out that our recommendations describe a curriculum that was a common pattern for college-bound students a generation ago. No evidence exists that the relaxation of this curricular pattern has led to enhanced preparation of college-bound students in California. On the contrary, increased numbers of remedial courses at the college level, and increased enrollments in these courses, indicate quite the reverse. Furthermore, other industrialized countries require secondary school course patterns similar to that which we recommend. For example, college-bound students in Japan take an average of three natural science courses and four mathematics courses in three years of high school.

*We recommend that, if secondary science students have been trained to use a computer as a tool in a science discipline, then efforts should be made to teach and encourage its use.

The role of computers in secondary science instruction seems twofold, first in computer-assisted instruction (CAI) and second, as a tool that greatly facilitates calculation and rapid graphic display of scientific results. As with any classification, the borderline here is not a sharp one, but the use of a computer as a data analysis tool is the primary mode in which computers are used by practicing scientists and engineers, and it requires a greater sophistication in mathematics, science, and knowledge of the computer, than does the former. The committee cautions that the intent of science courses should be to teach scientific content and process. When the use of a computer enhances this, it should be used; when the use of a computer detracts from this, or dilutes the laboratory experience, great caution should be used. Specifically, the teaching of computer programming should not be allowed to displace any part of the regular science curriculum.

C. Statement on Admissions Requirements to Baccalaureate Programs

As explained above, we feel that a broad background in science is necessary for every college-bound student and one of the ways by which colleges assure adequate preparation is to set minimum requirements for admission. Yet, we found it difficult to divorce a consideration of what is proper and adequate from what is possible to implement. The physical constraints on secondary schools seem to preclude requiring all college-bound students to take full-year laboratory courses in biology, chemistry, and physics, which is our preference. Accordingly we make the following recommendations.

*We recommend that the California State University and Colleges and the University of California implement an admission requirement of three years of science, including one-year long laboratory courses in two of the three disciplines of biology, chemistry, and physics.

This requirement is only one science course more than is required for high school graduation. The requirement is not excessive and corresponds to what other states, most recently Colorado, have already implemented. As formulated, the recommendation allows a freshman general science course to count as one of the three courses.

*We recommend that students who take one-year courses in all three disciplines (as described) should receive additional admission credit in an appropriate manner.

This practice would encourage students to take these courses rather than to take less substantial courses to secure a higher grade point average.

For students who are prospective science majors, these requirements would ensure that they have the fundamentals they need to start their college programs. For students who intend non-science majors, these courses would be a substantial portion of their total exposure to science. Because scientific literacy is so essential today, it is appropriate that even students who will not be science majors take several courses in science in high school. We strongly support this science admission requirement. It is a waste of scarce resources to teach at the college level a spectrum of courses that can be taught very effectively at the high school level. Furthermore, colleges and universities can do a more effective job with students who have comparable preparation.

Even if the UC and CSU systems implement more stringent admission requirements, students may enter the community colleges without these courses. We believe this is appropriate. It provides students with an entree to baccalaureate programs, even if they had chosen not to prepare for college in high school and subsequently had a change of mind. The community colleges traditionally have performed well in allowing students who are not fully prepared for admission to the CSUC and UC systems to obtain the proper background. However, since at this time transfer from a community college to those systems is based primarily on just the total number of college units passed, many students who transfer still have not taken the requisite courses, either in high school or at the community college. Therefore:

> *We recommend that students who have not fulfilled their science admission requirement while in high school, and who have attended a community college, should be required to fulfill the requirement by taking appropriate courses in these disciplines at the community college prior to transfer.

This provision would ensure that students have appropriate preparation for baccalaureate work. Community colleges generally offer a range of laboratory courses in scientific disciplines, including high school-equivalent and baccalaureate level courses. Any of these should fulfill the admissions requirement.

III. Course Contents

The Biology Course

Introduction

High school students who take biology in preparation for college should be presented with a wide range of subjects. There is a standard set of topics that are treated by most of the major texts. Table I lists the principal topics: the phenomenological, structural, and chemical characteristics common to all living organisms; basic aspects of reproduction and heredity; descriptions of the major groups of organisms; animal physiology (with particular application to humans); and principles of ecology and evolution theory. There are also laboratory skills and experiences that are invaluable, because they are uniquely important to biological science. These are listed in Table II. Though the constraints of time, space, and supplies may force some school programs to emphasize different topics, we feel that each student should have some exposure to each of the topics, skills, and experiences listed. After their high school biological science experience, students should be able to clearly differentiate between life and non-life, respect the living condition, and have knowledge of the variety of organisms that exist.

It is more difficult to define the depth required of a high school biology course than the breadth. The list of topics does not define depth, for the topics are much the same as those taught in introductory college courses and, in a less intensive fashion, in pre-high school science courses. In determining the proper depth, one must recognize that the students in most biology classes are young (14-15), and they have little background in mathematics, chemistry, and physics. Thus, the level of teaching will be descriptive and phenomenological, rather than quantitative and analytical. The only mathematics prerequisite should be arithmetic. The best way to illustrate the depth required may be to present a list of questions that an entering college student should be prepared to answer. Such a list is appended.

1. TABLE I: TOPICS IN BIOLOGY

This table supplies the proposed minimum content of a one-year general course in biology. Each topic should be covered to such depth that students master the basic vocabulary and concepts of the topic. Beyond this, emphasis may vary from teacher to teacher. Enrichment of the topics listed here with examples, laboratory demonstrations, and field trips is essential: see Table II (below). The addition of topics not listed here, for example plant physiology or animal behavior, is encouraged, but it should not prevent the class from receiving basic coverage of the topics that are listed.

1. The characteristics of protoplasm:

   Suggested topics include biological organization, the utilization of energy by living systems, growth, irritability, and cellular/organismic adaptation. This section should be an overview of the entire course.

2. The chemical basis of living things:

   Suggested topics include atoms, molecules, chemical bonds, and their relationships to chemical reactions. A discussion of the raw materials of life and how these materials are utilized in the production of protoplasm. Basic concepts of the energetics of chemical reactions, including enzymes and catalysis.

3. The structural basis of living things:

   A discussion of the structure of plant and animal cells, the cellular environment, movement of materials across the cell membrane and within the cell, and the levels of organization associated with multicellular structures.

4. Cellular energetics:

   An overview of the energy processes within cells, including cellular respiration, photosynthesis, and the uses and conversions of cellular energy.

5. Nucleic acids:

   A discussion of the nucleic acids, both DNA and RNA, their molecular structure, replication, and role in the synthesis of proteins.

6. Cellular growth and reproduction:

   A comparison of the critical roles of meiosis and mitosis in cellular and organismic reproduction, and a discussion of sexual and asexual reproduction as alternative means of species perpetuation.

7. Principles of heredity:

An exploration of the chromosome theory of heredity, Mendelian genetics, gene-enzyme relationships, and their applications to human inheritance.

8. Taxonomy:

A discussion of the concept of classification, including the contributions of Linneaus, modern taxonomic systems, scientific nomenclature, and present-day classification systems.

9. Animal phyla:

An investigation of the structural and functional similarities and differences of the major animal phyla with an emphasis on evolutionary relationships.

A. Invertebrates

B. Vertebrates

10. Other phyla or groups:

A discussion of the structure, evolutionary relationships, functional differences, economic significance, and organizational complexity of the following groups of organisms:

A. Viruses, monera, and protista

B. Fungi

C. Algae

D. Mosses, liverworts, and ferns

E. Gymnosperms

F. Angiosperms

11. Physiology:

A system-by-system analysis of the major organ systems of vertebrates, concentrating on the application of basic principles to humans.

12. Ecology:

The structure and function of ecosystems, with emphasis on population biology, community structure, energy flow within communities, and the impact of human society on the natural environment.

13. Evolution:

A survey of the major mechanisms of intraspecific evolution and specification, including a synthesis of the roles of genetic variation and selection on the habits and habitats of species. Discussion of the nature of evidence used in studies of evolution; speculations on the evolution of the human being.

2. SAMPLE QUESTIONS/PROBLEMS

3. TABLE II: LABORATORY EXPERIENCES

The goal of the laboratory in high school biology is to reinforce and enrich the subjects that are introduced in the textbooks and discussions. Each of the experiences listed below should be covered in the one-year course, though the emphasis and the materials used may vary from class to class. The general objectives of the laboratory are:

(A) Sharpening observational skills. This includes training in accurate perception and communication. A student should be able to describe a living system in sufficient detail to allow a fellow student to identify the organism and its salient characteristics. The training should also stimulate curiosity and imagination, so that a student will ask questions and make hypotheses on the basis of his or her observations.

(B) Connecting abstractions with real images. There are many subjects in biology that are outside the limits of normal experience. When described in a textbook, a student sees these as abstractions, rather than objective facts. The laboratory is a place to give meaning to such topics as microorganisms, cellular and tissue organization of plants and animals, and reproductive stages. Some concepts are truly abstract and require illustration. These include the principles of heredity and the principles of classification.

(C) Showing that living organisms are suitable for scientific study. A non-scientist's approach to living systems is often mystical. The laboratory is the proper place to show that biology rests on empirical observation, rather than mysticism. This can be accomplished through exercises demonstrating the chemical constituents and activities of cells and tissues, or through semi-quantitative studies in physiology or behavior.

1. Use of the compound microscope:

   Training in basic techniques, including focusing, determining magnification, making microscopic measurements, preparing wet mounted slides, and caring for the microscope.

2. Observation of a wide variety of organelles, cells, and tissues:

   Suggested materials: wet mounts of cheek, onion, potato, tomato skin, and Elodea leaf cells; prepared slides and cultures of unicellular organisms such as Amoeba, Paramecium, and Euglena; prepared slides of epithelial, connective, muscular, and nervous tissue.

3. Observations of characteristics of biological chemicals and chemical reactions:

   Suggested projects: tests for starch, sugar, proteins, and lipids; assays for amylase, pectinase, and polyphenol oxidase.

4. Observation of the total life cycle of an organism:

Suggested organisms: pea plants, Drosophila, and bread mold (asexual and sexual reproduction). Other useful materials: prepared slides showing stages of mitosis in animal (whitefish blastula) and plant (onion root tip) cells; prepared slides showing stages of meiosis in animals (grasshopper testis) and plants (lily anther and ovule). Principles of heredity may be illustrated with Drosophila or corn ears.

5. Observation and description (with drawings) of the external morphology and behavior of a wide variety of living plants and animals, including representatives of all major taxa:

Plants to include: blue-green algae; mushrooms; green, red and brown algae; mosses; ferns; gymnosperms; and angiosperms (from angiosperms forms with a variety of leaves, stems, roots, flowers, fruits, and seeds). Suggested invertebrates: sponges, Hydra, Planaria, Ascaris, snails, earthworms, crayfish, spiders, grasshoppers, and starfish. Suggested vertebrates: fish, frogs, turtles, snakes, birds, and mammals (study of mounted skeletons included). Field trips to zoos, natural history museums, botanical gardens, and aquaria are encouraged.

6. Dissection of a representative preserved invertebrate and a representative preserved vertebrate; description (with drawings) of anatomical features:

Suggested invertebrates: earthworms, crayfish, grasshoppers and sea urchins. Suggested vertebrates: fish, frogs, and foetal pigs.

7. Dissection and description of representative plant organs:

Suggested materials: leaves, stems, roots from plants grown in classroom: fruits, seed specialized stems and roots from the grocery (peas, tomatoes, apples, onions, carrots).

8. Work with classification systems (using keys):

Possible projects: identification of microscopic pond water denizens or identification of wild flowers, using appropriate manuals.

9. Demonstrations and experimentation with cellular and organismal physiology:

Possible phenomena: brownian movement, diffusion, osmosis, blood cell lysis; patella reflex, tasting, color blindness, respiration, pulse rate, seed germination, greening of etiolated shoots, photo- and gravitropism.

10. Conceiving, planning, organizing, executing, and summarizing a research project: include explicit hypotheses, data accumulation, and conclusions:

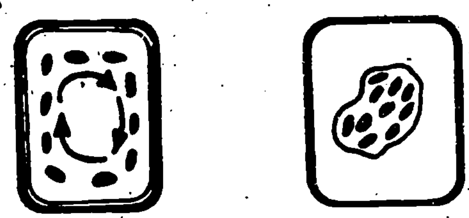
When available, computers may be used to simulate experiments, calculate results, perform statistical manipulations, and prepare reports.

Biological science questions appropriate for high school students in a college preparatory program appear below. These questions are taken, by permission, from a New York State Regents High School Examination. In order to receive an academic/college preparatory diploma, New York State high school students must pass standardized examinations in major subjects.

1 To collect mitochondria from cells and study their structure in fine detail, which instruments would a scientist most likely use?
1 microdissection apparatus and compound light microscope
* 2 ultracentrifuge and electron microscope
3 microdissection apparatus and dissecting microscope
4 ultracentrifuge and compound light microscope

Base your answers to questions 2 through 4 on the information below and on your knowledge of biology.

A student observed a green plant cell under the low-power objective of her microscope and noted the movement of organelles as shown in diagram *A*. She then added three drops of a 10% salt solution to the slide, waited a few minutes, and observed the cell as shown in diagram *B*.



A B

2 The organelles observed were most likely
1 centrosomes
* 2 chloroplasts
3 mitochondria
4 ribosomes

3 The movement of these organelles as shown in diagram *A* is known as
1 ingestion
2 transpiration
3 pinocytosis
* 4 cyclosis

4 The appearance of the clumped material as shown in diagram *B* is due to
* 1 loss of water from the cell
2 loss of salt from the cell
3 addition of water into the cell
4 addition of salt into the cell

5 A characteristic of all known living things is that they
1 use atmospheric oxygen
2 use carbon dioxide
* 3 carry on metabolic activities
4 are capable of locomotion

6 Blue-green algae lack a membrane separating their nuclear material from their cytoplasm. On this basis these organisms are classified as
1 fungi
2 protists
* 3 monerans
4 plants

7 Which word equation represents the process of photosynthesis?
* 1 carbon dioxide + water → glucose + oxygen + water
2 glucose → alcohol + carbon dioxide
3 maltose + water → glucose + glucose
4 glucose + oxygen → carbon dioxide + water

8 Which is a polysaccharide associated with the cells of a tomato plant, but not with the cells of a grasshopper?
1 hemoglobin
2 glycogen
3 protease
* 4 cellulose

9 A common characteristic of animals and fungi is their ability to carry on
* 1 heterotrophic nutrition
2 alcoholic fermentation
3 auxin production
4 transport through vascular tissue

10 The site of aerobic cellular respiration is the
1 nucleus
2 ribosome
3 chromosome
* 4 mitochondrion

11 Which organism carries on gas exchange in a terrestrial environment?

1 Ameba
2 shark
3 Hydra
* 4 grasshopper

12 A chemical injected into a tadpole caused the tadpole to undergo rapid metamorphosis into a frog. This chemical was most probably

1 an enzyme
2 a neurohumor
* 3 a hormone
4 a blood protein

13 According to the fluid mosaic model, a cell membrane is described as a structure composed of a

1 protein layer in which large lipids are found
2 carbohydrate structure in a "sea of lipids"
* 3 double lipid layer in which proteins float
4 phospholipid layer divided by carbohydrates

14 Which compounds are produced in human muscle cells as a result of the oxidation of glucose in the absence of oxygen?

1 lipase and water
2 sucrase and carbon dioxide
3 ethyl alcohol and ATP
* 4 lactic acid and ATP

15 Nitrogenous wastes may be produced as a result of the metabolism of

1 glucose
2 glycogen
3 fatty acids
* 4 amino acids

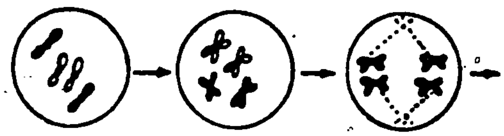
16 Compared to blood entering the human kidney, blood leaving the kidney normally contains a lower concentration of

1 red cells
2 proteins
3 white cells
* 4 urea

17 Each of the two daughter cells that result from the normal mitotic division of the original parent cell contains

1 the same number of chromosomes, but has genes different from those of the parent cell
* 2 the same number of chromosomes and has genes identical to those of the parent cell
3 one-half of the number of chromosomes, but has genes different from those of the parent cell
4 one-half of the number of chromosomes and has genes identical to those of the parent cell

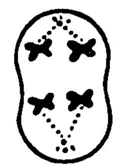
18 The diagrams below represent the sequence of events in a cell undergoing normal meiotic cell division.



(A) (B) (C) (D)

Which diagram most likely represents stage *D* of this sequence?

(1) 

* (3) 

(2) 

(4) 

19 In the diagrams below, $2n$ represents the diploid number of chromosomes in a cell of an organism, and n represents the monoploid number. Which diagram represents fertilization?

(1) $2n \rightarrow n, n$
* (3) $n, n \rightarrow 2n$
(2) $n \rightarrow 2n, 2n$
(4) $2n, 2n \rightarrow n$

20 In most species of fish, a female produces large numbers of eggs during a reproductive cycle. This would indicate that reproduction in fish is most probably characterized by

1 internal fertilization and internal embryonic development
2 internal fertilization and external embryonic development
3 external fertilization and internal embryonic development
* 4 external fertilization and external embryonic development

21 Curly hair in humans, white fur in guinea pigs, and needle-like spines in cacti all partly describe each organism's

1 alleles
2 autosomes
3 chromosomes
* 4 phenotype

22 The appearance of a recessive trait in offspring of animals most probably indicates that

* 1 both parents carried at least one recessive gene for that trait
2 one parent was homozygous dominant and the other parent was homozygous recessive for that trait
3 neither parent carried a recessive gene for that trait
4 one parent was homozygous dominant and the other parent was hybrid for that trait

23 Which series is arranged in correct order according to *decreasing size* of structures?

(1) DNA, nucleus, chromosome, nucleotide, nitrogenous base
(2) nucleotide, chromosome, nitrogenous base, nucleus, DNA
* (3) nucleus, chromosome, DNA, nucleotide, nitrogenous base
(4) chromosome, nucleus, nitrogenous base, nucleotide, DNA

24 One weakness in Darwin's theory of evolution was that he was *not* able to

1 explain selection of favorable traits
2 account for an increase in population
* 3 explain the genetic basis for variation in populations
4 understand competition among individuals of a species

25 A supporter of the evolutionary theory set forth by Lamarck would probably theorize that the giraffe evolved a long neck due to

* 1 need and inheritance of acquired traits
2 mutations and genetic recombination
3 variations and survival of the fittest
4 overproduction and struggle for survival

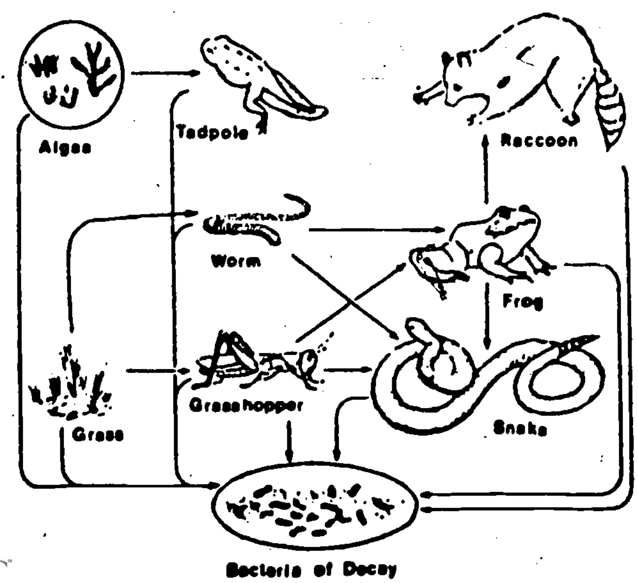
26 A change in the frequency of any mutant allele in a population most likely depends on the

1 size of the organisms possessing the mutant allele
* 2 adaptive value of the trait associated with the mutant allele
3 degree of dominance of the mutant allele
4 degree of recessiveness of the mutant allele

27 Which would be considered a biotic factor in a pond ecosystem?

* 1 snails
2 water
3 oxygen
4 sunlight

Base your answers to questions 28 through 31 on the diagram below and on your knowledge of biology. The diagram represents different species of organisms interacting with each other in and around a pond environment.



28 The adult frog represents a type of consumer known as a

1 producer
* 2 carnivore
3 saprophyte
4 parasite

29 Which organisms are classified as herbivores?

1 algae, tadpole, raccoon
2 worm, snake, bacteria
* 3 tadpole, worm, grasshopper
4 grasshopper, bacteria, frog

30 Which statement about the algae and grass is true?

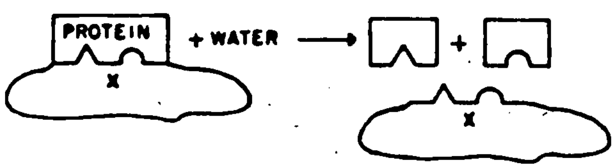
1 They are classified as omnivores.
2 They parasitize the animals that consume them.
* 3 They contain the greatest amount of stored energy.
4 They decompose nutrients from dead organisms.

31 The interactions among organisms shown in this diagram illustrate

* 1 a food web
2 geographic isolation
3 abiotic factors
4 organic evolution

32 In humans, anaerobic respiration of glucose is a less efficient energy-releasing system than aerobic respiration of glucose. One of the reasons for this is that in anaerobic respiration
* 1 lactic acid contains much unreleased potential energy
  2 water contains much released potential energy
  3 oxygen serves as the final hydrogen acceptor
  4 chlorophyll is hydrolyzed into PGAL molecules

33 The diagram below represents an enzyme-catalyzed reaction. Which substance is represented by letter *X*?



1 maltase
2 sucrase
3 lipase
* 4 protease

Directions 34-36: For each phrase in questions 34 through 36, select the food nutrient, *chosen from the list below*, that is described by that phrase.

Food Nutrients
(1) Carbohydrates
(2) Saturated fat
(3) Unsaturated fat
(4) Protein
(5) Water molecules

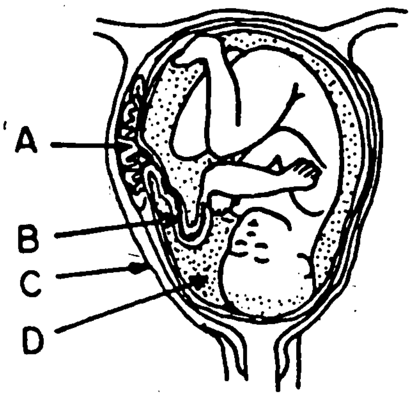
34 Serve as major sources of energy and also provide roughage 1

35 Provide a transport medium and help to regulate body temperature 5

36 Composed of amino acids and needed to maintain and repair body tissues 4

37 The right ventricle is the chamber of the heart which contains
* 1 deoxygenated blood and pumps this blood to the lungs
  2 deoxygenated blood and pumps this blood to the brain
  3 oxygenated blood and pumps this blood to the lungs
  4 oxygenated blood and pumps this blood to the brain

Base your answers to questions 38 through 40 on the diagram below which represents a stage in human development.



38 The exchange of oxygen, food, and wastes between mother and fetus occurs at
* (1) *A*
  (2) *B*
  (3) *C*
  (4) *D*

39 What is the function of the fluid labeled *D*?
1 nourishment
* 2 protection
3 excretion
4 respiration

40 The structure labeled *C*, within which development occurs, is known as the
1 oviduct
2 birth canal
* 3 uterus
4 placenta

41 In the early development of a zygote, the number of cells increases without an increase in mass by a process known as
1 ovulation
* 2 cleavage
3 germination
4 metamorphosis

42 The hollow-ball stage in the development of an invertebrate embryo is known as the
* 1 blastula
2 ectoderm
3 gastrula
4 endoderm

43 Which principal actions of genes insure homeostatic control of life processes and continuity of hereditary material?
1 oxidation and hydrolysis
* 2 enzyme synthesis and replication
3 oxygen transport and cyclosis
4 pinocytosis and dehydration synthesis

44 Human disorders such as PKU and sickle-cell anemia, which are defects in the synthesis of individual proteins, are most likely the result of

* 1 gene mutations
2 nondisjunction
3 crossing-over
4 polyploidy

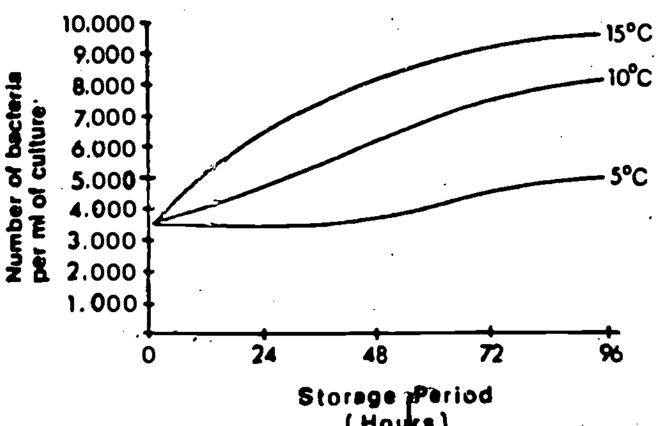
45 The gene pool in a population of *Rana pipiens* in a pond remained constant for many generations. The most probable reason for this stable gene pool is that

1 it was a small population with nonrandom mating and many mutations
2 random mating occurred in a small population with many mutations
3 no mutations occurred in a large, migrating population
* 4 no migration occurred in a large population with random mating

46 Following a major forest fire, an area that was once wooded is converted to barren soil. Which of the following schemes describes the most likely sequence of changes in vegetation in the area following the fire?

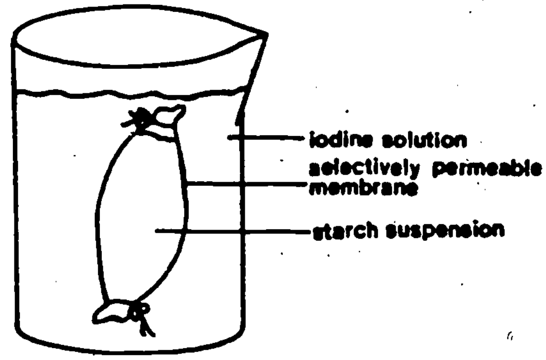
1 shrubs → maples → pines → grasses
2 maples → pines → grasses → shrubs
3 pines → shrubs → maples → grasses
* 4 grasses → shrubs → pines → maples

47 The graph below was developed as a result of an investigation of bacterial counts of three identical cultures grown at different temperatures. Which conclusion might be correctly drawn from this graph?



1 The culture contains no bacteria.
* 2 Refrigeration retards bacterial reproduction.
3 Temperature is unrelated to the bacteria reproduction rate.
4 Bacteria cannot grow at a temperature of 5°C.

Base your answers to questions 48 and 49 on the diagram below and on your knowledge of biology.



48 If iodine molecules passed through the membrane into the starch suspension, the

* 1 starch suspension would turn blue-black
2 starch suspension would turn brick-red
3 membrane would dissolve
4 membrane would become impermeable

49 What process accounts for the movement of the iodine?

* 1 diffusion
2 osmosis
3 phagocytosis
4 pinocytosis

50 Dissection of an earthworm is normally begun with a cut along a dorsal surface. What is an advantage of beginning the cut here?

1 The four-chambered heart will remain in place.
2 The kidneys will be clearly exposed.
3 The backbone would be damaged by any other incision.
* 4 The ventral nerve cord will not be damaged.

The correct answers are marked with an asterix (*).

THE HIGH SCHOOL CHEMISTRY COURSE

Introduction

In this part of the statement we provide a brief discussion of the context in which the high school chemistry course is taught, a list of topics to be covered, with recommended emphasis, a set of example problems with answers, and an annotated list of representative laboratory exercises. We hope this part of the statement will give the high school teacher a more detailed understanding of our recommendations.

Regarding the Chemistry Course

It must be recognized that the chemistry course has a dual purpose:

(1) to provide a foundation for the further study of chemistry; and

(2) to help all students, including those who will not continue in the sciences, to develop an appreciation and understanding of the power, methods, and limitations of the science of chemistry and its role in an ever-increasingly technological time in which students will live and work.

The course should be directed to the general college-bound student, not just the intended chemistry major or science major. Provisions can be made for appropriate enrichment activities in the context of the course for students who have a special interest in the subject. The course outline has been designed to provide flexibility in meeting the goals of the course. The Fundamental Topics which we recommend all teachers cover, cover 60-80% of the material. Consequently, up to 40% of the course can be covered at the option of the teacher. In covering both the Fundamental and Additional Topics, we strongly urge teachers to cover material and use examples that expose students to the applications and practice of chemistry. Developing interest and curiosity can often best be done with familiar examples. Chemistry provides an understanding of phenomena we encounter daily in our lives and these applications of chemistry to everyday life should be emphasized. In addition, chemistry is important to the study of such fields as biology, engineering, pharmacy, and medicine and this connection should be stressed. The chemical sciences also play a vital role in our economy and our culture. The chemical industry is one of the largest industries in the country and the world. New compounds are discovered or created daily that have applications as pharmaceuticals, structural materials, coatings, adhesives or fabrics, and a myriad of other uses. Many societal benefits have arisen from these applications of chemistry. Conversely, hazards are associated with the indiscriminate use of some of these chemicals (pesticides, PCBs, toxic wastes, etc.) and these hazards are a significant concern of society. When appropriate, the ramifications of these applications should be examined in selesctive cases.

Regarding Mathematics, Calculators, and Computers

To be taught most effectively, this course requires reasonable mathematical prerequisites. These should correspond to the recommendations made in the previous statement. Completion of Algebra I and concurrent enrollment in Geometry seem minimal. We recommend hand-held calculators for everyday use because they greatly facilitate the numerous computations involved in chemistry. By using calculators, students can learn much about data entry, the significance of calculated digits, and the inherent limitations of such devices. Larger computers should only be used when students are adequately prepared to benefit. They should not be used for trivial calculations. The calculations in a high school chemistry course are seldom sufficiently complex to warrent the use of a computer, especially when students are trying to learn how to do the calculation, rather than just trying to get an answer.

Regarding the Laboratory Program

The laboratory program, like the other parts of the course, needs to be oriented primarily to the general college-bound student. Chemistry is an experimental science and needs to be taught as such. The relationship between experimental evidence and scientific belief must be emphasized. The laboratory must involve the students' participation actively; it should not consist merely of passive demonstrations. The laboratory should emphasize the concrete over the abstract, but abstract thinking must not be eliminated, because many students are just learning to think abstractly and it is necessary to make them realize that they must continue to do so if they are to progress.

1. Topics to be Included in a One-Year Course in Chemistry

The topics are broken into two groups: Fundamental Concepts and Additional Concepts. At least 60% of the time and effort on the course should be spent on the Fundamental Concepts. None of the Fundamental Concepts should be left uncovered or poorly covered. Coverage of the Fundamental Concepts will be assumed by college instructors of general chemistry. A comparison of the Fundamental Concepts and Additional Concepts sections provides an indication of the depth of treatment expected for the Fundamental Concept section. Some measure of the depth of treatment also can be gained by an examination of the sample questions and answers contained in the next part of this report. Most of the questions deal with the Fundamental Concepts. The topics under Fundamental Concepts range from the qualitative to the quantitative. The topics are not expected to be covered for equivalent periods of time. Those topics which are more quantitative such as, 2 (Measurement), 6 (Calculations and Chemical Formulas), 7 (Chemical Equations and Calculations), 8 (Gases), 12 (Solutions), and 13 (Chemical Reactivity), probably will require more time to treat than other less quantitative topics such as, 10 (Geometry of Simple Molecules and Polyatomic ions) or 4 (Introduction to the Periodic Table). Common high school chemistry texts usually emphasize the time distribution for the topics in the Fundamental Concepts section in an appropriate manner.

The material in the Additional Concepts section is either new or an extension of that in the fundamental category. Approximately 20-40% of the course should consist of this material, which should be chosen at the discretion of the high school instructor. Material should be selected to illustrate chemical principles applied in contemporary society and/or to provide a more in-depth understanding of the principles. The material appropriately may be integrated into the Fundamental Concepts or in some cases, it may be treated separately. Neither the breadth or the depth of the coverage in the Additional Concepts section will be assumed by college instructors.

I. Fundamental Concepts

1. Introductory Concepts - Definitions and examples

states of matter
chemical and physical properties
pure substances and mixtures
heterogeneous and homogenous substances
physical change
chemical change

2. Measurement - Definitions and quantitative application

measurement systems - the Metric system and S. I. units
scientific notation - scientific notation and its relationship to metric prefixes
significant figures - the uncertainty of measurement
the qualitative concept of precision and error
dimensional analysis and unit conversions - emphasis on mass, volume and density

3. The Atomic Nature of Matter - Atoms and elements

the atomic theory
the nuclear atom
subatomic particles - proton, electron, neutron
qualitative introduction to atomic structure
elements - atomic number
chemical symbols and names of the elements
isotopes - mass number
atomic mass unit - the establishment of a standard
atomic weights - relative weights of the atoms
ion formation through electron gain or loss
the charges and nomenclature of common monatomic cations and anions

4. Introduction to the Periodic Table - To be discussed in a qualitative and descriptive fashion with the emphasis on periodicity.

atomic number and the periodic table
classification of the elements - metals, metalloids, and non-metals
classification of elements according to the periodic table - main group elements, transition elements, etc.
physical properties of the common elements - common physical states, densities, etc.
chemical formulas of the elements - allotropes
chemical families - names of the families and some simple illustrations of the chemical and physical properties of families

5. Compounds and Chemical Formulas -

elements and compounds
chemical formulas of compounds
binary compounds: molecular and ionic
nomenclature of binary compounds
molecules and ions containing three or more elements
formulas and names of common polyatomic ions
nomenclature of salts

6. Calculations and Chemical Formulas -

the mole
molecular weight (formula weight)
Avogadro's number
mass to mole and mole to number interconversions
elemental composition (percent composition)
empirical formula determination

7. Chemical Equations and Calculations -

writing and balancing equations
the conservation of atoms and charge and the meaning of a balanced equation
the conservation of mass and reaction stoichiometry - including mole to mole, mole to mass, and mass to mass calculations
the yield of a reaction and percent yield
limiting reagent calculations

8. Gases - these sections should be used to introduce graphical representation of mathematical relationships

the kinetic molecular theory of gases - qualitative discussion
pressure and its measurement - units of pressure
temperature and temperature scales - Kelvin scale
Boyle's law
Charles' law
Avogadro's law - law of combining volumes
the ideal gas law
standard temperature and pressure and molar volume
stoichiometry problems involving gases

9. Solids and Liquids -

comparison of the properties and characteristics of gases, liquids and solids
phase changes: evaporation and condensation; melting and solidification; sublimation
heat energy changes accompanying phase changes
qualitative introduction to the concept of dynamic equilibrium
vapor pressure - boiling point
qualitative structural picture of the nature of crystalline solids and of liquids

10. Geometry of Simple Molecules and Polyatomic Ions -

classification of common molecules and ions based on a central atom and pendant (ligand) atoms
geometric structure of simple molecules and ions
linear and bent triatomic molecules (2 ligands)
pyramidal and trigonal planar geometries (3 ligands)
tetrahedral and square planar geometries (4 ligands)

11. Chemical Bonding -

the concept of valence electrons in atoms
Lewis dot representations of atoms
Lewis dot representations of monatomic ions
relative sizes of monatomic cations and anions compared to atoms
the Lewis concept of covalent and ionic bonds
the concept of electronegativity - polarity of bonds in diatomic molecules
Lewis structures of simple molecules--the use of the octet rule

12. Solutions -

water and its properties
solutes and solvents
electrolytes and non-electrolytes in aqueous solution
concentration
concentration units - % by weight, molarity
calculations involving interconversions among moles, mass, volume and molarity, including dilution

13. Chemical Reactivity -

a. Precipitation Reactions in Aqueous Solution

qualitative aqueous solubility of common salts
strong electrolytic character of most common soluble salts
the deduction of a chemical equation for a precipitation reaction using the solubility data for common salts

b. Acid-Base Reactions in Aqueous Solutions

Arrhenius and Bronsted-Lowry definition of acids and bases
nomenclature of common inorganic acids and bases
the strong electrolytic character of many common acids and bases
the neutralization reaction
the deduction of a chemical equation for an acid-base reaction using the neutralization reaction - emphasize common strong acids and bases
definition of pH - qualitative applications
acid and base precursors - oxides of non-metals and oxides of metals

c. Oxidation and Reduction Reactions

the descriptive chemistry of oxygen and the halides including the preparation of simple oxides and halides of the common main group elements as examples of oxidation and reduction
the descriptive chemistry of the Group I and II representative metals including the action of other active metals on aqueous solutions--generation of hydrogen gas
the combustion of simple hydrocarbons
the definition of oxidation and reduction
the concept of oxidation numbers
balancing simple equations by inspection and checking the gain and loss of electrons by oxidation state changes
practical applications: combustion and batteries

14. Energetics and Dynamics -

energy changes during chemical reactions
dynamic equilibria in chemical systems
Le Chatelier's principle

II. Additional Concepts

1. Measurement -

the quantitative treatment of error and precision
statistical treatment of data
error analysis

2. Atomic Structure -

nature of energy
conversions of energy
the Bohr atom and its shortcomings
qualitative view of the modern picture of the atom
quantization of energy and quantum numbers
electromagnetic spectrum
shapes of s and p orbitals
atomic spectra

3. Periodic Trends -

electron configuration of atoms and the periodic table
periodic trends in ionization potential, electron affinity, atomic size

4. Gases -

partial pressure and Dalton's Law
the kinetic molecular picture of gases--ideal gases, real gases
the preparation of common gases (e.g. oxygen, hydrogen, carbon dioxide)

5. Solids and Liquids -

molecular picture of liquids and crystalline solids including ionic solids
phase diagrams - qualitative discussion
metals and semiconduction

6. Chemical Bonding -

the covalent bond - post Lewis
the ionic bond - post Lewis
electronegativity trends
Lewis structures of more complex molecules and ions
resonance
orbital hydridization
valence shell electron pair repulsion (VSEPR)
polarity of bonds
polarity of molecules

7. Interatomic, Intermolecular and Interionic Forces -

Van der Waals' forces
dipolar forces
the hydrogen bond
covalent solids
ionic solids

8. Solutions -

Raoult's Law
colligative properties--boiling point elevation, freezing point depression, osmotic pressure

9. Reactivity and Solution Stoichiometry -

a. Precipitation Reactions -

solution stoichiometry including molarity to mole to mass interconversions and the concept of the limiting reagent

b. Acids and Bases -

reactions of strong acids/weak bases, weak acids/strong bases as well as strong acids/strong bases
solution stoichiometry including molarity to mole to mass interconversions and the concept of the limiting reagent
titration - the concept of an endpoint and an indicator
the definition of pH - calculation of pH of strong acid solutions
K_w and the inverse relationship of $[H^+]$ and $[OH^-]$; calculation of pH in strong base solutions

c. Oxidation and Reduction -

balancing more complex equations using the half reaction method or oxidation state method
relative strengths of oxidizing and reducing agents

10. Dynamics

a. Equilibrium

equilibrium constants and calculations

b. Rates of Reactions -

the concept of reaction rate
the effects of variations in concentration - rate laws
temperature effects
catalyst effects
medium effects
activation energy - potential energy diagrams

11. Special Topics

a. Descriptive Chemistry of Common Metals and Non-Metals

chemistry of nitrogen, phosphorus and sulfur, emphasizing oxides, halides, and hydrogen compounds
chemistry of carbon and silicon
chemistry of iron

b. Simple Organic Molecules

composition, structure, and bonding of simple hydrocarbons--alkanes, alkenes, alkynes, and aromatics
the concept of isomers
functional group definitions--alcohols, ethers, aldehydes, ketones, carboxylic acids, amines, amino acids
simple organic reactions

c. Nuclear Chemistry

types of nuclear radiation
mass-energy relationship
nuclear decay of radioisotopes
half-life of radioisotopes
nuclear fission and fusion
isotopic tracers

Sample Questions/Problems in Chemistry

We have included two general types of questions: multiple-choice questions and questions for which no prompting by a set of responses is provided. The latter include some for which all work and reasoning is to be shown, as well as some for which only an answer (such as a formula or an equation or a definition) need be given. We recognize that grading the latter kind of question is far more difficult, which is why multiple-choice questions are almost invariably found on qualifying tests administered to large numbers of students. It is important that college-bound students be familiar with typical multiple-choice questions, but we urge teachers to use the other type as often as possible, for multiple-choice questions are seldom encountered by students in college and university chemistry courses.

These sample chemistry questions are to be worked accompanied by a periodic table that includes atomic weights. Correct answers are given at the end.

1. One of the isotopes of potassium has mass number 42. The singly charged positive ion of this atom contains:

(a) 19 protons, 18 electrons and 5 neutrons
(b) 19 protons, 18 electrons and 23 neutrons
(c) 19 protons, 19 electrons and 23 neutrons
(d) 18 protons, 19 electrons and 24 neutrons
(e) 39 protons, 38 electrons and 42 neutrons

2. The atomic number of an atom or monatomic ion is

(a) the number of neutrons in the atom or ion
(b) the number of protons in the atom or ion
(c) the number of electrons in the atom or ion
(d) the sum of the number of protons and the number of neutrons in the atom or ion
(e) the difference between the number of neutrons and the number of protons in the atom or ion

3. When a halogen molecule reacts with an alkaline earth metal, the halogen molecule usually forms:

(a) ions of charge (+2)
(b) ions of charge (+1)
(c) neutral atoms
(d) ions of charge (−1)
(e) ions of charge (−2)

4. The chemical properties of an atom depend principally upon its

(a) atomic weight
(b) nuclear configuration
(c) electron configuration
(d) number of isotopes
(e) net charge

5. Chromium forms an oxide of formula Cr_2O_3. The formula of the nitrate of chromium, with chromium in the same oxidation state, is:

(a) $Cr(NO_3)_3$
(b) $Cr_2(NO_3)_3$
(c) $Cr_3(NO_3)_2$
(d) $Cr(NO_3)_6$
(e) $Cr(NO_2)_3$

6. The total number of atoms in one mole of $CuSO_4 \cdot 5H_2O$ is

(a) 9
(b) 21
(c) 6×10^{23}
(d) 5.4×10^{24}
(e) 1.26×10^{25}

7. The percentage by weight of sulfur in SO_3 is:

(a) 25
(b) 32
(c) 40
(d) 46
(e) 50

8. A compound containing only carbon and oxygen has 53.0 percent carbon. What is its empirical formula?

(a) C_2O
(b) C_3O_2
(c) C_9O_8
(d) CO
(e) CO_2

9. How many moles of sulfuric acid, H_2SO_4, are needed to convert two moles of magnesium oxide completely to magnesium sulfate? Assume that no other product containing magnesium is formed.

(a) 1/2
(b) 1
(c) 3/2
(d) 2
(e) 4

QUESTIONS 10 AND 11 REFER TO THE REACTION OF CuO with NH_3:

$$\_\_\_\_ CuO + \_\_\_\_ NH_3 \rightarrow \_\_\_\_ Cu + \_\_\_\_ N_2 + \_\_\_\_ H_2O$$

10. When the equation is balanced with the smallest integer coefficients, the coefficient of Cu is:

(a) 1
(b) 2
(c) 3
(d) 4
(e) 6

11. In the reaction of CuO with NH_3,

(a) CuO is the oxidizing agent and NH_3 is reduced
(b) CuO is reduced and NH_3 is oxidized
(c) CuO is oxidized and NH_3 is reduced
(d) CuO is reduced and NH_3 is the oxidizing agent
(e) there is no oxidation or reduction

12. If 100 g of Mg and 100 g of O_2 are allowed to react, the only product formed being MgO, what is the maximum weight of MgO that might be formed?

(a) 40 g
(b) 100 g
(c) 126 g
(d) 166 g
(e) 200 g

13. Which of the following has the same total electron configuration as a neon atom?

(a) F
(b) Na
(c) Ne^+
(d) Na^+
(e) Ar

14. As atomic number increases, which of the following atomic properties also necessarily increases?

(a) electronegativity
(b) first ionization energy
(C) number of outer-shell electrons
(d) nuclear charge
(e) charge on the most stable ion formed from the atom

15. Which of the following terms best describes the bond between the atoms in a single molecule of hydrogen chloride, which is a gas under ordinary conditions?

(a) hydrogen bond
(b) gaseous bond
(c) pure covalent bond
(d) pure ionic bond
(e) partially ionic bond

16. Which of the following materials is an ionic solid?

(a) MgO
(b) CO_2
(c) graphite
(d) I_2
(e) ice

17. A sample of an ideal gas at a certain temperature and pressure has a volume V. If the pressure on the gas is increased by a factor of three and the absolute temperature of the gas is increased by a factor of 2, what will be the new volume of the gas?

(a) V/6
(b) 2V/3
(c) V
(d) 3V/2
(e) 6V

18. What is the approximate volume occupied by 0.0200 g of gaseous H_2 at 0°C and 1.00 atm?

(a) 22.4 ml
(b) 44.8 ml
(c) 224 ml
(d) 448 ml
(e) 2.24 liter

19. The unusually low volatility and high heat of vaporization and heat capacity of water can be attributed to the fact that water molecules

(a) have a molecular weight of 18
(b) form strong hydrogen bonds
(c) have amphoteric character
(d) are highly ionized
(e) contain 10 electrons

20. Which of the following lists processes that are the reverse of one another?

(a) ionization and dissociation
(b) sublimation and evaporation
(c) melting and sublimation
(d) condensation and evaporation
(e) melting and dissolving

21. The weight of Na_2CO_3 needed to prepare 0.50 liter of 0.20 M solution is:

(a) 10.6 g
(b) 21.2 g
(c) 53 g
(d) 106 g
(e) 5.3 g

22. Suppose that a sample of water taken from the ocean is filtered so that suspended sand and other solid particles are removed but that it is not otherwise purified. This sample of ocean water will, at a given pressure, have a

(a) higher freezing point and higher boiling point than pure water
(b) lower freezing point and lower boiling point than pure water
(c) higher freezing point and lower boiling point than pure water
(d) lower freezing point and higher boiling point than pure water
(e) the same freezing and boiling point as pure water

23. When solid magnesium nitrate dissolves in water, the reaction may properly be represented as:

(a) $Mg(NO_3)_2(s) \rightarrow Mg^{2+}(aq) + 2\ NO_3^-(aq)$
(b) $Mg(NO_3)_2(s) \rightarrow Mg^{4+}(aq) + 2\ NO_3^{2-}(aq)$
(c) $Mg(NO_3)_2(s) \rightarrow Mg^{2+}(aq) + NO_3^{2-}(aq) + NO_3(aq)$
(d) $MgNO_3(s) \rightarrow Mg^+(aq) + NO_3^-(aq)$
(e) $Mg(NO_3)_2(s) \rightarrow Mg(aq) + 2\ NO_3(aq)$

24. The term "base" is commonly used in chemistry to refer to any compound that
(a) contains the OH group
(b) forms a salt when neutralized
(c) gives a pH below 7 when dissolved in water
(d) is a donor of protons
(e) is an acceptor of protons

25. What volume of 0.12 M KOH will just be neutralized by 40 ml of 0.030 M HBr?

(a) 2.5 ml
(b) 10 ml
(c) 16 ml
(d) 40 ml
(e) 160 ml

26. Which of the following substances does not give an acidic solution when dissolved in water?

(a) CO_2
(b) HI
(c) H_2
(d) SO_3
(e) HNO_2

27. Assume that each of the following reactions is initially at equilibrium. For which of them will a decrease in pressure favor increased formation of products? Assume the temperature remains constant.

(a) $H_2(g) + I_2(g) = 2\ HI(g)$
(b) $2\ NOBr(g) = 2\ NO(g) + Br_2(g)$
(c) $H_2O(g) + CuSO_4(s) = CuSO_4 \cdot H_2O(s)$
(d) $CH_3OH(g) = CH_3OH(\ell)$
(e) $2\ NO_2(g) = N_2O_4(g)$

28. Which of the following statements does not apply to the alkali metal elements?

(a) They are found naturally in the uncombined state
(b) They readily form ions of charge +1
(c) They are relatively soft and low-melting
(d) Most of their common salts are soluble
(e) Their oxides are basic

29. Cobalt-60 is radioactive, with a half-life of 5.3 years. It emits gamma rays and is used in radiation therapy. Suppose a hospital director orders a supply of this material for use in therapy. What fraction of the original supply would have decayed radioactively after 10.6 years?

(a) None
(b) 0.25
(c) 0.50
(d) 0.75
(e) All

30. The term "isomer"

(a) refers to a compound that has the same properties as another compound
(b) is a synonym for isotope
(c) refers to the class of protein catalysts known as enzymes
(d) refers to a compound that has the same structure as another compound but differs from it in composition and properties
(e) refers to a compound that has the same chemical composition as another compound but differs from it in structure and properties.

31. The number of ml of 2.00 M HCl required to prepare 0.250 liters of .050 M HCl is:

(a) 12.50
(b) 6.25
(c) 5.00
(d) 2.50
(e) 25.00

32. If an aqueous solution contains 3.00 percent by weight of sugar, $C_6H_{12}O_6$, and has a density of 0.993 g ml^{-1}, how many grams of sugar are present in 500 ml of the solution?

(a) 12.0
(b) 15.1
(c) 14.9
(d) 50.0
(e) 37.5

Correct Answers:

1.	(b)	11.	(b)	21.	(a)
2.	(b)	12.	(d)	22.	(d)
3.	(d)	13.	(d)	23.	(a)
4.	(c)	14.	(d)	24.	(e)
5.	(a)	15.	(e)	25.	(b)
6.	(e)	16.	(a)	26.	(c)
7.	(c)	17.	(b)	27.	(b)
8.	(b)	18.	(c)	28.	(a)
9.	(d)	19.	(b)	29.	(d)
10.	(c)	20.	(d)	30.	(e)
				31.	(b)
				32.	(c)

Non Multiple Choice Questions

1) Calculate the molarity of sodium ion when 7.1g Na_2SO_4 is dissolved in 400 cm^3 of water.

2) Draw Lewis structures for;

NH_3
CCl_4
O^{2-}
PF_3
H_2O

3) How many grams of HF are required to react with 30.0g SiO_2 if the reaction proceeds according to the balanced equation

$SiO_2 + 4HF \longrightarrow SiF_4 + 2H_2O$

4) Name the following compounds:

NH_4NO_3
K_2SO_4
NaOH
PCl_3
$CaBr_2$

5) Give formulas for the following substances:

Ozone
Sodium carbonate
Sulfur dioxide
Ammonia
Sulfurous acid
Hydrochloric acid

6) Complete and balance the following equations

$$H_2SO_4 + NaOH \xrightarrow{H_2O}$$

$$Na_3PO_4 + CaCl_2 \xrightarrow{H_2O}$$

7) Select those molecules which have a dipole moment and explain why the dipole moment exists.

CO_2 H_2O HF BF_3

8) If 30ml of 0.50 M Na_2SO_4 solution reacts with 45ml of 0.40M $CaCl_2$ solution, calculate the grams of $CaSO_4$ that precipitate if the reaction proceeds according to the balanced equation. Also calculate the molarity of the excess reagent ion.

$$Ca^{2+} + SO_4^{2-} \longrightarrow CaSO_4$$

9) If 25ml of 0.40M $MgCl_2$ and 50ml of 0.60M NaCl are added to 25ml of water, calculate the molarity of chloride ion in the resulting solution. Assume the volumes are additive.

Answers to non-multiple choice questions

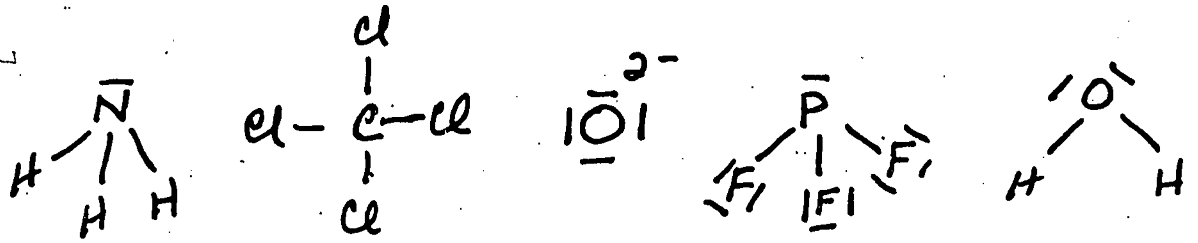
1) $$(7.1g\ Na_2SO_4)\frac{(1\ mol\ Na_2SO_4)}{(142g\ Na_2SO_4)} = 0.050\ mol\ Na_2SO_4$$

Since Na_2SO_4 is a strong electrolyte in water

$$(0.050\ mol\ Na_2SO_4)\frac{(2\ mol\ Na^+)}{(1\ mol\ Na_2SO_4)} = 0.100\ mol\ Na^+$$

Recall molarity is mol/L

$$\frac{(0.10\ mol\ Na^+)}{(400ml)\frac{(1L)}{(1000ml)}} = 0.25M$$

2) 

3) $(30.0\ g\ SiO_2)\ \frac{(1\ mol\ SiO_2)}{(60.0g\ SiO_2)} = 0.50\ mol\ SiO_2$

Using the equation

$SiO_2 + 4\ HF \rightarrow SiF_4 + 2H_2O$

$(0.50\ mol\ SiO_2)\ \frac{(4\ mol\ HF)}{(1\ mol\ SiO_2)}\ \frac{(20g\ HF)}{(1\ mol\ HF)} = 40g$ HF needed

4)

NH_4NO_3	Ammonium Nitrate
K_2SO_4	Potassium Sulfate
NaOH	Sodium Hydroxide
PCl_3	Phosphorus Trichloride
$CaBr_2$	Calcium Bromide

5)

Ozone	O_3
Sodium Carbonate	Na_2CO_3
Sulfur dioxide	SO_2
Ammonia	NH_3
Sulfurous Acid	H_2SO_3
Hydrochloric Acid	HCl

6) $H_2SO_4 + 2\ NaOH \rightarrow 2H_2O + Na_2SO_4$

If H_2SO_4 and NaOH are considered strong electrolytes then Na^+ and SO_4^{2-} are spectator ions and the net reaction is the neutralization reaction.

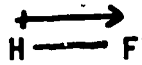
$$H^+ + OH^- \rightarrow H_2O$$

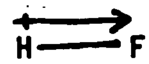
$2\ Na_3PO_4 + 3\ CaCl_2 \rightarrow \underline{Ca_3(PO_4)_2} + 6\ NaCl$

Recognizing Na_3PO_4 and $CaCl_2$ as strong electrolytes, the precipitation of $Ca_3(PO_4)_2$ is the driving force for the second reaction. If spectator ions are removed,

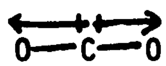
$2\ PO_4^{3-} + 3\ Ca^{2+} \rightarrow \underline{Ca_3(PO_4)_2}$

7) Because of the electronegativity differences between the atoms, all of the molecules have bond dipoles. However CO_2 and BF_3 have a molecular geometry that generates opposing bond dipoles and results in a molecular dipole of zero. HF and H_2O have bond dipoles, but these do not cancel and a molecular dipole results.

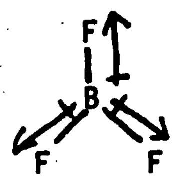


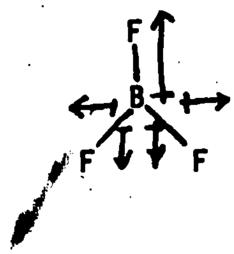


Bond dipole   molecular dipole

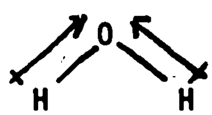


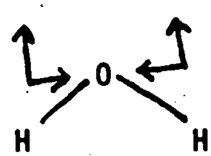
Bond dipoles   no molecular dipole

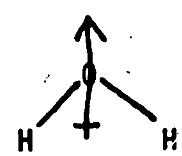




bond dipoles   bond dipole components   no molecular dipole







bond dipoles   bond dipole components   molecular dipole

8) $\frac{(0.50 \text{ mol } Na_2SO_4)}{L} (30 \text{ ml}) \frac{(10^{-3} L)}{ml} = 15 \times 10^{-3} \text{ mol } Na_2SO_4$

Recognize Na_2SO_4 is a strong electrolyte

$(15 \times 10^{-3} \text{ mol } Na_2SO_4) \left(\frac{1 \text{ mol } SO_4^{2-}}{\text{mol } Na_2SO_4}\right) = 15 \times 10^{-3} \text{ mol } SO_4^{2-}$

$\frac{(0.40 \text{ mol } CaCl_2)}{L} (45 \text{ ml}) \frac{(10^{-3} L)}{ml} = 18 \times 10^{-3} \text{ mol } CaCl_2$

Recognize $CaCl_2$ is a strong electrolyte

$(18 \times 10^{-3} \text{ mol } CaCl_2) \left(\frac{1 \text{ mol } Ca^{2+}}{1 \text{ mol } CaCl_2}\right) = 18 \times 10^{-3} \text{ mol } Ca^{2+}$

Using the equation

$$Ca^{2+} + SO_4^{2-} \rightarrow \underline{CaSO_4}$$

$$(15 \times 10^{-3} \text{ mol } SO_4^{2-})\left(\frac{1 \text{ mol } Ca^{2+}}{1 \text{ mol } SO_4^{2-}}\right) = 15 \times 10^{-3} \text{ mol } Ca^{2+} \text{ required}$$

SO_4^{2-} is the limiting reagent.

$$(15 \times 10^{-3} \text{ mol } SO_4^{2-})\left(\frac{1 \text{ mol } CaSO_4}{1 \text{ mol } SO_4^{2-}}\right)\left(\frac{136 \text{ g } CaSO_4}{\text{mol } CaSO_4}\right) = 2.0 \text{ g } CaSO_4$$

The mol of Ca^{2+} ion left over is

$$18 \times 10^{-3} - 15 \times 10^{-3} = 3 \times 10^{-3} \text{ mol } Ca^{2+}$$

Assuming additive volumes of solution, the new volume is 30 + 40 = 70 ml

Recall molarity is mol/L

$$\frac{(3 \times 10^{-3} \text{ mol } Ca^{2+})}{\left((70 \text{ ml})\frac{(10^{-3}L)}{ml}\right)} = 4.3 \times 10^{-2} \text{ M } Ca^{2+}$$

9) Recognize $MgCl_2$ and NaCl are strong electrolytes

$$\left(\frac{0.40 \text{ mol } MgCl_2}{L}\right)(25 \text{ ml})\left(\frac{10^{-3}L}{ml}\right)\left(\frac{2 \text{ mol } Cl^-}{\text{mol } MgCl_2}\right) = 20 \times 10^{-3} \text{ mol } Cl^-$$

$$\left(\frac{0.60 \text{ mol NaCl}}{L}\right)(50 \text{ ml})\left(\frac{1L}{1000 \text{ ml}}\right)\left(\frac{1 \text{ mol } Na^+}{1 \text{ mol NaCl}}\right) = 30 \times 10^{-3} \text{ mol } Cl^-$$

Total mol Cl^- = $20 \times 10^{-3} + 30 \times 10^{-3} = 50 \times 10^{-3}$ mol Cl^-

Total volume = 25 + 50 = 75 ml

$$(75 \text{ ml})\left(\frac{10^{-3}L}{ml}\right) = 0.075 \text{ L}$$

Recall molarity is mol/L

$$\frac{50 \times 10^{-3} \text{ mol } Cl^-}{0.075L} = 0.67 \text{ M } Cl^-$$

3. Sample Laboratory Exercises

Much effort has gone into developing experiments useful for teaching secondary school chemistry. As one example, note the Chemical Education Material Study. Because of these efforts, a number of effective laboratory manuals are available. Many of the existing experiments require little apparatus, while others require more elaborate equipment and facilities. A spectrum of experiments exists for a range of student abilities as well as for a range of classroom facilities. The strong recommendation of this report to incorporate a substantial laboratory component into the secondary school course can be met by the variety of experiments and manuals which already exist.

We list five general objectives for the laboratory program. These objectives are not unique to chemistry and are by no means distinct from one another; in fact they overlap substantially.

1. To connect thoughts and symbols to actions and bodies. The schematic or symbolic descriptions used during lectures and discussions need to be connected, as much as is possible, to student's senses; for example, the word copper must be associated with the symbol Cu and the properties of copper that students have sensed and can recall. Every attempt should be made to relate idealized apparatus and systems to real-life situations.

2. To develop experimental strategies. Students should learn the process of posing a question and devising an experiment to answer the question or test a putative answer to the question. If possible, students should help design at least one exercise by determining what to observe and how to observe it. Both conceptual and mathematical analysis must be addressed in the process. Frequently the qualitative and quantitative aspects both can be covered, for example in considering the properties of a gas. Qualitative. "When I push down harder on the cylinder the volume of gas in it goes down." Quantitative. "If I double the force with which I am pushing down on the gas in the cylinder, how much smaller does the gas volume become?"

3. To develop laboratory techniques and skills. Students need to be taught laboratory technique and observation skills. They should become familiar with laboratory apparatus and how it can be used in experiments. Careful observation and recording of experimental phenomena should be stressed.

4. To verify physical law. It is necessary to verify some of the laws of chemistry in the laboratory because hearsay extends only so far. Scientific belief is always subject to test and verification and should be so presented.

5. To discover physical behavior. To emphasize the laboratory as a place in which behavior is often discovered, some of the exercises should include discovery by the students. This means that some laboratory exercises must precede discussion of the results to be expected. In this fashion students can learn to interpret nature and generalize from the specific. These exercises also serve to orient students to real-world problems in which no "correct" answer is known ahead of time.

An annotated list of experiments is presented that is typical of the types available. This listing is meant to be indicative and is not inclusive nor a recommended set of experiments. However, one aspect of the laboratory is mandatory and must be emphasized. This is safety. Proper procedures must be taught and used throughout the course. Of course the simplest and most effective of these procedures is wearing safety goggles or glasses when carrying out experiments.

Combustion of a Candle - This classic experiment can be both qualitative and quantitative. It encourages observation and deduction and can be studied at several levels with relatively simple apparatus.

Warming and Cooling Behavior of a Pure Substance - The melting point and heating curve of a substance can be obtained with simple apparatus. The experiment utilizes graphing skills and introduces students to phase changes.

Measurement Exercises - Either weighing or measurements of length can be used to introduce the concepts of precision and accuracy in measurement. These are recurrent concepts in science with many levels of sophistication. They can be introduced at a simple level.

Determination of Avogadro's Number from a Monomolecular Film - This experiment allows the calculation of an important and commonly used number with a simple apparatus. Moreover students gain an appreciation of molecular size in the process.

Determination of the Formula of a Compound by Direct Combination of the Elements - Chemical formulas are central to our understanding of compounds and this experiment, which shows how a molecular formula is determined, is of substantial utility. Other variations of this experiment such as Determination of the formula of a Precipitate or Determination of the formula of a Hydrate are also available. All these experiments reinforce the importance of accurate weighing.

Determination of the Solubility of a Soluble Salt - This experiment reinforces the relative nature of solubility as well as showing that solubility is a function of temperature. Crystallization of a salt also is demonstrated. A related experiment of this type The Relative Solubilities of Some Compounds of Group IIA Metals shows the range of solubilities of salts of Group IIA Metals.

Determination of Acidity and Basicity with Indicators - This experiment exposes students to acid/base concepts and relates these to common solutions. A more advanced experiment is Acid-base Titration: Titration of Vinegar which reinforces the neutralization reaction and its quantitative application.

Some Investigations into the Corrosion of Iron - The use of chemistry to explain everyday observations highlights this experiment. The reactivity of the element is emphasized.

Packing of Atoms or Ions in Crystals - This experiment uses models to understand crystalline structures. It shows how models can be used to visualize structures built up from atoms and ions.

The Physics Course

Introduction The study of physics provides a systematic understanding of the fundamental laws of physical phenomena that govern physical, chemical, biological, terrestrial, and astronomical processes. An understanding of the basic principles of physics is a necessary foundation for the intensive studies of most of the other sciences and for an understanding of many technological applications of science. Physics is also a part of our culture and has had an enormous impact on technological developments. Many issues of public concern, such as air and water pollution, industrial energy sources, disarmament, nuclear power plants, and space exploration, involve physical principles and require an acquaintance with the nature of scientific evidence for indepth discussion. hence, an understanding of physics is important for a rational, enlightened citizenry, which is often required to participate in decisions on public policy regarding these complex technological issues.

Few of the people who study the fundamentals of physics go on to become physicists. Many go into related fields, such as engineering or other sciences, and many pursue non-scientific careers. Hence pre-college physics should be taught so to demonstrate the general principles of seeking and knowing in science. Physics is an experimental science in that every statement of physical law is subject to verification and should be taught with this in mind. The relevance of the understanding that which physics provides to present and future problems of, and opportunities for, our technological civilization should be constantly demonstrated and discussed.

The content lists below are offered as a best estimate of what we, as college faculty, think should constitute a high school physics course for college-bound students. Our wish is that our high school, university, and college colleagues will accept this as a starting point of continuous discussion regarding the nature and scope of the course.

Regarding Mathematics This course can be taught well with various levels of mathematical preparation. Since students possess more common experience relevant to physics than they do most other scientific disciplines, they can learn physics concepts relatively easily. Therefore, physics lends itself to introducing students to the mathematical aspects of science. But, because physics is easy to describe mathematically, there is a common inference that is easy to learn mathematically; this inference clearly does not follow from the premises. In fact, an overemphasis on mathematical analysis has disenfranchised many capable students from studying physics at the high school level. Ideally, a balance must be struck between the conceptual and mathematical aspects of physics with neither predominating. Physics teachers should make reasonable adjustments in their presentations to ensure this balance and to be compatible with the mathematical preparation of their students. Reasonable mathematics prerequisites can and should be set for the study of physics. These should correspond with the recommendations regarding mathematics made in the previous statement and could be expected to be Algebra I and Geometry with a corequisite of Algebra II.

1. Topics to be included in a one year course in physics (with particular emphasis given to topics that are underlined)

Mechanics

1. The metric system of units for length, time, and mass, and their relation to units commonly used in everyday life.
2. Concepts of velocity and acceleration.
3. Projectile motion in a vertical plane.
4. Newton's three laws of motion.
5. Gravity (Newtonian).
6. Concepts of torque, center of mass, equilibrium.
7. Concepts of work, energy, and power. Conditions for the conservation of energy.
8. Linear momentum. Conditions for the conservation of linear momentum.
9. Circular motion and centripital force. Discussion of centrifugal force, "fictitious" forces, and frames of reference.
10. Rotational motion and angular momentum. Conservation of angular momentum.
11. Fluids: statics and dynamics, e.g., Archimedes' principle and Bernoulli's equation.
12. Harmonic motion.
13. Waves in linear media and the principle of superposition.
14. Sound.

The fundamentals of simple machines (lever, wheel, pulley, etc.) and mechanical advantage should be addressed in this segment as these discussion have been largely displaced from the college curriculum.

Heat and Thermodynamics

1. Temperature and heat.
2. Thermal Equilibrium and Heat transfer.
3. Mechanical equivalent of heat.
4. Changes of state.
5. Thermal expansion of matter, thermal coefficient of expansion.
6. The ideal gas law.
7. Kinetic theory of heat and matter.
8. First and second laws of thermodynamics.

Electricity, Magnetism, and Electromagnetism

1. Coulomb's law.
2. Electric field and electric potential.
3. Ohm's law.
4. Capacitance.
5. The magnetic field.
6. Magnetic forces on a moving charge.
7. Electromagnetic induction.
8. Electric and magnetic field energy.
9. Alternating current.
10. Electromagnetic waves.

Light & Optics

1. Light and color.
2. Reflection and refraction. Observation and discussion of prism spectrometer.
3. Mirrors and lenses, fiber optics.
4. Diffraction and polarization. Observation and discussion of grating or prism spectrometer.
5. Coherent light: lasers.

Modern Physics

1. Special relativity.
2. The uncertainty principle
3. Atomic theory and structure (rudementary). ✓
4. Nuclear structure (rudementary). ✓
5. Radioactivity: fission, fusion.

2. SAMPLE QUESTIONS/PROBLEMS

3. Laboratory

The laboratory program, like the lecture program, needs to be primarily oriented to the general college-bound student, not the intended physics major, or even the intended science major. Provisions for science-intended majors can be made in the context of the course by providing them with additional performance expectations, more mathematical analysis, or other enrichment activities.

Listed below are general objectives for the laboratory program accompanied by specific objectives and/or suggestions. Following is a list of experiments that are suitable but, since the feasibility of a laboratory exercise is dependent on the availability of equipment, supplies, and facilities as well as the design of the exercises, these are not intended as specific recommendations.

General Laboratory Objectives These objectives are by no means distinct from one another; in fact they overlap substantially. Also, these are not unique to just physics.

A. To connect thoughts and symbols to actions and bodies. The schematic or symbolic descriptions used during lectures and discussions need to be connected, as much as is possible, to student's senses; for example, the word "torque" should be connected to a "twisting feeling" that students have sensed and can recall. Every attempt should be made to relate idealized apparatus and systems to real life situations. Certain life experiences can be expected of all students and it is necessary only to relate concepts to those experiences. But, in many cases, the laboratory supplies a common set of experiences/observations to use in such discussions. The laboratory must, therefore, emphasize the concrete over the abstract. Exercises requiring abstract thinking must not be eliminated though, in that many students are just learning to think abstractly and it is necessary to maintain an expectation that they do so if they are to progress.

We think it is obvious that the lab exercises must involve the student's participation actively and not be merely passive demonstrations if the above is to be accomplished.

B. To develop laboratory techniques/strategies, including measurement and observation skills and concepts. Students need to be taught measurement technique and observation skills and how to communicate their findings to others. If at all possible, students should be involved in the design of an exercise at some point (to decide what to measure or how to measure it) as well as in the ordinary data acquisitions and analyses. Both conceptual and mathematical analysis need to be addressed in relation to the skills possessed by the students. Some sort of balance needs to be sought between the two types of analysis. Experiments can be done entirely without numbers by having students note directions and relative effects ("When I push down harder on the cylinder the volume of gas in it goes down.") but pointing out that other questions require mathematical analysis ("If I double the force with which I am pushing down on the gas in the cylinder, how much smaller does the gas volume become?).

The proper use of computers as data analyzing tools must be addressed carefully. Laboratory exercises must not degenerate into computer programming sessions or computer simulations of exercises the students can perform for themselves. Simulations are best employed for situations that cannot be duplicated in the laboratory.

C. To verify physical law. It is necessary to verify some of the laws of physics in the laboratory because hearsay extends only so far. Scientific belief is always subject to test and verification and should be so presented. One of the best ways to accomplish this is to recreate crucial experiments in the conceptual history of physics. By setting the historical/conceptual scene before the experiment was conducted, then recreating the experiment, one can verify the results and also show how experiments change the way we view and question nature. From such experiences students can see the evolution of scientific laws and see how they differ from governmental and religious laws.

D. To discover physical behavior. To emphasize the laboratory as a place in which behavior is often discovered some of the exercises should include discovery by the students. This means that some laboratory exercises must precede discussion of what results are to be expected. In this fashion students can learn to interpret nature and generalize from the specific. These exercises also serve to orient students to real world problems in which no "correct" answer is known ahead of time.

List of Typical Laboratory Exercises

Laboratory Basics

Safety in the Laboratory
Measurement Basics

Mechanics of Solids

Verification of Hookes Law-Measurement of the Force Constant of a Spring
Determination of the Gravitational Constant by Pendulum
Measurement of Speed, Velocity, and Acceleration in an Automobile: A Time-Motion Home Study Assignment

Mechanics of Fluids

Determination of the Velocity of Sound in Air by Resonance Tube
Wave Tank (Ripple Tank) Exercises
Measurement of Surface Tension
Verification of Boyle's Law

Heat and Kinetic Theory

Measurement of the Specific Heat Capacity of a Metal
Measurement of the Heat of Fusion of Ice
Verification of Charle's Law

Electricity and Magnetism

Investigation of Electromagnetism
Investigation of Charge Interactions (Coloumb's Law)
Mapping of Electric and Magnetic Fields
Verification of Ohm's Law

Optics and Light

Basic Geometrical Optics
Observation of Light Polarization, Diffraction, Interference, Refraction
Observation of Solar and Line Emission Spectra
Determination of the Magnification of a Telescope

Radioactivity

Determination of Half-Life
Demonstration of a Cloud Chamber

Kinetic-Molecular Theory of Matter

Determination of the Size of a Molecule by Monomolecular Film
Demonstration of Brownian Motion

APPENDIX 1

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