



Laboratory exercises for use in a college science course for non-science majors
by James Wallace Cox

A thesis submitted to the Graduate Faculty in Partial fulfillment of the requirements for the degree of
DOCTOR OF PHILOSOPHY in Education
Montana State University
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Abstract:

A series of twenty-seven laboratory exercises are created for use in a college introduction to science for non-science majors.

The American Association for the Advancement of Science's new elementary school science program being released by the Xerox Corporation called Science, A Process Approach is used as the model. Every exercise is prepared to illustrate one of the scientific "processes" and behavioral objectives are stated for each exercise.

Only preliminary evaluation in the author's course at the University of Montana is made but many advantages for the model are apparent particularly if prospective elementary teachers are involved in the student population.

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LABORATORY EXERCISES FOR USE IN A COLLEGE SCIENCE COURSE
FOR NON-SCIENCE MAJORS

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fulfillment of the requirements for the degree

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TABLE OF CONTENTS

	Page
INTRODUCTION	viii

PART ONE. THE BACKGROUND, DESIGN AND EVALUATION OF NEW LABORATORY MATERIALS FOR NON-SCIENCE MAJORS

Chapter

I. America and the Spirit of Science.	1
II. "Scientific Method" and the Curriculum Upheaval.	8
III. The AAAS and the "Process Approach".	16
IV. Our Course and Our University.	29
V. Planning and Evaluating New Laboratory Materials	36

PART TWO. LABORATORY EXERCISES IN SCIENCE FOR NON-SCIENCE MAJORS INCORPORATING THE "PROCESS APPROACH"

Exercise

A. Measuring 1: A Loaf of Raisin Bread	54
B. Observing 1: Energy Transformations	58
C. Using Space/Time Relationships 1: The Motion of Heavenly Bodies	62
D. Interpreting Data 1: Intensity and Distance	71
E. Inferring 1: The Weights of Atoms	77
F. Using Numbers 1: Measuring a Molecule	82
G. Forming Hypotheses 1: Conductivity, Solubility and Volatility	89
H. Predicting 1: Boyle's and Charles' Laws	93

I. Experimenting 1: The Dynamic Nature of Chemical Systems.	102
J. Defining Operationally 1: The Electron.	107
K. Formulating Models 1: The Geometry of Compounds	111
L. Formulating Models 2: Maleic and Fumaric Acids.	118
M. Experimenting 2: Hydrolysis and Condensation.	122
N. Controlling Variables 1: Factors Affecting Enzyme Activity	128
O. Observing 1: Cells.	133
P. Inferring 2: Mitotic Time	139
Q. Controlling Variables 2: Photosynthesis and Respiration.	144
R. Classifying 1: The Fresh Water Algae.	148
S. Using Numbers 2: The Question of Size	152
T. Interpreting Data 2: Color in Nature.	158
U. Communicating 1: The History of Life on Earth	161
V. Observing 2: The Circulatory System	164
W. Observing 3: Anatomy of the White Rat	168
X. Classifying 2: Campus Conifers.	172
Y. Using Numbers 3: The Evolution of the Flowers	175
Z. Space/Time Relationships 2: The Broad Leaf Trees and Shrubs	182
AA. Classifying 3: Montana Wildflowers.	191
APPENDIX	198
LITERATURE CONSULTED	207

LIST OF TABLES

Table	Page
1. Elementary School Curriculum Project Implementation. . . .	18
2. A Chronology of the Development of General 125, 126, 127	31
3. Student Evaluation of Individual Laboratory Exercises.	45
4. Student Opinion of Time Spent in Laboratory.	48

LIST OF ILLUSTRATIONS

Figure

Page

1. Specimen Exercise from Part C, Science--A
Process Approach.23-26

ABSTRACT

A series of twenty-seven laboratory exercises are created for use in a college introduction to science for non-science majors.

The American Association for the Advancement of Science's new elementary school science program being released by the Xerox Corporation called Science, A Process Approach is used as the model. Every exercise is prepared to illustrate one of the scientific "processes" and behavioral objectives are stated for each exercise.

Only preliminary evaluation in the author's course at the University of Montana is made but many advantages for the model are apparent particularly if prospective elementary teachers are involved in the student population.

INTRODUCTION

The author's experience as a high school science teacher and his responsibility since 1964 for a one-year course sequence at the University of Montana called "Science for Elementary Teachers" suggested a need for new laboratory materials which show science in a more exciting, relevant and authentic light for university non-majors.

Our recent involvement with the introduction to Montana schools of the new textbook-free elementary school science program Science--A Process Approach now being released by the Xerox Corporation suggested it as an interesting philosophical and structural model on which to pattern new college laboratory experiences.

We had been introduced to the Xerox program in 1967 at the University of Texas in NSF sponsored discussions and had been intrigued by the stress placed on opportunity for students to be active participants in the many different aspects of scientific behavior rather than just the usual laboratory demonstration of established principles in science. The multiplicity of characteristic scientific behaviors, the so-called "processes of science," seemed well worked out by the psychologists and scientists of the Commission on Science Education of the American Association for the Advancement of Science which had developed the Science--A Process Approach program.

We were fascinated too by the emphasis on instructional procedures which seemed critical to the Commission in deciding whether a

certain idea in science would be used as a vehicle for "process" thinking or for just another verification lesson.

In 1968 we were able to get NSF help to introduce the elementary materials to Montana for the first time in seven pilot schools. Our institute and follow-up activities with teachers made us better acquainted with the program and with teacher response to the program.

Our favorable impression of the AAAS-Xerox program convinces us that it, or something very much like it, is well suited for its purposes with children and that if our prospective elementary teachers had related experience in their university science work their pre-service experience would be more valuable.

It seemed to us too that the process approach is equally valid for use with any non-science student whether or not he be in an elementary education curriculum because it represents science and scientists in their work more accurately and in doing so can be more fun.

It was with these background experiences and convictions that we sat down to write the college laboratory exercises as close imitations of our "process" model.

Part One of this work presents first, the history of the curriculum thinking that has produced the model, secondly, the structure of the model and then a discussion of our efforts to adapt the model to a new purpose. Part Two is the laboratory materials themselves written in close imitation of the model.

PART ONE

THE BACKGROUND, DESIGN AND EVALUATION OF
NEW LABORATORY MATERIALS FOR NON-SCIENCE MAJORS

CHAPTER I

AMERICA AND THE SPIRIT OF SCIENCE

In his classic, Science and the Modern World, Alfred North Whitehead contrasts the quiet advent of science among the intellectual elite of the seventeenth century with the popular religious uprising, the Reformation, which "drenched Europe in blood."

...The worst that happened to men of science was that Galileo suffered an honorable detention and a mild reproof, before dying peacefully in his bed. The way in which the persecution of Galileo has been remembered is a tribute to the quiet commencement of the most intimate change in outlook which the human race has yet encountered. Since a babe was born in a manger, it may be doubted whether so great a thing has happened with so little stir.¹

And yet what exactly it is at the heart of this new and subtle change called science that makes its outlook quite revolutionary has remained a question for continuing discussion into our own decade.

It is this consideration that proved to be the central question when, in 1956 (prior to Sputnik I), the first of dozens of committees sponsored by the National Science Foundation sat down to decide the directions that education in science should take in America. "In what way is science different that would suggest an appropriate method of presenting it?" they asked.

¹Alfred North Whitehead, Science and the Modern World (New York: The MacMillan Company, 1954), pp. 2-3.

It is interesting to speculate now in retrospect about the reason why education in science was, and still is, singled out for special and liberal appropriations by the U.S. Congress. Perhaps in the wake of the military successes of applied physics and electronics, science seemed the most palatable area of federal aid to schools to political constituencies always responsive to the word "defense." On the other hand it is also possible that America's past and future identification with science and the spirit of science was recognized and provided for.

It seems clear that the beginnings of the American republic and the spread of scientific values in the eighteenth century, occurring simultaneously, were interrelated. A healthy suspicion of authority is a major theme of both. If science affected American origins it is also true that America evolved its own relationship with science.

And it is American science and the related American attitudes, then, that we must consider because the deliberations of the NSF committees which effectively changed the course of American education were Americans meeting under American government auspices to discuss science in American schools.

American science and its pragmatic spirit which incorporates so comfortably William James' famous epigram, "damn the absolute," suggests that defining science in terms of efforts toward cosmological certainties cannot be the essence of science. The nineteenth century European tradition of science as "natural philosophy" has given way, at least in America. James Bryant Conant in his Modern Science and

Modern Man, wrote as follows:

The transition was complete; the scientist was no longer thought of as a man in an ivory tower, gradually unravelling the secrets of nature for his own spiritual satisfaction, but as a miracle worker who like Watt or Edison before him could bring about tremendous transformations of man's relation to his material surroundings.²

It appears that science can no longer be defined in terms of the problems to which it addresses itself except insofar as they are problems of the physical world; both cosmological questions and the most mundane and practical questions will yield to scientific thinking.

The interplay between the spirit of science and American society has been a recurrent theme of our historians, literary figures and philosophers. The genius of the American Constitution itself in its masterful plan for permanent pluralism in the face of kings and theocratic zealots would provide a fine organizational document for a scientific academy. The birth of this institutional pluralism is the subject of Arthur Miller's great play, "The Crucible."

A perceptive essay by the literary critic Van Wyck Brooks called "Highbrow and Lowbrow" in America's Coming of Age yields insight into the eventual and continuing competition in American society between the old "unbridled rationalism" as Whitehead calls it and the development of pragmatism (pragmatic sciencism?).

²James Bryant Conant, Modern Science and Modern Man (New York: Columbia University Press, 1952), p. 10.

Brooks thought that we as Americans have lived in a schizoid dilemma between the exalted "highbrow" heritage of New England puritanism and the "lowbrow" tradition of the frontier and the market place. In no European language, Brooks tells us, do such terms "highbrow" and "lowbrow" have any parallel. American science which applies its principles to manipulate the environment rather than abstractly glorifying or vilefying nature is distinctly lowbrow.

For three generations the prevailing American character was compact in one type, the man of action who was also the man of God. Not until the eighteenth century did the rift appear and with it the essential distinction between "highbrow" and "lowbrow." It appeared in the two philosophers, Jonathan Edwards and Benjamin Franklin....For no one has ever more fully than Jonathan Edwards displayed the infinite inflexibility of the upper levels of the American mind, nor has anyone displayed more fully than Franklin the infinite flexibility of the lower levels.³

While written in 1915 his essay is a succinct statement of the impatience of contemporary youth with the contradictions still with us. Indeed it reads very much like the Muscatine Report delivered to the administration by the faculty of the University of California at Berkeley after the first of the riots of the "Free Speech Movement."

...a typical American youth has grown up as an American typically does grow up, in a sort of orgy of lofty examples, moralized poems, national anthems and baccalaureate sermons; until he is charged with all manner of ideal purities, ideal honorabilities, ideal femininities, flag-waving and skyscraping of

³Van Wyck Brooks, High Brow and Low Brow, in Three Essays on America (New York: E. P. Dutton and Company, 1934), p. 20.

every sort--...[and at the same time] he has been encouraged to assume that the world is a stamping ground for his every untrained, greedy, and aggressive impulse, that, in short, society is fair prey for what he can get out of it.⁴

One does not need to be a particularly astute observer now in 1969, however, to realize that the victory of Dr. Benjamin Franklin's "lowbrow" syndrome is almost total. The philosophy of what works, the technological manipulation of our environment, the impatience with tradition, the permanence of change, the adoration of the young and the new, the frontier mentality (now somewhat frightening in the absence of land frontiers), "situation ethics," the poetry of Carl Sandburg, the clerical search for relevance ("they are answering questions nobody is asking")--all these things proceed smoothly from the spirit of Poor Richard's Almanac written by Dr. Franklin between amazing scientific excursions into the nature of electricity, the invention of the stove, the founding of the first public library and, apropos, the first non-classical high school. They all follow nicely, too, from the two American philosophers, William James and John Dewey, who codified this pragmatic spirit for American educators.

The issue as to why the fifty-year gap between the thought of John Dewey (circa 1900) and the program of the NSF (circa 1950) is an interesting one but perhaps tangential.

⁴Ibid. p. 24.

In a very incisive essay called "On Tradition, or What's Left of It," which appeared in Time on April 22, 1966, Oscar Wilde is quoted as follows: "The youth of America is their oldest tradition." and "...in the words of Robert Frost, most traditional of U.S. poets, 'We have ideas yet that we haven't tried.'"⁵

The evolution of American scientific pragmatism does not necessarily imply unequivocal progress in the minds of all observers by virtue of the fact that it is American and it is science. It would be less than candid to proceed with this work without, in the spirit of science itself, recognizing voices of dissent among us. We chose two such voices as being particularly clear and relevant:

Speaking of James and Dewey, Van Wyck Brooks writes the following:

...their whole training has gone to make them students of the existing fact. Unable as they were to alter the level of human vision, all they could do was to take men on the level where they found them and release their latent capacities at that level--an immensely valuable thing, of course, but not the vital thing for us, because it is the level itself that is at fault in America.⁶

And a more recent voice of caution is that of the great philosopher of science, Robert Sonne Cohen, in a paper addressed to teachers of science.

⁵"On Tradition, or What's Left of It," Time, April 22, 1966, p. 42-43.

⁶Van Wyck Brooks, Letters and Leadership in Three Essays on America (New York: E. P. Dutton and Company, 1934), p. 171.

A potential linkage between science and free society might therefore be strong and pervasive. Why, nevertheless, is there an evident potential for the frustration of humane living inherent in the science of the 20th century?

In social terms, the present tendencies toward inhumane conditions have come with modern science, the industrial revolution, and the emergence of very large populations, whether industrial or not. These tendencies are alike in their treatment of men as though they were things. Even more bitterly inhumane is a standardization of men...and as the engineer applies science to the economical attainment of material goals, so powerful men may measure and manipulate other men for the attainment of specific goals. Of course, these goals may be good or evil, or ethically neutral. Ethics is not a science.⁷

Later,

The classical view of Freud finds industrial society and its technological reasoning to be marked by inner demands for order, parsimony and obstinacy. The interpretation of the philosopher Simmel points to the nature of money, and a monied society, as a historical origin for the core of scientific thinking...These motives may, in fact, be satisfied by manipulating the world of man and nature, not by respecting it or appreciating it or enjoying it in wonder or play.⁸

⁶Van Wyck Brooks, Letters and Leadership in Three Essays on America (New York: E. P. Dutton and Company, 1934), p. 171.

⁷Robert Sonne Cohen, "Individuality and the Common Purpose," The Science Teacher, May, 1964, p. 27.

⁸Ibid. p. 33.

CHAPTER II

"SCIENTIFIC METHOD" AND THE CURRICULUM UPHEAVAL

We have discussed the intimate relationship of science and American society to elaborate the context in which educators have met during these thirteen years to decide about how to teach science. The conclusion that seems inevitable is that science is not merely the product of our culture but the very essence and origin of the culture for better or worse.

This is obvious in the 1966 Recommendations of the Educational Policies Commission in their publication called, Education and the Spirit of Science. (It is significant that no comparable document called "Education and the Spirit of Humanism," or "Education and the Spirit of History" was forthcoming.) The Commission is a unit of the National Education Association of the United States. We quote:

The world wide pursuit and spread of science and technology are commonly recognized. There is less recognition that the values and modes of thought which underlie science and technology also are becoming pervasive in the world. Yet these values and associated modes of thought may, in the long run, be more important to mankind and to education than the visible fruits of scientific and technological pursuits....

New or modified values and attitudes, combining to produce a new perspective on life, are gaining currency in the industrial countries. The spread of technology is accompanied by an increasing interdependence of individuals. The spread of science promotes respect for the role of reason in human affairs by demonstrating the power of the mind when used in accordance with the spirit of science. There is a tendency to be suspicious of absolutes, a respect for tentativeness, a kind of working skepticism. Science poses a clear challenge to pretensions of absolute certainty. It promotes respect

for individual flexibility and creativity, for the ability to revise or discard old hypotheses and to form and substantiate new ones. There is also a tendency to see the world in an evolutionary frame of reference, to recognize that what exists now may not have existed in the past and that all things are in the process of becoming.¹

The eventual recommendations of this august body fall far short of the quality of their introduction, however. These seven values, they claim, "underlie science":

1. Longing to know and to understand
2. Questioning of all things
3. Searching for data and their meaning
4. Demand for verification
5. Respect for logic
6. Consideration of premises
7. Consideration of consequences.²

Are these really values that distinguish science? Our own feeling is the entire list with the possible exception of number three might as easily have been written by the great scholastic rationalist, Thomas Aquinas, in the 13th century.

However, this whole idea that familiarity with the "facts" or findings of science could not possibly be the entire outcome of a science course did persist in many forms. It is expressed well by

¹Educational Policies Commission Recommendations of the Commission, Education and the Spirit of Science, Arthur F. Corey, chairman (Washington, D.C.: National Education Association, 1966), pp. 3-4

²Ibid., p. 15.

Paul deHart Hurd of Stanford:

What then should be the educational conditions under which new courses are developed? The thrust is for an education that will enable young people to live intelligently in a world in which they are going to live. What is taught must have value beyond the context in which it is learned. Learning in every course must be durable, counting for the rest of the student's life....Young people must be qualified to deal with ideas not yet born and discoveries not yet made,...There is too much to know and too much demanded of one today to be able to afford learning that frequently withers into obsolescence before the course is over.³

The present author began teaching high school in 1956, precisely the year the first NSF curriculum conference, the Physical Science Study Committee, met at MIT. Some of the early groups made up mainly of college scientists were content to devise programs which more accurately represented the state of knowledge in the scientific field but almost simultaneously there arose a cry for fundamental change so that students could "do science" using the methods of the working scientist with emphasis not only on the state of knowledge in the field but on future relevancy. But what really was the "method of science" from which all these educational benefits were to accrue? We can paraphrase the steps as it was expounded by some as follows: observe, quantify, classify, hypothesize, experiment, conclude.

³Paul deHart Hurd, "The New Curriculum Movement in Secondary School Science Teaching." (paper given before the Association for Supervision and Curriculum Development, Las Vegas, Nevada, March 6, 1962).

An event the author remembers distinctly in connection with the gradual demise of the "scientific method" bandwagon was a talk at Bozeman in 1964, by John Ciardi, poetry editor of the Saturday Review. Ciardi insisted that scientific creativity is not different from artistic inspiration and that the great intuitional leaps of Isaac Newton were very much akin to those of poets and prophets, i.e., the hypothesis may in fact precede the data.

Francis Bacon's contention that inductive reasoning from the observable fact to the generalization is the particular method of science is belied by the history of many modern scientific discoveries.

We may argue that it is the crucial experiment, the verification, then, which distinguishes science from other knowledge but imagination, intuition and creativity are still the crux of the way in which problems are solved both in and out of science.

In traditional science courses these are the 'steps' in an experiment. This is not, however, the way in which science works. While it is the experiment which typically distinguishes modern science from its forerunners, it is, as Karl R. Popper has pointed out, "the theory and not the experiment, which opens up the way to new knowledge."⁴

It is our feeling that if inquiry and problem solving are to be the format for science instruction, then imagination and creativity are still the limiting factors and that there is no flow sheet that

⁴Paul deHart Hurd, New Directions in Teaching Secondary Science (Chicago: Rand McNally, 1969), p. 17.

guarantees creativity as the outcome. It is entirely possible, in fact, that most scientists themselves are not really particularly creative people but mainly work-a-day types and hero worshippers like most everyone else. This, at least, is what James Watson tells us in his extraordinary book previewed in Atlantic as "The Race for the Secret of DNA."

Of course there were scientists who thought the evidence favoring DNA was inconclusive and preferred to believe that genes were protein molecules. Francis [Crick], however, did not worry about these skeptics. Many were cantankerous fools who unfailingly backed the wrong horses. One could not be a successful scientist without realizing that, in contrast to the popular conception supported by newspapers and mothers of scientists, a goodly number are not only narrow-minded and dull, but also just stupid.⁵

The initial impetus of NSF sponsored curriculum discussions was felt at the secondary level. In general these programs represented a compromise in which current knowledge in the various fields of physics, chemistry, biology, and earth science were presented with a view to college preparation within a framework of genuine laboratory investigations and model building.

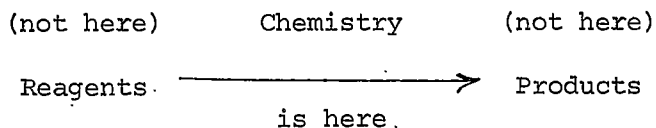
Older methods in which laboratory activities were simply verifications to be noted in the appropriate spaces on prepared laboratory report sheets were largely abandoned. The emphasis was on inquiry. Books posed problems rather than giving answers. Many really

⁵James D. Watson, "The Race for the Secret of DNA," The Atlantic, January, 1968, p. 80.

imaginative investigations were suggested. The BSCS laboratory blocks and the PSCC laboratory manual were classics of pedagogical ingenuity.

These new versions of physical sciences, earth science and biological science reached maturity and were available in hard cover, commercially, beginning in 1960. Perhaps the essence of the whole metamorphosis is conveyed in experiment number 45 of the laboratory manual of the Chemical Bond Approach. The only directions to the students are: "Conduct an extensive laboratory investigation to obtain data that can be used to advance an argument about the structure of solutions."⁶

It seemed that Valhalla was in sight at least to the working scientists who had participated in these curriculum reforms, but negative reaction was soon heard and not all of it from the older and poorly prepared secondary teachers who felt threatened. Some comment was directed at the highly theoretical concepts around which the programs were built. The symbolic representation of the Chemical Education Materials Study (CHEMS) is significant.



⁶Chemical Bond Approach Project, Investigating Chemical Systems (St. Louis: Webster Division, McGraw-Hill Book Company, 1963), p. 69.

The National Science Foundation, which has been asked by the Congress of the United States to make the decision, chose the professional scientist as the most qualified person to improve high school science courses....The new science education philosopher is not a generalist as are most educational theorists....This is one of the reasons the current curriculum reform movement has been labeled a "discipline-centered approach."⁷

The new curricula in secondary science were accused of lacking humanistic, social and historical perspective. They were thought to be too difficult for the average student. Decreasing enrollment in physics and chemistry was related historically if not causally to the PSSC physics program and the CBA chemistry program.⁸

Dean Charles Bradley of the College of Letters and Science at Montana State University in a 1967 letter to Science states the case well at the university level. How much more cogent his argument at the high school level and for university non-science students!

I seriously doubt that the high pressure for so-called "excellence" or the 17-hour work day of the student is responsible for the dropouts and lagging enrollments in the science and technological curricula. Even a young student is not above putting in long grinding hours if the candle seems worth it. There is at least one much more fundamental factor in this shift. This is the student's doubt concerning the relevance and value of the effort. On the one hand, he sees his progress down the trail of science as an excursion into more and more complicated meaninglessness, intriguing though it may be. On the other hand, he looks around at the landscape of technology and wonders if the antibiotics and automation justify all the smog and social

⁷Paul deHart Hurd, New Directions in Teaching Secondary Science (Chicago: Rand McNally and Company, 1969), pp. 14-15.

⁸Ibid., p. 48-49.

chaos. It is not surprising that they are turning to the social science, the humanistic studies, and the Peace Corps--or are dropping out. These young people are neither lazy nor stupid. They see where some real problems lie. The best are trying to prepare to meet these problems responsibly. Others--the dropouts--are unable to spot anything significant to struggle for in the jungle of curricular tabulations. As science teachers, it appears we either do not speak plainly, or young people of today doubt that we have anything important to say.⁹

Apart from the issues of relevance and degree of difficulty, however, it was again the question of "scientific thinking" that arose as the most vexing problem in high school science curriculum planning.

Students accustomed to schooling that stressed, for ten years of their lives, the "right answers" or, as Joseph T. Schwab describes it, "a rhetoric of conclusions" could hardly become instantly creative merely because they were presented with a question or some data.

It seemed universally agreeable that the medium was the message in science but it was not as it is with bacteria where, if the medium is suitable, the organism is sure to flourish.

The child must be introduced early to the several processes of science if he is to want to and be able to behave in scientific fashion.

At least this was the answer of the American Association for the Advancement of Science in the elementary school science revolution which followed and which is now in progress.

⁹Letter, Science, June 30, 1967, p. 1685.

CHAPTER III

THE AAAS AND THE "PROCESS APPROACH"

The curriculum upheavals at the secondary level that occurred from 1956 to perhaps 1962 were followed by an extensive investigation and radical modifications of elementary school science programs. At the elementary level there was rather little pressure present for retaining specific parcels of science content in the new science programs as there had been at the secondary level because of college preparation. In the words of Herbert Smith, quoted by Robert Karplus, the director of a very successful elementary school science program, in his Theoretical Background of the Science Curriculum Improvement

Study:

The big question is which concepts are most valuable in the further intellectual development of the child and which contribute most to the cognitive, affective, and social objectives of science instruction...what procedures and techniques are most appropriately employed in merging a series of simple concepts into a larger, more comprehensive understanding?¹

Both Karplus' SCIS program and Science--A Process Approach, the product of the Commission on Science Education of the American Association for the Advancement of Science, were initiated in 1962.

¹Robert Karplus, Theoretical Background of the Science Curriculum Improvement Study (Berkeley: The Science Curriculum Improvement Study, 1965), p. 4.

Both bear resemblances to one another and both are now appearing on the market commercially.

The purpose of our own writing project, Part Two, is the preparation of laboratory exercises in science for college non-science majors and particularly for use in the pre-service training of elementary teachers. In doing so we have chosen to model our exercises on Science--A Process Approach.

Of the several new elementary curricula that have gained currency as a result of the work of NSF committees we have chosen the AAAS, Science--A Process Approach, model not merely because it is the one new program that has proven most popular with elementary teachers as evidenced in the latest statistics of the International Clearing House on Science and Mathematics Curriculum Developments (See Table 1). Surely this would be an added recommendation if the college program would have the effect of previewing the structure of new elementary school programs for prospective elementary teachers.

To the author the real virtue of the AAAS model is that it constitutes the best single summation of progressive developments that have grown out of more than a decade of the expensive and intensive reappraisals in science curriculum that we have been discussing.

The essence of the AAAS program is implied in its name, "Process Approach." Rather than to outline the "steps" of scientific thinking or to suggest that science and creativity are somehow mysteriously linked, this program is based on a masterful dissection of the many

TABLE 1

ELEMENTARY SCHOOL CURRICULUM PROJECT IMPLEMENTATION

These data are excerpted from Sixth Report of the International Clearing House on Science and Mathematics Curriculum Developments, edited by J. David Lockard and published by the Science Teaching Center, University of Maryland, 1968. They represent use of the various new elementary programs during the 1967-68 school year.

AAAS--Science--A. Process Approach

Teachers	more than 25,000
Students	more than 750,000
Schools	not known

Minnesota Mathematics and Science Teaching Project (MINNEMAST)

Teachers	439
Students	15,000
Schools	76

Science Curriculum Improvement Study (SCIS)

Teachers	600
Students	19,000
Schools	not known

Elementary Science Study (ESS)

Teachers	7,500
Students	225,000
Schools	not known

Elementary School Science Project (Astronomy)

Teachers	400
Students	12,000
Schools	70

mental processes that one associates with the scientist in his work whether or not these processes are peculiar to science. The whole fruitless philosophical controversy regarding definitions of science is side-stepped in favor of considering science to be what scientists do--operationally! It is significant to see too that one of the "processes of science" as defined in the program is, in fact, to "define things operationally."

These "processes" are stated as characteristic behaviors, as follows:

When we watch scientists at work we see them at different times:

1. observing
2. classifying
3. measuring
4. communicating
5. inferring
6. predicting
7. using space/time relationships
8. using numbers

also involved in the so-called integrated processes of:

9. interpreting data
10. controlling variables
11. defining operationally
12. formulating hypotheses
13. experimenting
14. formulating models

Each exercise in Science--A Process Approach requires the student to do one of these things and subject matter is chosen as a vehicle in these behaviors. In this way the creative aspects of science in the process of predicting, formulating models, experimenting,

and formulating hypotheses are certainly provided for as well as those processes which can more accurately be identified as peculiar to science: measuring, using space/time relationships, using numbers, interpreting data, etc.

The psychological bases of the AAAS approach were stated by Robert M. Gagne, Berkeley psychologist, and perhaps the single most influential man in the origins of the AAAS program as follows:

The process approach rejects the "content approach" idea of learning highly specific facts or principles of any particular science or set of sciences. It substitutes the notion of having children learn generalizable process skills which are behaviorally specific, but which carry the promise of broad transferability across many subject matters. The process approach also rejects the notion of a highly generalizable "creative ability" as a unitary trait. Instead, it adopts the idea that novel thought can be encouraged in relation to each of the processes of science--observation, inference, communication, measurement, and so on. The point of view is that if transferable intellectual processes are to be developed in the child for application to continued learning in sciences, these intellectual skills must be separately identified, and learned, and otherwise nurtured in a highly systematic manner. It is not enough to be creative "in general"--one must learn to carry out critical and disciplined thinking in connection with each of the processes of science. One must learn to be thoughtful and inventive about observing, and about predicting, and about manipulating space and time, as well as about generating novel hypotheses.

And so we come to the process approach itself. Its basic premises may be stated as follows:

The scientists' behaviors in pursuing science constitute a highly complex set of intellectual activities which are, however, analyzable into simpler activities.

These intellectual activities (processes) are, as most scientists would agree, highly generalizable across scientific disciplines. It is not difficult for a physicist to become a biochemist, or vice versa, so long as language and techniques are learned. It is not even difficult for a meteorologist to become a psychologist--predicting the weather and human behavior may have comparable degrees of uncertainty.

These intellectual activities of scientists may be learned, and it is reasonable to begin with the simplest ones and build the more complex activities out of them, since this seems to be in fact the way they are organized.²

Another and perhaps the most controversial feature of the AAAS program (but certainly not unique to it) is its insistence on planned behavioral objectives. This idea of behavioral objectives which evokes applause or outrage among teachers at every level is, one might say, "what's happening" in science education today. Briefly stated the thinking of the proponents is this, "If we teach it should be for a purpose namely to change the behavior of the student. He should be able to do something different as a result of being taught. Behavioral changes should be measureable and therefore when we formulate the outcomes of instruction it can and should be in behavioral terms so we can know if we are successful."

We should not say then that the purpose of a certain lesson in biology is to "understand" something or to "appreciate" something

²Robert M. Gagne, "Psychological Issues in Science--A Process Approach" (a lecture delivered to regional conferences of tryout teachers in Washington, D.C., 1964 and in San Francisco and Chicago 1965).

because, while commendable as stated, we cannot without restatement decide when or if such vague objectives have been realized. Objectives stated behaviorally imply action rather than state of being e.g. "the student should be able to list reasons," or "the student should be able to describe something," or "the student should be able to state a rule for something."

The total involvement of Science--A Process Approach in the processes of science and in behavioral objectives is obvious when we look at the specimen exercise from grade two reproduced in Figure 1. This is the format of every exercise in the program from kindergarten through grade six. Notice that the behavioral point of view in the "objectives" section of the sample exercise is made quite clear and useable for teachers since the committee has chosen ten "action verbs" by which the result of an exercise is to be appraised. The teacher asks the pupils to

identify	}	something
distinguish		
construct		
name		
order		
describe		
demonstrate		
interpret		

or to

state a rule

or

apply a rule.

SCIENCE—A PROCESS APPROACH / PART C

COMMUNICATING 7

GRAPHING DATA

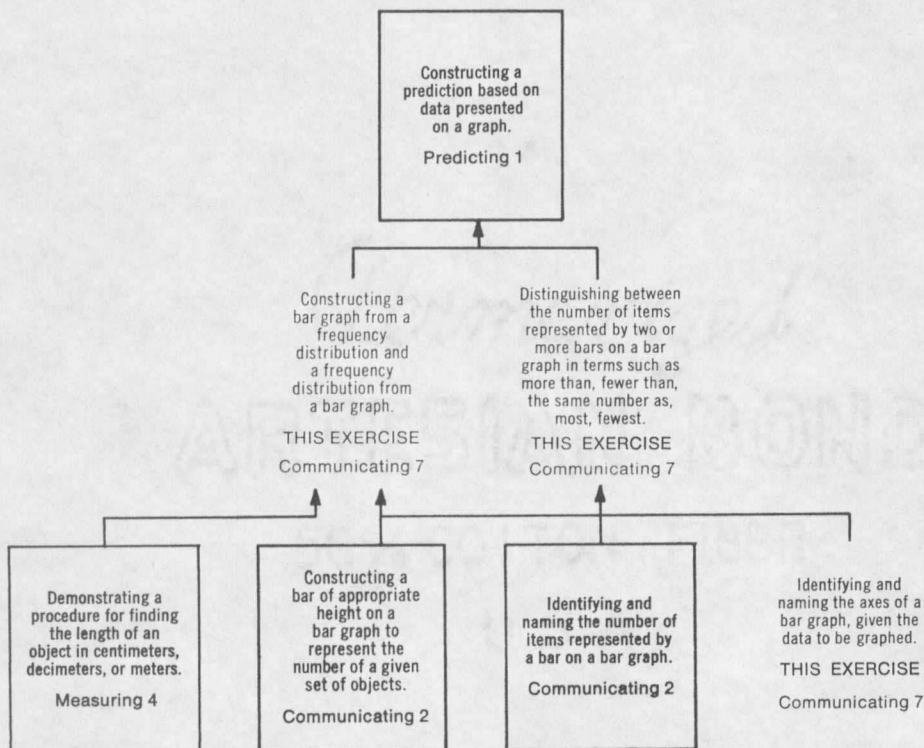
OBJECTIVES

At the end of this exercise the child should be able to

1. *NAME* the units along the vertical and horizontal axes of a bar graph.
2. *CONSTRUCT* a bar graph, given a frequency distribution.
3. *DISTINGUISH* between quantities shown on a bar graph in terms such as "greater than," "less than," "greatest," and "least."

g

SEQUENCE



RATIONALE

This exercise provides additional experience in drawing and interpreting bar graphs as a way to communicate information about a set of data. The graphs in this exercise are consistent with those used in *Introduction to Graphing, Communicating 2*, Part B. If you think it necessary, review that exercise with the class before starting this one.

In this exercise, the earlier experience of reading scales on a vertical line is extended to reading scales on a horizontal line, so that the scales on both lines can be read to fix a relationship represented by a given bar. The activities here will also familiarize the children with the use of bar graphs to represent frequency distributions for quantitative variables.

VOCABULARY

origin	horizontal
record	graph
data	grid
vertical	axis

RELATED MATERIALS

Listed below are the materials required to conduct this exercise.

Some items cannot be supplied at all or are not supplied by Xerox in the Standard Kit. These are designated as *NS*. Note, however, that many items so designated are supplied in the Comprehensive Kit. A separate list of these items is included with the comprehensive materials.

It should be noted that some supplied items are expended in the course of this exercise. These expendable items are designated as *EXP*.

Items too large for the Exercise Drawer will be found in the Teacher Drawer and are designated as *TD*.

Graph (as in Figure 1), 30 copies (*EXP*)

Red, green, and blue cubes, 13 (*NS*)
Graph paper, 1-cm squares printed in black ink, 200 sheets (*EXP*)

Rubber balls, 10

Box, 1 (*NS*)

Assorted small objects to put into box (*NS*)

Masking tape, 1 roll (*NS*)

Meterstick, 1 (*TD*)

Graph (as in Figure 6), 1 copy

INSTRUCTIONAL PROCEDURE

Introduction

Arrange a row of desks across the front of the room, and ask a child to sit at each desk. Point to one desk, and tell the class to note that there is one child at the desk. Point to two desks, and tell them to note that there are two children at two desks. And so on.

Next, give each child a copy of the graph in Figure 1. Ask different children to describe it. If necessary, pile colored blocks on a table to remind them that *numerals* are used to represent the number of blocks stacked in each pile, and that *colors* in a key are used to designate the different stacks. On the graph, the colors refer to the color of the blocks; the numerals, to the number of blocks of each color. Ask, **If you took this graph home and showed it to your mother, would she know how many red blocks are here on the table, even though she hasn't seen them?** (Yes.)

Is it possible to show the number of desks and the number of children in the same way? The children will probably think that it is, and you can proceed immediately to Activity 1.

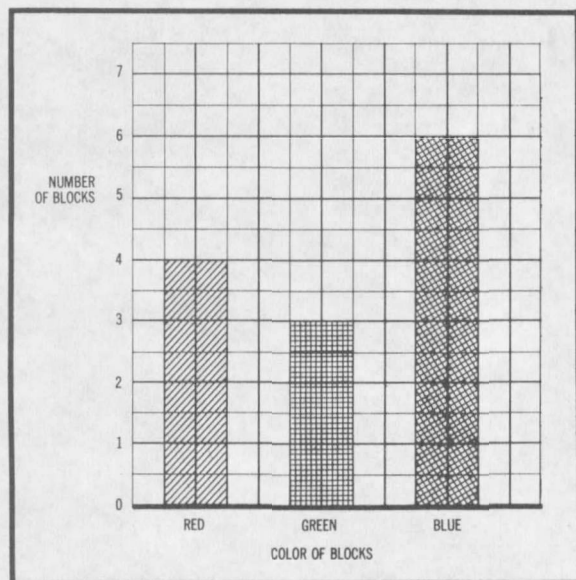


FIGURE 1

Activity 1

(This activity introduces the use of numbers on both the horizontal and vertical lines. For this activity, all of the children should be seated at their desks.)

Remind the class that they want to find out if it is possible to show on a graph the number of desks and the number of children. After pointing again to desk number one, point to the space next to it, where there is no desk, and ask, **How many children are sitting here?** (None.) This suggests the *origin*, or starting point, for the graph, namely, zero desks and zero children. Now put a grid on the chalkboard, and label it to show that the numbers begin at zero for both the horizontal and vertical lines. Let the children seated in the back of the room compare the number of children with the number of desks toward the front of the room by counting them. Since this relationship is rather obvious, continue only so long as you think it suitable.

Children	Desks
One child	One desk
Two children	Two desks
Three children	Three desks
Four children	Four desks

Construct the graph shown in Figure 2 on the chalkboard grid. Ask the children questions about the graph as you make the construction so that they will have a part in it. Then give each child a half sheet of graph paper, and ask the children to construct graphs on the paper similar to the one you have drawn on the chalkboard. Be sure to give help to individual children who need it.

To extend the graph, ask how many desks there would be for seven children.

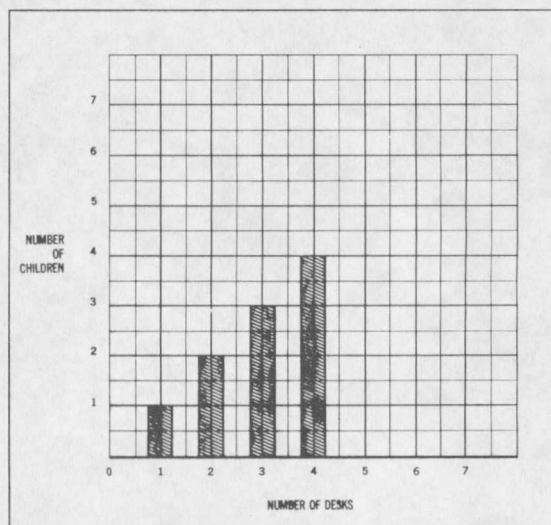


FIGURE 2

Activity 2

(Organize this activity before an outdoor play period.)

Plan an outdoor game with the children (for example, a game of "catch" or "keep-away") in which one ball is needed for every three children. Discuss the number of balls that will be required for this activity and how a bar graph might help to give the information. You may want to begin by arranging nine or more children in groups of three and giving each trio a rubber ball. Have one trio go to the front-left area of the room and bounce the ball among them; have the other trios line up beside the first, with ample room between groups. Then, with the help of the other children in the class, record the following information:

Children	Balls
Three children	One ball
Six children	Two balls
Nine children	Three balls

After listing the data, begin the construction of the graph on the board with the children's help. (See Figure 3.) Before completing the entire graph, ask questions such as the following in order to give the children an opportunity to continue the number relationship series:

How many balls would be needed for twelve children?

How many children, in groups of three, could play with six balls?

Give each child graph paper to graph these data. Tell the children to extend the information to include the number of balls required for the entire class and to put this number on their graphs too.

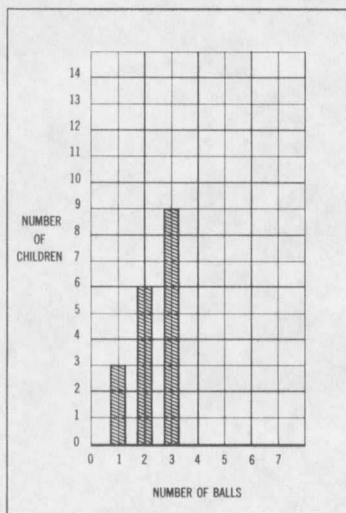


FIGURE 3

Activity 3

Pass a box containing a variety of small objects around the class, allowing each child to take a handful of items in "grab-bag" fashion. Tell each child to count the *number* of objects he has drawn and then to put them back in the box. He must *remember* the *number*. When everyone has "grabbed," go around the room and ask each child to report his number of objects. The tally might look like this:

Group	A	B	C	D	E	F
Number of Objects	1	2	3	4	5	6
Number of Children	III	II	IIII	IIII	IIII	I

There are three children in the first group, two in the second group, four in the third, and so on. Tabulate the data, and then construct the graph on the chalkboard. (See Figure 4.)

Now direct the children's attention to the graph by covering the table of data. Ask, **Which group had the largest number of pieces?** (E.) **The least?** (A.) **How many pieces did each member of Group D have?** (Four.) **If the box were passed around again, would you be able to say how many children would pick four pieces this time?** (No.) Encourage the children to use the numbered lines instead of counting squares when they read the graph.

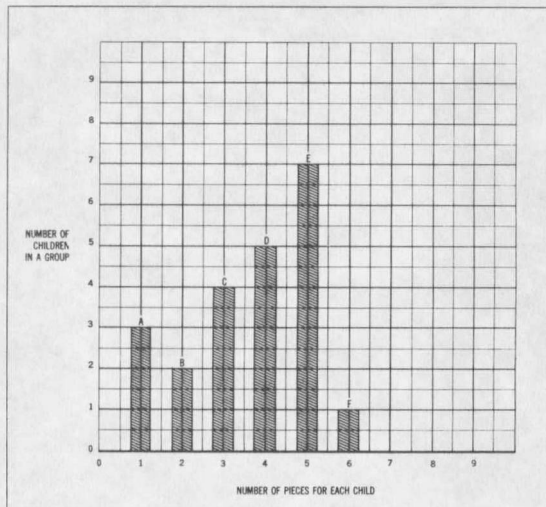


FIGURE 4

In our university laboratory exercises we expect to state behavioral objectives in other than these particular words alone but it is interesting to see that it is in these words only that Science--A Process Approach states its objectives.

We cannot conclude this discussion of Science--A Process Approach without again including opposing views. And it is this point of behavioral objectives to which critics take exception.

A leading figure in elementary science and Director of the ESSP (Astronomy) (See Table 1), Dr. J. Myron Atkin of the University of Illinois, writing about curriculum design says:

In fact, the behavioral objectives people are now near the center of curriculum decision making. Make no mistake; they have replaced the academicians and the general curriculum theorists--especially in the new electronically based education industries and in governmental planning agencies. The engineering model for educational research and development represents a forceful tide today. Those who have a few doubts about the effects of the tide had better be prepared to be considered uninitiated and naive, if not slightly addleheaded and antiquarian....

Delineation of lists of behavioral objectives, like broadly used testing programs, may admirably serve the educational researcher because it gives him indices of gross achievement as well as detail of particular achievement; it may also provide input for cost-benefit analysts and governmental planners at all levels because it gives them hard data with which to work; but the program in the schools may be affected detrimentally by the gradual disappearance of worthwhile learning activities for which we have not succeeded in establishing a one-to-one correspondence between curriculum elements and rather difficult-to-measure educational results.

Among the learning activities most readily lost are those that are long term and private in effect and those

for which a single course provides only a small increment. If even that increment cannot be identified, it tends to lose out in the teacher's priority scheme, because it is competing with other objectives which have been elaborately stated and to which he has been alerted.³

³J. Myron Atkin, "Behavioral Objectives in Curriculum Design: A Cautionary Note," The Science Teacher, May, 1968, pp. 27-28.

CHAPTER IV

OUR COURSE AND OUR UNIVERSITY

Before we can describe the use of the AAAS elementary school model in our university laboratory science exercises we should discuss the course sequence at the University of Montana for which these laboratory activities are designed.

At present it is a full year's course taken mainly by elementary teacher candidates but occasionally by other non-science majors for fulfillment of group requirements in science. It is not a "teaching methods" course but is designed to present science itself to non-science majors.

The topics for the course are chosen using the following criteria:

1. Particularly important scientific generalizations.
2. Indispensable ideas in the logical or historical development of topics.
3. Ideas which are particularly fruitful in their implications in other areas.
4. Ideas which show science as a developing, self-corrective enterprise--the critical experiment, the bit of discrepant data, the flash of intuitive genius, etc.
5. Ideas which illustrate the processes of science.

An abbreviated syllabus for the sequence follows as it has been organized since 1964. The three quarters are offered sequentially during fall, winter, and spring quarters and at least one of the courses

of the sequence is offered alternately each summer session.

A SYLLABUS FOR GENERAL 125, 126 and 127

General 125

The Scientist's View of Nature
Science as a Way of Thinking
Energy, Its Forms and Interconversions
Speculation and Discovery about the Heavens
Atoms and Molecules
The Nature of the Chemical Bond

General 126

The Fall of the Bohr Atom
The Organization of the Periodic Table
The Geometry of Molecules
Diversity in Carbon Compounds
Functional Groups
The Structure of Important Biochemicals, Polymers
Enzymes and the Rate of Reaction
Microbes
Cell Fine Structure and Mitosis
The Chemistry of Heredity, Mutation

General 127

Cellular Metabolism
Natural Selection and Genetic Recombination
The Origin of Life
The Animal Kingdom
Animal Systems Exemplified in Man
The Higher Plants
Man and Nature

The reader may be interested in the history of the course
which shows its evolution since 1955. Table 2 provides this information.

TABLE 2

A CHRONOLOGY OF THE DEVELOPMENT OF THE COURSE, GENERAL 125, 126, 127

AT THE UNIVERSITY OF MONTANA

- 1955 First appearance of a course in science specifically for teachers in the University of Montana Catalog, "General 25--Physical Science for Teachers," five credits, and taught by Dr. James Gebhardt.
- 1957 Number changed to "General 125" and "General 126 --Biological Science for Teachers" added for five credits.
- 1962 Dr. Richard Solberg takes over sequence after death of Dr. Gebhardt.
- 1963 Enlargement of program to 3 quarter sequence, General 125, 126, 127 with three hours lecture and two hours lab per week, total 12 credits. Enrollment about 70 in 1963.
1964. Author replaces Dr. Solberg.
- 1966 Professor Norman Jacobson appointed to assist the author because of growing enrollment.
- 1967 Sequence extended to 15 hours total, four lecture and two lab hours per week. Current enrollment 160 in autumn quarter with increase of about 20 students per year average.

The author will have taught the entire sequence seven times by summer 1969.

It is apparent that in writing such a one-year program detailed treatment of the various disciplines has been sacrificed for the sake of continuity in presenting the few chosen and important ideas. Such a decision is inherent in the nature of the course and its goals. Dr. Lee A. DuBridge, then President of the California Institute of Technology, expresses this well in his paper "Seeking Unity in Science":

There is no hope of providing, even to the scientific specialist, more than a brief glimpse of the vast array of scientific knowledge which now exists in the many scientific fields. And we, as teachers, will be butting against a stone wall if we attempt to move in this direction....

But today it is evident that the universe of science is a physical universe. It is a universe governed by a rather modest number of basic physical principles --broad basic principles which underlie a multifarious array of special exemplifications and applications.¹

Dr. Robert Jastrow of NASA says in his "Prospectus for an Introductory Science Course":

First, scientists have permitted, and occasionally encouraged, a public image of science to develop as an impersonal and dehumanized field of work, unintelligible and inaccessible to all but a gifted few....

¹Lee A. DuBridge, "Seeking Unity in Science," in Viewpoints on Undergraduate College Science Programs (Washington D.C.: National Science Teachers Association, 1966), p. 2.

The introductory science courses do not clearly explain the broad intellectual contributions which science has made to the western world, although these contributions are of the greatest interest to the general student, more so than the mastery of technique which the professional student requires. The science student only becomes aware of these broader implications of the scientific revolution when he has reached an advanced level of training. The student who is not oriented towards science is not likely to receive them at all, although it is he who most badly needs this broad point of view.²

In 1948 before there was such a thing as the National Science Foundation and modern curriculum reforms in science we find these same problems were being considered at many universities in an interesting reference entitled, Science in General Education, edited by Earl J. McGrath, then U.S. Commissioner of Education. Among the reports contained in this volume are such titles as "General Education in Natural Science at Colgate University," "The Single Science Course at Princeton," "Science in General Education at the University of Iowa," "Correlated Science Units at Northwestern," etc. All twenty-two reports delineate the same problem, similar goals and similar solutions. We find our own course typical rather than distinctive in organization and selection of lecture material.

The textbooks which are prescribed for our course are quite popular general treatments of physical and biological science.

²Ibid., Robert Jastrow, "A Prospectus for an Introductory Science Course," p. 21.

Slabaugh and Butler's College Physical Science and Villee's Biology have been used more than any others.

The subsequent evaluation of our writing project is related to the nature of our student population. From personal records of student data sheets which we use each quarter we find that well over one half of the students in General 125, 126 and 127 are freshmen. The remainder are distributed about equally among sophomore, junior and senior levels.

Montana's State University system is one of the few in the United States that operates under an open admission policy. It must accept any Montana high school graduate to its freshman class.

The open admission policies are reflected in the author's compilation of American College Testing Program scores for students who entered our course sequence in the fall of 1968. The median cumulative score on the ACT was 46.5th percentile for fall 1968 with the median percentile at 47.5th for natural science. The percentiles compare our course population to entering college freshmen nationwide. Among University of Montana freshmen the percentile in natural science scores is at only the 31st percentile for our same group.

We hope that our degree of success in achieving our stated laboratory objectives would represent, then, a minimal degree of success as compared with national college freshmen populations.

It should be clear that neither our students nor our course is unusual which might imply that related laboratory exercises might

have wide application to other courses of this type.

If our general affective and cognitive goals are not unique our process and behavioral format for laboratory is, as is our decision to closely imitate an elementary school experimental program for the benefit specifically of teacher candidates. The imitation of the process approach is completely original with the author and only recently in continuing discussions sponsored by the National Science Teachers Association⁴ are behavioral objectives being suggested as substitutes for the usual lofty but vague statements of scientific literacy on which everyone seems to have been in agreement for twenty years as a basis for teaching science to non-majors.

⁴Steps Toward Scientific Literacy, A Report of College-Level Conferences on Science for Non-Science Majors. The National Science Teachers Association (Washington, D.C.: National Science Teachers Association, 1968).

CHAPTER V

PLANNING AND EVALUATING NEW LABORATORY MATERIALS

At the university level the information that is a product of science becomes more appropriate for its own sake than it might be for school children. Lecture hours with dozens of lecture demonstrations can go a long way in accomplishing such cognitive objectives. However, if science is doing and if elementary teachers are to be expected to have children do science then it cannot all be vicarious.

Both for elementary teachers and non-science majors generally laboratory experiences, well-written, can make a great difference in affective goals in teaching science. College students should observe stars, classify flowers, predict what chemicals will do, measure mitotic times, etc., or they cannot possibly have as much fun, understand how scientists work or be required to use their imagination to the same extent in finding answers. For these reasons a two-hour lab per week has been a part of our own course for fifteen years.

At present there are few, if any, collections of laboratory exercises available commercially for a course of this type. In preparation under grants from various agencies are materials that in some ways are similar. While none is written specifically for teachers, two interdisciplinary programs are addressed to the needs of the non-majors. Both have originated at Rensselaer Polytechnic Institute at Troy, New York.

Professor Lewis Bassett's program under NSF sponsorship has built a physical science course for non-majors around the single theme, the structure of solids, in the interest of providing some depth coverage. Much imaginative laboratory work is incorporated in ways that stress science processes. The program is labeled PSNS, Physical Science for Nonscience Students.

Professor Lawrence Parsegian's Science Course for Baccalaureate Education: Introduction to Natural Science has support from the Charles F. Kettering Foundation and is aimed at attitudinal change and scientific literacy. It incorporates both physical and biological science but the complete program is not yet available.

The restricted scope of the PSNS we feel is unwarranted. The Parsegian program may on completion be excellent. Their advisory committee in preparing Science Courses for Baccalaureate Education includes some of the most prestigious names in the field of science teaching including Loren Eiseley and Ernst Nagel. We will be looking forward to its publication.

In writing our own materials certain relevant facts and goals must be established for the reader in advance. We hope these ground rules will fit the demands of another potential user. Some were our considered decisions; some were foisted upon us by our own situation. We enumerate them here as follows:

1. The format of the laboratories will conform as closely as possible to that of the exercise booklets of Science, a Process

Approach (See Figure 1, page 23).

2. The laboratories will complement the lecture sequence.

3. Each exercise will be useable during one laboratory session.

There will be no holdover laboratories of the type required in some genetic, population or nutrition studies. (It has been our experience that it is difficult to maintain both organisms and interest of the non-scientist over a period of weeks.)

4. Laboratory exercises will be appropriate for groups as large as twenty-four at a time.

5. Minimal physical facilities will be adequate. Only electricity is essential at work tables. Two sinks and a few propane torches must suffice as needs for water and gas arise.

6. The only capital items that might be considered at all expensive that are required are a scaler or ratemeter, now quite common on most campuses, and a photometer.

7. The various processes of science as identified by the American Association for Advancement of Science Commission on Science Education shall be represented about equally with laboratory exercises.

8. Time for grading laboratory reports is to be minimal. Laboratory activities requiring reports are to be spaced to provide instructor time for grading and returning reports.

9. Exercises will be prepared in enough detail that a teaching assistant, prepared in the subject matter, could do the job well. Materials, objectives, procedures, instructional aids will be clearly specified.

10. Student work sheets when required will be prepared for duplication verbatim.

11. The entire biology laboratory program will focus around organisms the students can collect from their own local environment both as students and, later, as teachers.

12. Two hours will be adequate time for each exercise.

13. The activities must be written with student enjoyment in mind.

We can report that these strictures have been observed fairly well with a few reservations. For example the algae are difficult to collect in Montana as early in the spring as the topic would fit the lecture schedule. It will be difficult to keep this activity "in phase" with lecture.

It is clear, too, that for outdoor biology laboratories a group of twenty-four is not prohibitive in size but neither is it optimal.

Another deviation from our guidelines has been the fact that, while all the "processes of science" have been well represented with laboratory exercises the process of observing, using numbers, and classifying have been the focal point of three exercises rather than two. Perhaps these emphases are not unwarranted because it was our experience with elementary teachers in-service during our NSF conference on Science--A Process Approach in Montana that classifying and metric system were the areas of greatest weakness with practicing elementary teachers as indicated by a national AAAS measuring instrument

called the "Process Measure."

Another point has to do with the processes themselves to one of which each exercise must be tied if the model is to be used closely. We might summarize our experience to the effect that while discrete processes seem to have been isolated in the model elementary program for each exercise, the processes are so interwoven in more sophisticated laboratory work as to seem inseparable.

In laboratory Exercise F, measuring a molecule, for example, it is possible to distinguish almost all the processes at work. One is observing, measuring, inferring, interpreting data, controlling variables, etc. It becomes necessary to decide what process this session exemplifies best. In this case we chose "using numbers" since the juggling of a geometric formula is the central theme.

We found the "process approach" as outlined in the model to be comprehensive and of great value in designing laboratories with different emphasis from the usual.

In trying to involve all the processes in laboratory activities one will be more inclined to keep student interest and to represent science more fully and therefore more accurately in its many facets.

Regarding the time required for grading laboratory reports we find only five exercises demand instructor follow up. These exercises (C, F, H, U and X) are well separated during the academic year. The reader will see in the Appendix on evaluation of specific exercises, the extent to which our 1968-69 test group were able to accomplish

the objectives prescribed for these "report" exercises along with the others and the author's method of grading these reports.

In arriving at appropriate exercises to conform to these specifications the author was able to make use of his own experience, the experience of colleagues and the many laboratory ideas in the literature cited. Often, however, it seemed necessary to invent something new. In retrospect we count fourteen of the twenty-seven exercises as either new or drastic modification of existing published materials. It might be interesting at this point to categorize the exercises as to our main sources as follows:

Ten Classic Exercises

"Measuring a Molecule"
 "Boyle's and Charles' Laws"
 "Dynamic Nature of Chemical Systems"
 "The Electron"
 "The Geometry of Compounds"
 "Hydrolysis and Condensation"
 "Cells"
 "Respiration and Photosynthesis"
 "The Circulatory System"
 "The White Rat"

Three Colleague Suggestions

"The Loaf of Bread" (Professor Norman Jacobson)
 "Campus Conifers" (Professor W. E. Booth)
 "The Flowers of Mount Sentinel" (Professor Richard Solberg)

Five Ideas from Current Publications

"Maleic and Fumaric Acids" (The Chemical Education Materials Study)
 "Factors Affecting Enzyme Activity" (George Wald's Twenty-six Afternoons of Biology)
 "Mitotic Time" (The Science Teacher)

"Color in Nature" (The Grade Teacher)
 "The History of Life on Earth" (The Earth Science Curriculum Project)

Nine Original Exercises

"Energy Transformations"
 "The Motion of Heavenly Bodies"
 "Intensity and Distance"
 "The Weights of Atoms"
 "Conductivity, Solubility and Volatility"
 "The Fresh Water Algae"
 "The Question of Size"
 "The Evolution of the Flowers"
 "Broad leaf Trees and Shrubs"

After having produced and used the materials which follow in Part Two during the academic year 1968-69, a brief commentary of a general nature might be in order.

The single most abiding impression one gets from this project is the suitability of the model for the new purpose. Even if college students were never to see the elementary program "Science--A Process Approach" again, its format would be completely appropriate for use as their laboratory model.

The structure seems designed to prevent an instructor from writing laboratory exercise solely "to keep students busy." Having to sit down and list behavioral objectives, particularly in the "affective domain," is a sobering experience but certainly these "affective" goals are of consummate importance for non-science people.

The details of instructional procedure required in the Science--A Process Approach format are another virtue of the model. The same scientific concept illustrated using the same materials can be

presented in a way which emphasizes process thinking or emphasizes the usual drab verifications. Because the essence of the value of any exercise is in the instructional procedure we wonder, after writing twenty-eight such instructional strategies, why this has not been done routinely for college science laboratories particularly since graduate assistants with no teaching experience are often used in the capacity of laboratory instructors. It now seems an indispensable part of any laboratory exercise that instructional goals and methods be prescribed.

If one had to choose only one aspect of this undertaking that had implications beyond the immediate use of some of the more imaginative materials of Part Two it would be the desirability of considering the AAAS processes in writing any future science laboratory experience at any level of instruction.

Time and time again during this writing project we found ourselves forced to use numbers in biology, to classify in physical science, to require students to differentiate between observations and inferences, to give students the chance to interpret data instead of merely gathering it, to invent explanations, to design experiments, and to look carefully. We had to do these things if we were to represent all the various scientific behaviors in our sessions. The increase in opportunity for creativity and for representing science more faithfully is an outgrowth of the model. An author of laboratory materials who will submit to the discipline of the model will

find himself not merely "covering" the lecture topics in lab but using the subject matter as a way of demonstrating what science is all about.

An attempt to evaluate the exercises with respect to specific stated objectives can only be preliminary at this time. Any sort of statistical inference based on our behavioral objectives is subject, in my mind, to a number of objections.

These are as follows:

1. Success of the materials in doing the job cannot be isolated from instructor behavior in spite of the fact that "instructional procedure" is fairly carefully prescribed. We realize that, in order to evaluate these exercises in a way that would obviate this factor of instructor behavior, we should test the sequence in dozens of situations on other campuses. We regret that this has not been possible for us as it is with funded curriculum studies prepared by committees on a national level.

2. It is virtually impossible to detach and isolate the effects of the laboratory from the lecture organization and presentation. It will be clear from the "rationale" of most exercises that they are lecture-related unlike the elementary school prototype, Science--A Process Approach, for which there is no text or lecture part. Achievement of laboratory objectives might be greatly enhanced, for example, if a better lecturer than the author had spent increased lecture time on lab-related topics. This independent variable could have great effect on evaluation of the materials.

3. To compare student reaction and achievement in one exercise to that in another exercise would be invalid unless both the exercises to be compared were traditional. We found ourselves continually revising our fourteen original labs during the week on the basis of student difficulties and often unpredictable reactions. Often the laboratory sections which meet early in the week during a given week did not have precisely the same materials that those students had who met late in the week. As an example we might choose a comparison of Exercises E and H during Fall Quarter.

The author has used the very popular Boyle's and Charles' Laws activities before at least seven different quarters at the University; Exercise E or the Weights of Atoms is completely original and underwent revision, substitution and deletion on the basis of our experience as the week of laboratory presentation progressed. Its low rating by students as compared with Exercise H or the gas laws is not really very indicative of its value.

On the other hand, new and original laboratory materials were not always problems. Exercise C, The Motion of Heavenly Bodies, for example, was an instant success with students. The reader will find student evaluation of the individual lab exercises for all three academic quarters in Table 2.

4. A fourth reservation we must make about our evaluative data to read it more intelligently is that the appraisal of "affective" behavioral change must be indirect. It would take years to know if

TABLE 3

STUDENT EVALUATION OF INDIVIDUAL LABORATORY EXERCISES

At the end of each quarter as part of the laboratory rating sheet students were asked to rank the laboratory exercises individually in order of preference from 1 to 9 on the basis of both fun and learning. Scores were totaled for each exercise and are expressed as percents of the numerical total for all exercises. Since there were nine laboratory sessions in each quarter 100 percent divided by 9 or 11.11% would be a median rating. The smaller the percent the better the exercise in the opinion of students. The reader is cautioned against comparing ratings of exercises from different quarters because this is not a valid comparison.

Notice that Exercises R and V do not appear in order because they were presented in a different sequence during the trial academic year.

<u>FALL</u>		<u>%</u>	<u>Rank</u>
A	The Loaf of Raisin Bread	10.8	5
B	Energy Transformations	10.5	3
C	The Motion of Heavenly Bodies	10.1	1
D	Intensity and Distance	12.1	8
E	The Weights of Atoms	13.0	9
F	Measuring a Molecule	10.7	4
G	Conductivity, Solubility and Volatility	10.8	6
H	Boyle's and Charles' Laws	10.1	2
I	The Dynamic Nature of Chemical Systems	11.9	7
<u>WINTER</u>			
J	The Electron	10.6	4
K	The Geometry of Compounds	10.9	5
L	Maleic and Fumaric Acids	12.8	8
M	Hydrolysis and Condensation	10.3	3
N	Factors Affecting Enzyme Activity	11.6	7
O	Cells	7.8	1
P	Mitotic Time	11.1	6
Q	Respiration and Photosynthesis	9.2	2
U	The History of Life on Earth	15.7	9
<u>SPRING</u>			
S	The Question of Size	14.3	9
T	Color in Nature	12.3	7
R	The Fresh Water Algae	12.4	8
V	The Circulatory System	8.8	2
W	The White Rat	7.7	1
X	Campus Conifers	11.2	4
Y	The Evolution of the Flowers	12.2	6
Z	The Broad Leaf Trees and Shrubs	11.2	5
AA	Naming the Flowers	9.9	3

there were any lasting attitudinal changes that resulted from these fifty-four hours of laboratory if we relied on observable behaviors. We are forced then to make some guesses about this, the most important goal of a program for non-scientists. To the question about whether or not students will ever again involve themselves in naturalist pastimes for enjoyment, an observable behavioral evidence of an affective goal, we can only ask them if they might be more inclined now to do so. To one of the basic objectives of all laboratory activities and one of our main criteria i.e. having fun in science we are still reduced to a verbal and non-behavioral measure, the question, "Did you enjoy the labs?"

We will leave for the Appendix the long lists of cognitive laboratory objectives and their achievement levels to be examined as the reader is inclined. Cognitive goals, expressed behaviorally, are an integral part of the model but their achievement levels are not substantive here for evaluation of the model. They are important, certainly, but not the reason why we chose the model; why we are experimenting with it; and the thing that makes it unique.

We have developed earlier the theme that the "process approach" was an attempt to teach science in such a way that students behaved like scientists and in the several ways that scientists characteristically work. In doing so affective goals would be achieved--goals related to problem solving, skepticism, enjoyment, humanistic implications, etc.

In discussing the affective domain we can assume more validity perhaps since we are dealing with general impressions students have gotten rather than with the success of specific laboratory exercises in achieving specific cognitive objectives.

To the overriding issue of whether or not the laboratories were enjoyable the data prepared in Table 3 tells us what part of the total number of students enjoyed laboratory each quarter. It is noteworthy then on a separate questionnaire item given at the end of the year students agreed that Spring Quarter (biology) laboratories were most fun. The questionnaire item was stated as follows: "If you were in General 125 or 126 please compare the labs with Spring Quarter labs. Spring Quarter labs were:"

Better (76)

Same (9)

Worse (7)

Related to this preference for the biology labs, perhaps, is the fact that physical and mathematical abstraction seemed to be the reason why those who disliked Fall and Winter Quarter labs disliked them. As an example, we separated the opinions during Fall Quarter of those who looked forward to lab and those who dreaded it and discovered that those 10% who disliked lab rated Boyle's and Charles' Laws, the Tracer Experiment, and the Inverse Square Law very low. They liked best the Motion of the Heavenly Bodies, The Loaf of Bread and Energy Transformation (labs with little mathematical involvement).

Those who enjoyed lab rated Boyle's Law first, Measurement of a Molecule second and the Tracer Experiment next. The Loaf of Bread

TABLE 4

STUDENT OPINION OF TIME SPENT IN LABORATORY

Students' general reaction to laboratory exercises, quarter by quarter, is tabulated. Response sheets were collected from the entire class, unsigned, at the time of each final examination. Different numbers of students were enrolled in different quarters as indicated. Exact phrasing of the question asked is reproduced as follows with percent response:

Fall Quarter (101 students)	Winter Quarter (115 students)	Spring Quarter (110 students)
--------------------------------------	--	--

Please mark the appropriate statement of your honest overall impression of the labs for this past quarter:

() a grim experience	10%	5%	1%
() a drag	13%	14%	6.5%
() a way to pass the time	5%	20%	8%
() enjoyable once you got there	59%	54%	65.5%
() something to look forward to	13%	7%	19%

and Energy Transformations ranked well down the list.

Perhaps there is no way to make chemistry as interesting in the laboratory as is biology for non-majors although those who stated they enjoyed lab or even looked forward to it in Fall Quarter, 72%, versus 84.5% in Spring is not too great a difference.

The fact that the biology labs were enjoyable to most was reflected in responses to another question related to affective behavior. The question was phrased as a criterion of whether or not students could be encouraged to continue an interest in and an affection for the organisms of their locale by observing, classifying and identifying them in laboratory and in the field.

To the question, "Would you now be more apt to observe, collect, photograph or identify local plants and animals?" almost 93 percent or 102 out of 110 replied that they would.

In their Taxonomy of Educational Objectives, Handbook II: Affective Domain, Krathwohl, Bloom and Masia discuss the phrasing of test items by which one may evaluate the achievement of such affective goals under several major headings.

Objectives which emphasize a feeling tone, an emotion or a degree of acceptance or rejection [are in the affective domain]...Affective objectives vary from simple attention to selected phenomena to complex but informally consistent qualities of character and conscience. We found a large number of such objectives in the literature expressed as

interests, attitudes, appreciations, values and emotional set or biases,¹

Our question on voluntary pursuit of further interest in plants would be an example of a "Satisfaction in Response" test item. So too would the question, "Do you think the sky is interesting enough on the basis of your laboratory exercise to warrant future reading and observation?" To this question posed at the end of Fall Quarter 95 percent of the total 102 students replied affirmatively.

Somewhat less apparent enthusiasm was registered to questions which the Taxonomy of Educational Objectives would call "Acceptance of a Value" objectives.

For example 11 of 102 students replied, "No" to the question, "Would you encourage students to choose careers in science?" and a disastrous 43 percent said they would not vote yes to have the United States adopt the metric system to replace feet, pounds, quarts, etc.

Whether this last item reflects unfavorably on those exercises involving the processes of measuring, using space/time relationships and using numbers or on methods of lecture and laboratory presentation during the first trial year can only be resolved during additional trials.

¹David R. Krathwohl, Benjamin S. Bloom, Bertram B. Masia, Taxonomy of Educational Objectives, Handbook II: Affective Domain (New York: David McKay Company Inc., 1956), p. 7.

While not an affective but a cognitive objective we can, nevertheless, enter here the fact that as a result of discussions the "processes of science" in laboratory sessions 69 percent of students on the spring final examination could list at least ten of the thirteen "processes of science."

Most autumn quarter students were willing to agree with a statement phrased by the author to try to capture the spirit of experimentation after completing Exercise F, Measuring a Molecule, as follows: "Some science experiments are like a good detective story." Response was 90 percent affirmative.

After the laboratory session on mitotic time we attempted to measure the extent to which students began to suspect books as not being necessarily a final authority but also subject to experimental validation. We asked the question "Do you take it for granted your textbook is correct?" Eighty-seven percent said "No."

With these verbal responses we have tried to predict what behavioral changes of attitudes, enthusiasms and understandings may have resulted from our project exercises. There is some evidence that students had a good time generally in laboratory work, that they were intrigued with some experiments, made more skeptical of books by others, and became disenchanted with the metric system by others. Most seemed to develop some sense of the aesthetic aspects of science particularly in astronomy and biology.

The author has a feeling of satisfaction about this writing effort, Part Two, and the use of the materials with students this past year. We have created some new laboratory exercises and tailored others to a new model which we find completely elegant and suitable for this university purpose.

We doubt we can convince anyone of transcendent worth for the model statistically not only because we could not count on a true experimental situation as would be true of national curriculum projects but because the whole idea of measuring behavioral affective goals is only now being considered by the experts in science teaching.

This past February there were conferences scheduled for San Francisco State College on the very topic of "Establishing Behavioral Goals for Scientific Literacy" and sponsored by the National Science Teachers Association. The author had been invited and had hoped to review methods of measuring affective behaviors with those on the "frontier" but in personal correspondence with the organizer, Dr. Albert F. Eiss of National Science Teachers Association, we learned the conferences had to be cancelled due to "student unrest" and will be rescheduled for October 1969.

If our evaluative efforts seem a bit awkward they are at least a beginning.

PART TWO

LABORATORY EXERCISES IN SCIENCE FOR NON-SCIENCE MAJORS

INCORPORATING THE "PROCESS APPROACH"

MEASURING 1

A

A LOAF OF RAISIN BREAD

OBJECTIVES

As a result of this exercise a student should be able to:

1. DESCRIBE the advantages of the metric system.
2. DISTINGUISH between mass and weight.
3. STATE A RULE for decimal place change in metric conversions.
4. USE metric linear units to calculate metric volumes.
5. CONSTRUCT a plan to determine volume of raisins by difference in water level.
6. COMPARE the density of two materials.
7. INTERPRET data from a sample in terms of the whole.
8. DESCRIBE the use of a balance in weighing.
9. USE the metric system in the future more readily. (Affective)

RATIONALE

Many beginning college students have not used the metric system before. In science the system is basic. The AAAS Program uses it exclusively. Students should be exposed to its advantages so that they can appreciate its ease of use. They can do this first in a more "unthreatened" context by using familiar materials and by doing calculations which answer commonplace questions. Each group will be asked to do at least three calculations in metric units requiring conversions. These calculations will require 1) volume determinations

from linear units, 2) use of mass units to determine density, and 3) use of a sample to determine the measurements of the whole.

VOCABULARY

cgs system.

mass and weight

specific gravity

MATERIALS

Sliced loaves of raisin bread

Triple beam balances

Meter sticks calibrated to mm.

Hot plate and wire gauze

Two objects of equal size and different density

Small beakers of water

10 cc Graduated cylinder.

Projectual with metric prefixes.

Decimeter cube lined in square cms.

INSTRUCTIONAL PROCEDURE

1. No lab sheet need be distributed in advance.

2. Ask about English units and their conversion to other

English units.

3. Ask about conversions if units were in multiples of ten.

4. Discuss metric system units and projectual of metric prefixes.

5. Ask dimensions of common objects in metric units.

6. Introduce mass unit and show by using balance how weight is used often as a measure of mass.

7. Introduce idea of density by posing problem of describing two objects of different densities. Relate cc. to ml.

8. Provide copies of question sheet below and ask students working in pairs to do at least one calculation in each box using metric units. Distribute a half loaf of raisin bread per pair of students and ask them to assume the other half matches exactly.

9. Gather class data on chalkboard as work progresses to detect misconceptions and need for help.

STUDENT WORK SHEET -- METRIC MEASUREMENT

Can you solve these bakery problems? Try at least one in each box.

What is the volume of the loaf of bread?

How many loaves can be put into a cubic meter space in the bakery truck?

What percent of raisin bread is just air?

How dense are raisins?

How much space will a kilogram of raisins occupy?

What is the specific gravity of the bread without the raisins?

How many raisins per loaf?

What percent moisture is present in the loaf?

How many loaves could I make from a kilogram of raisins?

OBSERVING 1

B

ENERGY TRANSFORMATIONS

OBJECTIVES

As a result of this exercise the student should be able to:

1. DISTINGUISH the various forms of energy.
2. DESCRIBE each form of energy.
3. GIVE examples of conversions of energy to other forms.
4. GIVE an example of the loss of useable energy that takes place during energy conversions.

RATIONALE

The concept of energy is so abstract that in a beginning course it seems good to provide students with an experience that might help them to visualize the forms energy may take using as many simple physical devices as possible. This early in the year no effort is made to provide quantitative studies of energy relationships but, since energy phenomena must have a place in astronomy, physics, chemistry and biology, it is often discussed in general terms this early in the sequence.

VOCABULARY

kinetic and potential energy,

electromagnetism

the electromagnetic spectrum

MATERIALS

The selection of materials and devices for use in this laboratory period can be supplemented or substituted at the discretion of the instructor and is contingent on the availability of equipment in one's own laboratory. The following are those used with good results by the author:

A radioscope

A model of Hero's engine made from a Florence flask and suspended by nylon filament

Iron filings, "Little Six" battery, insulated wire and large iron nail for students to use in making an electromagnet

A "Superball"

Two large glass containers, e.g. 2000 ml beakers

Dropper bottle of crystal violet stain or India ink

A model electric motor (St. Louis motor)

A hand cranked dynamo

An apparatus for electrolysis of water

An acetylene rocket

A radioactivity monitoring device or scaler

A flashlight

A light source, prism and white cardboard screen

Springs of elodea in water in a large test tube inverted in a container of water

Bright light source for illuminating elodea

Pulse glass

Brownian movement apparatus and microscope

INSTRUCTIONAL PROCEDURE:

Materials should be set up as a number of individual demonstrations at stations throughout the laboratory among which students may circulate during the laboratory period.

At some stations written directions for operation must be supplied as in the case of the acetylene rocket, the pulse glass, the electromagnet, etc.

In other instances a set of helpful questions to facilitate observation and explanation should be provided as in the case of the model electric motor.

It is assumed that previous discussion of the forms of energy (chemical, electrical, radiant, etc.) has taken place during lecture.

Perhaps the superball is the best single example of a loss of energy as its height of bounce continues to decrease after each collision with the floor. The superball's collisions might be contrasted with the elastic collisions that cause the Brownian movement phenomenon at the molecular level. The identity of heat and molecular motion can be developed too, from the demonstration of the rate of dispersion of drops of crystal violet in water of different temperatures (20-80°C. work well).

In the case of elodea the conversion of radiant to chemical energy must be inferred from observations of bubbles of oxygen gas being released in the inverted test tube.

Observation of the electromagnet should precede observation

of the electric motor.

The role of the instructor should be that of discussion leader late in the period to review each demonstration and to discuss the forms of energy involved in each conversion.

USING SPACE/TIME RELATIONSHIPS 1

C

THE MOTION OF HEAVENLY BODIES

OBJECTIVES

As a result of this exercise the student should be able to:

1. DESCRIBE evidence of the earth's rotation; of the tilt in the earth's axis from the plane of the ecliptic and of the spheroidal shape of earth based on the idea of latitude.
2. ESTIMATE distances by proportionality.
3. READ about astronomy with more interest. (Affective)

RATIONALE

The roots of science are intimately involved in astronomy. Even a beginner with little equipment can perform some interesting calculations which verify some of our basic beliefs about the motions of the solar system. In doing so the student can repeat some of the calculations of the ancients as they speculated about the heavenly bodies.

VOCABULARY

fixed stars

earth's axis

sextant

solstice and equinox

MATERIALS

The following must be available for activities 1 and 2 in lab:

Clear protractors.

Meter sticks

Dissecting scope or (better) a comparator

Star trail photographs

Copies of two aerial photos of the same terrain taken at different heights

To complete activities 3, 4 and 5 on their own students will need to locate the following:

A roll of tape

Protractor

String and bob

INSTRUCTIONAL PROCEDURE

Much of this laboratory (activities 3, 4, and 5) is done by students individually outside scheduled meeting time over a period of a month. The instructor collects the calculations from this laboratory and Exercise "F" on the same Friday. Two of the activities involve measurements to be made at night. The moon measurement requires that the moon be close to full phase.

The formal laboratory meeting can be quite brief and used only to clarify purposes and procedures and to suggest that activities 1 and 2 might be begun immediately as follows:

Activity 1 -- Have students examine and speculate about some negatives or prints of star trails made by a time exposure of the Northern Sky. (See illustration.) Have them try to explain what they see without saying what it is. Later ask them to find a way to calculate how long the camera lens was left open. Clear plastic protractors should be handy on lab desks.

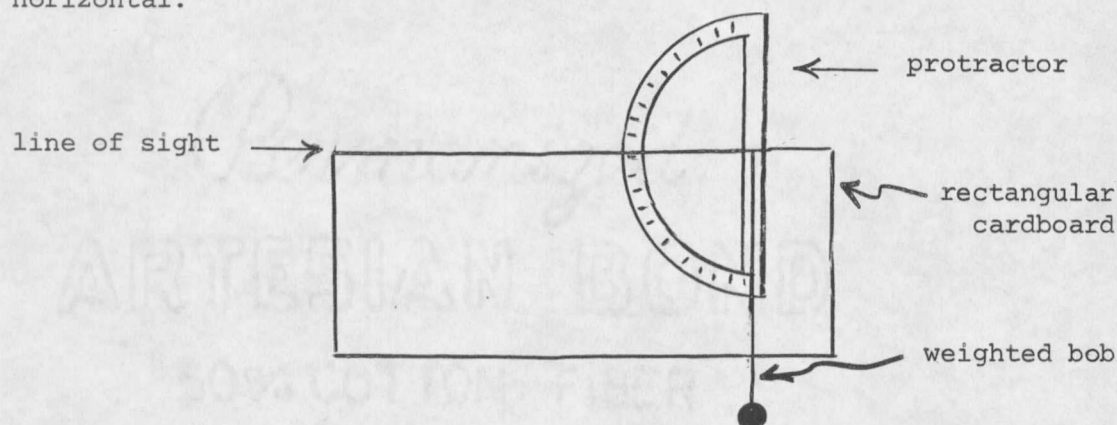
Activity 2 -- By proportionality a student can determine how far above the surface of earth he would no longer be able to see certain features by comparing the size of the object to the apparent size on a photo and the distance from the photo at which the same object can no longer be resolved. Such aerial photos as the ones used (illustrated) are available from the U.S. Department of the Army, U.S. Forest Service, U.S. Soil Conservation Service, etc.

The instructor merely suggests the true dimension of the feature, e.g., the bridge on the map illustrated is 9.25 meters in width, and asks for ways to use the map to tell how far in space we would be before we could no longer see it. In each lab group one student will usually come up with the comparison:

$$\frac{\text{map dimension of bridge}}{\text{true dimension of bridge}} = \frac{\text{maximum distance from map bridge is visible}}{\text{maximum distance from earth bridge is visible}}$$

The second map of different scale is used to verify the first estimate. The map dimension of the bridge or other feature is measured by using a comparator or by using a ruler, calibrated in millimeters, under a dissecting scope.

Activity 3 -- The latitude and the angle of Polaris in the Northern Hemisphere are the same. This idea can be discovered and used by students to locate their own town with respect to latitude. A circle on the chalkboard with parallel rays of light from the star can be used to demonstrate the principle using the North Pole and the Equator as the 0° and 90° extremes. The location of Polaris in the sky on line with the pointers of Ursa Major must be given. The following device is recommended to measure the angle of Polaris from the horizontal.

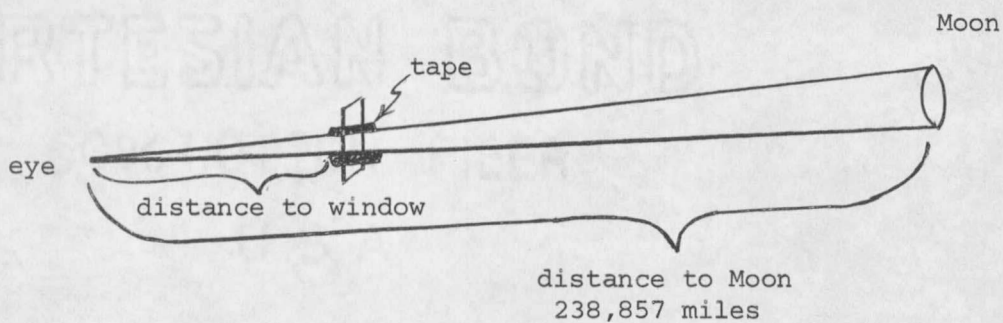


Activity 4 -- Using a styrofoam sphere pierced by a straight length of coat hanger wire as a model of the earth and its axis, show the counterclockwise revolution of the earth around a light source (the Sun). Ask about the different positions of the Sun at noon during the year as related to the tilt of 23.5° in the axis. During fall academic quarter the Sun will be at decreasing angles as the weeks progress and the earth approaches winter solstice. Using the apparatus from Exercise 3 students should each make one reading at noon

of the Sun's angle and record the day on a chart in the laboratory.
 (See below.) Over the month's time the decrease in the angle will
 be apparent.

Day	Oct. 6	Oct. 7	Oct. 8	Oct. 9	Oct. 10	etc.
Angle						

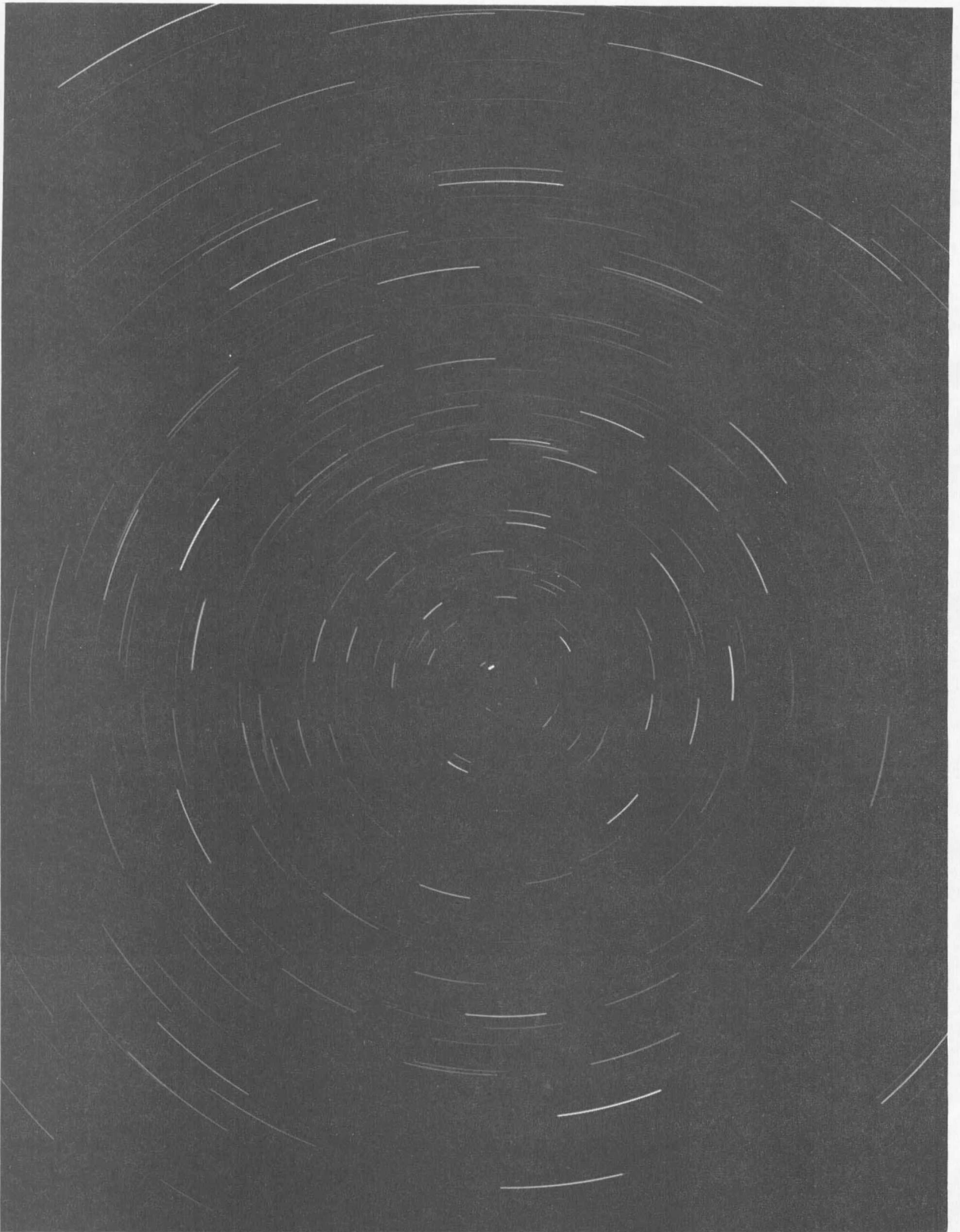
Activity 5 -- Show how, by using angles of observation from earth,
 it is possible to decide how large the moon is knowing its distance.
 Give the distance as 238,857 miles. Some students given the problem
 plus the data and materials (meter stick, tape, window) can see the
 relationship without being told. They will need to visualize them-
 selves looking at the moon in a south-facing window from a fixed
 point. A helper puts tape on the window at points which describe the
 apparent diameter of the moon on the window glass.



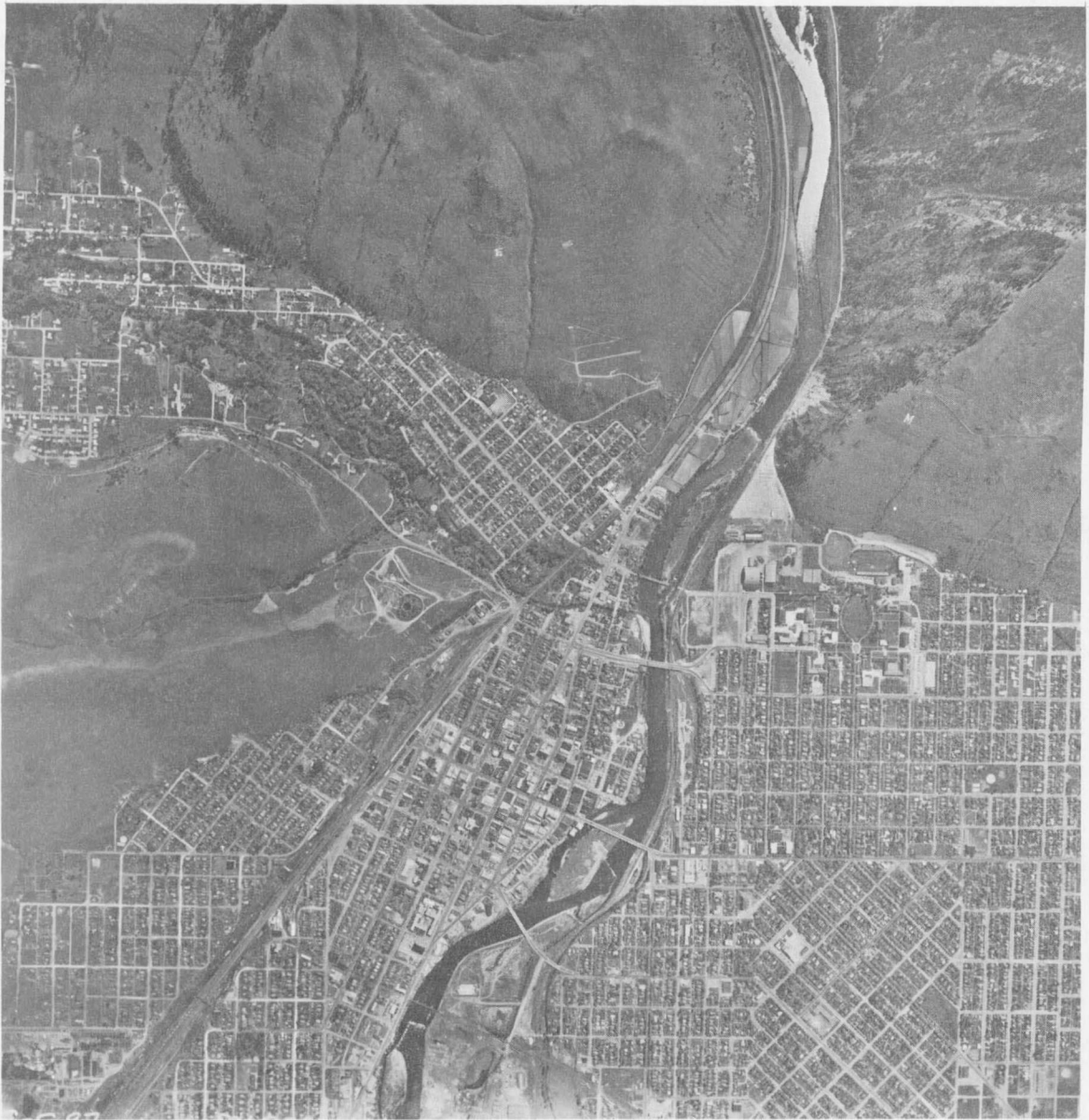
$$\frac{\text{diameter of Moon on window}}{\text{distance to window}} = \frac{\text{diameter of Moon (X)}}{\text{distance to Moon}}$$

STUDENT WORK SHEET -- ASTRONOMICAL OBSERVATIONS

1. Relate the period of earth's rotation to the apparent movement of the fixed stars in the photographs. How long was the camera shutter left open?
2. Estimate the distance in space at which the human eye can see a feature on earth by comparison with aerial photographs. Use the Van Buren Bridge.
3. By making a sextant and taking readings on Polaris, estimate the latitude of Missoula.
4. Measure the elevation of the Sun at noon some day during the following month. Add your data to that of other class members on the lab bulletin board and initial it. As the data is amassed what trend do you see? How do you explain it?
5. Estimate the diameter of the Moon knowing its distance to be 238,857 miles.



Star Trail Photographs



Aerial Photograph--Missoula



Aerial Photograph--Missoula

INTERPRETING DATA 1

D

INTENSITY AND DISTANCE

OBJECTIVES

As a result of this exercise a student should be able to:

1. STATE RULES which summarize simple relationships between two columns of figures.
2. CONSTRUCT mathematical expressions which express the relationships between two columns of numbers algebraically.
3. SUPPLY a number missing from the data by applying the rule.
4. IDENTIFY the mathematical relationship between distance from the radiation source and the intensity of radiation.
5. APPLY THE RULE to experimental data.
6. SUPPORT the importance of mathematical skills to progress in the physical sciences. (Affective)

RATIONALE

The inverse square law is one of the most fundamental equations in science expressing the "dilution factor" in gravitational and coulombic forces and in radiation intensity. By approaching the exercise as a game of supplying missing numbers in a series as is common in IQ examinations in testing an individual's ability to see relationships we hope to have students induce the inverse square relationship from idealized data. After they have stated the relationship in mathematical form we will identify the inverse square law data and suggest that the rule be tried in practice with new data gathered experimentally.

VOCABULARY

K , mathematical constant

$\propto$, proportionality sign

inverse relationships

MATERIALS

Ring stands with wide mouth clamps

Electrical cords and sockets for light bulbs, 115-volt with carbon filaments, 32 candlepower (Welsh 24444-33)

Meter sticks

Photometer

Inverse square law demonstration apparatus

INSTRUCTIONAL PROCEDURES

1. Distribute the prepared student work sheet which follows to each student and suggest that they work alone until finished or until 75 minutes have elapsed. The work sheet itself explains the problem of seeing relationships among numbers. Once the sheet is finished two sets of data are identified as data from a physical experiment on the inverse square law.

2. The instructor should go over each series of numbers asking for volunteers to tell what relationships they found. Ask what equation could be used to summarize each relationship between A and B.

3. Stress those equations in which a constant is included. Show the use of a constant in the relationship between the circumference and diameter of a circle where $\pi = K$. Introduce a direct and

inverse proportionality.

4. Emphasize that two of these series of numbers provided can be expressed as $B = K \cdot \frac{1}{A^2}$ which is the inverse square law $I = K \cdot \frac{1}{d^2}$ or $I \propto \frac{1}{d^2}$.

5. Show examples of the implications of this law as distance affects gravitational force, intensity of star light, the attraction of protons and electrons, etc., using the demonstration apparatus.

6. Suggest that using the materials provided on the lab desks, the rule can be tested using the equation.

7. To use the photometer as a measurement of candlepower received over varying distances the room will have to be darkened during readings as groups of students complete the experimental setup.

STUDENT WORK SHEET --- INTERPRETING DATA

Have you seen mental ability tests on which there appear series of numbers and you're asked to supply the missing numbers?

These series of numbers on such tests get more and more difficult to figure out as the relationships among the numbers get less and less obvious. Scientific laws are sometimes arrived at in this same way, by seeing relationships among numbers in experimental data and expressing the relationship mathematically.

See if you can supply the missing number in each of these series. After you supply the missing number then state the rule you have used in algebraic form.

For example:	A	B
	1	1
	2	4
	5	25
	6	
	9	81
	11	121

What's the missing number?

Yes, 36 is correct. The number under B is always the number under A times itself. Right?

How would you express this relationship mathematically as a rule?

Over.

Wouldn't it be $A^2 = B$?

And what about the following?

A	2	5	8	11	14	17
B	4	10	16		28	34

The missing number is 22 because $2A = B$.

Try the others on your own. Supply the missing number and the rule.

A	B
1	10
3	8
5	6
8	3
10	
12	-1

Rule: _____

A	B
$1/2$	2
$1/6$	6
$1/7$	
$1/8$	8
$1/12$	12
$1/15$	15

Rule: _____

A	B
1	4
$1\frac{1}{2}$	9
2	16
3	36
4	64
5	100
6	

Rule: _____

A	B
2	1
8	2
18	3
32	4
50	
72	6

Rule: _____

76

A B

1/10 100

1/5 25

1/4 16

1/3

1/2 4

1 1 Rule: _____

A B

1 63

2 60

3

4 48

5 39

6 28

8 0 Rule: _____

A B

17 2

15 0

12 -3

8 -7

3 -12

2

4 -11 Rule: _____

A B

1 1

1/4 2

1/9 3

1/16 4

1/64

1/100 10 Rule: _____

A B

1/10 200

1/8 128

1/6 72

1/5

1/3 18

1/2 8

1 2 Rule: _____

INFERRING 1

E

THE WEIGHTS OF ATOMS.

OBJECTIVES

As a result of this exercise the student should be able to:

1. INTERPRET the atomic weights of atoms given on the periodic table as a ratio of the mass of various atoms.
2. STATE THE RULE of definite composition by weight.
3. INTERPRET THE RULE as a statement of mass ratios of the constituent atoms which make up compounds.
4. GIVE AN EXAMPLE of compound formation, of compound analysis and of replacement reactions.
5. DESCRIBE the role of weight relationships in atomic theory.
6. READ about the alchemists and early chemists with enjoyment.
(Affective)

RATIONALE

A recurrent student question, year after year, when topics in chemistry are introduced is how scientists can weigh the various atoms when no one has ever seen an atom. Through experiments which relate the weights of the different atoms to each other in compounds we can demonstrate to students that it is possible to draw inferences about things we cannot observe.

During this laboratory period the relative weights of the elements in various binary compounds are determined to compare the weights of atoms of the elements. Hydrogen is used as a basis for comparisons with atoms of oxygen, calcium, magnesium and zinc successively.

VOCABULARY

element
binary compound
formula
electrolysis
periodic table
atomic weight
acid

MATERIALS

A periodic table to be used only after the exercise is complete
An apparatus for electrolysis of water with graduations for measuring gas volume
A 6-volt battery
30% hydrogen peroxide solution
Crucibles (approximately #1 Coors in size) or evaporating dishes (approximately #000 Coors in size)
50 ml burettes with ground glass stopcocks
Calcium metal flakes
Balances accurate to the centigram
One-hole rubber stoppers to fit burettes
Magnesium ribbon
Mossy zinc in pieces which can be inserted in burettes
6 Molar HCl
Burners, ring stands and clay triangles for crucibles
Data sheet on water electrolysis (see INSTRUCTIONAL PROCEDURE)

INSTRUCTIONAL PROCEDURE

1. Students are asked to supply the chemical formula for water, H_2O . They are asked the meaning of the small 2 in the formula. They are invited to observe the active electrolysis of water and to consider the following sample data which shows the ratio of the weights of the gases that result from the electrolysis of water.

*DATA SHEET -- ACTIVITY 1

Weight of Hydrogen		Weight of Oxygen
.0042 g	1st Trial	.0336 g
.0055 g	2nd Trial	.0440 g
.0027 g	3rd Trial	.0216 g

2. Allow students to consider what they have seen and decide how the two atoms compare in weight. They should, from H_2 and O_2 volumes, infer support for a later discussion of Avogadro's Hypothesis in lecture. They see evidence that twice as much hydrogen volume results from the fact that water has two hydrogen atoms per molecule. The weight ratios of 8:1 must then be modified since there are two H atoms for each O atom.

Activities 2 and 3 which follow should be done simultaneously by a pair of students each working on one of the two. The students then pool results of their findings to decide about the weights of the atoms investigated. Paragraphs with asterisks can be included in a student work sheet.

ACTIVITY 2

*The student should weigh out a few turnings of calcium metal (about $\frac{1}{2}$ gram) after first washing off the oil in which it may be stored by rinsing in a test tube first with 10 ml benzene and then with 10 ml of acetone. The weighed calcium is then placed in a clean evaporating dish or crucible. Weigh the dish with the calcium in it. Record weights. From a burette allow 30% hydrogen peroxide to drop slowly, one drop at a time, on the calcium in the crucible. Bubbling over or spattering during the reaction must be avoided by regulating the flow of peroxide. The calcium will be completely oxidized and disappear after 10 or 15 ml of peroxide are added. Gently drive off the water and, when the product is dry, heat intensely for 5 minutes. Allow the crucible to glow red with heat. Our dry product is the compound of calcium and oxygen atoms called calcium oxide. Weigh the crucible when cool.

The instructor, circulating about the lab should ask what the change in weight is due to. Since he has a comparative weight for calcium and oxygen, he should be able to compare both with hydrogen.

For ACTIVITY 2 the instructor should have the 30% peroxide already in the burettes when lab begins because filling a burette with this chemical could be dangerous for beginning science students.

ACTIVITY 3

If divalent metals of high activity are used, their comparative weights can be inferred from the weights of each which will replace

equal volumes of hydrogen. Magnesium and zinc work well for this but calcium whose comparative weight has already been inferred in ACTIVITY 2 gives a mixed product in a water solution of HCl. The theoretical weights of Mg, Ca and Zn, 24.3, 40, and 65.3 respectively can be approximated if idealized data for calcium is supplied for the experiment.

*The student should weigh out about 2 feet of magnesium ribbon and about one gram piece of mossy zinc. In turn each is reacted in a 50 ml burette stoppered with a one hole rubber stopper with the mouth of the burette submerged in a 800 ml beaker of water. Six molar hydrochloric acid is put in the burette first (to burette length of acid in the case of Mg; $\frac{1}{2}$ burette length in the case of zinc). Water is added to fill the burette before it is stoppered and inverted. The density of the acid carries it down to begin the reaction when the burette is inverted. Each reaction stops itself when the burette is filled with hydrogen. The remaining metal (Mg and Zn) pieces are then dried with acetone and weighed again and the difference in weight noted.

The instructor must supply a proportional weight of calcium based on the size of his burette which would theoretically react to release a similar volume of hydrogen. Knowing the comparative weights of calcium to hydrogen and oxygen from ACTIVITY 2, the comparative weights of Mg and Zn can be inferred.

The periodic table is then examined to evaluate the experimental conclusions.

USING NUMBERS 1

F

MEASURING A MOLECULE

OBJECTIVES

As a result of this exercise the student should be able to:

1. USE the concept of solution concentration.
2. DESCRIBE the behavior of stearic acid at the interface of the polar and non-polar solvent.
3. ENJOY imaginative experimentation. (Affective)

RATIONALE

The indirect measuring of a molecule which forms a monomolecular layer not only illustrates ideas of solubility and concentration which may be used in lecture but the experiment itself is an elegant piece of detective work which involves only simple mathematics and can be accomplished by beginning students.

VOCABULARY

fatty acid

hydrophilic

MATERIALS

800 ml beakers and 250 ml beakers

Dishwashing detergent

Droppers

Burners

Forceps

Acetone bath for cleaning droppers

Centimeter rulers

Solution of stearic acid in benzene of known concentration
(.12 g/liter works well)

INSTRUCTIONAL PROCEDURE

1. Because of a later laboratory exercise dealing with solubility it would be well to introduce the orientation of stearic acid on water in only the most general way with no discussion of bond types.

2. After describing the monomolecular layer which can be formed on the surface of the water within the beaker, ask what its geometrical shape would be. A circle cut from paper is a good visual aid. To the response, "a circle," ask if it doesn't have some thickness as well. How thick? A molecule length thick. What would its shape be if it had thickness? A cylinder.

3. Introduce the equation for the volume of a cylinder $V = \pi r^2 h$ but let the students supply the equation. Suggest we solve the equation for h if we can find values for V , π and r . Why? Because if we solve for h we have the length of the molecule.

4. If we know, r we can measure with the centimeter rules and we can get a value for V by knowing how much stearic acid we placed on the surface of the water and the fact that stearic acid has a density of .85 g/cm³. $\left(\frac{\text{grams of stearic acid}}{.85 \text{ g/cm}^3} = \text{Volume in cm}^3 \right)$

5. Give students the following work sheet and show them as a group how to draw out a glass dropper to a fine tip in a burner flame.

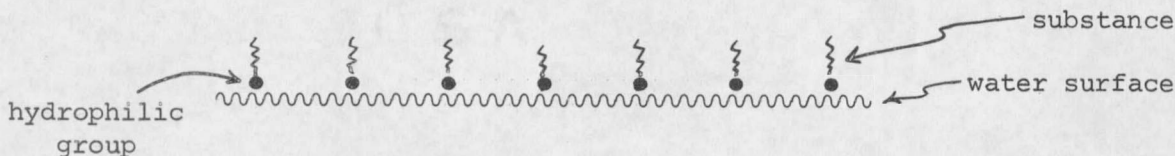
6. Only two of the first nine lab sessions require written student reports. This is one of the two. Reports have been collected by the author after one week or simultaneously with reports from lab session B, THE MOTION OF HEAVENLY BODIES.

7. The following student work sheet should be distributed for study during lecture in advance of laboratory.

STUDENT WORK SHEET -- DETERMINATION OF MOLECULAR DIMENSIONS

In this experiment a substance insoluble in water and less dense than water will be added to a water surface until a monomolecular layer (a layer one molecule thick) has formed over the water surface. From the weight of substance required and the density of the substance the volume required can be calculated. Since the area of the water surface is known the thickness of the monomolecular layer can be calculated.

The substance used has a chain-like molecule with a hydrophilic (water-liking) group of atoms at one end of the molecule. This group is attracted to the water molecules of the water surface, and crowding of the molecules as more substance is added causes the molecules to



align themselves vertically, as shown schematically above. Thus, the thickness of the monomolecular layer is the length of the molecule.

Since the amount of substance required for a monomolecular layer is very small, the most practical method of measuring the amount used is to use a solution containing a known concentration (known amount per ml) and to measure the volume of the solution used. Benzene is insoluble in water and quite volatile. As a result, it evaporates from the surface almost as fast as it is added and does not affect the result.

Unusual cleanliness is required for good results in this experiment. Traces of grease will also coat the water surface and yield bad data. The cleanser used to remove grease from the equipment must itself be removed, as soaps and detergents are "surface-active agents," concentrating at water surfaces. If you encounter persistent trouble with your beaker, get a new beaker from the instructor.

A. Preparation and calibration of capillary dropper

To measure accurately the small volumes that must be measured in this experiment you must use a calibrated capillary dropper. Draw out a dropper to a fine tip as shown by the instructor.

flange



When the glass has cooled calibrate the dropper so you know the size drop of benzene it delivers. To do this, draw into the dropper some benzene and slowly squeeze the bulb to force out drops of benzene. Allow the drops to fall into your 10 ml graduate, counting the number of drops required to deliver 1.0 ml of benzene. The dropper always should be held in the same position, vertical, and drops produced slowly. It may be necessary to refill the dropper in order to deliver 1 ml. The report sheet provides for listing any sub-totals. Repeat the calibration several times, refilling the dropper and counting the number of drops needed to carry the level in the graduate from 1.0 to 2.0 ml, then from 2.0 to 3.0 ml. For best results, 100 to 200 drops should be required per ml. DO NOT ALLOW BENZENE TO ENTER THE RUBBER BULB. To avoid this, do not invert the dropper nor lay the dropper down flat, which might permit benzene to run into the bulb.

B. Preparation of monomolecular layer

Carefully wash your 800 ml beaker and a smaller beaker with detergent, and rinse them thoroughly. Keep your hands out of the beakers while rinsing and until the run is completed. Fill the rinsed 800 ml beaker with cold tap water and set the beaker on a sheet of white paper at your desk. Using the other rinsed beaker, add more water until the 800 ml beaker is almost ready to overflow at the pourout.

Rinse your calibrated dropper a couple of times with your stearic acid solution. Then, add the solution a drop at a time to the surface of the water in the beaker. Hold the dropper vertically as for the calibration. Count the drops as you add them. Wait until each drop has disappeared before adding another. At first, each drop added will spread over the water surface. As the completion of a monomolecular layer is approached the spreading of each drop will become slower. After a monomolecular layer has formed, the next drop will not spread, but will instead form a globule of liquid. Do not include this drop in the number required to form a monomolecular layer. Do not let the solution enter the rubber bulb of the dropper.

Repeat the determination at least three more times. For each run, (1) wash and rinse the 800 ml beaker as carefully as for the first run, and (2) rinse the capillary dropper with a small amount of your solution. If your runs do not agree within two drops, additional runs should be made. The smaller beaker need not be rewashed for re-runs if it has only been used for clean water and your fingers have been kept out of it.

By laying your ruler across the top of the beaker and sighting down at the sides determine the diameter of the water surface.

The density of the substance is 0.85 g./ml. Following the calculation outline on the report sheet determine the length of the molecule in cm. The concentration of the solution will be announced.

C. Comments on the procedure.

1. We have verified by experiment that the capillary droppers deliver the same size drop of benzene as they deliver of the benzene solutions of the unknowns used.

2. The major sources of error in this experiment all come under the heading of lack of cleanliness. The following advice should be taken seriously:

a. The beaker must be well cleaned and rinsed.

b. Fingers must be kept out of the beaker and water used. In one of our experiments, touching the water surface with a well-washed finger tip, just for an instant added enough grease to cut in half the amount of solution needed to form a monolayer.

c. The benzene used for calibration and the solution must not enter the rubber bulb of the dropper. Either solution will dissolve material from the rubber bulb and create large errors. In one of our experiments, letting the unknown solution run into the rubber bulb for an instant cut the amount of solution needed for a monolayer to one-third of the proper amount. The dropper should never be inverted or laid flat. The best technique is to lay the dropper across the top of a fair-sized beaker, in such a way that the pourout of the beaker keeps the dropper from rolling and provides a slope that prevents the dropper contents from entering the rubber bulb. Supporting the dropper in this way also protects the tip of the dropper from breakage and contamination.

Name _____

Determination of Molecular Dimensions -- Report Sheet

Data:

Dropper calibration runs			
Number of capillary drops of benzene per milliliter	Trial 1		
	Trial 2		
	Trial 3		
	Trial 4		
Total/ml			
Concentration of solution (g. per ml of benzene solution)			
Diameter of water surface			cm
Number of capillary drops of solution required			

Calculations:

Average number of capillary drops per ml of benzene (from above)	
Volume of one capillary drop of benzene	
Average number of capillary drops of solution required to form monomolecular layer (from above)	
Volume of solution required to form monomolecular layer	
Mass of substance required to form monomolecular layer (g. contained in volume of solution used)	
Volume of substance required to form monomolecular layer (density of stearic acid gives us its volume per gram)	
Area of water surface	
Thickness of monomolecular layer	
Length of molecule	

FORMING HYPOTHESES 1

G

CONDUCTIVITY, SOLUBILITY AND VOLATILITY

OBJECTIVES

As a result of this exercise the student should be able to:

1. DEFINE conductivity and volatility and recognize soluble and insoluble combinations of chemicals.
2. CLASSIFY like and unlike chemicals with respect to these three characteristics.
3. STATE RULES which would help predict how chemicals, different from those used, would behave with respect to these three characteristics.
4. USE THE CONCEPT of electronegativity in predicting the characteristics of compounds.

RATIONALE

The kinds of chemical bonds that contribute to the structure of compounds determine the behavior of those compounds. Before or during a lecture sequence on chemical bonds it seems desirable to have students gather data, organize data and try to explain data on behavior of compounds rather than to simply verify rules provided by the instructor. In this lab students are encouraged to come up with theories derived from data to explain the behavior of about a dozen different compounds. A copy of the Pauling electronegativity numbers and three dimensional models of all the compounds are available.

VOCABULARY

electronegativity

polarity

MATERIALS

Sheet of electronegativities

Conductivity apparatus (a clear light bulb in a 110 volt circuit does nicely)

Small test tubes

Dropper bottles

Paper towels

Small quantities and styrofoam models of the following compounds: methanol, butanol, oleic acid, glacial acetic acid, propionic acid, hexane, paraffin, BaCl_2 , NaCl_2 , HCl in dilute solution, CCl_4 , water

INSTRUCTIONAL PROCEDURE

1. Students are encouraged to test the solubility of pairs of compounds in each other, particularly solubilities in water and hexane, and to collect data. They can dip electrodes into beakers containing the various liquids and into solutions of the acids and inorganic salts. By dropping drops of the various liquids on the paper towel they can gather data on comparative volatility.

2. They should classify the chemicals into groups on the basis of these three characteristics and try to find patterns emerging from their classifications by examining the molecular models.

3. The instructor should emphasize that science is a way of

predicting and that their rules should help to decide what the behavior of other different compounds would be.

4. The instructor should remember that any statement in keeping with the data should not be considered "wrong." A dozen different rules will be provided by students. Some are excellent and comprehensive. Some are of limited use and application but nonetheless true of the data and acceptable. Typical statements include the following examples:

"Chlorine atoms, when present, increase conductivity."

"Acids conduct."

"Carbon atoms seem to decrease conductivity."

"Lots of oxygen increases both solubility and conductivity."

"Water soluble chemicals are inclined to conduct."

"Like dissolves like."

"Great differences in electronegativity produces conductivity."

"Among compounds with similar structures large molecules are less volatile."

5. To summarize the instructor should use a few of the models as examples of charge distribution differences. Polar and non-polar molecules can be discussed as a way of explaining these phenomena.

STUDENT WORK SHEET -- ELECTRONEGATIVITIES OF THE ELEMENTS

F	4.0	Se	2.4	Ge	1.7	Ca	1.0
O	3.5	I	2.4	Sn	1.7	Li	1.0
Cl	3.0	H	2.1	Ti	1.6	Sr	1.0
N	3.0	Te	2.1	Zr	1.6	Ba	0.9
Br	2.8	P	2.1	Al	1.5	Na	0.9
S	2.5	As	2.0	Be	1.5	K	0.8
C	2.5	B	2.0	Sc	1.3	Rb	0.8
Si	2.5	Sb	1.8	Mg	1.2	Cs	0.7

King and Caldwell. COLLEGE CHEMISTRY. 4th. ed. New York:
American Book Co. pp. 126,

PREDICTING 1

H

BOYLE'S AND CHARLES' LAWS

OBJECTIVES

As a result of these laboratory exercises the student should be able to:

1. IDENTIFY correct algebraic statements of Boyle's and Charles' Laws.
2. CALCULATE new volumes of gas that result from non-simultaneous changes in pressure or temperature.
3. RELATE absolute zero, zero volume and absence of molecular motion.
4. CONVERT centigrade to absolute temperature.

RATIONALE

The value of any scientific theory is in its ability to predict what will happen in the future. There are comparatively few quantitative physical experiments which require very simple apparatus and yet produce data as close to theoretical as does this inexpensive Boyle's Law apparatus. The apparatus can be made by lab assistants for next to nothing in cost.

VOCABULARY

Celsius and Kelvin temperature

barometer

atmospheric pressure

MATERIALS

Transparencies for projection on Boyle's and Charles' Laws

A barometer for reading current atmospheric pressure in millimeters of mercury

Plastic rulers calibrated in millimeters

Ring stands and clamps

A source of cold water (a refrigerated drinking fountain does nicely)

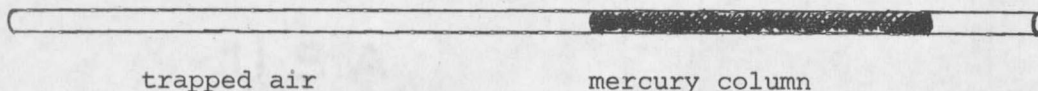
Centigrade thermometers

Rubber bands

Large test tubes

Burners

Boyle's Law apparatus (one per pair of students) -- this is a piece of tubing about 25 cm. long with a bore of about 1 mm. The tubing is sealed on one end and contains a column of mercury that traps a small amount of air. The mercury is inserted using a fine capillary dropper of the type used by students in determining the length of stearic acid molecules. As illustrated in the drawing below the air column and the mercury column should each be about 8 cm. in length. (See The Science Teacher, April 1967, pp. 67-68)



INSTRUCTIONAL PROCEDURE

If it has not already been accomplished in lecture it will be necessary to build up the idea of a gas exerting pressure and this pressure being measured in a certain length of mercury. Topics 1-4, below, pertain to such an introduction. Since the actual data

gathering in this exercise is not time-consuming one has a full hour to devote to introduction and it is time well spent in making the purpose and procedure clear to beginning students.

1. Review the experiments of Galileo and Torrecelli using water and mercury which destroyed the "nature abhors a vacuum" explanation for the rise of liquids in an evacuated tube (as in a drinking straw).

2. Show that air can, in fact, exert a force by collapsing an evacuated metal container.

3. Discuss the fact that at different depths (altitudes) in the "sea of air" the pressure changes as it does in water.

4. Relate such pressure changes to the rise and fall of mercury in a barometer so length of mercury column can be considered a measure of pressure. Demonstrate a mercury barometer of the simplest kind, a tube of mercury inverted in a dish of mercury.

5. Try to elicit from students the various pressures on the trapped air in the Boyle's Law apparatus when it is held in different positions.

6. Introduce first Boyle's Law and then Charles' Law by using a proportionality, e.g. $V \propto \frac{1}{P}$ before using the constant, $V = \frac{K}{P}$.

7. Show using an overhead projectual (Technifax 01704) that in several situations of pressure $VP = K$ and of temperature that $\frac{V}{T} = K$ (Technifax 01705).

8. Arrive at the working equations $V_2 = \frac{V_1 P_1}{P_2}$ and $V_2 = \frac{V_1 T_2}{T_1}$.

9. Discuss Celsius and Kelvin temperatures.

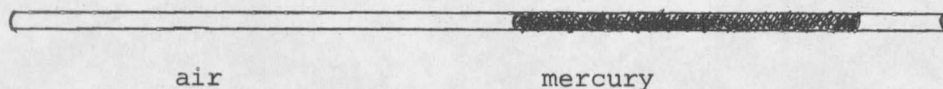
10. Distribute work sheet which follows to students to be turned in for grading at the instructor's convenience after at least one week has elapsed.

STUDENT WORK SHEET -- BOYLE'S AND CHARLES' LAWS

You are asked in this experiment to first measure the effect on the volume of a sample of gas due to changing its pressure or temperature and then to calculate the effect expected on the basis of the appropriate Law, and finally to compare those results to see if the Laws are valuable in predicting new volumes using the equations

$$V_2 = \frac{V_1 P_1}{T_2} \quad \text{and} \quad V_2 = \frac{V_1 T_2}{T_1}$$

The special apparatus for this experiment is a "gas law apparatus." The apparatus is a piece of tubing about 25 cm. long with a bore of about 1 mm. The tubing is sealed on one end and contains a column of mercury that traps a small amount of air. The apparatus you use must have a trapped air space at least 100 mm. long when the tube is held open end up.



When the tube is in a horizontal position the trapped air is at the atmospheric pressure prevailing at the time of the experiment. If the tube is held vertically, open end up, the trapped air is under a pressure equal to that of the atmosphere plus that due to the column of mercury in the tube. With the tube held open end down the trapped air is under a pressure equal to that of the atmosphere minus that due to the column of mercury. Since the tube has a constant cross-sectional area, it is not necessary to actually measure the volume of the trapped air as the volume is proportional to the length of the air space. You will have to handle the tubes carefully. Jarring them may cause the mercury column to separate or may spill the mercury.

Measure all lengths to the nearest mm. and all temperatures to the nearest °C. Tap the tube lightly before each reading is made.

A. Boyle's Law

Lay the tube in a horizontal position. Measure the length of the mercury column to the nearest mm. This value will be constant throughout the experiment. Record the barometer reading to the nearest mm. Measure the length of the trapped air space, first with the tube lying horizontal, then with the tube vertical, open end up, and finally with the tube vertical, open end down. Record the measurements of the

air space length to the nearest mm. In measuring the length of the air space, measure from the inside of the closed end to the nearest part of the mercury surface. Keep your hands away from the trapped air space to keep the trapped air at room temperature.

When you have done the above you will have measured the changes in volume accompanying the pressure changes brought about by placing the tube in the several positions. Now calculate the air space lengths that would be expected on the basis of Boyle's Law when the tube is held open end up and when it is held open end down, knowing the length when the tube is horizontal and knowing the changes in pressure accompanying the changes in position.

Compare the calculated length of the air space with the measured length by calculating the percent deviation of the calculated value from the measured length as follows:

The deviation of the calculated length from the measured length is equal to the calculated length minus the measured length.

The percent deviation of the calculated length from the measured length is equal to:

$$\frac{\text{the deviation}}{\text{measured length}} \times 100 .$$

For example, if the measured value is 64 mm. and the calculated length is 62 mm., the deviation is $62 - 64 = -2$.

$$\text{The percent deviation is: } \frac{-2}{64} \times 100 = -3\% .$$

B. Charles' Law

Mount your large test tube on the ring stand in a vertical position and fill it with cold water to within 3 cm. of its top. Attach the apparatus to your thermometer with the aid of rubber bands in such a way that the thermometer bulb is even with the center of the air space and the apparatus, with its open end up, lies along the stem of the thermometer. Mount the thermometer on a second ring stand in such a way that the attached gas law apparatus hangs within the test tube, reaching to about 1 cm. above the bottom of the test tube.

Stir the cold water for about a minute or until the temperature becomes constant. Measure the temperature of the water. Without removing the apparatus from the water measure the length of the air space to the nearest mm. as well as you can. Heat the water until the temperature reaches about 80°C. Stop heating, but continue to stir

the water until the temperature stops rising. Quickly, before the temperature starts to drop, measure and record the temperature and the length of the air space.

When you have done the above you will have measured the change in volume brought about by the change in temperature. Now calculate the volume (that is, the air space length) that would be expected at the higher temperature, knowing the length at the lower temperature and the change in temperature. Compare the two answers by calculating the percent derivation.

Determine also from your data the Centigrade temperature at which the volume of the trapped air would be zero, that is, the temperature at which the length of the air space would be zero if the length of the air volume is directly proportional to the temperature. You must assume in this calculation that you have never heard of the absolute temperature scale. (Suggestion: Calculate how much the temperature changed for each mm. change of length observed. Then calculate how much of a temperature change would be required to use up all the length of air at your lower temperature. The air length would then be zero this many degrees below your lower temperature.)

Name _____

STUDENT REPORT SHEET -- BOYLE'S AND CHARLES' LAWS

WARNING: Should your Boyle's Law apparatus break or release drops of mercury, call the instructor. Direct skin contact with mercury or breathing mercury vapors can be dangerous.

Boyle's Law:

Experimental data:

Atmospheric pressure	
Length of Mercury column	
Length of air space, tube horizontal	
Length of air space, tube vertical, open end up	
Length of air space, tube vertical, open end down	

Calculation outline:	Horizontal	Open end	
		up	down
Pressure on trapped air			
Measured length of air column			
Length of air column calculated by Boyle's Law from length in horizontal position and change in pressure			
Percent deviation of calculated length from measured length			

Charles' Law

Experimental data:

Initial (lower) temperature
Initial length of air space
Final (higher) temperature
Final length of air space

Calculation outline:

	Initial	Final
Temperature of trapped air, °A		
Measured length of air column		
Length of air column calculated by Charles' Law from initial length and temperature change		
Percent deviation of calculated length from measured length		
Centigrade temperature at which length of air column would be zero, based on the above data		

EXPERIMENTING 1

I

THE DYNAMIC NATURE OF CHEMICAL SYSTEMS

OBJECTIVES

As a result of this laboratory exercise students should be able to.

1. DEFINE an isotope and a radioisotope.
2. DEFINE half-life.
3. INTERPRET the role of a control in experimentation.
4. DESCRIBE dynamic equilibria.

RATIONALE

Even chemical systems that have achieved equilibrium are constantly changing. This principle is particularly important in visualizing the dynamics of living systems.

The exchange of iodide ions between solid AgI and dissolved I^- ions can be traced using the radioisotope I^{131} .

The theory behind the experiment is elementary enough to provide students with a chance to design for themselves an experiment requiring a control. This is in part what science is all about, i.e. planning an experiment rather than doing someone else's.

VOCABULARY

pipette	radioisotope
control	half-life
equilibrium	

MATERIALS

Centrifuge

Scaler

Carrier free I^{131} as soluble iodide

Gummed labels

Centrifuge tubes, corks and holders

$AgNO_3$ and NaI solutions (0.1 Molar)

Autopipette or fine droppers

Planchettes

INSTRUCTIONAL PROCEDURE

1. Demonstrate the $Ag^+ + I^- \longrightarrow AgI\downarrow$ reaction.
2. Centrifuge product and decant solution. Fill test tube containing the insoluble AgI product with distilled water. Discuss the infinitesimally small Ag^+I^- amounts in solution. ($K_{sp} = 10^{-16}$)
3. Pose the question as to static or dynamic nature of system.
4. Suggest that pairs of students work on a solution to the problem using the radioisotope, $(I^{131})^-$ as a tracer.
5. Discuss and demonstrate the activity of the isotope using the scaler.
6. Ask for written experimental designs to be ready in half hour. List materials available for use (above).
7. Discuss plans for the experiment with students. Stress the importance of controls. After discussion distribute the following

student work sheet. Compare the students' experimental design with instructor's.

8. If too few scalers are available for lab group, samples can be read more quickly with ratemeter.

STUDENT WORK SHEET -- A TRACER EXPERIMENT

A. Warning

The student must remember that radioisotopes can be dangerous if used carelessly. Please observe these simple rules and all will be well.

1. Don't touch, heat or splash any radioactive solution.
2. Except when actually using scaler, work over a pan or foil. Don't put hands near mouth.
3. Report all spills to instructor.
4. Have instructor examine hands with scaler before leaving.

B. Experiment

1. Mix in two separate test tubes each of prepared solutions of Na^+I^- and Ag^+NO_3^- . An excess of AgNO_3 produces a less turbid product. Centrifuge both and carefully pour off the solution on top. Wash the AgI precipitate with distilled water and decant the water.
2. Mark both test tubes and a third with the numbers 1, 2 and 3, respectively. Number 3 will be your control.
3. Now add 5 ml of distilled water to each tube and, USING THE AUTOPIPETTE, add 1 ml of the solution containing $(\text{I}^{131})^-$ solution. Cork all three tubes immediately, shake and place in test tube holder.
4. After 5 minutes centrifuge down tube #1, place in holder and do not disturb.
5. At 10 minute intervals shake tube #2 to keep the precipitated AgI agitated. Tube #3 need not be disturbed.
6. After 45 minutes centrifuge down tube #2 and remove 100 drops of clear solution from each tube to planchettes marked, #1, #2 and #3.
7. CAREFULLY WITHOUT SPILLING read each sample on the scaler for $\frac{1}{2}$ minute and subtract the background count.
8. Enter your data on the following chart and explain the results of your experiment.

Contents

#1

#2

#3

Number of
Times Agitated

Isotope added

at _____ o'clock

Final Centrifuge

at _____ o'clock

of drops
transferred
to planchette

Counts per
minute on
scaler

Background
counts per
minute

(I^{131}) count
per minute

9. Leave all experimental materials on your desk top. Don't clean up but see instructor to examine your hands with the counter before leaving.

DEFINING OPERATIONALLY 1

J

THE ELECTRON

OBJECTIVES

As a result of this exercise students should be able to:

1. GIVE EVIDENCE for the electrical nature of matter.
2. COMPARE the mass of an electron with that of an atomic nucleus.
3. DESCRIBE a method of determining the number of donable electrons possessed by metals.
4. DEMONSTRATE that atoms produce characteristic spectral emissions when excited.

RATIONALE

Perhaps even in an elementary course the particle versus wave character of the electron must be considered. If the Bohr atom and quantum mechanical models are discussed the periodic table and the three-dimensional orientation of organic molecules becomes more intelligible. This laboratory attempts to provide experimental evidence for much that will be discussed in lecture where contradictory evidence suggests that what an electron is is less important than what it does.

VOCABULARY

electrostatic charge

spectroscope

alpha and beta particles

outer electrons

MATERIALS

Bright light source with columnated beam (slide projector works well) for cloud chamber

A cloud chamber with both alpha and beta sources

Dry ice for cloud chamber

Cathode ray tube (deflection effect) and horseshoe magnet

Gas discharge tubes (H, He, Hg, Ne)

Tesla coil

Hand spectroscopes with diffraction grating

Magnesium ribbon and aluminum wire

Graduated cylinders or beakers

4 M and 2 M hydrochloric acid

250 ml Erlenmeyer flasks with one hole stoppers

Iron nails and dilute CuSO_4 solution

Electroscope

Pith ball suspended from nylon filament

Glass and rubber rods, silk cloth and fur

INSTRUCTIONAL PROCEDURE

Students are asked to observe and make sense of a series of demonstrations which follow. In each case the important characteristic of electrons involved and relevant procedural information are given.

1. A cloud chamber which is very dependable can be purchased cheaply from supply houses. If alcohol is not supplied duplicator fluid with black Tempera color dissolved in it for a non-reflective

background works well.

Students should alternate alpha and beta sources in the chamber and see the differences in the vapor tracks attributable to difference in mass and charge of electrons as opposed to helium nuclei.

2. By deflection with the magnet of an electron beam in the cathode ray tube the charged nature of the electron can be substantiated.

3. When static charges on the glass rod (rubbed with silk) and on the rubber rod (rubbed with fur) are applied to the pith balls and the electroscope, evidence of the repulsion of like charges and attraction between unlike charges are observed.

4. The plating out of copper metal and the loss of color of the solution when a nail is placed in copper sulfate solution gives evidence that some atoms attract and hold electrons more effectively than others. In discussion the students should be able to supply the idea that resultant copper atoms have taken electrons from iron atoms.

5. Using the hydrogen, helium, neon and mercury tubes illuminated by the tesla coil and passing light from each source through the hand spectroscope students can observe examples of bright line spectra.

6. This next exercise should be reserved until the other five are completed. It can be started at several different lab stations by several different groups of students.

While the aluminum is reacting slowly the other observations can be discussed at the end of the lab session and the data for this then collected and discussed.

Magnesium and aluminum have similar atomic weights but equal amounts of the two metals displace very different amounts of hydrogen from acids. The reason, of course, is that Mg is in group 2 and Al is in group 3. They will have different equivalent weights. Their equivalence can be gauged by the amount of hydrogen released by the same fraction of a mole of each. Use about 10 inches of Mg ribbon in 2 Molar HCl and a like weight of Al wire in 4 Molar HCl. The reactions should be conducted in 250 ml Erlenmeyer flasks with one-hole rubber stoppers and delivery tubing. Capture the hydrogen in graduated glassware inverted in water by displacement of water. Eight hundred milliliter graduated beakers do nicely. The aluminum reaction will begin slowly but will become vigorous after the thin oxide coating is penetrated. Good quantitative results relating the volumes of hydrogen to the 2:3 electron ratio can be obtained.

FORMULATING MODELS 1

K

THE GEOMETRY OF COMPOUNDS

OBJECTIVES

As a result of this exercise students should be able to:

1. CONSTRUCT models of molecules and compounds in the correct ratio of atoms.
2. IDENTIFY the symmetry of those binary compounds and ions used.
3. GIVE REASONS based on electron repulsion for the symmetry of compounds and ions.
4. NAME some polar and non-polar compounds.
5. DRAW examples of coordination structures using electron dot notation.
6. CONSTRUCT three-dimensional models of balanced equations for some very simple reactions.

RATIONALE

Orbital theory makes it possible to understand the three-dimensional nature of molecules and crystals. This concept of molar geometry becomes very important later in biological systems.

Also, in a review of fundamental chemical ideas at the beginning of Winter Quarter, the electron shifting that characterizes chemical reactions is clarified with models.

It must be said that mere use of styrofoam balls in not, in itself, the scientific process of FORMULATING MODELS even though the product may be called a "model." We hope to have students visualize

abstract ideas by manipulating concrete representations. This, we believe, involves process thinking.

MATERIALS

Colored pipe cleaners cut into one inch lengths

An assortment of rough surface styrofoam spheres from 3/4" to 3" dyed according to some arbitrary but consistent color code and sized roughly in proportion to atomic radii of atoms to be considered (1 inch = 1 angstrom). One such code for color and size is as follows:

Hydrogen -- white (undyed) -- 3/4" spheres

Carbon, Boron or Silicon -- black -- 1 1/2" spheres

Nitrogen -- red -- 1 1/2" spheres

Oxygen -- blue -- 1 1/2" spheres

Chlorine -- yellow -- 2" spheres

Metal atoms -- green -- 3" spheres

"Tempera" water colors can be used in coloring styrofoam if a wetting agent such as dishwashing detergent is added to the color suspension. Rough surfaced spheres permit penetration by pipe cleaners.

A periodic table listing electronegativities

Student work sheet as included under INSTRUCTIONAL PROCEDURE below

INSTRUCTIONAL PROCEDURE

1. Students should work in pairs. They will use the work sheet that follows to first produce electron dot diagrams of compounds and reactions and secondly to symbolize these compounds and reactions in three-dimensions using styrofoam models.

2. The compounds and reactions should be taken one at a time with a model following each diagram. After each is discussed by the instructor the next diagram and model is attempted.

3. The instructor must circulate among students to ask questions and direct student thinking.

4. For discussion of bond angles see Sanderson's Teaching Chemistry with Models, Chapter 2.

5. This laboratory is based on extensive lecture discussion and no effort is made here to review these discussion topics extensively during laboratory sessions.

STUDENT WORK SHEET -- CHEMICAL MODELS

Purpose:

When we considered conductivity, solubility and volatility earlier we saw that models of chemicals are used to help understand their behavior.

This laboratory session will involve production of some chemical models by students. It is easier to predict what chemicals will do if we can visualize them in three-dimensions.

Procedure:

Before we can build models of compounds we must know how many atoms of each kind are involved. This involves the electrons of the outer cloud of each atom. Attached is a periodic table to help visualize the various electron arrangements. Begin by drawing electron dot diagrams for each compound or reaction before you build the model.

Once you have the diagram complete construct the model using the following color code. You will notice that the styrofoam balls are sized roughly proportionately to the atoms they represent so the models will be more realistic.

In deciding the angles for the bonds remember that electrons repel one another and will get as far as possible from one another because of their like charge.

After each diagram and model the instructor will stop for discussion before you proceed. Models under #7 are for use in discussion of bond types, polarity and physical properties.

Hydrogen -- white ball
Nitrogen -- red ball
Oxygen -- blue ball
Carbon, Boron, Silicon -- black ball
Chlorine -- yellow ball
Metal atoms -- green ball

Red pipe cleaners -- dominantly covalent bond
White pipe cleaners -- dominantly ionic bond
Green pipe cleaners -- a coordination bond

1. Beryllium fluoride

Electron dot diagrams

2. Carbon dioxide

3. Boron fluoride

4. Nitric acid

5. Ammonia

6. Silicen hydride

7. Do the following three before discussion:

Potassium chloride

Carbon hydride

Hydrogen chloride

8. The ClO_3^- and ClO_4^- radicals.

9. Nitrogen + hydrogen $\longrightarrow$ ammonia (balanced equation)

10. Ammonia + HCl $\longrightarrow$ ammonium chloride (balanced equation)

FORMULATING MODELS 2

L

MALEIC AND FUMARIC ACIDS

OBJECTIVES

As a result of this laboratory exercise the student should be able to:

1. DEFINE an isomer.
2. CONSTRUCT three-dimensional models of a typical cis-trans isomer.
3. NAME some ways in which isomers may differ chemically, physically or biologically from one another.

RATIONALE

As a demonstration of the possibilities for diversity in organic chemistry and as an example of the importance of spacial orientation in molecules these cis-trans isomers are interesting. A similar laboratory exercise was incorporated in the Chemical Education Materials Study (CHEMS) but the present author has altered it to a more inductive approach to the question of isomerism as opposed to a verification.

VOCABULARY

isomer:

cis-trans positions

carboxylic acids

MATERIALS

Distilled water

Solid fumaric and maleic acids

Capillary melting point tubes (1.0 to 1.5 mm. diameter, 6 cm. long)

-10 to 150°C. thermometers

Rubber circles cut from plastic lab tubing

Black, white and blue styrofoam spheres and pipe cleaners (Lab K).

Filter papers

Vegetable oil

Narrow range indicator paper (1.0-3.5)

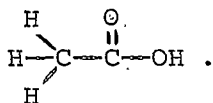
Magnesium ribbon

Sodium carbonate

Erlenmeyer flasks and 2 hole rubber stoppers

INSTRUCTIONAL PROCEDURE

1. The instructor will explain that formulas for carbon compounds are written several different ways. Acetic acid might be used as an example where we may see it written alternatively as $\text{HC}_2\text{H}_3\text{O}_2$ or CH_3COOH or structurally



2. Students are given two samples marked #1 and #2 (#1 is maleic acid; #2 is fumaric acid). They are told to use the student work sheet which follows for comparing the properties of each. Students

are asked to keep accurate data.

3. Later, the formula for each is given on the chalk board as $\text{HOCH}_2\text{C} = \text{CH}_2\text{COOH}$ after differences in properties are discussed.

4. Styrofoam models used in Lab K are again used by students to determine if there can be two different structural forms with the same formula given above.

While not an essential part of the learning objectives of this lab, a discussion of the greater solubility, acidity and reactivity of maleic acid and its lower boiling point is presented in The Teacher's Guide, which accompanies the CHEM Study text.

STUDENT WORK SHEET -- COMPARISON OF TWO SAMPLES

- A. Compare the solubility of the two samples by placing 1.0 ± 0.1 g of each into separate 18 x 150 mm test tubes, properly labeled. Add 10 ml of distilled water to each and make a qualitative comparison of solubility.
- B. Compare the melting points of the acids as follows:
1. Obtain two capillary melting point tubes (1.0-1.5 mm diameter and 6-12 cm long). Make one tube shorter than the other by cutting off a centimeter or so. Seal one end of each tube in a burner flame. Place sample #1 in the shorter tube to identify it.
 2. Push the open end of the shorter capillary tube into some dry sample #1. Tap the closed end gently on the table so the solid packs down into the tube. Continue to do this until the depth of solid is one or two centimeters. Similarly fill the longer tube with a sample of dry sample #2.
 3. Attach the tubes to a -10 to 150°C . thermometer with a small rubber circle cut from the end of a piece of rubber tubing. The liquid in the flask is vegetable oil.
 4. Clamp the melting point apparatus in place and heat it gradually with a low burner flame. Move the flame occasionally to achieve more uniform heating of the oil bath. Heat slowly and watch the capillary tubes closely as the temperature approaches 120°C . At the sign of first melting of either solid record the temperature. CAUTION: Do not exceed the 150°C limit of the thermometer. The melting point of the other sample is 287°C .

- C. Compare the chemical properties of the two isomers as follows:

Prepare a solution of sample #1 by adding approximately 0.1 g to about 20 ml of distilled water. Divide the solution among three small test tubes. Estimate the hydrogen ion concentration by testing one portion with indicator paper. To another portion add a 3 cm strip of magnesium ribbon. Record the results. To another portion add a small amount (size of a pea) of sodium carbonate. Record results.

Repeat the above tests, using sample #2. Record the results and compare them with those obtained with #1.

Results: Record all results in a systematic manner to show clearly the differences and similarities in properties of the two acids.

EXPERIMENTING 2

M

HYDROLYSIS AND CONDENSATION

OBJECTIVES

As a result of this exercise students should be able to:

1. STATE A GENERAL RULE for the rate of organic reactions as contrasted with reactions of more ionic compounds.
2. CONSTRUCT generalized formulas for organic acids, alcohols, esters, and aldehydes.
3. DEFINE a polymer.
4. GIVE AN EXAMPLE of an organic reaction which occurs through condensation or hydrolysis.

RATIONALE

In a survey of science only as much organic chemistry is appropriate, we feel, as is needed to show, first, the potential multiplicity of organic structures; secondly, the comparative sluggishness of organic reactions and, thirdly, the common functional groups which appear important in biological chemicals. The chemicals and reactions chosen for this laboratory session illustrate these ideas and offer the student an opportunity to recognize for himself the recurrence of condensation and hydrolysis reactions among functional groups.

VOCABULARY

organic acid

sugar

alcohol

polymer

ester	condensation
aldehyde	hydrolysis

MATERIALS

Ethyl alcohol
Concentrated sulfuric acid
Glacial acetic acid
Amyl alcohol
Methyl alcohol
Salicylic acid
Formic acid
Glass tubing
40 Percent formaldehyde solution
Saturated solution of aniline hydrochloride
Benedict's reagent
Pink litmus paper
Saturated sodium carbonate solution
One percent sucrose solution
Large and small test tubes
One hole stoppers for above
Ring stands and clamps
Large beakers (1000 ml)
Small beakers (250 ml)
Droppers

INSTRUCTIONAL PROCEDURE

1. Two student work sheets should be prepared for this laboratory session. On one, the various organic reactants listed under MATERIALS are given with their structural formulas. This sheet also contains information on experimental procedures and is appended.

2. The first sheet serves students as a review of the structures of alcohols, acid and aldehydes. It is distributed and discussed at the first part of the laboratory session. Two students work together on the syntheses.

3. The second sheet, which shows the names and structures of the products, is distributed only after the experimental work is complete. Ether, ester and polymer linkages are then discussed. The terms condensation and hydrolysis are not.

After the students have completed the laboratory activities outlined on work sheet number 1, the question is posed as to what these reactions all have in common. Students are asked to compare the structures of the reactants and of the products and find out. A half-hour should be allowed for students to consider what has been removed or added (water) in each reaction.

STUDENT WORK SHEET -- SOME ORGANIC REACTIONS

1. Preparation of an ether.

Pour 2 ml of ethanol into a dry test tube and add, a drop at a time, 2 ml of concentrated H_2SO_4 shaking it occasionally. Carefully heat the mixture with shaking. Stop heating when gas bubbles first appear (ethene). Pour the mixture into a small beaker containing 2 ml of ethyl alcohol (ethanol). Mix well and cautiously smell the contents. Can you detect the odor of ethyl ether (a hospital smell)?

ethanol is $\text{C}-\text{C}-\text{OH}$

2. Preparation of an ester.

Use a large test tube fitted with a one-hole rubber stopper in which is inserted (barely through the stopper) a two-foot length of glass tubing to serve as a condenser.

Place 5 ml of ethanol, 6 ml of glacial acetic acid, and 8-10 drops of concentrated H_2SO_4 into the container.

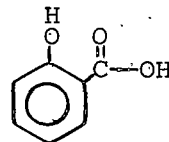
Do not heat the reaction mixture directly with a flame since the organic liquids and their vapors are flammable. Clamp the container in an upright position partially immersed in a 250 ml beaker about half full of water. Attach the stopper and condenser tube. Heat until the reaction mixture is gently boiling. Continue heating for about 15 minutes, allow to cool.

acetic acid is $\text{C}-\overset{\text{O}}{\parallel}\text{C}-\text{OH}$

Some groups of students may substitute amyl alcohol for ethanol. Amyl alcohol is



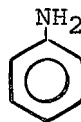
Others may use methanol with salicylic acid. $\text{C}-\text{OH} +$

3. Preparation of a polymer.

Simultaneously pour 20 ml of a saturated solution of aniline hydrochloride and 20 ml of methanal solution into a large expendable container. Stir with a glass rod.

Methanal is $\text{C}=\text{O}$

Aniline is

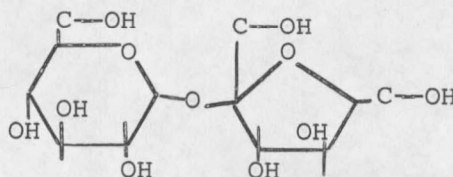


4. Inversion of a disaccharide.

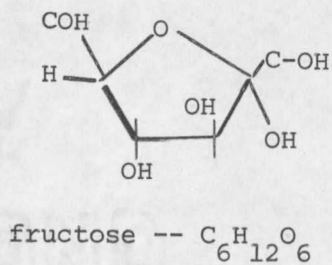
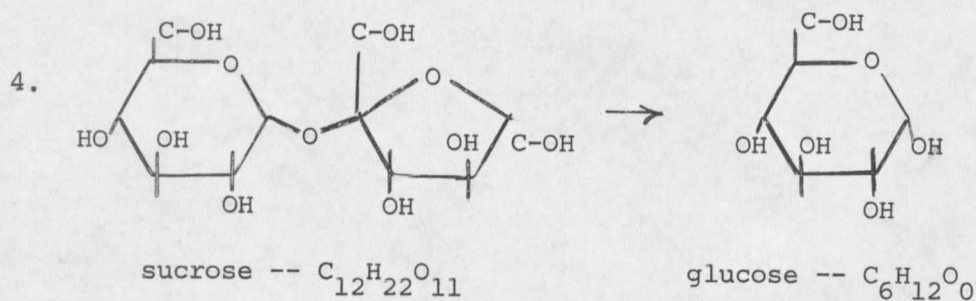
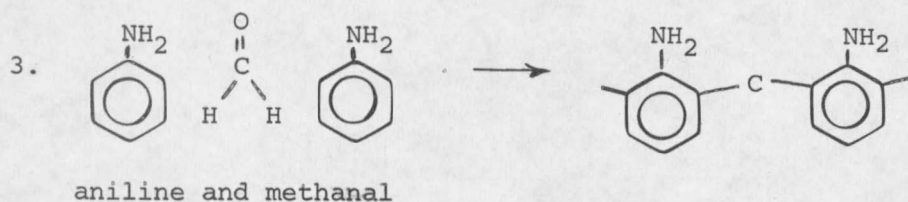
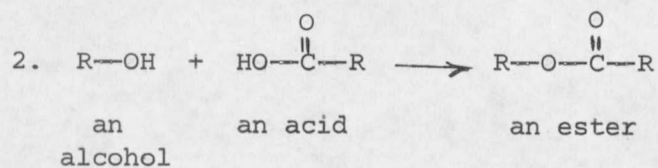
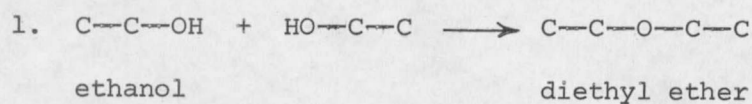
Heat 10 ml of a one percent sucrose solution and 20 drops of concentrated sulfuric acid in a test tube for ten minutes. Cool. Neutralize the acid with saturated Na_2CO_3 solution, using litmus as the indicator and perform Benedict's test as follows:

Add 20 drops of the sugar solution to 5 ml of Benedict's reagent and shake the tube. Place the tube in the boiling water bath and continue boiling for 3 minutes. A brick red color indicates that the monosaccharide glucose has been produced.

Sucrose is $\text{C}_{12}\text{H}_{22}\text{O}_{11}$ or



STUDENT WORK SHEET 2 -- REACTANTS AND PRODUCTS



CONTROLLING VARIABLES 1

N

FACTORS AFFECTING ENZYME ACTIVITY

OBJECTIVES

As a result of this laboratory exercise students should be able to:

1. DEFINE and GIVE AN EXAMPLE of an enzyme and a substrate.
2. NAME those conditions investigated which affect the rates of enzyme activity.
3. DESCRIBE the role of enzymes in biological systems.

RATIONALE

In this session we will attempt to convey through student observations some basic ideas about enzymes and their importance. The first activities demonstrate respectively, (1) the similarity between an inorganic catalyst and an enzyme, (2) the universal presence of enzymes in living materials and (3) the relationship of genetic differences to enzyme activity. The largest part of the time, however, is spent studying the effects of temperature, concentration and pH on the rate of activity of enzymes. Students are encouraged to construct experimental designs which test one variable at a time.

VOCABULARY

catalyst

enzyme

substrate

MATERIALS.

Wood splints

Thermometers

Sticks of chewing gum

Sterile blood lancets

Raw ground meat

Potato slices

Dry yeast

Test tubes, medium

125 ml Erlenmeyer flasks

Droppers

Dropper test plates

5 ml pipettes

3% Hydrogen peroxide solution in familiar drug store bottles
if possible

Aqueous solution of I_2 in KI

Seed packets of Little Marvel and Alaska garden peas.

Fresh suspensions of powdered peas of each of the above varieties
in water (10 g/ 100 ml).

Aqueous solution of glucose-1-phosphate (0.5 g/500 ml)

Dropper bottles of buffer solutions 5.0 and 8.0 made from
buffer tablets

A starch solution colored blue with iodine prepared most easily
as follows:

Spray only enough spray laundry starch from a pressure can to turn blue the amount of water (with a few drops of iodine added) which will be required to produce the amount of solution needed (see INSTRUCTIONAL PROCEDURE No. 4). Spray starch eliminates the need for boiling and produces, conveniently, a dilute starch solution which hydrolyzes completely very quickly.

INSTRUCTIONAL PROCEDURE

The first three activities listed below are completed first as an introduction to the nature of catalysts. The instructor discusses these three observations before beginning number 4 which requires most time and student effort.

1. Students are asked to work in pairs and to first add a pinch of MnO_2 to 5 ml of 3% H_2O_2 solution in a medium test tube. The gas produced is tested with a glowing splint.
2. Similar reactions are observed as the experiment is repeated using a small thin slice of fresh potato, a small fragment of ground meat, a few grains of dry yeast and a drop or two of student blood obtained by using a sterile lancet. From these first two activities some evidence is obtained to compare enzymes and catalysts to infer the presence of similar enzymes in diverse living things.
3. The fact that organisms which are very closely related may vary in enzyme chemistry is demonstrated in this third activity.

Students are instructed to take 2 ml of the clear water extract (previously prepared) from the powdered peas of each variety and, in separate test tubes, mix this with 5 ml of the glucose-1-phosphate solution. The tubes are shaken. Little Marvel peas contain a

dehydrogenase that converts glucose-1-phosphate to starch. Alaska peas cannot produce starch in this way since the dehydrogenase is lacking.

Over a period of 15 minutes, at 3 minute intervals, several drops from each of the test tubes (glucose-1-phosphate solution and pea extract) are tested on the test plate with a drop or two of iodine solution ($I_2 + KI$) to detect the synthesis of starch if and when it occurs.

4. The question of the factors which may govern the rates of enzyme activity might be introduced after activity No. 2 in which different materials decompose the peroxide at different rates. Often students suggest concentration as a reason for this difference but temperature and pH are also suggested as important. The amylase present in saliva combined with a starch solution with iodine added can be used to "clock" the rate of enzyme activity. Using in each "clocking" 60 ml of starch solution in a 125 ml graduated Erlenmeyer flask, the rate of reaction can be measured by waiting for the solution to become colorless while being swirled with saliva at varying conditions of concentration, pH and temperatures as follows:

STUDENT WORK SHEET -- EXPERIMENTS ON RATE OF AMYLASE ACTIVITY

Factor varied	Time	Factors controlled
1. Concentration	Blue to colorless at	Temperature con-
1 ml of saliva	_____ sec.	trolled at _____
2 ml saliva	_____ sec.	pH controlled at _____
2. pH		Concentration con-
5 ml of 5.0 buffer	_____ sec.	trolled at 2 ml
5 ml of 7.0 buffer	_____ sec.	saliva in 60 ml
5 ml of 8.0 buffer	_____ sec.	starch
3. Temperature		Temperature con-
room temperature	_____ sec.	trolled at room
_____ C°	_____ sec.	temperature
_____ C°	_____ sec.	pH controlled at
_____ C°	_____ sec.	Concentration con-
		trolled at
		2 ml saliva in
		60 ml starch
		solution

OBSERVING 1

O

CELLS

OBJECTIVES

As a result of this laboratory exercise students should be able to :

1. DISTINGUISH autotrophs and heterotrophs.
2. IDENTIFY in the microscope or in microphotographs cell walls, cell nuclei and chloroplasts.
3. ENJOY working with a microscope. (Affective)

RATIONALE

Students who have never used a good quality microscope before, thoroughly enjoy just looking at well chosen living or prepared material. Motivation to use the instrument effectively is high. Rather than to suggest some work with specific organisms we will just let students, during this session, sample the tremendous diversity of the microscopic world for fun. As much "do it yourself" material rather than prepared specimens and media are included as practical.

VOCABULARY

protista	nuclei
procaryotic cells	heterotrophs
eucaryotic cells	cyclosis
organelles	cell walls
chloroplasts	
autotrophs	

MATERIALS

Elodea sprigs in cool water in darkness

Yeast culture in sugar or molasses solution

Diverse protozoa and algae cultures

Euglena culture

Fresh onion

Toothpicks

Petri plates with 2.3% nutrient agar (disposable type)

Bacteriological loops

Methylene blue solution in dropper bottles

Methyl cellulose

Slides and cover slips

Droppers

A hot plate with water bath to keep agar in fluid condition

Two Erlenmeyer flasks, one with 2.3% nutrient agar and the other with 2.3% nutrient agar with streptomycin (10 micrograms/ml streptomycin sulfate).

Microscopes

INSTRUCTIONAL PROCEDURE

1. At least three days before the first laboratory section meets, the lecturer will distribute nutrient agar plates to each lecture student. The plates should be the disposable plastic type and the cover sealed with masking tape to facilitate carrying it in pocket or purse. The agar gel must be deep enough so that it will not dry out before lab.

A slip of paper is distributed to each student containing the following instructions:

Your Petri plate contains nutrient agar, an excellent growth medium for many microbes. Three days before laboratory or sooner, open the Petri plate and inoculate the surface of the agar with bacteria. This can be done by merely leaving it open to the air for a few minutes, by touching it with one's finger, a door knob, a coin, etc. Replace the tape to seal the Petri plate shut and store it out of the sunlight and at room temperature. Store it with the large half of the plate on its back. Bring it to lab this next week.

2. When students meet for laboratory bringing with them cultures of bacteria, they are first introduced to the use of the microscope and preparation of wet and dry slides. In discussing the microscope an overhead transparency (Keuffel and Esser Biology Transparency #1) is a great help rather than trying to use the microscope itself as a visual aid.

3. Instructor and students together each prepare a dry mount of epithelial cells from the mouth using a toothpick to scratch the inside of the face. The cells are heat fixed and stained with the methylene blue solution. The instructor must check to see that every student has seen the material successfully in the microscope.

4. The following worksheet is distributed by which students can proceed from simpler to more difficult material. The instructor

must circulate among students to help them use the microscopes correctly. Students are advised that to economize on lab time they should do the first part of Activity G first. They should finish pouring the agar slant shown in the diagram on the worksheet so it can cool while they are engaged in other activities.

STUDENT WORK SHEET -- MAKING SLIDES

A. Make a wet mount of a tiny bit of onion skin by placing a few drops of methylene blue stain on it. Lower cover slip. Examine under low and then high powers. Can you see the cell walls?

B. A small tender leaf of elodea, a water plant, is pressed in a wet mount next. As it warms up you should be able to see the cell contents, particularly the chloroplasts (the green spheres) moving about inside the cell.

C. Yeast cells are small and more difficult to see. Under high power you may be able to distinguish cells in the process of "budding" by which new individuals are generated. Make a wet mount of a drop of the yeast culture.

D. Somewhat more difficult to keep track of is the mobile Euglena, an animal-like plant or plant-like animal. Slow it down by mixing a drop of Euglena culture with a drop of methyl cellulose in a wet mount.

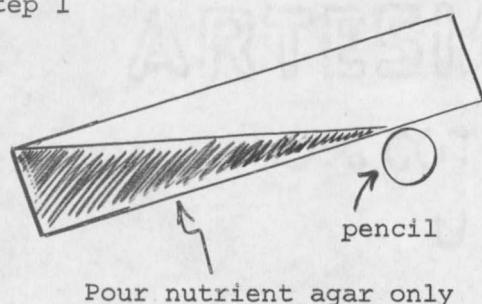
E. Now examine the organisms from other mixed protist cultures available. Do you have plants or animals or both?

F. Recall how, earlier, we made a dry mount of epithelial cells from inside our mouths and stained them. We will now try it with the bacteria we grew in our Petri plate cultures. Quickly, without leaving the plate open too long, gather a little of one of your colonies on the end of the bacteriological loop and smear it on a clean slide. Heat fix over the burner and add a drop of two of methylene blue to flood the area on which you have smeared the bacteria, wait one minute, then rinse the slide with a few droppers full of water. Gently blot with a paper towel. Examine the slide at once under high power and oil immersion. Is it a rod, sphere or coil shaped bacterium?

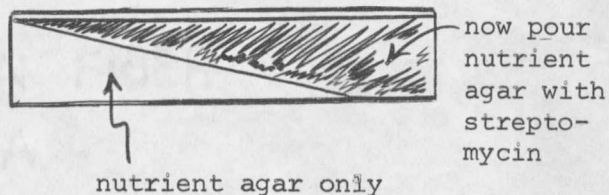
G. You may want to find out how resistant your bacterium is to the antibiotic streptomycin.

Prepare your own agar plate containing an antibiotic concentration gradient by the following procedure: Draw an arrow on the bottom of the dish to indicate the eventual gradient of increasing antibiotic concentration (see diagram). Prop up the end of the dish toward which the arrow points with a pencil and pour enough melted nutrient agar from the deep into the dish so that the agar at the lower end does not come any closer than $\frac{1}{2}$ cm. from the top. Cover the dish

Step 1



Step 2



and let the agar harden. Then place the plate in a horizontal position and add a volume of agar containing streptomycin, equal to that already in the dish. When cool the agar should establish by diffusion a gradient of streptomycin in the dish so that we can test the resistance of our bacterium.

Innoculate the plate by using a sterilized loop of bacteria and spreading gently back and fourth on the surface a dozen or more strokes parallel with the arrow. The instructor will demonstrate this "streak plate" technique.

We will examine these plates next lab session.

INFERRING 2

P

MITOTIC TIME

OBJECTIVES

As a result of this exercise students should be able to:

1. DISTINGUISH meristematic tissue in a stained root tip.
2. IDENTIFY mitotic stages.
3. STATE the nature of the inference involved in this activity.
4. DISTINGUISH it from a direct observation.

RATIONALE

Understanding of the chemistry of cell reproduction logically follows and is made more vivid by observing mitosis in stained meristematic tissue. The dynamic nature of chromosome division can be stressed if a time sequence is studied.

In an ordinary laboratory situation this time sequence cannot be observed but can be inferred by examining and counting mitotic figures in actively dividing tissue. By introducing the exercise with discrepant textbook references a healthy skepticism and a strategy for posing the question is encouraged.

VOCABULARY

chromosome

anaphase

mitosis

telophase

prophase

interphase

metaphase

MATERIALS

Series of mitosis transparencies for overhead projection
(Keuffel and Easer, Biology Series #6-15)

Student work sheets No. 1 and 2 (See INSTRUCTIONAL PROCEDURE)

Allium root tip slides, meristem shown, for example Turttox
B7.224

Microscopes and illuminators

Adding machine and slide rule for instructor's use

INSTRUCTIONAL PROCEDURE

1. By use of overhead transparencies the instructor illustrates the phases of mitosis.
2. Students are asked to examine in the microscope the slide of Allium root meristem section for examples of each phase.
3. The question, "Do cells spend equal amounts of time in each phase?" is introduced and student worksheet No. 1 (following INSTRUCTIONAL PROCEDURE) is distributed and read by students. The greatest discrepancies, in telophase, are pointed out.
4. An idea is called for which, using Allium slides, will help decide experimentally which author, if any, is correct. The idea of cell phase count and cell phase time being proportional is almost always supplied.
5. The instructor distributes worksheet No. 2, (the text of which follows) and the students work in pairs. One counts and one records.
6. After an hour, data on each phase is reported orally by each group of two and tabulated on the adding machine. Sub-totals are

divided by total for percent. Lab to lab uniformity is good and reference two of WORK SHEET ONE seems the best set of figures in our experience.

7. Students are encouraged to consider what factors may have led to the differences noted in the references.

STUDENT WORK SHEET 1 -- REFERENCES ON MITOTIC TIME

"Mitosis is generally divided into four phases:

prophase 60%, metaphase 5%, anaphase 5%, telophase 30%."¹

"Proportionally, prophase is the longest and metaphase the shortest. The following figures serve as a rough guide:

prophase 55%, metaphase 10%, anaphase 15%, telophase 20%."²

"Diagram of the percent time spent in each phase of mitosis by a meristematic tissue cell in the root tip of a pea plant.

prophase 70.8%, metaphase 14.7%, anaphase 2.6%, telophase 12.4%."³

"Duration of Allium mitotic phases:

prophase 85%, metaphase 7.7%, anaphase 2.9%, telophase 4.4%."⁴

¹Robert C. King, Genetics (N.Y.: Oxford University Press, 1962) p. 32.

²J. A. Ramsey, Experimental Basis of Modern Biology (London: Cambridge University Press, 1965) p. 83.

³Baker and Allen, The Study of Biology (N.Y.: Addison-Wesley, 1967) p. 33.

⁴Ronald F. Romig, "Determining Duration of Stages of Mitosis" (The Science Teacher, February, 1968).

STUDENT WORK SHEET 2 -- MITOTIC COUNTS

A question that frequently arises during the study of mitosis concerns the length of time required for the entire process. The question might be posed as follows: "Do the stages of cell division each take the same length of time?" One method used to find answers to these questions is to set up a slide with living cells and simply time the sequence of events. However, the equipment, time and procedure required for such an investigation would probably be beyond the facilities available in our laboratory. Following is an alternative method which can be used in the average laboratory.

Place a slide of Allium root tip under the high power of the microscope. Find a portion of the root tip in which active mitosis was taking place before the cells were fixed.

Two students work together, one as an observer and the other as the recorder. The observer ranges up and down the vertical rows of cells and calls out his observations and judgments about the particular phase of mitosis each cell is in as he comes to it. The larger the number of fields surveyed, the larger will be the sample group, and, consequently, the greater the reliability of the data. The results of the tallies will be computed to percentage figures by the instructor for the whole class late in the period on the adding machine.

Phase	Vertical rows of cells										Totals
	1	2	3	4	5	6	7	8	9	10	
Prophase											
Metaphase											
Anaphase											
Telophase											

Tally for number of cells observed in each phase.

CONTROLLING VARIABLES 2

Q

PHOTOSYNTHESIS AND RESPIRATION

OBJECTIVES

As a result of this exercise students should be able to:

1. STATE A RULE for the relationship between light intensity and rate of photosynthesis in plants.
2. STATE A RULE for the relationship between temperature and the rate of respiration in animals.

RATIONALE

What happens at the organismic level of life is eventually explainable by events at the cellular and molecular levels. By manipulating the light conditions on a plant and the temperature of an animal, the rates of photosynthesis and respiration respectively can be altered. The elodea plant has already been used and its chloroplasts examined (EXERCISE O). The circulatory system of the goldfish and the movement of capillary blood will be examined in EXERCISE V. They are the organisms chosen for this exercise.

VOABULARY

nene

MATERIALS

Small bore glass tubing

Fresh elodea

1000 ml beakers

Wide mouthed glass funnels

Light bulb sockets with plug-in cords

Ring stands with clamps for holding light bulbs

Reflector type light bulbs e.g. General Electric Reflector
Flood, 125 watts

500 ml beakers.

Centigrade thermometers

Goldfish

Ice cubes

Graph paper.

INSTRUCTIONAL PROCEDURE

1. Pairs of students are asked to work on either the photosynthesis or the respiration experiment as they choose and as equipment allows and then to return to the second project later.

2. A brief resume of lecture material on cellular respiration and photosynthesis is presented and the role of oxygen in each is reviewed.

3. Students are asked how we can judge the respiration rate of the fish. The movements of the operculum are related to goldfish respiration rate and will be suggested. Students can graph the number of movements of the operculum against temperature as a fish in a 500 ml beaker has his body temperature lowered from room temperature to nearly 0°C . by floating ice cubes on the water surface. In general chemical reactions double in rate for every 10°C . rise in temperature.

Students can discuss reasons why a 10° change in the fish will not change the rate of movement of the operculum by a factor of two.

Students should take readings on the fish operculum for one minute intervals at each five degree change in temperature. Sudden movements which cause the fish to be active will make readings more difficult and cause higher respiration rates. Ask students why this should be.

4. The rate of oxygen production by a plant is a measurement of non-cyclic photophosphorylation. Students can relate and graph light intensity to oxygen release by elodea by submerging fresh elodea sprigs in a test tube filled with 1% sodium bicarbonate solution which supplies carbon dioxide for the reaction. The tube is filled to within a few millimeters of a small-bore one-hole rubber stopper. A drop of ink is drawn into a piece of fine glass tubing bent into a 90° angle. The tube is inserted in the stopper to serve as a measurement of oxygen production by elodea as the drop of ink moves in the glass tubing.

Light intensity can be measured by using a photometer and readings of evolution of oxygen at different intensities of light are graphed during 2 minute measurement intervals.

Two precautions are required. A beaker containing a copper sulfate solution is situated between the light source and the test tube to absorb infrared radiation which will tend to heat the experimental plants. In addition, a second tube with 1% sodium bicarbonate solution, stopper and ink dropper volumeter is assembled but without

elodea. It is used next to the experimental tube as a thermobarometer. Any changes in the thermobarometer readings are subtracted from the elodea system.

Before the initial readings five minutes should be allowed for oxygen saturation of the solution.

A model experimental setup is provided and the instructor should allow students to speculate about the function of each piece of apparatus in control of potential variables.

CLASSIFICATION 1

R

THE FRESH WATER ALGAE

OBJECTIVES

As a result of this exercise students should be able to:

1. DISTINGUISH examples of cyanophyta from examples of chlorophyta.
2. RECOGNIZE diatoms and desmids.
3. DESCRIBE some of the various shapes that chloroplasts may have.
4. IDENTIFY from pictures some common algae found in local collections.
5. EXPRESS an aesthetic feeling for variety, symmetry and color variation in what seems to the unaided eye to be just green slime. (Affective)

RATIONALE

The spring quarter is devoted to the study of specific life forms as examples of biological principles. Origins of life, diversity, and primary productivity are ideas presented early for which the algae are well suited to complement lecture. They are excellent, too, for achieving affective goals because of their beauty and variety. Our laboratories will not use preserved specimens and the ubiquitous algae are examples of excellent biological materials students can collect locally in a short time before laboratory. While the algae are a difficult group to identify with a taxonomic key, they can be identified using colored plates.

VOCABULARY

binomial classification	chlorophyta
thallophyta	diatoms
algae	desmids
cyanophyta	

MATERIALS

Copies of: James W. Cox, "The Algae--A Hidden Teaching Resource" in Helping Children Learn Science (Washington, D.C.: The National Science Teachers Association, 1966) p. 112.

Microscopes

Slides and coverslips

Dissecting needles and droppers

Copies of: C. Mervin Palmer, Algae in Water Supplies, U.S. Department of Health, Education and Welfare (Washington, D.C.: U.S. Public Health Service 1962).

Copies of: G. W. Prescott, How to Know the Fresh Water Algae (Dubuque, Iowa: William C. Brown, 1954).

INSTRUCTIONAL PROCEDURE

1. Several days before the first lab section meets the instructor will announce in lecture that algae should be collected by each student for use in lab. Pertinent information on collecting and storing the materials may be given orally or as a work sheet at that time or copies of "The Algae--A Hidden Teaching Resource" may be placed on reserve in the library. The latter is suggested if the class is composed mainly of elementary teacher candidates.

2. At the beginning of each lab section the taxa into which the algae are placed are discussed with the characteristics of each taxon. The peculiarities of color, size, cell structure are described for the blues, the greens and for the diatoms. The economic importance of the diatom, the primitive nature of the cyanophyta and the hypothetical ancestry of the higher plants among the greens may be mentioned for interest value.

3. Students are asked to pick out examples of each of the types discussed from the colored plates in "Algae in Water Supplies" which must be available in the ratio of one copy for each four students. This paperback costs only one dollar per copy.

4. Working in pairs students are asked to identify as many genera as possible during the lab period. After the instructor is satisfied that an alga has been identified correctly to genus the name of the genus is recorded on the chalkboard by that student pair.

5. Records can be kept during the laboratory week to see which lab sections are most successful to encourage interest.

6. Drawings in G. W. Prescott's How to Know the Fresh Water Algae may be used to supplement the colored plates in Algae in Water Supplies for unusual forms. A collection of colored 35 mm. microphotographs of additional algae spread out on a "light table" is another valuable asset.

Note: Between 10 and 24 genera are usually collected and identified by any single lab section.

7. The instructor should hold over particularly productive collections in finger bowls from one lab section to another. Refrigeration will be required for collections overnight if kept indoors.

USING NUMBERS 2

S

THE QUESTION OF SIZE

OBJECTIVES

As a result of this exercise students should be able to:

1. STATE A RULE for the relative rate of increase in surface compared to volume as an object gets larger.
2. DESCRIBE some of the implications of the surface to volume relationship in biology.

RATIONALE

Comparative anatomy, one author states, is the study of the search of plants and animals to conquer the surface/volume problem. Before beginning topics in biology that have to do with evolution and natural selection in higher animals it seems important to understand the biophysical reasons why specialized organs and systems are indispensable and why size is not an accidental property of each organism but an essential attribute. Styrofoam and clay objects are used to represent organisms of various sizes.

VOCABULARY

none.

MATERIALS

An overhead transparency listing basic formulas concerned with the geometry of a sphere.

Centogram balance

Meter sticks.

Graph paper

Styrofoam spheres of sizes $\frac{1}{2}$ ", 1", 2", 4", and 6"

Several pounds of ceramic clay wrapped in plastic while not in use

Paper copies or original copies of the following references:

The Physical Science Study Committee, Physics, Second Edition
(Boston: D. C. Heath & Company, 1965) pp. 48-51

J. B. S. Haldane, "On Being the Right Size" in The World of Mathematics. Edited by James R. Newman, II (New York: Simon and Schuster, 1956) pp. 952-957.

F. W. Went, "The Size of Man," American Scientist, Winter, 1968, pp. 400-413

Florence Moog, "Gulliver Was a Bad Biologist," Scientific American, November, 1948, pp. 52-55.

E. Lendell Cockrum, William J. McCaulty, Newell A. Younggren, Biology (Philadelphia: W. B. Saunders Company, 1966) pp. 13-14.

INSTRUCTIONAL PROCEDURE:

1. The instructor should introduce the topic with an example of the role of size in biology. Perhaps the fallacy of scaling in man as described in Activity 5 is most appropriate. Calculations on the diameter of a 12 foot man's ankle should be discussed by the instructor with student suggestions as to the giant's weight as related to his new volume. Actual calculations as to the cross-section of the giant's ankle should be left for students.

2. After introducing the problem of size in this way students are directed to work in groups of two or three and to try at least three of the activities as described. Sheets describing each of the six

activities separately are placed at six different work stations, and students may pick any of the activities that seem most interesting. Sheets that describe those activities involving clay spheres should be placed at adjacent stations so that both groups may have access to the clay simultaneously.

3. While each activity sheet has listed at the bottom appropriate references, which are to be made available in the lab (see MATERIALS) the data suggested should be gathered first, the implications considered and only then are the references to be consulted by students.

STUDENT WORK SHEET -- THE QUESTION OF SIZE

Activity 1

Calculate the volume and surface of a series of spheres of diameters 1", 2", 6", 8" and plot these values on a graph. Let the "x" axis be diameters of each sphere numbering the heavy lines 1, 2, 3, 4, 5, 6 etc.

Let the "y" axis be the number of cubic inches of volume or square inches of surface. Do the lines (one connecting surface increase and the other connecting volume increase) have the same slope? What does the relationship of the two lines mean for a cell as it grows larger? Think about it and then consult the following reference.
E. L. Cockrum, William J. McCauley, Newell A. Youngren, Biology.
(Philadelphia: W. B. Saunders Company, 1966) pp. 13-14.

Activity 2

Make five balls of soft ceramic clay varying in size from about half a centimeter up to about ten centimeters. Measure the diameters carefully.

Drop each sphere from the first floor landing on to the basement floor. Gather data about how badly deformed each sphere is after impact. What part of the diameter of each has been lost in the impact? What does this suggest about animal life? Think and then consult the following reference. J. B. S. Haldane, "On Being the Right Size," in The World of Mathematics. Edited by James R. Newman, Volume 2 (New York: Simon and Schuster, 1956) pp. 952-957.

Activity 3

Make a ball of clay of about 4 centimeters in diameter. Calculate the surface area of the ball.

If it were an organism how might it increase surface without dividing? Try your idea and calculate the new surface present. Did it work? Has the volume changed? What implications do these data have for living things?

Reference: J. B. S. Haldane, "On Being the Right Size" in The World of Mathematics, Edited by James R. Newman, Volume 2 (New York: Simon and Schuster, 1956) pp. 953-954.

Activity 4

Let's say styrofoam balls are little animals and the four-inch styrofoam ball (a rabbit?) eats 2 grams of food every day. If food requirement is proportional to surface area how much will a half-inch ball (a shrew?) eat in a day? What percent of the body weight of each must be taken in food daily?

To figure the percent weight in daily diet you must weigh the spheres. Any implications for animal life?

Reference: J. B. S. Haldane, "On Being the Right Size" in The World of Mathematics. Edited by James R. Newman, Volume 2 (New York: Simon and Schuster, 1956) p. 955.

Activity 5

Picture a well proportioned man, six feet tall. Let's say he weighs 200 lbs. What would be the diameter of his ankle? About four inches?

What would a 12 foot man look like? Wouldn't he have a better chance of survival in natural selection? How come no 12 ft. men have evolved? What would he weigh? How thick would his ankle be to support him? What implications does all this have for large animals?

References: The Physical Science Study Committee, Physics, Second Edition, pp. 48-49; Florence Moog, "Gulliver Was a Bad Biologist" Scientific American, November 1948, pp. 52 and following.

Activity 6

Compare the behavior of the tiny spheres of styrofoam in the plastic sack with the behavior of a group of larger ($\frac{1}{2}$ inch) spheres. Are you reminded of any behavior in small animals? Why should size make a difference?

Reference: F. W. Went, "The Size of Man," American Scientist, Winter, 1968, pp. 405-407.

INTERPRETING DATA 2

T

COLOR IN NATURE

OBJECTIVES

As a result of this exercise students should be able to:

1. GIVE REASONS why different numbers of toothpicks of different colors were found in the experiment.
2. STATE EXAMPLES of protective coloration in nature and of attractive coloration.
3. INTERPRET these examples in terms of evolutionary adaptation.

RATIONALE

The theme of evolutionary adaptation in nature should run through any course in biology. Sometimes it is difficult to demonstrate this principle quantitatively in the field. This laboratory attempts to provide data and, later, living examples of color as a factor in natural selection.

VOCABULARY

adaptation

mimicry

MATERIALS

About 200 toothpicks each of five different colors for each laboratory section. Blue, yellow, green and red are available at supermarkets. Black must be produced by spraying uncolored toothpicks.

Five small beakers for holding toothpicks.

Meter sticks

INSTRUCTIONAL PROCEDURE

1. The instructor asks students to divide into pairs and to work together.
2. He asks one member of each pair to leave the room and wait until called by the partner.
3. The remaining partner is asked to establish an experimental plot on the campus lawn in a dense sod. The plots will measure about one square meter. In this square meter of grass he is to stick 12 toothpicks of each of the five colors in the grass imbedding the toothpick up to half its length. The toothpicks are not to be hidden but placed randomly and upright.
4. The instructor then asks the students to bring their partners to the plots only after the toothpicks are placed. The second member of the pair is then asked to hunt toothpicks much as a bird would hunt insects in the grass. He may not feel for them but must depend on vision. About one minute is allowed for student members of each pair to gather toothpicks in this way.
5. On returning to the laboratory data for the entire section is entered on a chalkboard table. Number of each color hidden and number found are recorded. Numbers hidden and found for the class are totaled for each color and percent of each color found is established.
6. A discussion to rationalize the results should be held. Most often blue and red are the highest percents recorded; black is invariably found least. The implications in nature are brought out.

proceeding usually from the idea of camouflage to mimicry and finally to attraction during reproduction in angiosperms and animals.

7. Collections of interesting pictorial examples should be made available and discussed. Life Magazine's Nature Library is a good source of excellent color photos.

8. Several 8 mm. single concept loop projectors and the following 8 mm. film loop cartridges are made available for students to view at their own speed:

Mimicry -- B.S.C.S. Single Topic Film.

Nature's Use of Color -- International Communication 8 mm.
Film #1116.

Colors are Useful -- International Communication 8 mm. Film
#1117.

COMMUNICATING 1.

U

THE HISTORY OF LIFE ON EARTH

OBJECTIVES

As a result of this exercise the student should be able to:

1. DESCRIBE the duration of man's recorded history on earth in comparison to the magnitude of the history of life, vertebrate life and mammalian life on earth.
2. DESCRIBE a dependence on and a continuity with the organism in the past history of life on earth.

RATIONALE

Because the origin of life is often discussed in conjunction with topics in microbiology and cytology and because the time sequence in the history of life gives perspective to biology, we will attempt here to make the history of the earth more vivid.

Students will use space to represent time on a long length of adding machine tape so that a graph of geological, biological and social history results.

VOCABULARY

none

MATERIALS

Rolls of adding machine tape, minimum width.

Meter sticks calibrated to mm.

Scissors

Reference copies to be left in laboratory:

1. George Wald, The Origin of Life, Scientific American Offprint No. 47 (San Francisco: W. H. Freeman & Co.)
2. Loren Eiseley, The Immense Journey, a Vintage Book, (New York: Random House, 1957)
3. Lincoln Barnett, The World We Live In (New York: Time-Life Inc, 1955)

INSTRUCTIONAL PROCEDURE

This laboratory exercise is to be accomplished informally.

Students meet only to be introduced to the assignment, something which could be accomplished more easily in a lecture situation with the entire group early in the week.

The laboratory is kept open for students to work in during the entire week. Meter sticks and adding machine tape are on hand continuously. No supervision is required.

In the laboratory should be found appropriate numbers of copies of references (see MATERIALS). The work sheet which follows is made available to every student at the time the assignment is made.

The tapes will be collected from each student and assigned a grade two weeks after the assignment is made.

STUDENT WORK SHEET -- THE HISTORY OF LIFE ON EARTH

There will be no formal lab meetings this week. Instead we would like you, for a grade, to accomplish a "do-it-yourself" project on the subject of the Earth's history as follows:-

In the lab are rolls of adding machine tape and meter sticks.

Take six meters of tape. Using space on this tape as a visual equivalent of time, e.g., 6 meters = 6 billion years, chart these important geological, biological and social events in man's evolution on the tape in correct scale of time. Include the origin of the earth, the origin of life, the first land plants, the first land animals, the first flowering plants, the first vertebrates, the first modern horses, the age of dinosaurs, the first mammal, the first man, the first civilization and Christianity.

In addition to naming and locating events on the tape, make whatever notes you think are needed and cite references to those readings listed below which you have found time to look at. These references are in the lab for your convenience. They are enjoyable reading.

1. George Wald, The Origin of Life, Scientific American Offprint No. 47 (San Francisco: W. H. Freeman & Co.)
2. Loren Eiseley, The Immense Journey, a Vintage Book, (New York: Random House 1957) The Snout, p. 45 and How Flowers Changed the World, p. 61.
3. Lincoln Barnett, The World We Live In (New York: Time-Life Inc., 1955).

OBSERVING 2

V

THE CIRCULATORY SYSTEM

OBJECTIVES

As a result of this exercise students should be able to:

1. PREPARE a stained blood slide.
2. DISTINGUISH white blood corpuscles.
3. DESCRIBE an open circulatory system.
4. IDENTIFY the chambers, vessels and valves of the heart.
5. NAME the chambers and vessels in the sequence of blood flow.

RATIONALE

Of the several animal systems our experience has been that a more interesting elementary laboratory session can be built around readily available materials related to the circulatory system than any other animal system. Observations of microcirculation in Daphnia and a goldfish in addition to those observations of the gross circulatory structures in the mammalian heart make a good comprehensive series of activities.

VOCABULARY

open circulatory system	leucocyte.
atrium	ventricle
semilunar valves	tricuspid valve, bicuspid valve
aorta, pulmonary artery	veña cava, pulmonary vein.

MATERIALS

A pork heart for each three students ordered with valves attached from a slaughter house (request that cut not be made in ventricles during meat inspection procedures).

Wide rolls of aluminum foil

Overhead projector transparency of heart cross-section, well labeled

Single edge razor blades

Foreceps

Microscopes, slides and cover slips

Sterile lancets

Wright's stain in dropper bottles

Cotton

95% Ethyl alcohol

A goldfish for each two students (if several lab sections are meeting each week allow for some goldfish mortality)

Daphnia from a biological supply house

Petri plates

Depression slides

INSTRUCTIONAL PROCEDURE

1. Students are asked first to make a blood slide of human blood working in pairs using the standard technique for Wright's stain. For a high percent success, speed in smearing the drop of blood and the use of clean slides are both important factors. The instructor must suggest ways of distinguishing the leucocytes from red cells on the basis of differential staining, size, shape and their relative scarcity. A

good spot on the slide must be found under low power before the high power objective is used.

2. The second activity, introduced after the slides have been examined, is the observation of microcirculation in the goldfish tail. Students, working again in pairs, will place a goldfish on its side in a petri plate and envelop the fish in wet cotton leaving the tail exposed. Under low power the movement of blood through the arterioles, capillaries and venules can be seen clearly.

3. Each pair of students is then asked to draw up a single Daphnia into a dropper from the culture bottle and place it on a depression slide. A cover glass is set in place and the Daphnia's circulation is observed. The bubble-like heart is seen easily under the low power but careful darkening of the field by closing the iris diaphragm is required if the cyclic movement of blood in the tissues is to be seen. The lack of vessels characteristic of an open circulatory system is evident.

4. Dissection of the pork heart by groups of three students takes the remainder of the session if done well. Price and availability of such hearts may be discussed as the activity is introduced. Students are advised to trim fatty tissue from the heart first. If a section of the trachea is attached it too should be removed. The first cut should be in removing about an inch and a half from the tip of the heart until the left and right sides of the heart can be identified. The pad-shaped atria should be pointed out before the students proceed

on their own. It should be suggested that the dark blood clots be removed carefully as students cut upwards into the ventricles. The instructor should project on a screen a labeled heart transparency for students and circulate among the groups to ask questions and assist in the identification of the semilunar valves in particular.

The entire dissection should be done with razor blades and forceps on a sheet of foil for easy disposal.

OBSERVING 3.

W

ANATOMY OF THE WHITE RAT

OBJECTIVES

As a result of this exercise a student should be able to:

1. IDENTIFY those gross anatomical features of the white rat that have been included in discussions of human systems in lecture.
2. NAME examples of differences between rat and human structures.
3. DO an animal dissection without being revolted. (Affective)

RATIONALE

Because human systems and their evolution have been central themes for lecture during the middle of Spring Quarter we have chosen to dissect the white rat because of the great resemblance to human anatomy. The rat is inexpensive, large enough for beginning students, and available alive making it unnecessary for students to breathe formalin for two hours.

VOCABULARY

The names of all organs and anatomical features of the human with homologous structures visible in the rat are reviewed.

MATERIALS

Cotton

A white rat for each three students. The rats should be of mixed sex. Discarded breeders are least expensive and very satisfactory.

Animal cages in which to hold rats

A few potatoes for rat feed

A pint of diethyl ether

Large rolls of aluminum foil

A killing container for rats (small fish tank works well)

New razor blades, forceps, dissecting needles, scissors

Droppers and small beakers.

Pipettes

Microscopes and illuminators

Slides and cover slips

Multiple copies of the following journal article:

"Most Destructive Creature on Earth" by Fred Warshofsky in
Reader's Digest, September, 1967, pp. 175-180.

Multiple copies of Laboratory Anatomy of the White Rat by
B. Chiasson, published by Wm. C. Brown Company, Dubuque,
Iowa, 1958.

INSTRUCTIONAL PROCEDURE

1. When students first enter the laboratory they are asked to read Warshofsky's interesting sketch on the rat called "most Destructive Creature on Earth." See MATERIALS.

2. Students are asked when five minutes have elapsed to choose groups of three to work in. The instructor should ask that students who resist the idea of touching the rat distribute themselves and not gather together in groups. Groups may elect to work on a dead rat or on one anaesthetized with ether.

3. Before the rats are received students are instructed on how to make an incision from xiphoid process to sex organs cutting carefully through both skin and abdominal muscles. They can observe waves of muscular contractions in the caecum by touching it with a metal probe. Those who have chosen rats not completely dead can see the motion of the diaphragm by moving the liver off to one side and looking upwards in the abdominal cavity. Often the beating of the ventricles can be observed through the intact diaphragm.

The second incision is made with scissors by cutting into the diaphragm and rib cage to one side or the other of the sternum and xiphoid process keeping scissors high to prevent cutting blood vessels. The atria, even on a dead rat, will be pulsating.

4. Once the above methods of examining heart, diaphragm and muscle motion are clear students are advised, again before the rats are received, that they could then relax and use the Laboratory Anatomy of the White Rat as a guide in further dissection. It is suggested that they consult diagrams of the various systems as they work. Since only two hours are available the muscle and skeletal systems diagrams will be ignored.

5. Rats are then etherized in the killing container by transferring them individually or in pairs from the cages. If a group of students wishes a rat in which respiration has not completely stopped, that group will need some cotton soaked in ether to maintain the unconscious state after the rat is removed from the killing

container. Students receive rats on a large sheet of foil in which the remains can later be gathered up with little mess or inconvenience.

6. After the groups are well into the rat systems the instructor should suggest that some groups inflate the lungs by blowing into the trachea with a pipette after cutting it in two. Those with male rats can make a slide of rat sperm cells by mascerating a section of caput epididymus tissue in a dropperful of water and making a wet mount for examination under 400 power.

7. Before students are permitted to leave the laboratory, they should be required within their work groups to identify a short list of organs or structures provided orally by the instructor, e.g., bile duct, pancreas, ureter, prostate glands, etc.

CLASSIFYING 2

X

CAMPUS CONIFERS

OBJECTIVES

As a result of this exercise a student should be able to:

1. DEFINE a taxonomic key.
2. CONSTRUCT a simple dichotomous key for a series of common objects.
3. DISTINGUISH a spruce, a pine, a larch, and a fir.

RATIONALE

If we know more about living organisms in our community we may be more likely to respect them. To know their names requires that we see their similarities and differences. We are classifying. The simplest of all the taxonomic keys to organisms immediately available in our community is the key to the gymnosperms.

Conifers dominate the vegetation of Western Montana and excellent examples are found on campus.

VOCABULARY

dichotomous key	petiole
bract	

MATERIALS

Sets of common items containing one per set for each pair of students as follows:

bouillon cubes	glass slides
sugar cubes	small styrofoam balls

paper clips	red toothpicks
rubber bands	beans
gum drops	small pieces of paraffin
single paper matches	small corks

Multiple copies of Flora of Montana, Part 1, Conifers and Monocots, by W. E. Booth, published by the Research Foundation, Montana State University, Bozeman, Montana, 1950.

INSTRUCTIONAL PROCEDURE

1. Assume that students have never used a taxonomic key before. Suggest that they classify the common items on the tables in terms of observable characters. Have them separate the objects into piles then subdivide the piles on the basis of another difference. They should continue until each object is in its own pile, writing down each dichotomy in road map style on a sheet of paper.
2. Suggest that if these items were plants or animals that they would have produced a taxonomic key. Have pairs of students exchange keys and see if another group arrives at the same end in the key for some one object chosen.
3. Using a conifer bough and Booth's printed key to gymnosperms, show how the various dichotomies are indented one after the other and how one would identify the tree from which the bough was taken by using the key.
4. During the second hour have students identify for report and grading purposes a series of numbered and brightly-banded campus conifers. Ten trees are enough and they should represent several genera. These trees are recommended.

Western larch
Scotch pine
White spruce
Ponderosa pine

Engelmann spruce
Rocky Mtn. juniper
Giant arborvitae
Douglas fir

Blue spruce
Grand fir
Swiss Mtn. pine
Lodgepole pine

5. For beginning students some time before students leave the laboratory must be spent discussing such conifer characteristics as needles flat or angular, cones papery or leathery, cones with bracts, etc.

STUDENT REPORT SHEET -- CAMPUS CONIFERS

Tree #1	Common name	Genus and species name
#2		
#3		
#4		
#5		
#6		
#7		
#8		
#9		
#10		

USING NUMBERS 3

Y.

THE EVOLUTION OF THE FLOWERS

OBJECTIVES

1. IDENTIFY the parts of flowers.
2. DISTINGUISH flowers which are irregular, imperfect, incomplete.
3. DESCRIBE a flower of advanced evolutionary structure.
4. ORDER a group of plants with respect to evolutionary floral divergence.

RATIONALE

The taxonomic features of the flowers which will be used later in identifying local plants are here presented in an interesting fashion, i.e., the degree to which they suggest evolutionary complexity. Numbers are assigned flowers in the hope of quantifying evolutionary sophistication. Two important ideas, diversity and evolution in living things, are presented. Since many other factors besides floral characteristics must be used in establishing a true phylogenetic scheme for plants, our numerical and phylogenetic relationships should be considered only as a teaching tool and subject to drastic revision if other plant characters are considered.

VOCABULARY

angiosperm	pistil
inflorescence	ovary
whorl	receptacle

calyx	complete flower
corolla	perfect flower
stamens	regular flower
monocot.	dicot

MATERIALS

Dissecting scopes and/or

Tripod lenses

Plastic flower model such as Welsh #95281 or 95282

Dissecting needles

Forceps

Scratch paper

A supply of eight different flowers for each student
(See INSTRUCTIONAL PROCEDURE.)

INSTRUCTIONAL PROCEDURE

1. Students are first asked to pick apart an angiosperm seed about to germinate. A maple samara or a soaked dry lima bean works well. The embryo and the seed coat help students to understand the Embryophyta, Tracheophyta, Angiosperm and Dicot classifications.

2. Flower parts are then discussed using a plastic flower model (see VOCABULARY).

3. Monocot and dicot plants are compared using field or garden examples.

4. Using real flowers as examples of unusual structures examine, along with students, such features as the separate flowers of a composite,

the inferior ovary of an apple, the imperfect flower of the squash, the incomplete flower of clematis and some irregular flower. Choose other appropriate examples as substitutes or additional examples.

5. Suggest that the many differences we see in flowers are due to evolutionary changes and adaptations. Consult, with students, the work sheet and go over instructions together before beginning flower dissections.

6. Choose eight different wild or garden flowers avoiding monocots, flowers of small size and flowers high in evolutionary sophistication. The author has found that a random sample of garden and wild flowers are not as satisfactory in building a ground plan which proves sequential as do collections of the more simple dicots.

STUDENT WORK SHEET --- EVOLUTION OF THE FLOWERS

According to a widely accepted scheme for the classification of the angiosperms, it is possible to characterize the evolutionary position of flowering plants on the basis of floral organization.

Primitive	Advanced
Petals separate	Petals united
Sepals separate	Sepals united
Stamens separate	Stamens united to petals
Stamens separate	Stamens united to each other
Flowers regular	Flowers irregular
Superior ovary	Intermediate or inferior ovary
Petals more than 5	Petals 5 or less
Stamens more than 10	Stamens 10 or less

Evolution of flowering plants seems to be characterized by the reduction in number and the fusion of parts.

Determine the degree to which a specific flower represents an advanced condition. Use a scoring system based upon a point for each advanced feature. Examine each of eight flowers, noting each of the features listed on the next sheet. For each feature present in the advanced condition, record a point. When the entire list of features has been checked for the flower, total the number of points and the letters telling which advanced characters are present.

Under this scoring system the numerical score represents the degree of change from the primitive condition. The higher the score the more advanced the condition of the flower. The scores obtained for the flowers studied will reveal several degrees of evolutionary advancement.

We should now be able to plot each flower on the ground plan analysis sheet on the basis of the fact that organisms evolve from the simple to the complex and seldom backwards.

Enter on the appropriate circle of your ground plan sheet the simplest plants first (those with the lowest number totals). Remember, however, in establishing your relationships you may not drop advanced characters in the next plant in the order of evolutionary advancement.

An example of a good ground plan for some imaginary flowers is attached.

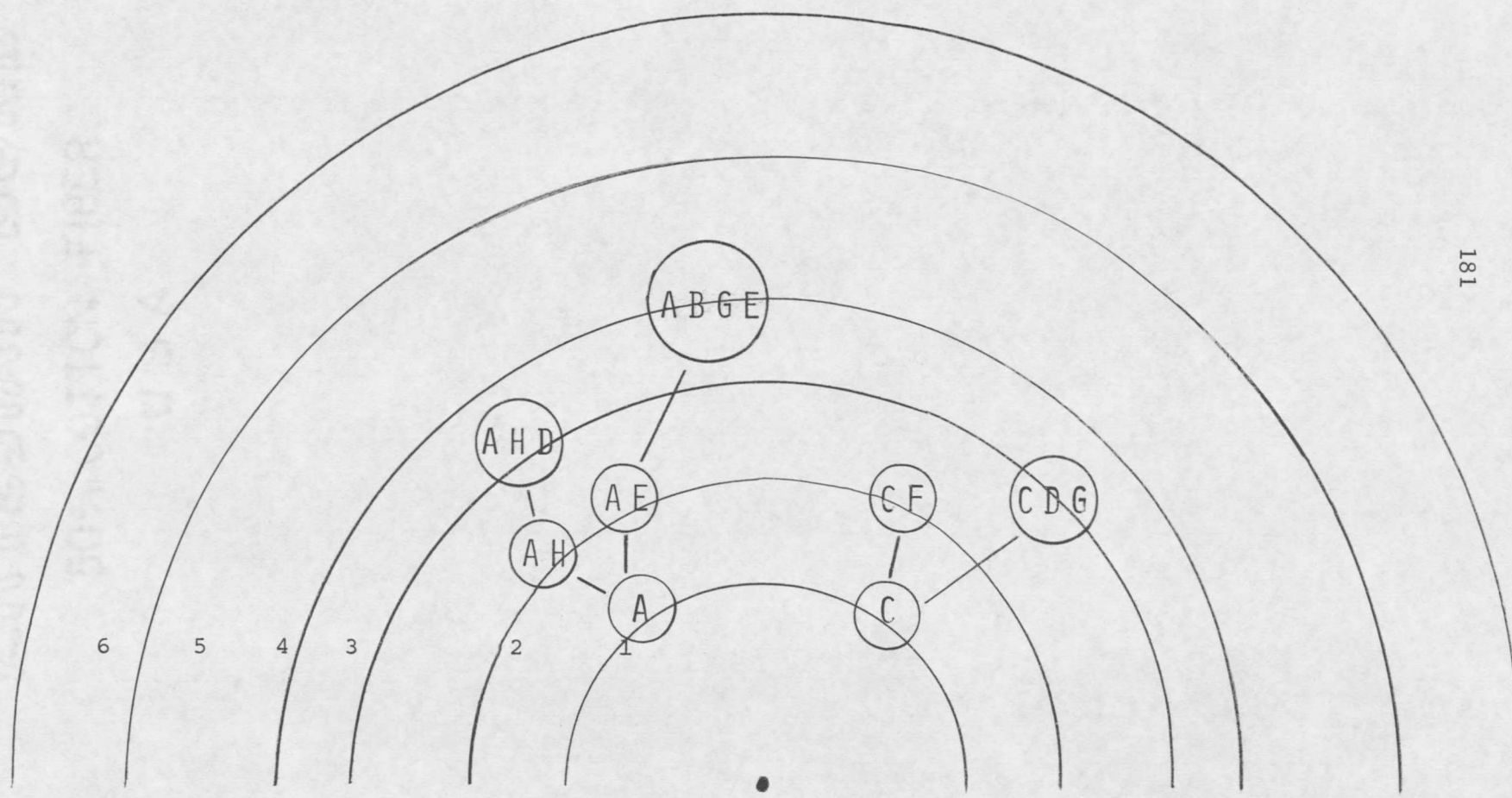
STUDENT WORK SHEET -- FLORAL SCORE SHEET

Mark the letter in the space under each flower if an advanced characteristic is present.

Flower #1	2	3	4	5	6	7	8
A Petals united							
B Sepals united							
C Stamens united to petals							
D Stamens united to each other							
E Flowers irregular							
F Ovary inferior							
G Petals 5 or less							
H Stamens 10 or less							
Total score (a number and the appropriate letters)							

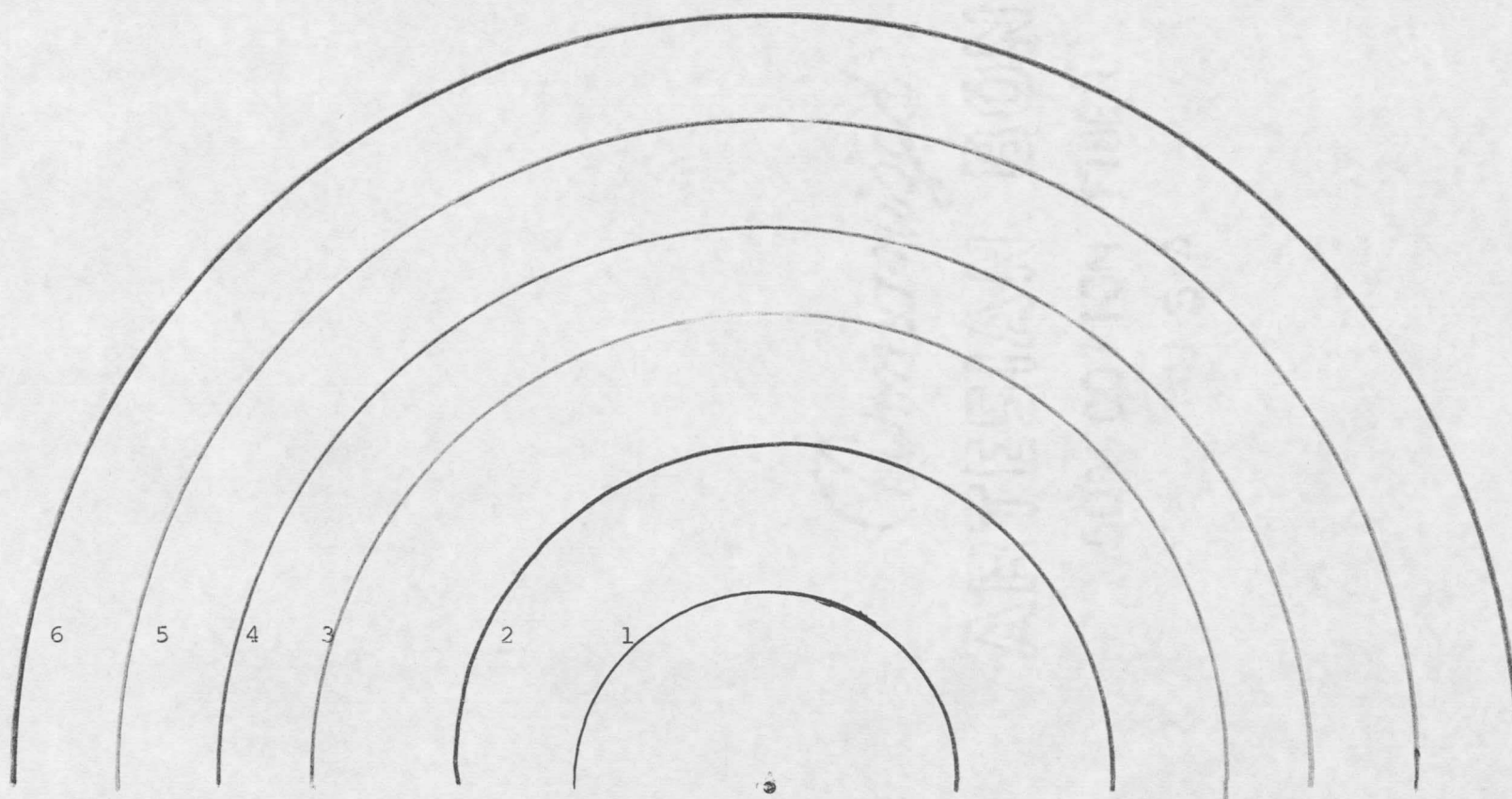
A Method for Expressing Evolutionary Data (after W. H. Wagner, Jr.)

Assumption: Those character-states which are similar between related taxa are those that were present in their common ancestry. Those character-states which are dissimilar have diverged.



A Method for Expressing Evolutionary Data (after W. H. Wagner, Jr.)

Assumption: Those character-states which are similar between related taxa are those that were present in their common ancestry. Those character-states which are dissimilar have diverged.



SPACE/TIME RELATIONSHIPS 2

Z

THE BROADLEAF TREES AND SHRUBS

OBJECTIVES

As a result of this exercise a student should be able to:

1. DEMONSTRATE an ability to use various media for recording permanently the shapes of leaves.
2. IDENTIFY the types of leaf structures collected.
3. NAME some common native and introduced broadleafed trees and shrubs present on campus.

RATIONALE

The evolution of leaves to compete for sunlight and the anatomy of leaves are both discussed in lecture. The diversity and beauty of leaves are ideas better communicated in the laboratory and in the field. The artistic aspects of this lab session are justified on the basis of the importance of affective goals.

VOCABULARY

simple and compound leaves

leaflet

pinnate and palmately compound

pinnate and palmate venation

alternate and opposite leaf arrangement

MATERIALS.

Seal-Lamin plastic rolls (Seal-Lamin Inc., Derby, Connecticut)

Several colors of spray paint

Rubber cement

Revolute 29-2051 Direct Positive Paper manufactured by the Charles Bruning Company

Overhead projector

White spirit duplicator paper

Sheets of white poster cardboard

Household iron

Student worksheet

Several copies of What Tree is This? by C. A. Barbour and E. Sinnamon published by the Denver Botanic Gardens, 49 pages.

Several copies of Trees and Shrubs for Montana, by R. T. Marks published by the Cooperative Extension Service, Montana State University, Bozeman, Montana, in October 1963, Bulletin 323, 65 pp.

A large wide-mouthed jar with cover into which the 8½ x 11" sheets of direct positive paper can be placed for developing. At the bottom of the jar wadded cotton with concentrated ammonia solution is placed. A square of wire gauze is placed on top of the cotton to prevent the direct positive paper from contacting the ammonia soaked cotton.

INSTRUCTIONAL PROCEDURE

1. The instructor should furnish each member of the group with one or other of the elementary pamphlets on trees, "Trees and Shrubs for Montana" or "What Tree is This?" (See MATERIALS). Both pamphlets should be about equally represented in the distribution.

2. The instructor should lead a 45 minute field trip with the group during which time, in addition to asking the question, "What Tree Is This?" about selected broad leafed trees and shrubs on campus, he can point out resemblances and differences in the structures of leaves.

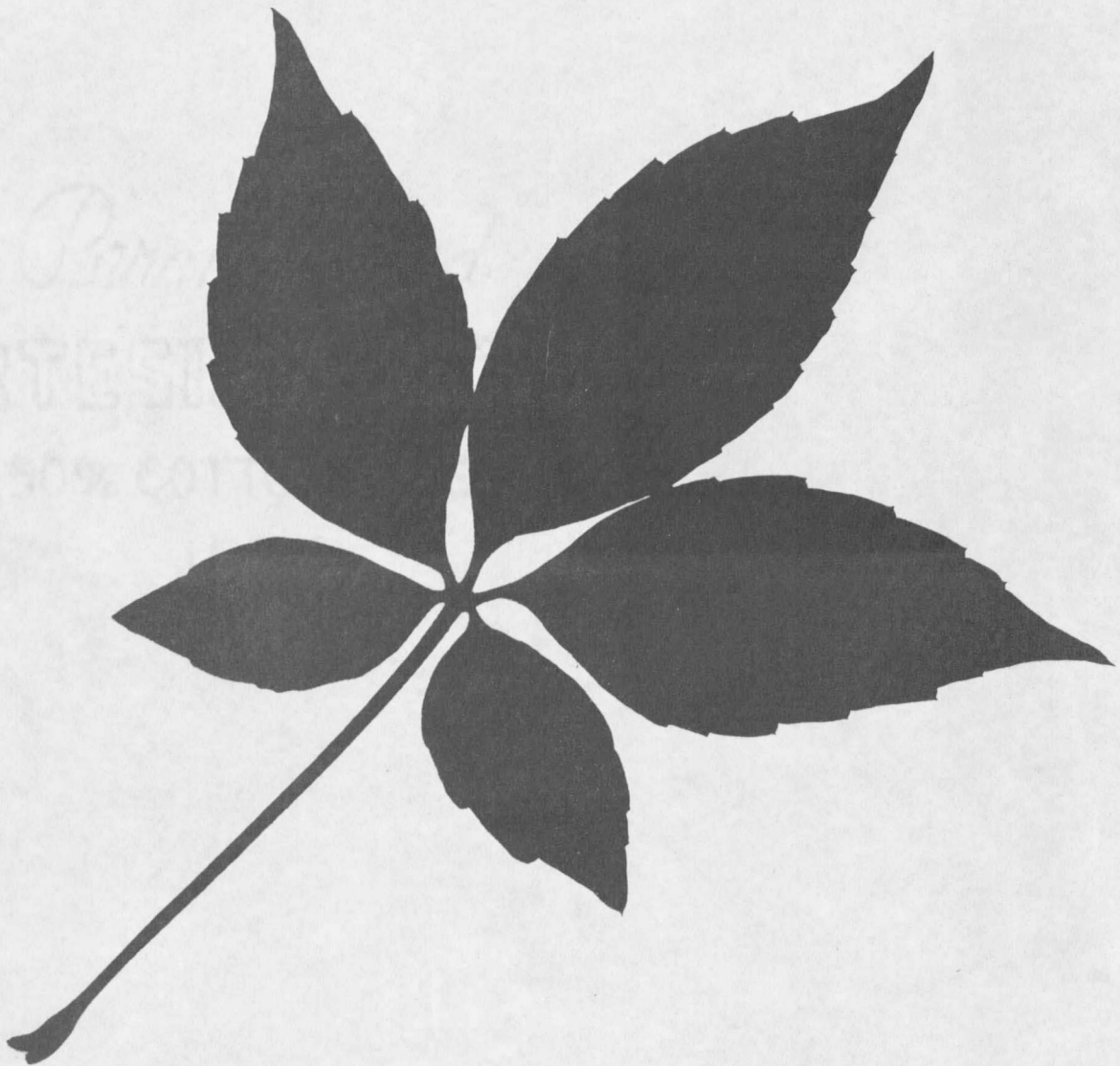
3. Burr oak, Norway maple, ginkgo, caragana, red oak, honey locust, Virginia creeper, mountain ash, paperbark birch, American elm, aspen, Lombardy poplar, golden willow, Russian olive and wild plum are some that should be pointed out during the trip. Students are asked to take a leaf from about eight different plants back to the laboratory.

4. Working in pairs in the laboratory leaf mounts or leaf patterns are produced by students by each of the following methods:

a) The leaf itself is laminated to small pieces of white cardboard using the method described by the manufacturer of Seal-Lamin (See MATERIALS).

b) An impression of the leaf is made by sticking the leaf to a sheet of spirit duplicator paper with a small amount of rubber cement and then spraying the sheet with spray paint. A rectangular space at the lower right of the paper is covered before spraying with cardboard to provide space, when removed, for leaf descriptions. (See Student Work Sheet which follows.)

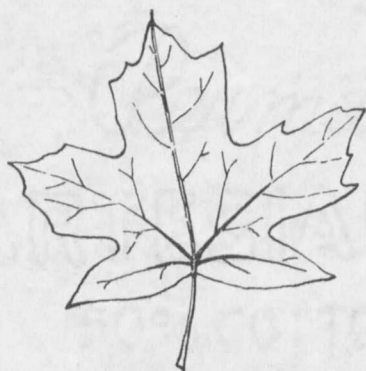
c) A "blueprint" impression of leaves can be made with light using direct positive paper (see MATERIALS) and exposing the paper to light on the platform of an overhead projector a minute or less. Longer times produce light penetrations and leaf veins are copied.



This space for genus and
species, common name and
brief description of leaf
from illustrations.

Student Work Sheet - Leaves

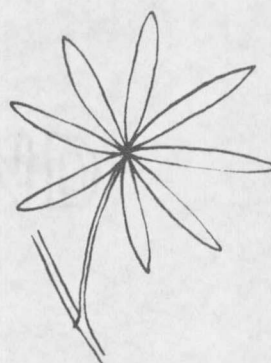
Leaf Types and Venation



palmately lobed
palmately veined



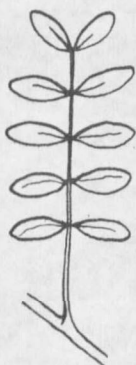
parallel veined



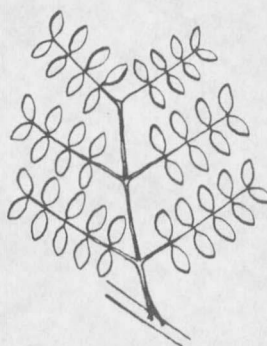
palmately compound



odd pinnately
compound leaf



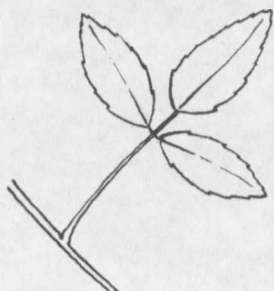
even pinnately
compound leaf



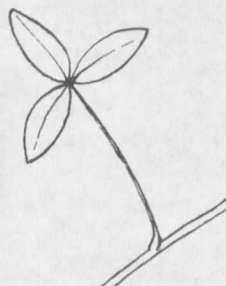
double pinnately
compound leaf



whorled
leaves



pinnately
trifoliate leaf



palmately
trifoliate leaf

Student Work Sheet - Leaves

Leaf Shapes



lanceolate
(like a lance)



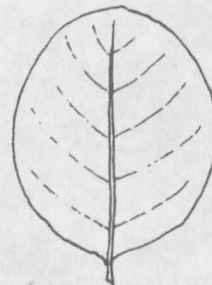
ovate



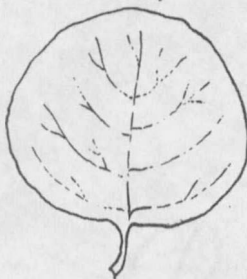
oblong



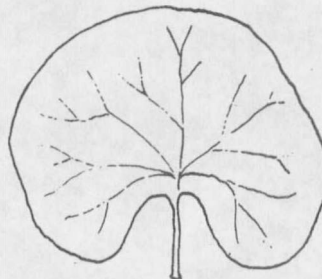
elliptical



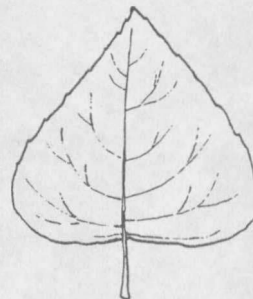
oval



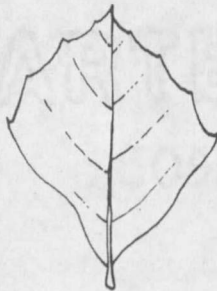
orbicular
(spherical)



reniform
(kidney shaped)



deltoid
(triangular)



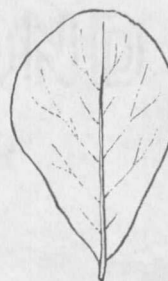
rhomboidal



oblanceolate



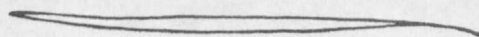
spatulate



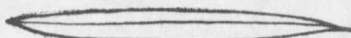
obovate



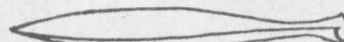
cuneate



filiform
(thread like)



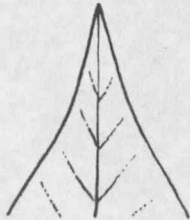
linear



subulate
(cylindrical)

Student Work Sheet - Leaves

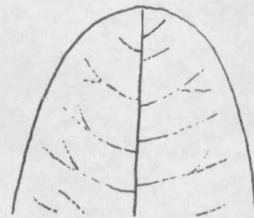
Leaf Tips



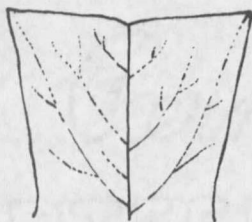
acuminate
(tapered to a point)



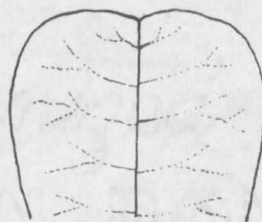
acute
(pointed)



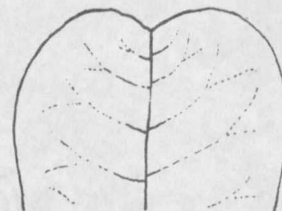
obtuse
(blunt)



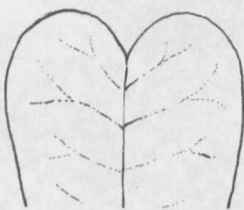
truncate
(cut short)



retuse
(blunt with notch)



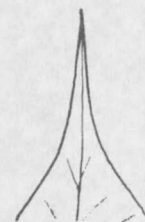
emarginate
(deeply notched)



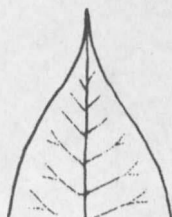
obcordate
(inversely heart shaped)



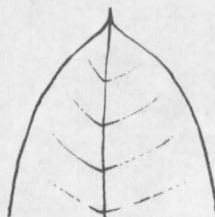
awned
(with a bristle)



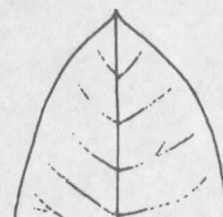
caudate
(with a tail)



cuspidate
(tooth shaped)



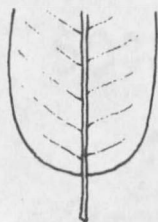
mucronate
(abruptly pointed)



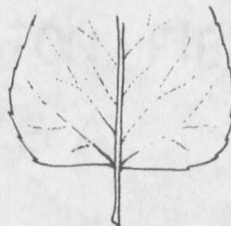
apiculate
(small pointed)

Student Work Sheet - Leaves

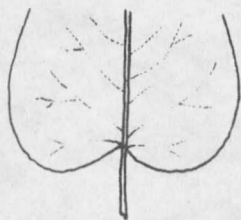
Leaf Bases



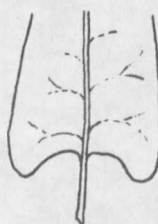
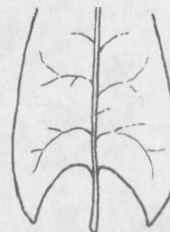
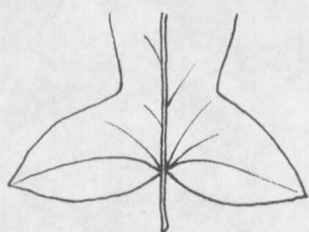
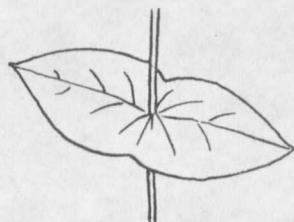
obtuse



truncate

oblique
(not equal)

cordate

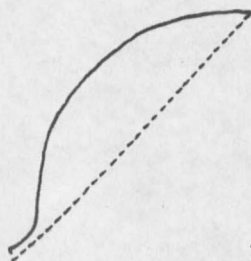
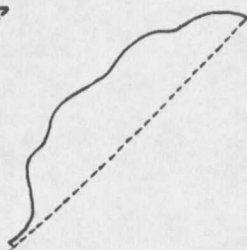
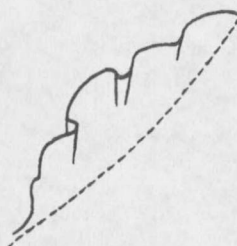
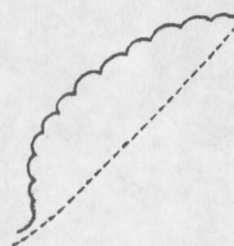
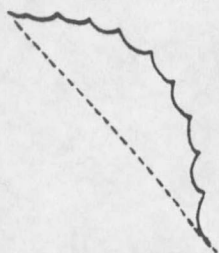
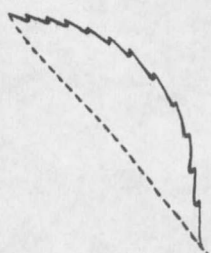
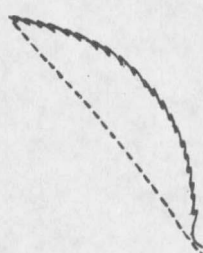
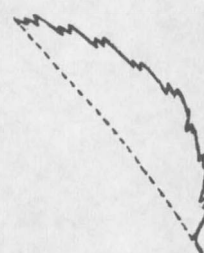
auriculate
(ear like)sagittate
(arrow like)hastate
(basal lobed)attenuate
(becoming slender)perfoliate
(through the leaf)

connate-perfoliate

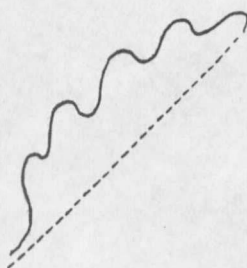
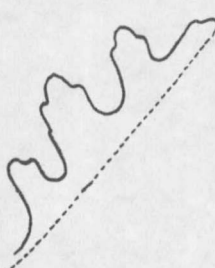
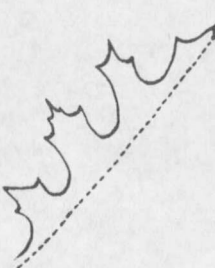
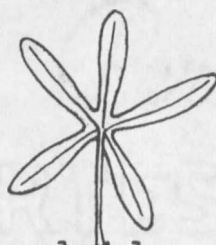
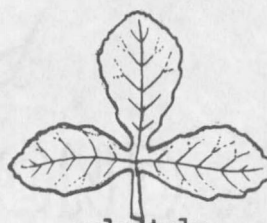
decurrent
(clasping stem)

Student Work Sheet - Leaves

Leaf Margins

entire
(even)undulate
(wavy)sinuate
(bent in and out)crenate
(scalloped)dentate
(toothed)serrate
(fringed)serrulate
(small fringes)

double serrate

pinnately
lobedpinnately
partedpinnately
cleftpinnately
dividedpalmately
partedpalmately
cleftpalmately
divided

CLASSIFYING 4

AA

MONTANA WILDFLOWERS

OBJECTIVES

As a result of this exercise the student should be able to:

1. IDENTIFY a few of the more striking Montana spring wild-flowers by sight.
2. USE a simplified dichotomous key to angiosperms based on flower characteristics.
3. ENJOY knowing and learning about native plants. (Affective)

RATIONALE

After learning to dissect flowers in laboratory session Y, students should now be well prepared to "key out" a dozen or so of the spring flowers native to Montana that appear in profusion on Mount Sentinel, only a few hundred yards east of our laboratory. The local emphasis of all our biology laboratory sessions, we hope, will have the cumulative affective result of respect, if not affection, for the organisms of our immediate environment.

VOCABULARY

herbaceous--woody

MATERIALS

Needles and forceps

A plastic sack for each pair of students

A tripod magnifier for each pair of students.

A mimeograph copy of Spring Flora of University Mountain by Dr. Richard A. Solberg, Professor of Botany, University of Montana, for each student. This unpublished key is a simplified key for only the 100 most common species on the mountain and can be used with beginners. It was prepared in May, 1963. Because it is unpublished two typical pages are printed by permission of the author for the reader's information.

Several copies of A Field Guide to Rocky Mountain Wildflowers by J. J. Craighead, F. C. Craighead, Jr., and Ray J. Davis. This is number 14 of the Peterson Field Guide Series published by Houghton, Mifflin Company, Boston.

INSTRUCTIONAL PROCEDURE

1. The first part of the laboratory session is a sixty minute walk up the slope of the mountain for collecting. Students are asked to carry plastic sacks in which to store plants to prevent wilting. During the walk the instructor might try to show students how plants of the same family have common characters. Legumes, mustards and the parsley family show this commonality of appearance well. He might wish to show the students grass flowers in bloom, leaf stipules, stoloniferous plants or other interesting structures.

2. Upon return to the lab the students will attempt to identify the flowers using the simplified key, Spring Flora of University Mountain (see MATERIALS). Students will work in pairs. Verification can be provided by the instructor or in most cases by the colored plates of Rocky Mountain Wildflowers (see MATERIALS).

KEY

Family

1. Flowers like daisies, dandelions, or sunflowers - COMPOSITAE.
(Composite family) p. 5-6.
1. Flowers not like daisies, dandelions, or sunflowers.
 2. Flowers inconspicuous, subtended by prickly bracts, plants forming - tumbleweeds. CHENOPODIACEAE (Goosefoot family) p. 5
 2. Flowers conspicuous, though sometimes small, no prickly bracts.
 3. Flowers irregular
 4. Flowers appearing like common orchid, purplish white - ORCHIDACEAE (Orchid Family)
 4. Flowers not orchid-like.
 5. Petals distinct from one another, purplish
 6. Stamens usually 5. - VIOLACEAE (Violet family) p. 10
 6. Stamens numerous, usually more than 10. - RANUNCULACEAE (Buttercup family) (Delphinium spp.) p. 8-9.
 5. Petals united, or at least some so.
 7. Stamens equal to or less than corolla lobe number
 8. Stamens equal to corolla lobe number - CAPRIFOLIACEAE (Honeysuckle family) p. 5
 8. Stamens not equal to corolla lobe number
 9. Two fertile stamens only - LABIATAE (Mint family) p. 7.
 9. More than two fertile stamens - SCROPHULARIACEAE (Figwort or Snapdragon family) p. 10
 7. Stamens twice the number of corolla lobes - LEGUMINOSAE (Pea family) p. 7
 3. Flowers regular
 10. Stamens twice the number of petals (Note: sepals may be petaloid)
 11. Petals 3, sepals 3. - LILIACEAE (Lily family) p. 7-8
 11. Petals 4 or 5
 12. Petals yellow - CRASSULACEAE (Stonecrop family) p. 6
 12. Petals not yellow

GENUS AND SPECIES KEY

BORAGINACEAE

1. Flowers light to bright blue.
 2. Flowers nodding, bell shaped -- Mertensia oblongifolia (Bluebells)
 2. Flowers not nodding or bell shaped.
 3. Plants less than 5 inches high -- Myosotis stricta (Forget-me-not)
 3. Plants more than 5 inches high -- Lappula spp. (Stick seed)
1. Flowers white or yellow
 4. Flowers white, densely hairy -- Cryptantha sheldonii (Cat's eye)
 4. Flowers dull yellow, but densely hairy -- Lithospermum ruderale (Stone seed)

BERBERIDACEAE

Berberis repens (Oregon grape)

CAMPANULACEAE

Campanula rotundifolia

CAPRIFOLIACEAE

Pink flowered shrub -- Symphoricarpos occidentalis (Snow berry)

Yellow-white flowered shrub -- Lonicera utahensis (Honeysuckle)

CARYOPHYLLACEAE

1. Petals 2-lobed or cleft -- Cerastium arvense (Chick weed)
1. Petals not 2-lobed or cleft
 2. Petals with small teeth -- Holosteum umbellatum
 2. Petals without small teeth -- Arenaria congesta (Sand wort)

CHENOPODIACEAE

Salsola Kali var. tenuifolia

COMPOSITAE

1. Flowers yellow, at least in part.
 2. Flower heads large size of dollar or larger
 3. Flowers red & yellow -- Gaillardia artistata (Gaillardia)
 3. Flowers yellow only
 4. Stems and leaves with milky juice
 5. Bracts longer than flowers -- Tragopogon dubis (Oyster plant, or Goat's beard, or Salsify)
 5. Flowers longer than bracts -- Tragopogon pratense (Oyster plant, or Goat's beard, or Salsify)
 4. Stems and leaves without milky juice
 6. Plants in large clumps, leaves shaped like arrowheads -- Balsamorhiza sagittata (Balsam root)
 6. Plants not in large clumps, nor leaves like arrowheads
 7. Lower leaves heart shaped -- Arnica cordifolia
 7. Lower leaves not heart shaped -- Arnica fulgens (Arnica)

RECOMMENDED LABORATORY READING

The following is a list of papers from Scientific American and elsewhere which pertain to the laboratory sessions as listed. Six copies of each are on hand to be placed on the laboratory tables during the appropriate session for enrichment reading. Questions raised by the laboratory are often dealt with in an interesting and comprehensive fashion. Numbers in parentheses refer to the offprint catalog numbers of W. H. Freeman Company, publishers of Scientific American.

Exercise I, A Tracer Experiment--"Tracers," Feb. 1949 (100) M. D. Kamen.

Exercise J, The Electron--"What is Matter?", Sept. 1953 (241) E. Schrödinger.

Exercise N, Enzyme Activity--"Protein Digesting Enzymes," December 1964 (198) H. Neurath.

Exercise O, Cells--"The Living Cell," Sept. 1961 (90) J. Brachet.

Exercise P, Mitotic Time--"Cell Division," August 1953, D. Mazia.

Exercise Q, Photosynthesis and Respiration--"The Role of Light in Photosynthesis," Nov. 1960 (75) D. I. Arnon.

Exercise R, Algae--"The Blue-Green Algae," June 1966 (1044) P. Echlin.

Exercise S, Size--References are incorporated into laboratory activities (see MATERIALS).

Exercise T, Color--References are incorporated into laboratory activities (see MATERIALS).

Exercise U, History of Life on Earth--References are incorporated in laboratory activities (see MATERIALS).

Exercise V, Circulatory System--"The Heart," May 1957 (62) C. J. Wiggers.

Exercise W, Rat--"Most Destructive Creature on Earth," The Denver Post,
Empire, August 13, 1967.

Exercise Y, Evolution of Flowers--Excerpt from The Incredible Journey
"The Coming of the Flowers," L. C. Eiseley.

Exercise AA, Montana Wildflowers--"The Fertilization of Flowers," June
1951 (12) V. Grant.

APPENDIX

ACHIEVEMENT OF COGNITIVE BEHAVIORAL OBJECTIVES
OF LABORATORY EXERCISES

Note: Laboratory exercises requiring reports (Exercises C, F, H, V and X) are reported first with instructor grading procedures. Percent always refers to the part of the group who answered the item correctly.

Exercise C--See Student Work Sheet

Four points were awarded students, one for each of the activities for which a good close answer was obtained. We here define "a close answer" and give the percent of the class to be awarded the point.

Shutter opening of camera--55 to 57 minutes--68 percent

Latitude of Missoula--46 to 48 degrees--64 percent

Diameter of Moon--2150 to 2475 miles--91 percent

Distance to Bridge--40 to 60 kilometers--76 percent.

Exercise F--See Student Work Sheet.

A possible three points were awarded students as follows:

Method correct, answer within two angstroms--33 percent

Method correct; answer within four angstroms--26 percent.

Method correct; answer not within four angstroms--22 percent

Exercise completed badly--19 percent

Exercise H--See Student Work Sheet

Students were awarded three points as follows:

Method correct; less than two percent deviation on both
exercises--23 percent

Method correct; less than two percent deviation on one
exercise--52 percent

Method correct; bad data or bad answers--12 percent

Exercise completed and not understood--13 percent

Exercise U--See Student Work Sheet

Three points awarded, one for completeness, one for correct
spatial proportions and one for reading detail. Grades
ran as follows: three, 31 percent; two, 40 percent; one,
29 percent.

Exercise X--See Student Work Sheet

Points were awarded for correctly identifying conifers
as follows:

Ten out of ten--8 percent

Nine out of ten--26 percent

Eight out of ten--54 percent

The following test items measure directly or indirectly the achievement of most of the stated cognitive behavioral objectives exercise by exercise. Percent correct responses are given. It should be remembered that these test items were administered on an average of 2.5 weeks after the laboratory exercise was completed and that students were not apprised of what the cognitive objectives were that the author had written for achievement in any laboratory session.

Exercise A

T or F--Mass is defined as gravitational attraction.
78 percent

A rectangular solid measures 1 cm by 1 cm by 1 dm. Its volume would be:

1) 5 cm² 2) 1 dm² 3) 1 cm³ 4) 10 cm³ 5) 100 cm³
70 percent correct

An object weighs 16 grams; when dropped into water it raises the level 3 cc. How many times more dense is the object than water? 1) 3 times 2) 48 times 3) 0.3 times 4) 8 times
5) none of these
50 percent

Exercise B

The following devices and demonstrations should be matched with the type of energy conversion involved:

Dye crystals in water--64 percent	1. Chemical to electrical
Magneto or generator--81 percent	2. Radiant to chemical
Photosynthesis--83 percent	3. Heat to mechanical
Washing machine--93 percent	4. Light to mechanical
Radiometer--72 percent	5. Mechanical to electrical
Battery--66 percent	6. Electrical to mechanical

T or F--No conversion of energy is ever 100 percent efficient.
92 percent

Exercise C

T or F--The varying angles of Polaris as we go North and South demonstrate the fact that the earth is round.

78 percent

Exercise D

If we get 4 times as far from the gravitational center of Earth we would change the gravitational force to

1) 4 times
2) 8 times 3) 1/4th 4) 1/8th 5) 1/16th

50 percent

Exercise E

According to the law of definite proportions the percent by weight of each element in a compound is constant. For example the percent hydrogen in water would always be about

1) 2% 2) 11% 3) 20 % 4) 67% 5) 33%

52 percent

Exercise G

See earlier discussion of "report labs."

Exercise H

Matching

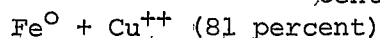
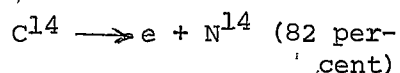
$$I = \frac{1}{D^2} \quad (61 \text{ percent})$$

$$A = C + 273 \quad (55 \text{ percent})$$

$$V = \pi r^2 h$$

$$KE = \frac{1}{2} m v^2$$

$$\frac{\text{Area}^1}{\text{Area}^2} = \frac{T_1}{T_2}$$



$$760 \text{ mm} \longrightarrow 690 \text{ mm}$$

As, Sb, Bi

$$\text{Hg} = 13.5$$

1. Kepler's Second Law

2. beta emission

3. Torrecelli climbs a mountain

4. Mendeleev

5. replacement

6. measuring a cylinder

7. Coulombic force

8. molecular collisions

9. grams per ml

10. Charles' Law

Exercise I

T or F--Oxygen¹⁶ and Oxygen¹⁷ are isotopes.
91 percent

T or F--After 3 half lives 100 C¹⁴ atoms would be reduced to only 33 C¹⁴ atoms.
86 percent

Exercise J

The characteristic spectral emissions from excited atoms are caused by:

- 1) the chemical activity of certain metals
 - 2) the falling back of promoted electrons to ground state
 - 3) unpaired "d" electrons
 - 4) neutron absorption
 - 5) radioactive decay
- 89 percent

T or F--The electronegativity number for boron is probably higher than for carbon.
89 percent

Exercise K

If atom #9 and atom #5 combine the correct formula would be:
1) XY 2) X₂Y 3) X₂Y₃ 4) XY₂ 5) none of these
78 percent

Which of the following would be the most polar molecule?
1) CO₂ 2) Cl₂ 3) CCl₄ 4) H₂ 5) HCl
72 percent

Exercise L

A prerequisite for a cis-trans isomer is a:
1) double bond
2) branched chain
3) asymmetric carbon
4) sugar
5) none of these
47 percent

Exercise M

T or F--Esterification from alcohols and acids is an hydrolysis reaction

60 percent

Exercise N

T or F--The substrate for lipase is a fat.

78 percent

Enzymes are not which?

- 1) destroyed in reactions
- 2) protein
- 3) influenced by H^+ conc.
- 4) found in all organism
- 5) biochemical catalysts

76 percent

Exercise O

Matching:

- | | |
|--|-------------------------------------|
| Phage labeled with isotopes | 1. spindle fibers |
| 2N cell $\rightarrow$ two 2 N cells (81 percent) | 2. phenyl alanine |
| Polyribosomes | 3. enzyme |
| Centriole (69 percent) | 4. mitodrondrion |
| Kinetin; gibberilin; 2,4,D | 5. mitosis |
| gene | 6. centromere |
| Cristae | 7. 4 N tetrad $\rightarrow$ gametes |
| Adenine | 8. reticulum |
| U U U | 9. blue green algae |
| chromatid (68 percent) | 10. thymine |
| meiosis | 11. 3 nucleotides |
| procaryotic cell | 12. Hershey and Chase |
| codon | 13. G - C |
| hydrogen bonds | 14. triggers mitosis |
| heterotrophic (71 percent) | 15. yeast |

Exercise P

T or F--DNA replicates in mitosis during metaphase.

83 percent

T or F--Mitosis involves crossing over.

85 percent

Exercise R

Essay: How would you distinguish a blue-green from a green alga and both from a diatom under the microscope?

32 percent correct and complete

Exercise S

Essay: Define the surface/volume problem.

80 percent correct and complete

Exercise T

Essay: Give examples of protective color in nature.

79 percent correct and complete

Exercise U

See earlier evaluation of "report exercises."

Exercise V

Red blood cells are:

- 1) spherical
- 2) larger than leucocytes
- 3) capable of initiating blood clotting
- 4) recycled to the heart through the lymph
- 5) none of these

44 percent

From the right ventricle the blood will flow next into the:

- 1) right atrium
- 2) vena cava
- 3) left ventricle
- 4) pulmonary vein
- 5) none of these

57 percent

Exercise W

Name two internal anatomical differences in the anatomy of the rat compared to the human. (69 percent)

Exercise X

See earlier evaluation of "report exercises."

Exercise Y

T or F--This plant (a rose) which you have in your hand:
 is a composite (72 percent)
 is a dicot (91 percent)
 indicates a high degree of evolutionary advancement
 in its number of stamens (60 percent)

A monocot does not have:

- 1) flowers
 - 2) parallel veined leaves
 - 3) lilies as examples
 - 4) woody tissue
 - 5) flower parts in 3's
- 91 percent

Which characteristic is associated with an advanced evolutionary condition?

- 1) Ovary inferior
 - 2) petals many
 - 3) stamens many
 - 4) flowers regular
 - 5) none of these
- 44 percent

Exercise Z

T or F--This plant (a rose)
 has leaves that are palmately compound (91 percent)
 has pinnate leaf venation (96.5 percent)
 has leaves with stipules (88 percent)

LITERATURE CONSULTED

LITERATURE CONSULTED

PART ONE

Chapter I

Whitehead, Alfred North. Science and the Modern World.

New York: The MacMillan Co., 1954.

Conant, James Bryant. Modern Science and Modern Man.

New York: Columbia University Press, 1952.

Brooks, Van Wyck. Three Essays on America. New York: E. P.

Dutton and Co., 1934.

Chapter II

Educational Policies Commission. Report of the Commission.

Education and the Spirit of Science. Washington, D. C.: National

Education Association of the United States, 1966.

Hurd, Paul deHart. New Directions in Teaching Secondary Science.

Chicago: Rand McNally and Co., 1969.

Lee, Eugene C. New Developments in Science Teaching. Belmont,

California: Wadsworth Publishing Co., 1967.

Schwab, Joseph C. Biology Teachers Handbook. New York:

John Wiley and Sons, Inc., 1963

Commission on Undergraduate Education in the Biological Sciences.

Report of the Commission. Biology for the Non-Major. Washington, D. C.:

The George Washington University, 1967.

Chapter III

Commission on Science Education, American Association for the Advancement of Science. The Psychological Bases of Science--A Process Approach. Washington, D.C.: American Association for the Advancement of Science, 1967.

Karplus, Robert. Theoretical Background of the Science Curriculum Study. Berkeley: The Science Curriculum Improvement Study, 1965.

Wailes, James R. ed. Elementary School Science Experimental Projects. Boulder, Colorado: University of Colorado Press, 1965.

Lockard, J. David. ed. Sixth Report of the International Clearinghouse on Science and Mathematics Curriculum Developments, 1968. College Park, Maryland: University of Maryland Press, 1968.

Chapter IV

Eiss, Albert F. ed. Viewpoints on Undergraduate College Science Programs. Washington, D.C.: National Science Teachers Association, 1966.

McGrath, Earl J. ed. Science in General Education. Dubuque, Iowa: Wm. C. Brown Co., 1948.

National Science Teachers Association. Steps Toward Scientific Literacy. Washington, D.C.: National Science Teachers Association, 1968.

The Pennsylvania Academy of Science. Report of a Conference on Science Education. Guidelines for Improving College Science Programs. Harrisburg: The Pennsylvania Academy of Science, 1964.

Chapter V

Krathwohl, David R.; Bloom, Benjamin S.; and Masia, Bertram B.

Taxonomy of Educational Objectives. New York: David McKay Co., Inc.,

1956.

PART TWO

Note: Works are listed in the order of the sequence of laboratory exercises.

The Elementary School Curriculum Project. Astronomy. Vol. 4:
The Message of Starlight. Urbana: The University of Illinois, 1966.

The Elementary School Curriculum Project. Astronomy. Vol. 2:
The Universe in Motion. Urbana: The University of Illinois, 1966.

Physical Science Curriculum Project. Design of the Cosmos.
New York: Holt, Rinehart and Winston, Inc., 1965.

Physical Science Study Committee. Laboratory Guide--Physics,
Second Edition. New York: D. C. Heath and Co., 1965.

Chemical Education Material Study. Laboratory Manual--Chemistry,
An Experimental Science. San Francisco: W. H. Freeman and Co., 1963.

Eblin, Lawrence P. The Elements of Chemistry in the Laboratory.
New York: Harcourt, Brace and World, Inc., 1965.

Postl, Anton. Laboratory Experiments in Physical Science.
Minneapolis: Burgess Publishing Co., 1966.

Weaver, Elbert C. ed. Scientific Experiments in Chemistry.
New York: Holt, Rinehart and Winston, Inc., 1966.

Joseph, Alexander; Brandwein, Paul F.; Morholt, Evelyn; Pollack,
Harvey; Castka, Joseph F. A Sourcebook for the Physical Sciences.
New York: Harcourt, Brace and World, Inc., 1961.

Maurer, Robert; Krauskopf, Konrad B. Experiments and Exercises
in Physical Science. New York: McGraw-Hill, 1967.

PSNS Project Staff. An Approach to Physical Science, Teacher's Resource Book. New York: John Wiley and Sons, Inc., 1969.

Hart, Harold; Schuetz, Robert D. A Laboratory Manual for a Short Course in Organic Chemistry. Boston: Houghton Mifflin Co., 1953.

Harrow, Benjamin; Borek, Ernest; Mazur, Abraham; Stone, Gilbert C. H.; Wagreich, Harry. Laboratory Manual of Biochemistry, Fifth Edition. Philadelphia: W. B. Saunders Co., 1961.

Wald, George; Hopkins, Johns; Albersheim, Peter; Dowling, John; Denhardt, David. Twenty-Six Afternoons of Biology, Second Edition. Reading, Massachusetts: Addison-Wesley Co., 1966.

Morholt, Evelyn; Brandwein, Paul F.; Joseph, Alexander. A Sourcebook of the Biological Sciences. New York: Harcourt, Brace and World, Inc., 1958.

Humphrey, Donald G.; Van Dyke, Henry; Willis, David L. Life in the Laboratory. New York: Harcourt, Brace and World, Inc., 1965.

Solberg, R. A.; Preece, S. J. Introduction to Biology Laboratory. Missoula: Mountain Press, 1968.

National Science Teachers Association. Helping Children Learn Science. Washington, D.C.: National Science Teachers Association Publications, 1966.

The Earth Science Curriculum Project. Investigating the Earth. Boston: Houghton Mifflin Company, 1967.

Lawson, Chester A.; Paulson, Richard E. Laboratory and Field Studies in Biology. New York: Holt, Rinehart and Winston, Inc., 1960.

Greulach, Victor A.; Adams, J. Edison. Plants, Introductory Investigations in Botany. New York: John Wiley and Sons, 1962.

Baker, Jeffrey J. W.; Allen, Garland E.; Gage, Elizabeth; Webster, Steven K. Experiments in the Study of Biology. Reading, Massachusetts: Addison-Wesley Publishing Co., 1967.

Nelson, Gideon E.; Latima, Albert A. Laboratory Manual: Fundamental Concepts in Biology. New York: John Wiley and Sons, Inc., 1968.

Seeley, Harry W.; Van de mark, Paul J. Microbes in Action: A Laboratory Manual of Microbiology. San Francisco: W. H. Freeman and Co., 1962.

International Communications Films. Catalog of 8 mm. Films and Filmstrips. Monterey Park: Doubleday and Co., Inc., 1968.

Eiseley, Loren. The Immense Journey. New York: Vintage Books, 1957.

Turttox. Biological Supplies, 1969/70 Catalog. Chicago: General Biological, Inc., 1969.

The Welsh Scientific Company. Laboratory Apparatus, 1968 Edition. Skokie, Illinois: The Welsh Scientific Company, 1968.

Macalester Scientific Corporation. Science Catalog. Waltham, Massachusetts: Macalester Scientific Corporation, 1968.

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