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PHYSICS

FOR IOWA SCHOOLS

STATE OF IOWA
DEPARTMENT OF
PUBLIC INSTRUCTION

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FOREWORD

Recent developments in world affairs and recent advances in the field of science have focused attention on physics and related subjects. One needs but to scan the daily news reports to realize the impact of science upon the nation, state, and community.

The courses offered in our schools must be as timely as the morning newspaper. If this is not the case, we will be doing an injustice to the children of Iowa by teaching them to live in the past rather than preparing them to live in the future.

The purpose of this physics guide is to assist the teacher in developing his own course to meet the needs of two types of students: (1) those who plan further study, and (2) those who will terminate their formal education with high school graduation.

The Iowa Department of Public Instruction hopes that physics teachers throughout Iowa will find viewpoints and ideas in this course of study that will enable them to fulfill the role of physics teacher more effectively.

PAUL F. JOHNSTON
State Superintendent of Public Instruction

COURSE OF STUDY RATIONALE

This course of study for physics has been planned to serve as a guide for those schools that are not teaching physics as outlined by the Physical Science Study Committee. The program outlined here is intermediate between the traditional physics of the past and the new approach. Laboratory activities prepared by the Physical Science Study Committee could well be used to enrich and supplement this Iowa physics group and to provide a course which should fulfill the needs of any school. Even those schools that are following the Physical Science Study Committee program should find much in this course of study which would benefit and broaden their approach to physics.

The Science Area Committee recommends the modification of this physics course of study to meet the local needs of each school. For this reason, it should not be accepted *en toto* but adapted to serve best the needs of the students in each school. "Write-in" space has been provided throughout the outline to allow the teacher to add his own suggestions for activities, references, aids, and ideas.

No course of study is the ultimate, and this one is no exception. Each teacher is urged to use films, supplementary references, and other aids which will help the students understand the basic concepts included in this program.

T. R. Porter
Chairman, Science Area Committee

TABLE OF CONTENTS

APPENDIX

* Directions to be reprinted and distributed to students.

** Enrichment material for teachers to use in discussion preparations.

FIRST SEMESTER

I. FUNDAMENTALS

A. INTRODUCTION AND SCOPE

1. Concepts and Understandings

Define physics, its purposes, and potentials.

Outline the course to be offered. At least a semester outline should be prepared and distributed during the first meeting. This outline need not be dated.

The semester program can be arranged by numerical reference, with each item including sufficient material for a daily reading assignment, a practice assignment, a homework assignment, and a possible laboratory experiment or demonstration. Each student will then be familiar with the course content.

The outline can include suggested reference reading, advanced "extra credit" reports or experiments, and approximate test periods.

2. Suggested Activities

Activities during the first few periods of the physics course can determine definitely the degree of success the course will experience. Plunging into the complexities of physics with problems, new terms, and formidable equipment, is not desirable. Neither is a wishy-washy discussion of basic science.

The teacher should strive to introduce physics as an interesting part of our daily life. It should be presented as a major influence in the past, present, and future of the individual, the country, and the world. It should be considered also as a factor in economic and political decisions affecting each individual.

Assignments should not be lengthy during the first few days but should be made for each period. Particular attention should be given to their correct completion, with definite well-publicized penalties for non-compliance. Class members who may have attended seminars and conferences during the summer should give oral reports and show slides or pictures. So should those who have visited areas with scientific displays (Corning Glass Works Museum, Museum of Science and Industry, hydro-electric power systems, etc.). Some very good introductory movies are available for presenting scientific facts (*Precisely So, The Day Before Tomorrow, Leverage*). Current movies on satellite and rocket experiments would be appropriate during this period (*Atlas Missile, Project Echo, etc.*)

3. Teacher and Pupil References

See Appendix A, "Introduction and Scope."

See Appendix B, "Films."

4. Audio-Visual Aids, Equipment, and Supplies

See Appendixes A and B.

5. **Teacher Notes**

Define physics; develop an understanding of its purpose and potential.

B. PRACTICE ASSIGNMENTS

1. **Concepts and Understandings**

Practice assignments should be made each period. The instruction covered in the period will dictate whether the assignment will concern reading, a set of practice problems, or a laboratory report.

At least one scientific book should be read by each student during the physics course.

2. **Suggested Activities**

A short quiz at the beginning of the next class can be a check on reading assignments. Practice problems should be written out. They can either be collected and graded by the teacher, or placed on the blackboard by students for class discussion. In either case, records should be maintained on student participation. See Problem Solving (I, K) for additional discussion on this. A written report should be required for scientific reading.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

5. **Teacher Notes**

Book reports may be completed cooperatively with English classes.

Practice assignments will assist pupils in learning physics techniques.

Practice assignments include reading textbook material, working text problems assigned by the instructor, preparing laboratory reports for experiments completed in class, and reading assigned reference material in scientific books other than textbooks.

C. LABORATORY

1. Concepts and Understandings

The laboratory is an integral part of the physics course. Having it occur at a definite time is desirable (e.g., Wednesday of each week).

The equipment available will determine the extent and type of laboratory. If there is sufficient equipment, a recommended arrangement is two persons working together, with each group doing the same experiment. This partner arrangement should be on a rotating basis so that a student does not work with another student more than two or three laboratory periods. If there is only one set of apparatus, the laboratory session will consist of a teacher-conducted experiment, with students performing various functions during the experiment. Often films can be used, especially the PSSC series, to introduce an experiment. An experiment conducted outside the classroom could be a group experiment.

2. Suggested Activities

A laboratory period does not necessarily take place in a classroom. Trips to locations in the school building (switchboard, power system, etc.) can provide laboratory experience. Trips to nearby industries or utilities (radio stations, power companies, telephone companies, bakeries, etc.) are also valuable and can usually be scheduled during the assigned periods. The possibility of visits to the school by industrial representatives should be considered.

Some national industries have prepared demonstrations and will spend a few days at the school. The Visiting Scientist program is a valuable aid in this regard.

Local industries should be remembered when considering visits, since arrangements and displays usually can be made through a pupil in the class. Occasional after-school or Saturday programs or trips are suggested.

3. Teacher and Pupil References

See Appendix C, "Laboratory Procedures."

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix D. Recommended laboratory apparatus from two sources is contained in this appendix.

Industries such as G.E. (House of Magic), Oak Ridge Atomic Energy Commission, Westinghouse, and National Aeronautics and Space Administration (Space Mobile) schedule demonstrations.

Use the blackboard, with pupils showing problems on the board and having work reviewed by the teacher and the rest of the class.

Have pupils maintain workbooks, preferably in the form of loose leaf notebooks. Encourage them to jot down notes during the class period.

5. **Teacher Notes**

Laboratory work is an integral part of the physics course. Experiments explain theoretical physical principles. They may include trips outside the classroom to observe physical principles.

Have students show each step in solving a problem.

D. MATHEMATICS REVIEW: MATHEMATICS AS A TOOL

1. **Concepts and Understandings**

Several periods should be spent in review of mathematics. During this review the teacher should also guide the mathematical thinking of the student into the areas that will be used. Any feeling of inadequacy in mathematics should be dispelled during this time. Many misunderstandings of physics are derived from poor instruction in applicable mathematics or a student feeling completely lost in mathematical manipulations. Introduce mathematics as a tool, perhaps showing the simplified applicable aspects without going deeply into various laws, rules, and theory.

2. **Suggested Activities**

Review mathematics as a language and as a tool. Discuss:

- Literal number
- Addition
- Subtraction
- Multiplication
- Division
- Negative numbers
- Exponents
- Radical
- Powers of ten
- Multiplication with powers of ten
- Division with powers of ten

3. **Teacher and Pupil References**

See Appendix E, "Mathematics for Physics." This reference includes a sample assignment for arithmetic.

Any basic mathematics book.

Mathematics for Electricians and Radio Men, Cooke (McGraw-Hill) 1942.

4. **Audio-Visual Aids, Equipment, and Supplies**

Appendix I discusses mathematics vocabulary terms useful in understanding physical operations.

5. **Teacher Notes**

The mathematics used as a tool for physics principles and problems should be thoroughly understood by students.

A fear of mathematics generated through former contacts must be dispelled.

While it is definitely suggested that mathematics be thoroughly reviewed, there are reasonable factors that may influence offering this review at the beginning of the physics work.

The material outline is considered the minimum mathematics review required for the secondary physics course. It can be offered as a unit at the beginning of the physics course or integrated into the subject material as needed.

E. MATHEMATICS REVIEW: ALGEBRA

1. **Concepts and Understandings**

Review problem-solving operations, including word problems and symbols. Introduce the idea of learning a concept rather than a manipulation.

2. **Suggested Activities**

Review algebraic operations, especially emphasizing those applicable to physics.

- Algebraic expressions, signs, and symbolisms
- Factor
- Coefficient
- Evaluation, terms, grouping
- Equations, literal equations, formulas
- Primes and subscripts
- Special products and factoring
- Simultaneous linear equations
- Quadratic equations

3. **Teacher and Pupil References**

See Appendix E, "Mathematics for Physics." Includes sample assignment for algebra.

Any basic algebra book.

Mathematics for Electricians and Radio Men by Cooke (McGraw-Hill) 1942.

Mathematics Tables—Burrington Company (current edition).

4. **Audio-Visual Aids, Equipment, and Supplies**

See D above.

5. **Teacher Notes**

See D above.

The algebra used as a tool for physics

principles and problems should be thoroughly understood.

F. MATHEMATICS REVIEW: TRIGONOMETRY

1. Concepts and Understandings

Review problem-solving having to do with triangles.

Introduce the concept of vectors.

2. Suggested Activities

Review trigonometric operations as follows:

- Angles
- Radian
- Triangles
- Similar triangles
- Right triangles
- Trigonometric functions to include: sine, cosine, tangent
- Signs of the functions
- Functions of 0°, 30°, 45°, 60°, 90°, 180°, 270°, 360°
- Line representation of the functions
- Logarithms

3. Teacher and Pupil References

See Appendix E, "Mathematics for Physics." This reference includes a sample assignment for trigonometry.

4. Audio-Visual Aids, Equipment, and Supplies

See D above.

5. Teacher Notes

See D above.

Students who have not had trigonometry will require special attention. If the entire class has not had trigonometry, several periods of instruction on trigonometric functions should be held. If most have had the subject, instruction for the others after school might be arranged; or students might be enrolled in a trigonometry class concurrent with physics.

Logarithm tables are available in most handbooks. Study of instructions should enable even the inexperienced student to use them.

G. MATHEMATICS REVIEW: GRAPHS

1. Concepts and Understandings

Review problem-solving properties of graphs and pictorial representations.

2. Suggested Activities

Review the methods of expressing relationship existing between quantities by a pictorial representation.

Review:
- Axis
- Reference point
- Ordinate
- Abscissa
- Methods of plotting
- Quadrants
- Graphs of linear equations
- Variables
- Graphical solutions of simultaneous linear equations
- Graphs for experimental data
- Graphic charts

3. Teacher and Pupil References

See Appendix E, "Mathematics for Physics." This reference includes a sample assignment for graphs.

Any basic trigonometry or algebra text.

Mathematics for Electricians and Radio Men by Cooke (McGraw-Hill) 1942.

Mathematics Tables — Burrington Company (current edition).

4. Audio-Visual Aids, Equipment, and Supplies

Graph paper should be furnished for plotting the assignments. See D above.

5. Teacher Notes

See D above.

H. HANDBOOK USE

1. Concepts and Understandings

The student should be introduced to various handbooks used in mathematics, physics, and chemistry. Their use during problem assignments and laboratory work to obtain standard values or formulas should be emphasized.

2. Suggested Activities

Several handbooks should be available in the department or school library. During the periods when this area is being discussed, other handbooks of mathematics and science should be secured from area industry or by students whose fathers are scientists or engineers. The use of these handbooks should be explained.

3. Teacher and Pupil References

Handbook of Physics and Chemistry — Chemical Rubber Publishing Company (current edition).

4. Audio-Visual Aids, Equipment, and Supplies

Handbooks (at least 3 copies) should be available in the school and community library for use by the students.

5. Teacher Notes

A practice assignment on use of handbooks is suggested.

General physics formulas, tables of experimental information, mathematics tables, and chemistry information are contained in prepared handbooks. This information often assists in developing an understanding of principles and problems.

I. SIGNIFICANT FIGURES

1. Concepts and Understandings

The student should learn to simplify his mathematical manipulations to appreciate the physics learned. All but the simplest computations can be made using logarithms or a slide rule. The accuracy of any result cannot exceed the accuracy of the data. Measurements encountered in this course usually will not exceed three numerical places or "significant figures." The student can save much time by using the rules for mathematical operations dealing with significant figures. His answer will be just as accurate as the one he would obtain in a half hour multiplying and dividing a long string of mathematical numbers.

2. Suggested Activities

Have the student measure a block of wood or a cylinder of metal with a ruler and figure the surface area and volume. Go through the mathematical computations showing how significant figures enter into the operation. Measure the block or cylinder with a more accurate device (a caliper) and compute the volume. Note the difference with the more accurate measuring device.

3. **Teacher and Pupil References**

See Appendix G, "Significant Figures."

4. **Audio-Visual Aids, Equipment, and Supplies**

For each two students:
- Block of wood
- Cylinder
- Ruler

5. **Teacher Notes**

The teacher can introduce more accurate measuring devices like calipers or micrometers. A large class model is recommended for discussion.

A practice assignment could be to compute the error obtained by using the "significant figure" concept. The accuracy of a solution to a physics problem or experiment is determined by the "significance" of the measured properties.

Significance can be increased by specially-designed measuring adjuncts.

J. USE OF SLIDE RULE

1. **Concepts and Understandings**

Students can save much time learning to solve problems in physics by using a slide rule. Much of their assumed difficulty comes from inability of the student to accurately use mathematics. The slide rule is suggested for use in obtaining solutions and answer checks.

2. **Suggested Activities**

Instruct in basic mathematical operation of the slide rule, including: the principle, multiplication, division, roots, and powers.

3. Teacher and Pupil References

Slide Rule Operations (Pamphlets are available with the purchase of slide rules)

Keuffel Essler Company, *Slide Rule Manual* by Kells, Kern, Bland

Sample assignment, "Handbooks and Slide Rule," Appendix E

4. Audio-Visual Aids, Equipment, and Supplies

Classroom demonstration on slide rule

5. Teacher Notes

The slide rule is a valuable tool and time saver in solving physics problems.

K. PROBLEM SOLVING

1. Concepts and Understandings

Application of textbook learning to practical problems will help the student understand the subject matter of the problems and fix in mind the mathematical principles involved. The working of the simpler problems first will tend to make the more difficult ones easier to solve. A student should be encouraged to do all problems in the order assigned. At times this may appear useless, and the student may want to do more interesting things, but time spent in working the problems will amply repay him in giving a depth of understanding. Progress should not stop if a problem appears impossible to solve. The student should return to such problems when the mind is fresh—or do a similar problem in class.

2. Suggested Activities

Problems are perhaps the major method of presenting applicable outside assignments in physics for the student. The student, however, must do the problems and arrive at an understanding of them. A sample of the type assigned could be worked at the end of each class period. Problems placed on the board by students could be used to start the next day's materials.

3. Teacher and Pupil References

See Appendix H, "Problem Solving."

4. **Audio-Visual Aids, Equipment, and Supplies**

Blackboard space for three or four students to put problems on board.

How to Solve Physics Problems by Edwin M. Ripen, Rider Publishing Company (current edition)

5. **Teacher Notes**

It is difficult to decide whether or not problems should be counted as part of an over-all grade. A suggestion is to require that a certain percentage (say 60 per cent) must be turned in before a passing grade is given. Problems then should appear on daily quizzes. Problem assignments turned in should be neat and complete.

The application of physics principles to practical problems provides the foundation for technical advancements. Physics problems, no matter how complex, are the compilation of fundamental physics principles, and even the most complex problem can be solved by patiently applying these principles.

L. LANGUAGE OF PHYSICS AND UNITS

1. **Concepts and Understandings**

Physics will deal with objects and concepts of widely differing sizes. When one goes beyond the limits of normal observations in largeness or smallness, it becomes difficult to grasp their actual size. Standards are used particularly in mass, length, and time; and measurements larger or smaller are noted in relations to these standards. Different systems will be encountered (e.g., metric and English) and should be noted.

2. **Suggested Activities**

Use a space and time scale chart of the universe to demonstrate the ratio of sizes and time. Discuss the metric and English systems of measurement. Distinguish between fundamental (L, M, T) and derived units.

Emphasize the relationship between the numerical value of a quantity and the unit used in the measurement.

3. **Teacher and Pupil References**

Most physics textbooks have a section on references.

See Appendix I, "Concepts and Terms."

4. **Audio-Visual Aids, Equipment, and Supplies**

Space-time chart

Charts and equipment demonstrating fundamental units of length, mass, time in metric and English systems.

5. **Teacher Notes**

Physics deals with objects and concepts of widely differing sizes. The limits of normal observations must be expanding in all dimensions to grasp this phenomenon. Standards are used as comparisons. Different measuring systems will be encountered.

II. MECHANICS

A. MATTER AND ENERGY—INTRODUCTION

1. Concepts and Understandings

Matter and energy are the two fundamental agents of the physical universe. These items are the subjects of this section.

Mechanics is the application of energy by means of material items.

2. Suggested Activities

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix D, "Lists of Laboratory and Demonstration Equipment."

Laboratory experiment on density and volume.

5. Teacher Notes

B. PHYSICAL ASPECTS

1. Concepts and Understandings

Matter — What is it? Atoms, molecules, crystals? What form is it in? Solid, liquid, gas?

Energy—What is it and what are the various units used to measure it? What are the different forms that energy may assume (heat, light, sound, electricity)?

How is energy transmitted from one body to another by means of mechanics, heat conduction, and radiation?

How is energy in its different forms used to change matter?

2. Suggested Activities

Simple classroom demonstrations can be made of the different kinds of energy. Gas flame, light bulb, musical horn, etc.

A visit to an electric power plant would show the way energy is transmitted from place to place.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

5. Teacher Notes

C. FORCE

1. Concepts and Understandings

Units of force (Scaler and vector quantities)
Methods of measuring force
Force vectors
Resultant force
Forces in a straight line
Forces at right angles
Forces at acute angles
Forces at obtuse angles
Multiple forces acting on a point
Equilibrium of forces
Resolution of forces
Forces of gravity
Parallel forces
Moment of force—Torque
Equilibrium of parallel forces
Center of gravity
Equilibrium, stable, unstable, and neutral
Conditions of equilibrium (point, extended body)
Friction, sliding, coefficient of friction

2. Suggested Activities

The opening section on force may be handled best by a combination of lecture, working models (using strings, weights, and spring scales) and blackboard work.

Numerical problems can be illustrated with a model. The various components can be represented on the blackboard accompanied by the solution of the problem numerically.

The section on forces is most important, for the concepts and skills involved will be used by the student in further work.

The areas from moments to friction are best covered by demonstrations followed by students' lab experiments. Evaluation of the force section may be accomplished by problems (numerical) for the first part with the student then performing a short experiment.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

Demonstration and laboratory experiment on vectors.

See Appendix D. Demonstration equipment and laboratory experiment available in all cases.

5. **Teacher Notes**

Force—Students should master the methods of solving force problems. Mastery of the skills and methods in this section will be very beneficial in future work. Heavy emphasis on problems and the solving of many problems is best.

Definition of force: A physical phenomenon incorporating applications of matter and energy. Force is measurable.

D. MOTION

1. **Concepts and Understandings**

Speed $\left(\text{speed} = \dfrac{\text{distance}}{\text{time}}\right)$

Velocity (Vel = s/t)

Velocity vectors (resolution of)

2. **Suggested Activities**

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D. Demonstration equipment and laboratory experiment available in all cases.

5. **Teacher Notes**

E. ACCELERATION

1. **Concepts and Understandings**

   Equation for uniform acceleration, motion
   Equation for uniform retarded motion
   Equation for freely falling bodies
   Effect of atmosphere on free fall
   Terminal velocity
   Path of a projectile

2. **Suggested Activities**

   Acceleration can be shown by means of free fall apparatus in which an electric current pierces a tape as the object falls. The increasing distance between the holes in the tape shows the acceleration.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

5. **Teacher Notes**

   Acceleration—The free fall apparatus previously described can be used both for demonstration before the class and as equipment for the student's own determination of acceleration. If the apparatus operation is fully and clearly explained, there should be no difficulty for the student.

F. LAWS OF MOTION

1. **Concepts and Understandings**

   Inertia
   Acceleration
   Force and mass units
   Force on a body of known weight
   Impulse and momentum
   Law of interaction

2. **Suggested Activities**

Laws of motion—limited to lecture

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D. Demonstration equipment and laboratory equipment available in all cases.

5. **Teacher Notes**

Definition of motion: Motion is the application of force. There are fundamental laws dealing with motion.

G. GRAVITATION

1. **Concepts and Understandings**

Law of universal gravitational attraction
Variation of weight with location
Operation of balance scales
Satellites (Welper)

2. **Suggested Activities**

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D. Demonstration equipment and laboratory equipment available in all cases.

5. **Teacher Notes**

H. CIRCULAR AND ROTARY MOTION

1. **Concepts and Understandings**

   Circular motion
   Centripetal force
   Calculation of centripetal force
   Satellite motion
   Rotary motion
   Precession
   Gyroscope

2. **Suggested Activities**

   Circular motion may be demonstrated by weight and string, actual gyroscope, or other rotating apparatus. Problems should be thoroughly covered as the concepts and skills are used in future work.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

   See Appendix D. Demonstration equipment and laboratory experiment available in all cases.

5. **Teacher Notes**

I. HARMONIC MOTION

1. Concepts and Understandings

Relation between rotary and harmonic motion

Pendulum, calculation of the period of a pendulum

Definition of work

Units of work W = f × s

Metric system of units

2. Suggested Activities

The pendulum is a good example of harmonic motion and calculation of its period will cover most of the concept.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix D. Demonstration equipment and laboratory experiment available in all cases.

5. Teacher Notes

Pendulum — The pendulum problems should be easily mastered by the student.

Problems concerning the gyroscope may cause difficulty.

J. WORK

1. Concepts and Understandings

Definition of work

Units of work, W = f × s

Metric system of units

2. Suggested Activities

Work is best covered by simple problems (numerical).

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

5. **Teacher Notes**

K. POWER

1. **Concepts and Understandings**

   Definition of power, $P = W/t$
   Units of power, erg/ sec, f lb/sec

2. **Suggested Activities**

   Limited to numerical problems. (Special attention should be given to manipulation of units of work and power.)

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

   See Appendix D. Demonstration equipment and laboratory experiment available in all cases.

5. **Teacher Notes**

L. ENERGY

1. Concepts and Understandings

Definition of energy

Kinds of mechanical energy (potential and kinetic)

Measurement of energy

Mass and energy (variation of mass with velocity, Einstein's equation)

2. Suggested Activities

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix D. Demonstration equipment and laboratory experiment available in all cases.

5. Teacher Notes

M. MACHINES

1. Concepts and Understandings

Six simple machines
Mechanical advantage
Efficiency of machines
The lever
The pulley
The wheel and axle
The inclined plane
The wedge
The screw
Compound machines
Gear wheels
Worm wheel
Differential pulley

2. Suggested Activities

Class demonstrations using simple machines. A possible construction of a compound machine by a student or group.

Observing and listing the simple machines seen during the day.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D. Demonstration equipment and laboratory experiment available in all cases.

5. **Teacher Notes**

What is a machine? Mechanical advantage and efficiency measures the ability of a machine to perform a function.

N. MECHANICS OF GASES

1. **Concepts and Understandings**

Atmosphere
Pressure and weight
Barometers
Units of pressure
Boyle's law
Gauge pressure
Using air pressure
Lift and the airplane
Venturi effect
The helicopter

2. **Suggested Activities**

Generation of steam
Creating a vacuum with a pump
Observing barometric changes
Film on what makes an airplane fly

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D. Demonstration equipment and laboratory experiment available in all cases.

5. **Teacher Notes**

The principles of mechanics can be applied to gaseous material.

O. MECHANICS OF LIQUIDS

1. **Concepts and Understandings**

Pressure and surface area
Pressure in a liquid
Pressure and liquid depth
Pascal's law
Hydraulic press
Buoyancy
Archimedes' principle
Specific gravity

2. **Suggested Activities**

Archimedes' principle can be demonstrated easily with simple apparatus.

Measurement of a body in air and water

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D. Demonstration equipment and laboratory experiments available in all cases.

5. **Teacher Notes**

The principles of mechanics can be applied to liquids.

III. HEAT

A. INTRODUCTION

1. Concepts and Understandings

Before the 1800's, heat was thought to be an invisible weightless fluid. This fluid was called caloric. It was produced when a substance burned. James Joule showed by experiment that a given amount of work always produces the same amount of heat. He thus proved that heat is a form of energy, which we call thermal energy.

2. Suggested Activities

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix D.

5. Teacher Notes

Experiments
Calibrating a thermometer
Coefficient of linear expansion
Charles' law
Thermal expansion
Heat and work

B. SOURCES

1. Concepts and Understandings

Heat units (calorie and BTU)

Sources of heat, such as sun, electricity, chemical reaction, and nuclear reaction, should be explained.

2. Suggested Activities

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

5. **Teacher Notes**

C. HEAT AND TEMPERATURE

1. **Concepts and Understandings**

   The difference between heat and temperature should be carefully explained. Heat is measured by changes it produces on materials.

2. **Suggested Activities**

   Students could be asked to define the difference before a formal explanation is given. This will illustrate the various conceptions on this point.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

5. **Teacher Notes**

D. TEMPERATURE SCALES

1. Concepts and Understandings

Centigrade, Fahrenheit, and Kelvin scales: How they were derived. Methods used in converting from one scale to another. Advantages and disadvantages of each scale.

2. Suggested Activities

Charts showing relationship between the scales may be prepared, and for best results, given to each student.

Other methods of thermometry resistance, thermocouple, optical Pyrometer.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

Different types of thermometers and different scales available for demonstration.

5. Teacher Notes

When doing experiments, mix the thermometer scales used so students will learn to convert readings.

E. EXPANSION OF SOLIDS, LIQUIDS, AND GASES

1. Concepts and Understandings

The coefficient of linear expansion and the coefficient of volume expansion should be defined. The abnormal expansion of water and the fact that all gases have approximately the same coefficient of expansion may be discussed.

Thermometers and methods of graduating them may be discussed.

2. Suggested Activities

Demonstrations of many kinds can be prepared. Formula should be written in words, and mathematically.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D.

5. **Teacher Notes**

F. CHARLES' AND BOYLE'S LAWS

1. **Concepts and Understandings**

Charles' law and Boyle's law should be defined.

2. **Suggested Activities**

Experiments on this section are valuable.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D.

5. **Teacher Notes**

G. VERY LOW TEMPERATURES

1. Concepts and Understandings

Unattainability of absolute zero should be thoroughly discussed. Cryogenics should also be considered. "Cryo" is a Greek word meaning "icy cold." "Genics" means to generate. Thus cryogenics is the generation of very low temperatures. Here conduction, convection, and radiation may be discussed.

Uses of liquid gases in rockets, breathing, etc., may be mentioned. Critical temperature and critical pressure should be considered.

Production of liquid air

2. Suggested Activities

If possible a demonstration on liquid gases should be arranged, either with a manufacturer of the gases or local industry which uses them.

3. Teacher and Pupil References

See Appendix K, "Cryogenics."

4. Audio-Visual Aids, Equipment, and Supplies

Liquid nitrogen demonstration.

5. Teacher Notes

Unattainability of absolute zero should be thoroughly discussed. Cryogenics should also be discussed.

H. SPECIFIC HEAT

1. Concepts and Understandings

Heat capacity of a body is the quantity of heat needed to raise its temperature 1°.

Heat capacity $= Q/\triangle T$.

Specific heat is the ratio of heat capacity of mass or weight.

$$c = \frac{Q}{T/M}$$

Heat is equal in English and metric systems.

Methods for measuring specific heat should be shown.

2. Suggested Activities

Experiments for measuring specific heat should be conducted, using standard apparatus.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
See Appendix D.

5. **Teacher Notes**

I. FUSION, EVAPORATION, SUBLIMATION

1. **Concepts and Understandings**
Melting (fusion)
Freezing
Boiling (evaporation)
Condensing
Heat exchanges
Effect of pressure on freezing point
Methods of measuring
Heat of fusion
Vapor pressure
Boiling nucleate film vapor
Effect of pressure on boiling point and melting point
Equilibrium vapor
Pressure

2. **Suggested Activities**

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
See Appendix E.

5. **Teacher Notes**

There are three states of matter.

J. FIRST LAW OF THERMODYNAMICS

1. **Concepts and Understandings**

Thermodynamics

Quantitative relationships between heat and other forms of energy

First Law: "When heat is converted to another form of energy, or when other forms of energy are converted to heat, there is no loss of energy."

Isothermal and adiabatic processes

2. **Suggested Activities**

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix D.

5. **Teacher Notes**

K. CARNOT CYCLE

1. **Concepts and Understandings**

Carnot cycle engine

2. **Suggested Activities**

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
See Appendix D.

5. **Teacher Notes**

L. SECOND LAW OF THERMODYNAMICS

1. **Concepts and Understandings**
It is impossible for an engine to transfer heat from one body to another at a higher temperature unless work is done.

2. **Suggested Activities**

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
See Appendix D.

5. **Teacher Notes**

M. IDEAL GAS

1. Concepts and Understandings

Discuss $PV = nRT$

2. Suggested Activities

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix D.

5. Teacher Notes

What is an ideal gas? What is the importance of considering an ideal gas?

N. HEAT ENGINES

1. Concepts and Understandings

Operation of:
- Refrigerator
- Steam engine
- Diesel engine
- Gas turbine
- Turbojet
- Ramjet
- Rocket
- Heat pump

2. Suggested Activities

Small steam engines, available at local hobby stores, are good for demonstrations.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
   See Appendix D.

5. **Teacher Notes**

SECOND SEMESTER
IV. SOUND

A. WAVE MOTION

1. Concepts and Understandings

Energy transfer by waves
Characteristics of waves
Transverse waves
Longitudinal waves
Phase, period, and frequency of waves
Wave length
Properties of waves
Reflection
Refraction
Wave interference, constructive and destructive

2. Suggested Activities

Waves can be readily illustrated by use of shallow pans of water. Almost all aspects can be demonstrated.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

5. Teacher Notes

Define wave motion. Discuss measurement, units, and properties of a wave motion.

B. SOUND

1. Concepts and Understandings

Nature of sound
Transmission of sound
Production of sound
Speed of sound
The ear
Intensity
Loudness
Intensity measurement
Decibel
Pitch
Doppler effect
Audible frequency range
Inaudible sound
Ultrasonics
Forced vibrations
Resonance
Beats
Harmonics

2. **Suggested Activities**

Explanation of sound, especially the audible range, can be enhanced by the use of an audio-signal generator. Wave trains can be viewed by use of the vibrating string apparatus or an oscilloscope.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

Bell Telephone Labs have a very good phonograph record that illustrates principles of sound.

5. **Teacher Notes**

C. SONICS

1. **Concepts and Understandings**

Industrial and medical uses of ultrasonics have focused attention on these areas of sound. The principles of ultrasonics should be noted.

2. **Suggested Activities**

Demonstration or film on sonics. Also an industrial or hospital lab could be scheduled if there is a sonic unit available.

3. **Teacher and Pupil References**

See Appendix L, "Ultrasonics."

4. **Audio-Visual Aids, Equipment, and Supplies**

Sonic unit literature and demonstration may be available through Pioneer-Central Division, The Bendix Corporation.

5. **Teacher Notes**

V. LIGHT

A. INTRODUCTION: NATURE, SOURCES, VELOCITY

1. Concepts and Understandings

The study of light is a most important part of physics since most knowledge concerning the world about us is gained through seeing. We learn about properties of giant stellar systems by means of light traveling for millions of years through empty space. We learn about properties of minute atoms through light that is emitted by them and that carries in hidden form important information concerning their internal structure. Most information in our everyday life is also obtained through the medium of light.

It is not advisable in this secondary course to get too deeply involved in an attempt to explain concepts of physical phenomenon. The PSSC and Advanced Science (or Honors) courses in secondary schools are designed for this purpose. As noted previously, this regular physics course is designed to consider more the mechanics of physics.

Optics (or light) contain many areas where these fundamental concepts and historical theories could be enumerated in detail. However, the teacher must be careful not to have the instruction too complex or uninteresting. The subject of optics presents a marvelous opportunity for demonstrations and experiments to interest the student.

2. Suggested Activities

Introduce by use of films or demonstrations, some concepts of light, its nature, its sources. (See Appendix B.)

Discuss velocity of light and methods for determining it.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

Applicable movies

Various sources of light (light bulb, fluorescent light, candle, sodium or mercury light, etc.)

Chart of electromagnetic spectrum

5. Teacher Notes

What is light? What are its properties?

B. REFLECTION AND REFRACTION

1. Concepts and Understandings

Light falling on surfaces follows certain basic fundamental principles, depending upon nature and condition of surface and nature of light. Proper introduction to these principles will condition students for more advanced study in optical phenomena. Fundamental principles should include:

Reflection principles
Plane mirror reflection
Curved mirror principles
Refraction
Refractive index
Ray diagrams of reflection and refraction
Apperture
Principal axis
Principal focus
Radius of curvature
Object distance
Image distance
Focal length
Concave mirror
Convex mirror

2. Suggested Activities

Use optical wheel or similar device to demonstrate these fundamental principles. Have class participate.

Perform laboratory experiment using mirrors.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

Optical wheel with facilities to attach different apparatus to demonstrate optical principles

Mirrors, prisms, etc.

Light sources: Appendix D

Film, "Introduction to Optics," PSSC (23 minutes)

5. Teacher Notes

Light falling on a surface follows basic physics principles, depending upon nature of the light and the nature and condition of the surface. Discuss reflection and refraction.

C. LENSES

1. Concepts and Understandings

The phenomenon of refraction of light is used in construction of optical instruments that are similar in their operation to those based on reflection. These refracting instruments contain convex and concave lenses. An understanding of lenses is essential for a comprehensive understanding of optical systems. Principles should include:

- Lens definition
- Concave lens
- Ray diagram
- Principal axis
- Focal point
- Focal length
- Object distance
- Image distance
- Real image
- Virtual image
- Combination lenses

2. Suggested Activities

Use optical wheel or similar device to demonstrate principles of the lens.

Of special interest is a demonstration making use of virtual image condition. This could be an "extra credit" student assignment.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

Individual class laboratory experiment on lenses. See Appendix D.

Class members should bring for discussion devices having any lens systems. Typical objects are glasses, hand magnifiers, cameras, microscopes, and telescopes.

5. Teacher Notes

Lenses are used to control light.

D. ILLUMINATION AND COLOR

1. Concepts and Understandings

The ability to distinguish objects optically in a physical sense is determined by either the light they emit or the light they reflect. Comparisons of light intensities are necessary in either case. The student should be familiar with methods of measurement. This familiarity should logically lead into a more complete discussion of methods for obtaining light and to the atomic concept of electron readjustment to generate light. The spectrum can then be discussed, and color can be explained. Various properties of color, reflection, absorption, and refraction, should be discussed.

2. Suggested Activities

The optical wheel or similar device is again suggested for demonstrations of the properties of light to be explained in this section.

Some texts recommend work in photometry as a laboratory for this work. The experiments in photometry are not recommended for secondary schools. Instead, class experiments on light intensities in various rooms, using light meters and class demonstrations on color, are suggested.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

Classroom demonstration equipment for color. See Appendix D. Different light sources or filters can be used to explain color principles.

A class participation experiment using light meters (borrowed from camera stores if class members do not have them) would have the students take readings at various places in the home and the school. Possible situations might include: classroom with lights on and curtains drawn, classroom with curtains open and sun shining, cafeteria, gym, swimming pool, office area, school library, study desk at home. Readings could be used to make recommendation for improvement if needed.

5. Teacher Notes

The ability to distinguish objects optically is determined by either the light they emit or reflect. Comparisons of intensities of light are necessary in either case. The student should be familiar with methods of measurement.

E. POLARIZATION, INTERFERENCE—DIFFRACTION

1. Concepts and Understandings

This area of instruction incorporates material that could encompass complex explanations and derivations. It is advisable to reduce these to a minimum. However, phenomena should be explained, discussed, and demonstrated.

2. Suggested Activities

Demonstrations of these optical phenomena are suggested. There are some good films that could be used. See Appendix B. Field trips scheduled to view optical instruments will also be useful in noting these optical conditions. This is an area in which advanced students might devise "extra credit" experiments or papers.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

Interference plates
Diffraction grating
Polaroids
Film *Polarization* by Polaroid Corporation, Cambridge, Massachusetts

5. **Teacher Notes**

Optical phenomena include polarization, interference, and diffraction.

F. OPTICAL INSTRUMENTS

1. **Concepts and Understandings**

By combining the optical principles previously discussed, the student can determine how many everyday optical devices work. He also should be introduced to optical devices found in industrial organizations and required to reduce operations of these instruments to fundamentals. Some instruments that should be discussed are:

Eye, camera, microscope
Telescope, spectroscope
Polarimeter

2. **Suggested Activities**

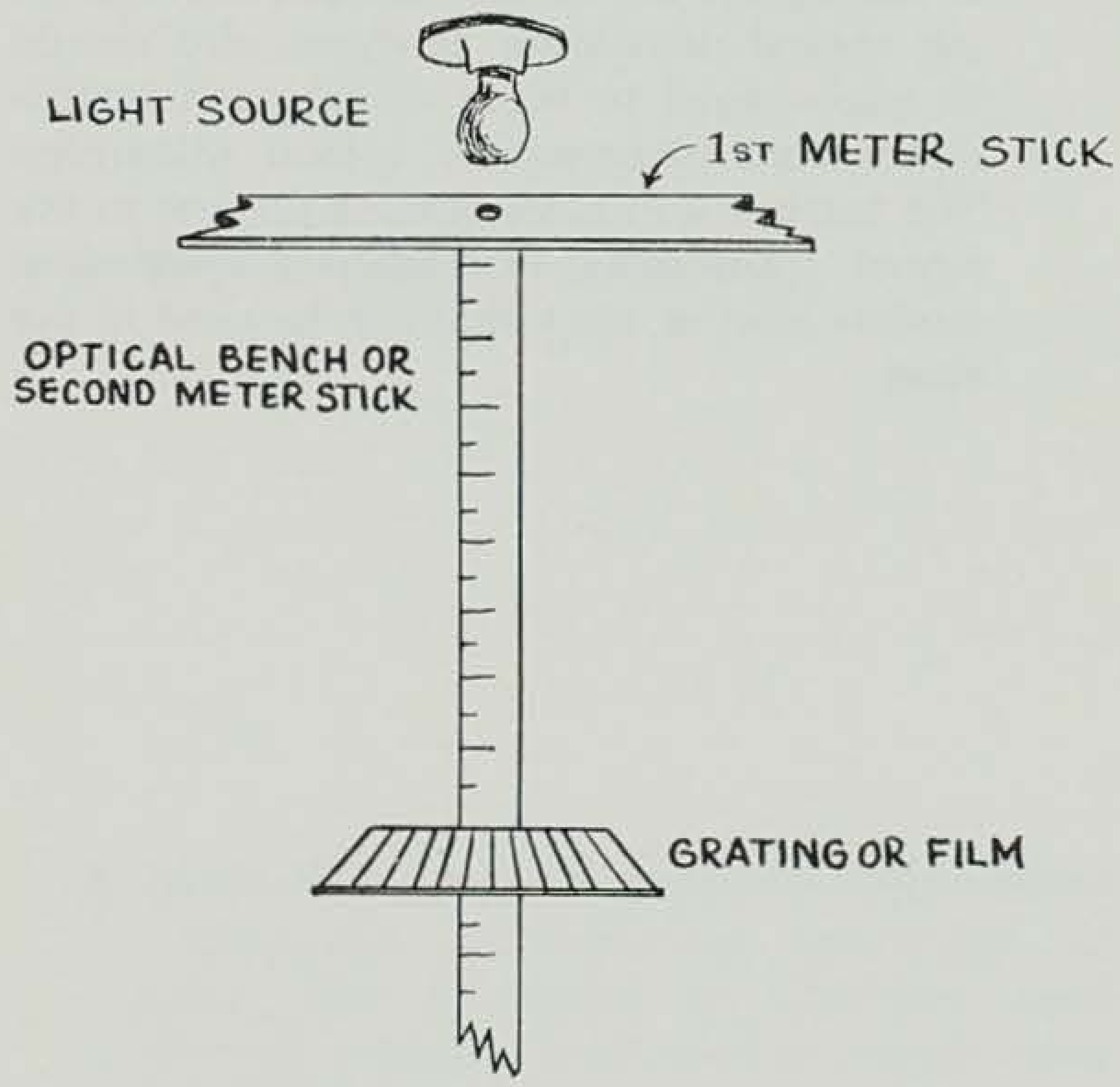
A trip to an industrial laboratory is useful in noting the use of instruments incorporating optical principles. Students also should be encouraged to bring objects and instruments that demonstrate optical principles. The teacher will have devices present in the school (projectors, microscopes, eyeglasses, models of eyes, etc.) that can be used in the class.

3. **Teacher and Pupil References**

Most optical companies will send information on instruments. Often optical glass companies will have eyeglass lenses and other devices useful in demonstrations.

4. **Audio-Visual Aids, Equipment, and Supplies**

Some optical instruments are available as regular visual aids. It is not advisable to have high school physics departments purchase expensive instruments that would be used only for demonstrations. Often optical instruments can be borrowed or observed on field trips. A simple spectroscope can be made with an optical bench, a meter stick, a grating, and a light source as shown.



There should be a hole in the first meter stick.

A filter can be used with the light source. A replica grating is inexpensive.

A pinhole camera is also suggested.

5. **Teacher Notes**

VI. ELECTRICITY

A. ELECTROSTATICS

1. Concepts and Understandings

Static electricity
Discovery
Two kinds of charges
Likes repel; unlikes attract
Electron structure of matter
Electroscope
Conductor and non-conductor
Force between charges (Coulomb's law)
Electric fields of force
Potential difference
  Electric potential
  Distribution of charges
  Effect of shape of conductor
Methods of transferring charges
Electrostatic generators

2. Suggested Activities

Demonstrate static electricity, using rubber rod, skin, silk.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

Wimhurst machine
Electroscope
Pith balls
Rubber rod
Glass rod
Cut fur, silk
Electroscope and charging rods
See Appendixes B and D.

5. Teacher Notes

B. CAPACITANCE

1. Concepts and Understandings

Define capacitance, capacitor
Discuss units, types (Leyden jar, mica, oil)
Combinations
Factors which affect capacitance

2. Suggested Activities

Assemble various types of condensers. Local radio-TV repair shops may be good sources.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

Static machine for building high charge
Laboratory and industrial capacitors
See Appendixes B and D.

5. **Teacher Notes**

Caution handling charged objects.

C. DIRECT CURRENT CIRCUITS

1. **Concepts and Understandings**

Motion of charges
Current, units of current
Resistance
Continuous current flow
Sources:
- Chemical
- Photoelectric
- Thermoelectric
- Piezoelectric
- Electromagnetic

2. **Suggested Activities**

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
Large demonstration DC meter is useful for demonstrations. Good laboratory experiments are available.

5. **Teacher Notes**

D. CELLS

1. **Concepts and Understandings**
Voltaic cell and its chemistry
Dry cell, storage cell, primary and secondary cells
Combination of cells—series, parallel

2. **Suggested Activities**
Disassemble an old car battery to show plates.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
See Appendixes B and D.

5. **Teacher Notes**

E. SERIES AND PARALLEL CIRCUITS

1. **Concepts and Understandings**
Ohm's law
Determination of internal resistance of a cell
Resistance in series, parallel
Various networks
Factors determining resistance
Measuring volt and amp
Use of Wheatstone bridge

2. **Suggested Activities**

Establish a circuit with a variable resistance and show how this affects the circuit.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendixes B and D.

5. **Teacher Notes**

F. HEATING AND CHEMICAL EFFECTS

1. **Concepts and Understandings**

Energy
Converting electricity to heat
Joule's law
Household appliances
Household electricity
Use of fuse
Electrolytic cells
Electroplating
Electrolysis of water
Faraday's law
Electrochemical equivalent

2. **Suggested Activities**

Have the students check in their homes for possible appliances which are electrically heated. Visit the local power company for a field trip or a school electric shop.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
See Appendixes B and D.

5. **Teacher Notes**

G. MAGNETISM

1. **Concepts and Understandings**
Relationship between electricity and magnetism
Magnetic and non-magnetic substances
The domain theory
Force between magnets
Magnetic fields
Magnetic permeability
Induced magnetism
Electro-magnetism
Field around a conductor
Electromagnets

2. **Suggested Activities**
Use iron filings on paper over magnet to show magnetic lines of force.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
See Appendixes B and D.

5. **Teacher Notes**

H. DC METERS

1. Concepts and Understandings

Operation and theory of the DC meter
- Galvonometer
- DC Voltmeter
- DC Ammeter
- Ohmmeter

2. Suggested Activities

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix D.

5. Teacher Notes

I. ALTERNATING CURRENT

1. Concepts and Understandings

Induced currents
Faraday's induction experiment
Cause of induced emf
Generators
Instantaneous voltage
$E = Emax \quad Sin\ \theta$
Self-excited
Series wound
Shunt wound
Compound wound
AC circuits
Sine wave
Power
AC impedence
(L, C, R) circuits

2. Suggested Activities

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
   See Appendix D.

5. **Teacher Notes**

J. MOTORS

1. **Concepts and Understandings**
   Magnetic torque
     Back emf
     DC motors
     AC motors

2. **Suggested Activities**
   Have students construct a simple motor.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**
   See Appendix D.

5. **Teacher Notes**

K. INDUCTANCE

1. Concepts and Understandings

Mutual inductance
Self-inductance
Networks
Induction coil
Spark coil
Transformers
Power transmission

2. Suggested Activities

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix D.

5. Teacher Notes

L. ELECTRONICS

1. Concepts and Understandings

Electronics is very important today since more operations are electronically controlled. History should be discussed including Edison effect.

- Vacuum tubes
  - De Forest triode
  - Thermionic emission
  - Triode characteristics amplification
  - Other tubes
- Circuits
  - Amplifier class A, B, C
  - Response—very important in hi-fi and stereo
  - Oscillator circuits
  - Heterodyne principle
  - Detection
  - Power supply circuits
- Half-wave and full-wave circuits

2. Suggested Activities

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

Demonstration

Radio transmitter and receiver available.

Radio and TV repair stores will usually donate used equipment for class demonstration.

5. **Teacher Notes**

M. COMMUNICATIONS SYSTEMS

1. **Concepts and Understandings**

A means of mass communications is very important today.

Radio
- Electromagnetic radiation
- (Discuss frequency spectrum)
- Antennae
- Ground and sky waves
- Ionosphere
- Receivers
  - AM
  - FM
  - Single-side band
  - Suppressed carrier

Television
- Cathode ray tube
- Image orthicon
- Television receiver

Radar
- Scatter communications

2. **Suggested Activities**

Visit local radio or TV station transmitter.

3. **Teacher and Pupil References**

4. **Audio-Visual Aids, Equipment, and Supplies**

Used equipment from local radio and TV station is good.

5. **Teacher Notes**

N. SEMI-CONDUCTORS

1. **Concepts and Understandings**

New branch, continually growing
- Transistor
- Tunnel diode
- Masers
- Other recent developments

2. **Suggested Activities**

3. **Teacher and Pupil References**

See Appendix M, "The Peltier Effect."

General Electric Company Transition Manual—latest edition

4. **Audio-Visual Aids, Equipment, and Supplies**

Electronic companies will send literature and sometimes samples of material on request.

5. **Teacher Notes**

Usually there is a student in class who is also a radio amateur. He can assist by bringing some of his equipment.

VII. SPACE, TIME, AND MOTION

A. MODERN CONCEPTS

1. Concepts and Understandings

The physics course is incomplete without spending some time on the attention physics is receiving in the world today.

2. Suggested Activities

Bulletin boards should be kept current. Good films on various subjects can be scheduled. Scientists can be invited to speak. A visit to the laboratories of the state university is suggested. The universities usually schedule "open houses" each spring.

3. Teacher and Pupil References

Current newspaper and magazine articles
Iowa Visiting Scientist Program—c/o Dr. T. R. Porter, Science Education Department, University of Iowa, Iowa City, Iowa, 52240

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix B, "List of Physics Films."

5. Teacher Notes

B. ATOMIC STRUCTURE

1. Concepts and Understandings

Basic structure of the atom to include some fundamental historic experiments and theories

- Bohr atom
- Rutherford model
- Milikan oil drop experiment
- Protons
- Electrons
- Neutrons
- Other atomic particles
- Particle accelerators
  (Betatron, Van de Grauff, etc.)

2. Suggested Activities

Either films (see Appendix B) or actual experimental equipment demonstration is suggested. Again, a visit to a university laboratory would be worth while.

3. **Teacher and Pupil References**

Current newspapers and magazine articles

Iowa Visiting Scientist Program—c/o Dr. T. R. Porter, Science Education Department, State University of Iowa, Iowa City, Iowa, 52240

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix B, "List of Physics Films."

5. **Teacher Notes**

C. RADIOACTIVITY

1. **Concepts and Understandings**

The historical development and modern technique of radioactivity provide very good material for discussion.

The works of Becquerel, the Curies, Einstein, Rutherford, and others should be described. Measurements of radioactivity and current practices of handling should be discussed.

Alpha, Beta, and Gamma emissions should be mentioned.

2. **Suggested Activities**

Demonstration of radioactivity by local civil defense members or laboratory personnel from an industry using radioisotopes would be of interest.

3. **Teacher and Pupil References**

Numerous government publications may be obtained through Superintendent of Documents, Washington, D.C. 20402, or Atomic Energy Commission.

4. **Audio-Visual Aids, Equipment, and Supplies**

Radiation counters available from civil defense.

See Appendix B, "List of Physics Films."

5. **Teacher Notes**

3. **Teacher and Pupil References**

The Effects of Nuclear Weapons, Superintendent of Documents, Washington, D.C. 20402.

D. FISSION AND FUSION

1. **Concepts and Understandings**

A session on the principles of nuclear power is a "must" for this physics course. The use of nuclear power should be discussed. Nuclear reaction for medical purposes and scientific experimentation is suggested.

2. **Suggested Activities**

A discussion by local civil defense officials can serve to acquaint the student with potentials of nuclear energy as a destructive force. Power companies have been instrumental in developing nuclear energy for power, and may have models or speakers available.

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix B, "List of Physics Films."

5. **Teacher Notes**

E. X-RAY MICROWAVES

1. Concepts and Understandings

Modern concepts should include these important areas of industrial, medical, and experimental physics.

2. Suggested Activities

Observations at industrial laboratory or hospital.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

See Appendix B, "List of Physics Films."

5. Teacher Notes

F. SPACE

1. Concepts and Understandings

Discussion on this subject will depend on activities in field during period of the course. As noted in Section I, this outline should be interrupted to discuss rocket firings and satellite activities. A basic understanding of space, the Van Allen Belts, and problems in space travel should be considered.

2. Suggested Activities

3. **Teacher and Pupil References**

See Appendix J, "Sample Test and Examination Questions."

See Appendix N, "The Human Factor in Space Environment."

"Radiation Belts Around the Earth," James A. Van Allen, *Scientific American*, March 1959. (Reprints available.)

U. S. Air Force Specification Bulletin No. 523, Nov. 18, 1960, Commander, Wright Air Development Division. Attn: WWFEVC, Wright Field, Ohio.

The Next Ten Years in Space 1959-1969. House of Representatives Document, Superintendent of Documents, Washington, D.C. 20402.

Project Mercury, Senate Report #1014, Superintendent of Documents, Washington, D.C. 20402.

Space Handbook, Astronautics and Its Applications, House of Representatives Document, Superintendent of Documents, Washington, D.C. 20402.

Survey of Space Law, House of Representatives Document No. 89, Superintendent of Documents, Washington, D.C. 20402.

4. **Audio-Visual Aids, Equipment, and Supplies**

See Appendix B, "List of Physics Films."

5. **Teacher Notes**

VIII. TEACHING TOOLS

A. TESTS, QUIZZES

1. Concepts and Understandings

Test questions requiring comprehensive thinking, descriptive explanations, and applications of scientific principles and mathematics are recommended.

The argument is often noted that essay tests require more time to correct and evaluate. This need not be the case. Essay test questions can emphasize the discussion and application of a principle. The student either understands this principle thoroughly, partly, or not at all. Proper evaluation can be awarded to each type of answer. Labortory-type tests or questions using the equipment are recommended.

Sample questions of this type will be found in the "Activities" subdivision of this outline.

Tests may contain a combination of open and closed book questions. A two-hour test (one-hour closed book, one-hour open book) is suggested. The closed book questions should emphasize principles, theorems, laws, and simple problems. Mathematics used should be of a type that can be done in the head.

Open book questions should emphasize the more complex problem work, including use of slide rule, tables, handbooks, and other references.

At least four two-hour tests are recommended per semester.

Short quizzes of one or two questions should be used to check on reading assignments. Open book quizzes from problem assignment are also recommended.

2. Suggested Activities

SAMPLE PROBLEMS: CLOSED BOOK
MATHEMATICS REVIEW

Three men, Tom, Bill, and Joe, and their wives, Sue, Mary, and Anne, buy as many Christmas gifts as each pays in dollars for each gift. Each man pays $48 more than his wife. Tom buys nine more gifts than Mary, and Joe buys four fewer than Anne. What are the names of each wedded couple?

Perform the following operations. When answers are not in round numbers, express to three significant figures.

$$\frac{63 \times 10^{3} \times 46 \times 10^{-8} \quad ^{2}}{0.0000051}$$

$$(5 \times 10^{4})^{3}$$

Simplify:

$$\frac{Z_1 - \dfrac{Z_1 - Z_2}{Z_1 - Z_2}}{\dfrac{Z_1 - Z_2}{Z_1 - Z_2} + Z_1}$$

SAMPLE PROBLEMS: CLOSED BOOK
MECHANICS REVIEW

Define: (a) resultant, (b) resolution, (c) vector, (d) scalar, (e) force, (f) fundamental unit.

Young's modulus for a "steel" is 20×10^{11} dynes/cm^2 and for a "copper" 10×10^{11} dynes/cm^2:

Which will stretch the more, a wire of steel or a wire of copper, if all other factors (cross-section area, original length, etc.) are the same?

Which will stretch more, a .2 mm^2 wire of copper or a .1 mm^2 wire of copper if other factors are the same?

Which will stretch more, a 1-meter length of copper wire or a 2-meter length of steel wire if all other factors are the same? Explain in detail how you arrive at the answers to the above.

Calculate the period of a meter stick vibrating with axis through one end. (Answer should be in seconds.)

SAMPLE PROBLEMS: CLOSED BOOK
HEAT REVIEW

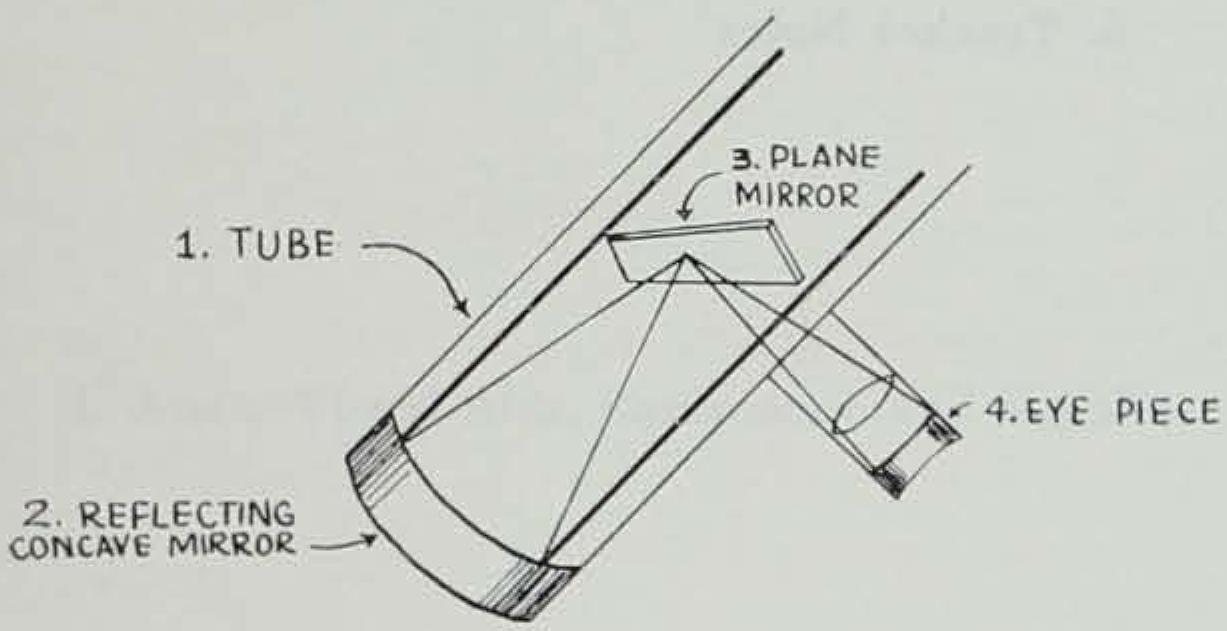
Derive the expression used to convert °C to °F.

Define the following: (a) calorie, (b) BTU, (c) water equivalent, (d) thermal capacity, (e) specific heat. What is the relationship between c, d, and e?

SAMPLE PROBLEMS: CLOSED BOOK
OPTICS REVIEW

A converging lens is placed 15 cm from an object. The enlarged, erect image is formed 60 cm behind the lens: (a) What is the focal length of the lens? Give the focal length in cm and diopters. (b) If the object is 4 cm high, what is the height of the image? (c) Draw schematic diagram showing object, image, lens and rays of this problem. (d) Is the image real or virtual? Explain.

Explain the functions of each numbered part of the Newtonian type telescope below:



Open book problems can be taken directly from textbook and should include some problems that have been assigned for homework.

3. Teacher and Pupil References

See Appendix J, "Sample Test and Examination Questions."

4. Audio-Visual Aids, Equipment, and Supplies

5. Teacher Notes

B. EXAMINATIONS

1. Concepts and Understandings

Examination questions should be taken from the tests. The examination should be scheduled approximately 1½ times as long as the tests in the same length of time—i.e., five questions on an hour closed book test; eight questions on an hour closed book examination.

A laboratory examination is suggested if the school equipment is such that at least one-third of the course time can be spent on laboratory experiments. Sample laboratory questions will be found in activities section.

2. Suggested Activities

Sample Questions: Laboratory Examination

Determine the focal length of lens found on your table. Use at least two arrangements. Compute the per cent of error of each method.

From instruments located in the laboratory, record the barometric pressure, room temperature (in °C and °F), and relative humidity.

Determine the specific gravity of the unknown solution using Archimedes' principle. Check your work and compute the per cent of error by reading the hydrometer located in the front of the room.

Suppose you wish to know the specific heat of zinc as determined by the method of mixtures. Assign another student to perform the experiment. Prepare a data sheet of all measurements you wish to record, write the equation to be used, and list the three most probable reasons for error.

3. Teacher and Pupil References

See Appendix J.

4. Audio-Visual Aids, Equipment, and Supplies

5. Teacher Notes

C. OUTSIDE READING

1. Concepts and Understandings

This phase of education should be encouraged. All class members should read at least two books from a prepared list each semester. Formal reports should be required. Appropriate books discovered by students should be approved and added to the recommended list.

2. Suggested Activities

Formal book reports required.

3. Teacher and Pupil References

4. Audio-Visual Aids, Equipment, and Supplies

5. Teacher Notes

Do not return the formal book reports turned in; either keep for your reference or destroy.

D. EXTRA CREDIT WORK

1. Concepts and Understandings

Work for extra credit should definitely be encouraged. This can include Science Fair projects, papers for Westinghouse Talent Search, etc.

2. Suggested Activities

A school science fair in cooperation with other science departments is suggested. There are three Iowa science fairs: Quint-Cities, Hawkeye, and Cedar Rapids. Students should be encouraged to enter projects. This encouragement should be more tangible than just a vocal expression. Recognition for good exhibits in the form of better grades is suggested. This is done in many other areas of education.

Extra experiments, particularly those of a type where the student designs or builds equipment that may be used by the physics department, should be encouraged. (See Appendix M.) The school should have a science club; perhaps if it is large enough, a radio club and a photography club. Sponsorship by parents who are scientists or engineers is suggested. The Explorer Scouts are sponsoring groups interested in single phases like rockets, engineering, and physics. Activities in these organizations should be recognized. Attendance at a lecture by a well-known physicist should be recognized. The student could write a paragraph on the talk as substitute for a test or quiz question.

3. Teacher and Pupil References

4. **Audio-Visual Aids, Equipment, and Supplies**

5. **Teacher Notes**

APPENDIX

Appendix A
INTRODUCTION

The secondary school physics course provides the initial introduction to principles of science, technology, and engineering as used in industrial research, design, and development. It introduces the complexities of college undergraduate and graduate science and technical courses. It provides a preview of formal written technical reports, recording of data, and the handling of pieces of equipment that sometimes are dangerous or expensive.

Current activities in the world reflecting scientific achievements should, when of a prominent nature, supersede outlined assignments in the physics course. A class period occurring after a successful space shot, satellite orbit, nuclear test, or Nobel prize award in physics should be used to discuss these events and emphasize scientific principles employed.

A physics current events period each week during part of a class period would seem appropriate. "Our New Age," a science series by Dr. Athelstan Spillhaus, dean of the Institute of Technology at the University of Minnesota, appears in state newspapers and is suggested for a current events bulletin board. Newspapers and weekly magazines frequently contain scientific articles. Among them are *Life*, *Newsweek*, and *Saturday Evening Post*. Numerous industries (Convair, G.E., G.M., and others) prepare scientific charts for poster purposes.

The lists, tables, references, tests, and added information included in the Appendixes should make a valuable supplement to the material in the front of the book.

Appendix B
FILMS

A specially prepared series of motion pictures has been developed by the Physical Science Study Committee for the PSSC course. Modern Learning Aids, 5 East 54th Street, New York, New York, 10022, is one source of the PSSC series. Films can be purchased or rented.

There are other very good movies that are recommended especially as an occasional inspirational device. The Armed Services have an excellent supply of scientific films. They are usually available to educational institutions if they are handled properly and returned promptly. Fifth Army Central Film Library, Fort Sheridan, Illinois, 60038, is a source of armed services films for this area.

Government installations from which films are available are: (1) Weather Bureau Offices, (2) Armed Forces Locations (Army, Navy, Marine, and Air Force Permanent Bases or Reserves), and (3) Agricultural Bureaus. They are available on a postage return payment basis.

Films on atomic energy, radioisotopes, and similar subjects can be obtained through: U. S. Atomic Energy Commission, c/o Public Relations Officer, P.O. Box 59, Lemont, Illinois, 60439. These are available on a postage return payment basis. Many industries, especially those that are divisions of national organizations, have films and other training aids available generally through their public relations staffs. General Electric, General Motors, Shell Oil Company, Alcoa, and Bell Laboratories are a few of the companies that have excellent films on physics subject matter. The record on sound by Bell Labs, available from the local telephone system public relations staff, is an example of an excellent training aid. These industrial films and aids are usually available on a return postage cost and guarantee of careful handling. Local utilities also have excellent films and other aids available.

Modern Talking Picture Service, a nationwide organization, has films available on a loan basis through the courtesy of business firms, trade associations, and other organizations. The cost is film transportation averaging 25 cents per film. Pratt Sound Films, Inc., Cedar Rapids, Iowa, is an Iowa representative for this organization.

Following is a partial list of films:

Physical Science Study Committee (PSSC) Films
Available from Modern Learning Aids
3 East 54th Street
New York, N. Y. 10022

Learning Physics (Color). Jerrold R. Zacharias and Nathaniel H. Frank, Massachusetts Institute of Technology.

Discusses and demonstrates the evidence for our belief that the earth is round and contrasts it with the evidence for atoms and molecules; offers evidence from (1) monomolecular layers, (2) Brownian motion, and (3) the ion emission microscope for an atomic theory; emphasizes the need to observe the very small, very large, very brief, and very long to gain an understanding of the universe; suggests some subjects (light, mechanics) which the pupil will study as he proceeds through the course. (18 min.)

Measurement. William Siebert, Massachusetts Institute of Technology.

Measurement of the velocity of a rifle bullet is used as basis for a discussion of the art of measurement. Problems discussed include noise, bias, use of black boxes, and the element of decision in all measurement. (22 min.)

Change of Scale. Robert Williams, Massachusetts Institute of Technology.

Demonstrates that change of size necessitates change in structure of objects; uses specially constructed props to emphasize scaling problems; then shows practical applications of scale models as used in the construction of harbors, study of ship design and movie making. (23 min.)

Straight Line Kinematics. E. M. Hafner, Rochester.

Notions of distance, velocity and acceleration are discussed; graphs of all three are generated using special equipment in a real test car. Relationships among them are shown by measurements and estimates of slopes and areas from the graphs. (33 min.)

Vectors. Albert V. Baez, PSSC.

Vectors are demonstrated in an actual high school classroom. Rubber models are used to show vector displacement in two and three dimensions. Vector addition, scalar multiplication of a vector, and other concepts are introduced. (28 min.)

Crystals. Alan Holden, Bell Laboratories.

Demonstrates the nature of crystals, how they are formed, and why they are shaped as they are. Observes actual growth of crystals under a microscope; discusses how they may be grown. Relates these phenomena to the concept of atoms. (25 min.)

Pressure of Light. Jerrold R. Zacharias, Massachusetts Institute of Technology.

Light pressure on a thin foil suspended in a high vacuum sets the foil into oscillation. The film leads to this by discussion of the Crookes radio-meter and the effect—not light pressure—that causes it to rotate. The role of light pressure in the universe is also discussed. (21 min.)

Speed of Light. William Siebert, Massachusetts Institute of Technology.

Speed of light is measured on a school playing field using an oscilloscope as a timing device. In the studio the speed in air is compared with speed in water, using a high-speed rotating mirror. (23 min.)

Simple Waves. John Shive, Bell Laboratories.

The behavior of pulse propagation on ropes and "slinkies" is used to show velocities in differing media and other elementary characteristics of waves. A torsion bar wave machine is then used to repeat these and demonstrate phenomena of reflection and refraction. (27 min.)

Forces. Jerrold R. Zacharias, Massachusetts Institute of Technology.

Introductory to mechanics in general, this film foreshadows later work with various kinds of forces. The Cavendish experiment is performed showing gravitational forces between small objects. Also, by means of this experiment, gravitational force is compared with electrical force in a simple demonstration. (23 min.)

Inertia. E. M. Purcell, Harvard.

Demonstrates Galileo's principle of inertia, using dry ice packs and strobe photography; develops the relation that acceleration is proportional to force when mass is constant. (27 min.)

Falling Bodies. N. H. Frank, Massachusetts Institute of Technology.

Shows proportionality of inertial and gravitational mass from free fall experiments, especially the monkey-and-gun experiment. Discusses independence of vertical and horizontal components of motion. (30 min.)

Frames of Reference. J. N. P. Hume, and D. G. Ivey, University of Toronto.

By means of a variety of experiments on rotating turntables, this film demonstrates the distinction between an inertial and non-inertial frame of reference and the appearance of fictitious forces in a non-inertial frame. (26 min.)

Energy and Work. Dorothy Montgomery, Hollins College.

Demonstrates that work put into raising a heavy ball transfers to kinetic energy gained when it falls; this equality emphasized by a situation where force required to pull on a device is not proportional to distance pulled. Next a "Rube Goldberg" invention demonstrates a series of energy transfers; finally, conversion of energy to heat is demonstrated as original ball drops and hits a spike. (29 min.)

Mechanical Energy and Thermal Energy. Jerrold R. Zacharias, Massachusetts Institute of Technology.

This film shows several models to help students visualize both bulk-motion and the random motion of molecules. It shows their interconnection as the energy of bulk motion turns into thermal energy of random motion. Demonstrates random motion, and how such motion can average to a smooth effect. Shows model of thermal conduction. Demonstrates a model using dry ice disc and small steel balls, in which bulk mechanical energy of the disc is converted to "thermal" energy of the balls' random motion. Develops a temperature scale by immersing canisters of two gases in baths of various temperatures, reading the resulting pressures; through this, explains the origin of the absolute temperature scale. (22 min.)

Coulomb's Law. Eric Rogers, Princeton.

Demonstrates the inverse square nature of electric force, and also the fact that electrical force is directly proportional to charge. Introduces the demonstration with a thorough discussion of the inverse square idea. Also tests inverse square law by looking for electrical effects inside a charged hollow sphere. (28 min.)

Millikan Experiment. F. L. Friedman, Massachusetts Institute of Technology, and A. Redfield, IBM.

Simplified Millikan experiments described in the text are photographed through the microscope. Standard spheres substituted for oil drops, E-rays used, charge related to velocity of sphere across field of view of microscope. Emphasis is on presenting on the screen evidence that charge comes in natural units that are all alike; numerous changes of charge are shown, with the measurements clearly seen by the audience. Professor Friedman gives an introduction and running commentary; Doctor Redfield does the experiment. (30 min.)

Electric Fields. Francis Bitter.

An electric field discussed as a mathematical aid and as a physical entity; experiments demonstrate: (1) vector addition of fields, (2) shielding effects by closed metallic surfaces, and (3) the electric force which drives an electric current in a conductor for both straight and curved conductors. Physical reality of fields discussed briefly in terms of radiation. (24 min.)

Moving Charges (Color). Jerrold R. Zacharias, Massachusetts Institute of Technology.

This film discusses electrical currents in terms of the transport of positive or negative charges or both. It demonstrates some ways in which electrical charges can move—by being carried; through conductors; through gases, in vacuums and solutions—and shows how these currents can be measured. Through a Faraday electrolysis experiment in which the volume of hydrogen and oxygen gas is carefully measured, we show that an ampere consists of 6.25×10^{18} elementary charges or one coulomb passing any point in a circuit per second. (20 min.)

Electric Energy. Jerrold R. Zacharias, Massachusetts Institute of Technology.

In this film we show that there is energy associated with elementary charges moving under the influence of electric forces, in this case, in a specially built evacuated tube. The energy of electrons striking the plate in this tube causes a temperature rise in the plate. We demonstrate how a similar temperature rise in an identical plate is achieved through mechanical means in transfer of a known amount of energy. The energy achieved by mechanical means can then be related back to the energy of the charges striking the plate in the tube. By knowing the current in the tube circuit, and the voltage applied to the plate, we are able to determine the energy associated with each electron in this situation. (25 min.)

Electrons in a Uniform Magnetic Field. Dorothy Montgomery, Hollins College.

A Leybold tube (spherical cathode-ray tube with some gas to show path of electron beam) is used for fairly precise measurements for determining the mass of the electron as the electron beam is deflected by Helmholtz coils. Arithmetic involved is worked with the experiment. (10 min.)

Mass of the Electron. Eric Rogers, Princeton.

Using a cathode ray tube encircled by a current carrying a loop of wire, measurements are taken which enable the demonstrator to calculate the mass of the electron. The calculations are developed in detail, step by step. (18 min.)

Franck-Hertz Experiment. Byron Youtz, Reed College.

A stream of electrons is accelerated through mercury vapor, and it is shown that the kinetic energy of the electrons is transferred to mercury atoms only in discreet packets of energy. Association of the quantum of energy with a line in the spectrum of mercury is established. The experiment retraced in this film was an early indication of the existence of internal energy states within the atom. (25 min.)

Horizons of Science Films (25 Minutes)
Educational Testing Service
Princeton, N. J. 08540

Visual Perception. Princeton, New Jersey.

A vivid examination of the way we "see" the world around us, with psychologist Hadley Centril.

The World of Dr. Vishniac.

Extraordinary microscopic photography of living creatures and insights into the complexities of evolving life, with zoologist Roman Vishniac.

Exploring the Edge of Space.

Development and use of the plastic balloon systems, with Otto C. Winzen, aeronautical engineer-designer.

Thinking Machines.

Approaches and experiments in machine intelligence, with Claude Shannon of Massachusetts Institute of Technology; Alex Bernstein of IBM; Leon Harmon of Bell Laboratories.

The Mathematician and the River.

The relationship between the "abstract" world of mathematics and the "real" world of nature, with Eugene Isaacson of NYU's Institute of Mathematical Sciences.

Project "Mohole."

Report No. 1 on a major scientific project to drill a hole to the interior of the earth; exclusive films of the United States oceanographic expedition surveying possible sites.

The Galaxies.

An inquiry into the farthest reaches of the universe, with staff members of the Mt. Wilson and Palomar Observatories.

Rocket Combustion.

What goes on inside the rockets and missiles, with George Sutton of the Advanced Research Projects Agency.

Sterling Movies, Inc.
100 West Monroe Street
Chicago, Ill. 60603

The Day Before Tomorrow (Color).

The dynamic atmosphere of scientists at work in the Army's huge Ballistic Research Laboratories at Aberdeen, Maryland, is vividly portrayed in "The Day Before Tomorrow." The audience looks into the world's future as they are shown the many rewarding careers available in ballistic research. Their view of the future is crystallized by the impact of seeing and understanding the vital work now being done in numerous fields, including: How science determines the best complex of weapons to keep the nation's defenses at peak efficiency; the means by which motion is imparted to a missile; the forces which effect the flight of missiles; the effects of weapons on target; weapons systems analysis from an engineering and operations viewpoint; and future weapons systems. (30 min.)

Bell Telephone Films
Telephone Company Public Relations Offices

Seconds for Survival (Color).

A mock air attack dramatically illustrates how lightning-fast communications spring into action to alert the nation, and how our combined defense system strikes back to destroy the "invaders." (27½ min.)

The Big Bounce (Color).

This documentary film about Project Echo shares on-the-spot excitement of two history-making experiments; the first telephone conversation ever carried on by bouncing signals off a man-made satellite, and the sending and receiving, via satellite, of a tape-recorded message from the President of the United States. (14½ min.)

The Sandia Story (Color).

This film shows how Sandia Corporation, a non-profit subsidiary of Western Electric and prime contractor for the Atomic Energy Commission, goes about the task of designing, developing, and testing the fusing and firing mechanisms, internal components, and electronic gear used in nuclear systems. (34 min.)

The Nike-Hercules Story (Color)

The giant Nike-Hercules solid fuel missile is a formidable defense against hostile bombers or missiles approaching our country. (27½ min.)

Tools of Telephony (Color).

The story of Western Electric—manufacturer, purchaser, distributor, and installer for the Bell System. (30 min.)

Making Conversation (Color).

How handsome color telephone sets are made at Western Electric's ultra-modern Indianapolis plant. Shows how skilled hands and amazing machinery combine to produce today's phones. (12½ min.)

Your Voice and the Telephone (Color).

This film uses animation to demonstrate what the telephone does to the human voice to transmit it electrically to another telephone and faithfully turn it back into its original sound. Recommended for upper elementary and junior high general science classes. (7 min.)

The Voice Beneath the Sea (Color).

The camera takes you aboard the cable ship H.M.S. Monarch on a memorable trip across the Atlantic, laying the first under-ocean transatlantic telephone cable. (Two versions—15 and 27 min.)

Bell Solar Battery.

How the Bell solar battery is made, how it works, and its usefulness in electronics and communications are shown in this film. (12 min.)

The Strange Case of the Cosmic Rays (Color).

Tells the story of how scientists around the world track cosmic rays and establish their mysterious character and behavior. (59 min.)

The Unchained Goddess (Color).

This Bell System science picture deals with the story, in its many facets, of what scientists today know about weather. (59 min. in two parts)

Our Mr. Sun (Color).

This picture covers facts which man has discovered about the sun through centuries. The sun's corona, spots, and the explosions on its face are shown. Thermonuclear reaction, photosynthesis, and the solar battery are explained. (59 min. in two parts)

Westinghouse Electric Corporation
Merchandise Mart Plaza
Chicago, Ill. 60654

Dawn's Early Light (Color).

A moving drama about the practically unlimited uses for atomic power in our everyday living. (33 min.)

Atomic Power at Shippingport (Color).

Depicts the basic nuclear, chemical, mechanical, and construction problems encountered during the development, design, and installation of America's first nuclear-powered generating station at Shippingport, Pennsylvania. (26 min.)

A Heart for Yankee (Color).

The film explains how the core of an atomic reactor is made. (13 min.)

Commutation of DC Machines.

Animated drawings explain the theory of commutation and the troubles that arise from stray oil and grease, moisture, looseness of mounting, worn brushholder boxes, grooving, poor seating of new brushes, and irregular inspection. (24 min.)

General Motors Corporation
Public Relations Staff—Film Library
General Motors Bldg.
Detroit, Mich. 48202

The ABC of Internal Combustion.

An animated motion picture explaining basic principles of the internal combustion engine. (13 min.)

The ABC of the Automobile Engine.

An animated motion picture explaining in graphic detail the parts and workings of the modern automobile engine. (18 min.)

The ABC of the Diesel Engine.

Fundamentals of the operation of a diesel engine are explained in this animated film. (18 min.)

The ABC of Jet Propulsion.

Basic principles of jet propulsion are explained simply and entertainingly in this animated film. (18 min.)

Firebird III.

New ideas take shape in ultra-advanced experimental car. (13 min.)

Challenge and Response.

A comprehensive insight into modern industrial research. (20 min.)

The Electra Propulsion Story.

A case history of aircraft power-plant development. This film is of particular interest to engineering and aeronautical students. (23 min.)

Shell Oil Company
624 S. Michigan Avenue
Chicago, Ill. 60605

The History of the Helicopter.

The very idea of a helicopter may seem improbable, but is one of the oldest in the history of aviation. Now, at last, the helicopter has come into its own as a practical and important part of aviation. A new Shell film, "The History of the Helicopter," tells the fascinating story of rotating-wing flight in easy, understandable terms. Combining historic footage and shots from private collections with new materials, the film traces development of the helicopter from the visionary drawings of Leonardo da Vinci to today's troop-carrying giants. (20 min.)

How an Airplane Flies.

A series of six films which break down the theory of flight into its major components and make each simple enough for the average layman to understand. (6 to 15 min. each)

The Gas Turbine.

This film presents a clear, understandable account of basic principles upon which the gas turbine works and tells why this engine—of all recent aeronautical developments—has had the greatest influence on the direction of progress in flight. (15 min.)

Leverage.

"Leverage" shows how both the toothed wheel, discovered ages ago, and the smooth-running gears of today spring from the simple principle of the lever, with its ability to multiply a small force, or reverse its direction.

United States Atomic Energy Commission Films
H. C. Baldwin, Information Assistant
to the Manager
U.S.A.E.C., Chicago Operations Office
P.O. Box 59
Lemont, Ill. 60439

A Is for Atom. Produced by General Electric Company.

An animated cartoon-film explaining atomic structure, nuclear fission, and the peacetime applications of the atom. In color. (15 min.)

The Atom Comes to Town (Color). Produced by the Chamber of Commerce of the United States.

A survey in color of peacetime uses of atomic energy; how heat from nuclear fission in a reactor can be used to make electricity, and what nuclear power will mean to the man on the street and to

America; scenes of various experimental and prototype power plants, discussing types, kilowatt capacity, principles, future developments; explanation of radioisotopes, how they are made and used to alleviate suffering and raise the standard of living; uses of radioactive materials in the diagnosis and treatment of disease; uses of radioisotopes in agriculture to produce better crops; atomic energy as a means of quality control in manufacturing and industrial operations (washing machines, engine wear, tires, toothpaste, plastics, etc.); food preservation. (29 min.)

Tagging the Atom. Produced by the Handel Film Corporation.

The story of one of the most important scientific research tools of all time: the atomic tracer. Complete details of the "manufacture" of these radioisotopes, including their production at EAC's Oak Ridge reactor, the method of handling them, their purification and packaging. Some of the many valuable uses for these atomic tracers are explained. (12½ min.)

* * *

NOTE: This is only a partial listing of good physics reference films. A teacher showing all the films would have very little time for actually teaching physics. Some would not fit properly into the teacher's planned program. Others may be useful only as teacher-enrichment material.

Films should not take more than 10 per cent of class instructional time and should be closely integrated with the material presented. Films do offer change in instructional methods and are definitely an asset to a course when properly coordinated.

Appendix C
LABORATORY PROCEDURES

A laboratory course such as this serves several purposes. Physics is a science which seeks to understand and explain natural phenomena and the relationships which exist between these phenomena. Before any process can be understood and explained, before one can say *how* or *why* a certain event occurs, he must know precisely *what* occurs. The entire history of physics has been one of alternate periods of (1) accumulation of data on *what* occurs, and (2) development of theories which attempt to explain the observations (to say *how* and *why*) and to predict new phenomena. For this reason, one can hardly hope to gain any real understanding of the principles underlying these phenomena without having some knowledge of the methods by which the data are collected.

This laboratory course will serve to supplement the textbook and illustrate the principles described there. It should enable the student to make his own measurements and discover for himself some of these laws of nature. For the engineer and the physicist, it will serve a purpose even more important than any of those mentioned above. The pupil's "data-taking" days will not end with completion of this course; they will be just beginning. The thing that one must learn is not merely how to manipulate apparatus and obtain data, but how to record and present results in such ways that they will be useful and understandable to someone else.

The teacher should supply directions for performing some experiments—not "cookbook" directions, but a general outline of procedure to be followed. Supplementary materials can always be found in the textbook. The student should refer to it as often as necessary.

Keep the laboratory operation orderly. Reduce communications between groups. If desirable, assign students work in groups of two or three persons.

Procedure During the Laboratory Period

It is essential, before starting an experiment, that the students have a definite idea as to what they are going to do and how they are going to do it. The laboratory period should be long enough to enable students to take data and to make calculations. Preparatory work must be done before students come to the laboratory if experiments are to be completed in allotted time.

After a trial run to determine whether the apparatus is in working condition, begin to collect data. Everything pertinent should be recorded on data pages of the report when observations are made. Students should not write things on a loose sheet of paper to be transferred to the report at a later time. Actual observations should be recorded, not just averages and differences. Reports can be included in a pupil's laboratory notebook but should have some type of formal suggested arrangement as noted below.

Reports

The following is a suggested form for physics laboratory reports:

1. Experiment number and title
2. Date
3. Your name and your partner's name
4. A brief statement as to purpose of the particular experiment and the method of measurement involved
5. A labeled diagram of apparatus used
6. Data, usually in tabular form. All data and tables should be labeled carefully. A measurement is meaningless unless the *units* in which it is expressed are stated
7. Calculations
8. Conclusions and results *based on data taken*
9. A discussion, whenever possible, of the sources of error and their effects on accuracy or reliability of results
10. Answers to questions in experiment sheet or suggested by instructor

Appendix D

LISTS OF LABORATORY AND DEMONSTRATION EQUIPMENT

List 1

30	Plastic ruler, clear plastic, 1-12 inches and 0-30.4 cm.
15	Vernier caliper, stainless steel, metric and English scales
15	Micrometer caliper, 0-25 mm., corrosion and rust-proof
15	Meter stick, stainless steel
30	Slide rule, Mannheim, aluminum
30	Protractor, 0-180°, 4″, metal
30	Plastic curve, two types
30	Plastic triangle, two types
1	Ream squared paper, recommended type
15	Beam balance, with 2 hanging pans
30	Set of metric weights, 10 gm to 500 gm
15	Specific gravity bottle, 50 ml, unadjusted
15	Force table with pulley clamps, 10″ diameter circle
60	Weight hanger, 25 gram
15	Knife-edge meter-stick clamp with wire hooks
15	Pulley on rod plus table clamp
60	Density cylinder, assorted materials and sizes
15	Specific gravity sinker, assorted sizes
30	Spring balance, 0-2 kg
30	Ring collar clamp, ¾″
30	Right angle clamp, ¾″
30	Calorimeter outfit
15	Boiler, glass
15	Electric hot plates for boiler
100	Ft tubing to conduct steam
20	Thermometer, —10 to 110 C
20	Thermometer, 10 to 300 C
10	Lb lead shot
10	Lb copper shot
5	Lb aluminum shot
3	Doz small towel, cotton
15	Linear expansion outfit
30	One-cm compass
15	Galvanometer, 30-0-30 scale
15	Meter movement, 0-3.0 scale (DC)
45	Series resistance for meter, 3 sizes
45	Shunt resistance for meter, 3 sizes
15	Slide wire bridge, 100 cm long
15	Decade resistance box, 1-110 ohms
15	Tap switch
36	Dry cell, No. 6, steel-cased type
15	Rheostat, 2.2 ohm
15	Rheostat, 22 ohm
15	Rheostat, 220 ohm
15	Rheostat, 2200 ohm
60	Resistor, with binding posts
100	Wire leads with connector tips, assorted lengths
15	Resonance tube apparatus
15	Heavy tuning fork, 256 cps
15	Heavy tuning fork, 341 cps
15	Heavy tuning fork, 480 cps
15	Vibrator for Melde's experiment
15	Spring for simple harmonic motion
15	Glass triangle, 30-60-90°
15	Glass square, 2″
30	Optical bench support to fit stainless steel meterstick
15	Light source, optical, electric
45	Optical bench item holder
15	Lens, focal length +20 cm
15	Lens, focal length +10 cm
15	Lens, focal length —15 cm
15	Mirrors, convex and concave
15	Optical bench screen holder

(Compiled by Dr. Sherwood Githens, Jr., Office of Ordnance Research, U. S. Army, Box CM, Duke Station, Durham, North Carolina, as minimum equipment for setting up a pupils' laboratory.)

List 2

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Quantities listed are for *12 stations*. For a smaller number of stations the quantities should be reduced accordingly. The *equipment* lists are subdivided for Mechanics, Heat, Sound, Light, and Electricity and Electronics. *Supplies* listed cover the complete range of experiments. Equipment needed in more than one section is listed in each section in which it is used. NOTE TO TEACHER: If this list is used for drawing up an order for equipment, please bear in mind that there is some duplication of standard items such as balances, beakers, meter sticks, etc.

EQUIPMENT LIST (*Mechanics*)

12	Balance, accurate to 0.01 g
12	Balance, platform with set of weights, 1-1000 g or
12	Balance, triple beam
12	Balance, spring, 250-g capacity

36		Balance, spring, 20-nt capacity (2000-g capacity may be used)
1		Balance, spring, 30-lb capacity
12		Balance support, demonstration
12		Battery jar
24		Beaker, 100 ml
1		Bicycle, demonstration
12		Block, metal
12		Block, wood, rectangular
12		Block, wood, rectangular, paraffin coated
12		Buret, 50 ml
12		Car, metal (Hall's car)
12		Catch bucket
1		Cat's fur
6		Clamp and rod, for table top
12		Clamp, buret
6		Clamp, right angle
12		Compass, pencil
12		Composition of forces apparatus
12		Crane boom, simple
12		Cylinder, numbered, of brass or aluminum
12		Dividers
1		Electroscope, simple
12		Glass bulb or glass stopper
12		Graduated cylinder, 100-ml or 250-ml capacity
1		Hard-rubber rod
12		Hooke's law apparatus
12		Hydrometer jar
1		Hydrometer, battery
6		Hydrometer, 0.600-1.000
6		Hydrometer, 1.000-2.000
12		Inclined plane board and table support
12		J-tube, apparatus
1		Lactometer
12		Medicine dropper
12		Meter stick
60		Meter stick clamp
12		Micrometer caliper
12		Overflow can
12	blocks	Paraffin
12		Pendulum bob, metal
12		Pendulum bob, wood
12		Pendulum clamp
1	pkg	Pins, straight
12		Protractor
12		Protractor, 6 in. radius or greater
24		Pulley, single sheave
24		Pulley, 2 or 3 sheaves, each
12		Pycnometer, 25 ml
1		Radioactive mineral sample
1		Radioactive sample
1		Radioactivity demonstrator
12		Ring stand
1	box	Rubber bands, assorted
12		Ruler, metric, 30 cm length
15		Sheet, aluminum, 4 in. square × 1/32 in. thick
20		Sheet, cardboard, 4 in. square × 1/32 in. thick
15		Sheet, lead, 4 in. square × 1/32 in. thick
12		Solid, irregular, lumps of coal, rock, or metal
12		Solid, numbered, rectangular, of metal or hard wood, with no dimension greater than 2 cm
1		Stop watch
12		Thermometer, −10°—110° C
1	spool	Thread, No. 8
12		Tray, large, shallow
1	ball	Twine
1		Uranium, metal or compound sample
12		Vernier caliper
60		Weight hanger
1		Weight, 2 lb
12		Weights, set
12		Weights, slotted, set
6		Wheel and axle apparatus
¼	lb	Wire, copper, bare, No. 18
¼	lb	Wire, copper, bare, No. 22
¼	lb	Wire, copper, bare, No. 30
1		Wire-testing machine
1		Wrist watch with illuminated dial
1		Yardstick

EQUIPMENT LIST (*Heat*)

12		Asbestos board, 12 in. × 12 in.
1	roll	Asbestos paper
12		Aspirator
12		Balance, platform with weights, or triple beam
12		Beaker, 100 ml
12		Beaker, 600 ml
24		Block, metal, assortment of lead, aluminum, brass, and copper
12		Burner and tubing
12		Calorimeter
12		Charles' law tube
1	pkg	Cheesecloth
24		Clamp, burst
24		Clamp, pinch
12		Coefficient of linear expansion apparatus
12		Funnel, 4 in. diameter
8	ft	Glass tubing, 6 mm

12		Hydrometer jar
12		Magnifier
12		Manometer tube
12		Medicine dropper
12		Meter stick
4		Pan, for ice (pneumatic trough may be used)
12		Ring, iron
12		Ring stand, tall, or table support
24		Rod for expansion apparatus, assortment of aluminum, brass, copper, and steel
1	box	Rubber bands, assorted
12		Rubber stopper, 1 hole, No. 7
12	ft	Rubber tubing 3/16 in.
30	ft	Rubber tubing, ¼ in.
12		Steam boiler
12		Stirring rod
12		Test tube, 125 mm × 15 mm
12		Thermometer, −10°—110° C
12		Tripod for steam boiler
12		T-tube
1	ball	Twine
12		Water trap
12		Wire gauze

Equipment List (*Sound*)

1		Glass, flat, shaped like a prism or lens, for ripple tank
12		Glass tube, 2.5 cm-4.0 cm in diameter, 40 cm long
12		Hydrometer jar
12		Meter stick
4		Paint brush, 1 in.
3		Paraffin blocks or separators with no openings, one ⅜″ opening, and two ⅜″ openings with ½″ separation respectively, for ripple tank
1		Protractor
1		Ripple tank, with attachments to produce linear waves and waves from a point source
1		Sheet of metal, thin, bent in the shape of concave and convex mirrors, and other irregular shapes, for ripple tank
1		Stop watch
12		Thermometer, −10°—110° C
24		Tuning fork, assortment of C, E, G, and C′ forks, concert pitch. (Physical pitch forks may be used)
12		Tuning fork hammer
1		Vibrograph
12		Vibrograph glass plate or strip of paper

Equipment List (*Light*)

12		Bristol board, white, at least 12.5 × 15 cm
12		Bunsen burner, with hose
12		Calcite (Iceland spar) crystal, approx. 2 cm long
24		Candle, standard
12		Candle holder
12		Cardboard disk, 8-cm diam
12	pkg	Cellophane sheets, for thickness plates
12		China-marking pencil
1		Color apparatus, Von Nordroff, or other suitable type
12	sets	Color filters, various colors
12		Compass, pencil
1	pkg	Construction paper, containing red, orange, yellow, green, blue, and violet
12		Diffraction slits, single and double, of various widths and spacings
12		Evaporating dish, size 00
12		Ferrotype plate, 5 × 5 cm
12		Glass cube, 5 cm^3, or plate, 7 × 7 × 0.9 cm
1	gro	Glass plate, 5 × 5 cm
12		Glass prism, equilateral, faces 7.5 cm long and 9 mm thick
1	set	Glass slides, including red, yellow, green, and blue, to fit color apparatus
30		Glass stirring rod
12		Grating holder and support for meter stick
12		Image screen, Bristol board with metric scale
1		Image screen, 25-cm square
1	pkg	Index cards, white
12		Lamp, 7.5 watt, standard base
12		Lamp socket, standard base, with extension cord and plug
24		Lens, converging, 5-cm focal length, 3.75-cm diam
12		Lens, converging, 10-cm focal length, 3.75-cm diam
12		Lens, converging, 15-cm focal length, 3.75-cm diam
12		Lens, converging, 25 to 35-cm focal length, 3.75-cm diam
12		Lens, diverging, 10-cm focal length, 3.75-cm diam
12		Lens, diverging, 15-cm focal length, 3.75-cm diam
24		Lens holder, for 3.75-cm diam lens
12		Magnifier
12		Meter stick
24		Meter stick supports

12	Metric scale and slit for meter stick mounting
36	Metric paper scale, 20 cm for horizontal use
12	Metric rule, steel, graduated in 0.5 mm
12	Microscope, 16 mm (10×) and 32 mm (4×) objectives (Borrow from Biology Dept.)
12	Microscope objective lens, 32 mm (4×) (Needed only if 16 mm (10×) objective is not divisible)
½ gro	Microscope slides, 2.5 × 7.5 cm
12	Mirror, plane, rectangular
1	Mirror, spherical, demonstration, 40-cm diam, concave
1	Mirror, spherical, demonstration, 40-cm diam, convex
12	Object box, with electric lamp, extension cord and plug
12	Object screen
12	Object screen, black bristol board with triangular wire-gauze aperture
1 ream	Paper, drawing
12	Photometer, Joly or Bunsen
12	Photoelastic specimens, U-shaped transparent plastic
1 box	Pins, large, straight
12 pr	Polaroid disks, 4-cm diam, or 5-cm square
1 set	Poster paints, containing red, yellow, green, and blue
12	Protractor
12	Ring stand, rectangular base, with 1-1 in ring and 1-2 in ring
1 box	Rubber bands
12	Ruler, metric
36	Screen holder
1	Tape measure, metric
12	Wooden block, rectangular, to support plane mirror

Equipment List (*Electricity and Electronics*)

12	Ampere's law stand
1	Audio signal generator
12	Balance, platform, to 0.1 g
12	Balance, triple beam, 0.01 g sensitivity
12	Balance, platform, to 0.1 g
12 sets	Balance weights, brass, in wood block, 1 g to 1 kg
12	Ball, brass, drilled, 1 in. diam
36	Battery, "B," 22.5-v and 45-v terminals, Burgess 5308 or equivalent
12	Battery, "C," 9 v
12	Calorimeter, electric, 2-5 ohm heating coil
12	Capacitor, 25 microfarads, 25 v
24	Capacitor, 50 microfarads, 25 v
1	Capacitor, demonstration, for gold-leaf electroscope
1	Capacitor decade box, 0.01 microfarad to 1.1 microfarad in 0.01 microfarad steps
2	Capacitors, paper, 0.002 μf, 400 v
1	Capacitor, paper, 0.05 μf, 400 v
24	Coil, for induction, on brass spool to accommodate 19 × 6 mm bar magnet
12	Coil set, primary and secondary, student type
48	Compass, 1-cm diam
12	Compass, 5-cm diam
6 doz	Connector, brass, double
12	Contact key, or push-button switch
4 ft^2	Copper sheet
6 pkg	Cross-section paper, cm-square
12	Demonstration cell, student form
12	Diode, type 6H6
48	Dry cell, standard No. 6
12	Electric bell, 1-3 v
12	Electrode, carbon, flat, 12.5 × 2 cm
12	Electrode, copper, flat, 12.5 × 2 cm
24	Electrode, lead, flat, 12.5 × 2 cm
24	Electrode, zinc, flat, 12.5 × 2 cm
1	Electroscope, gold leaf, demonstration type
12	Electroscope, leaf, flask type
12	Electroscope, pitch-ball
12	Enameled pan
12	Exciting pad, fur or wool
12	Exciting pad, silk
12	Extension cord, split line, and plug
3	Filter chokes ranging from 8 h to 30 h
24	Flexible leads, short, with alligator clips
12	Friction rod, ebonite or hard rubber
12	Friction rod, glass
24	Fuse, 6 a, standard screw base
12	Fuse block, double, for standard screw base
1	Galvanometer, lecture form, zero center
12	Galvanoscope, 3 windings of 1, 25, and 100 times
1	Generator, demonstration
12	Lamp, carbon, 32 candle
12	Lamp, tungsten, 40 watt
48	Lamp, tungsten, 60 watt
12	Lamp board, 3 socket
12	Lamp, 6 v, No. 40 miniature screw base, 150 ma

12	Lamp, 6 v, carbon, standard base
1	Lamp, 117 v, clear glass, 7-25 watts
12	Lamp, straight filament, clear glass, standard base
12	Lamp base, miniature screw receptacle
12	Lamp base, with standard receptacle, extension cord and plug, for vertical mounting of lamp
12 pr	Magnets, bar, 19 × 6 mm cross section
12	Magnet, horseshoe, with keeper
12	Magnet core, iron, 10 cm long, 8 mm diam
12	Magnet core, wood, 10 cm long, 8 mm diam
12	Magnifier, 3 to 10×
12	Meter, a-c ammeter, 0-3 a
12	Meter, a-c milliammeter, 0-50/200/500 ma
12	Meter, a-c voltmeter, 0-7.5 v
12	Meter, a-c voltmeter, 0-150/300/600 v
1	Meter, a-c/d-c VTVM multirange
12	Meter, d-c ammeter, 0-1/3/30 a
12	Meter, galvanometer, zero-center
12	Meter, d-c milliammeter, 0-15/50/150 ma
12	Meter, d-c voltmeter, 0-3/7.5/15 v
12	Meter, d-c voltmeter, 0-150 v, 20,000 ohms/volt
12	Motor, St. Louis type
12	Octal socket, mounted
1	Oscilloscope
12	Potentiometer, 1000 ohms, 4 watts
12	Potentiometer, 4000 ohms, 10 watts
1	Power supply, 6.3 vac at 0.3 a, 180 vdc at 10 ma
12	Resistance box, plug type, of the order of 100 ohms
2	Resistance box, plug type, of the order of 1000 ohms
1	Resistance box, plug type, of the order of 10000 ohms
12 sets	Resistance spools, consisting of each of the following spools: 30 GS 200 cm, 28 GS 200 cm, 30 GS 120 cm, 30 Cu 2000 cm
12	Resistor, 10000 ohms, 5 watts
12	Resistor, 20000 ohms, 5 watts
12	Resistor, 40000 ohms, 5 watts
12	Resistor, 80000 ohms, 5 watts
1	Resistor, carbon, 1800 ohms, ½ watt
1	Resistor, carbon, 10,000 ohms, ½ watt
1	Resistor, carbon, 15,000 ohms, ½ watt
1	Resistor, carbon, 22,000 ohms, ½ watt
1	Resistor, carbon, 47,000 ohms, ½ watt
3	Resistors, carbon, 1,000,000 ohms, ½ watt
1	Resistor, carbon, 1,000,000 ohms, ½ watt
12	Rheostat, 10 ohms, 25 watt
12	Rheostat, 50 ohms, 25 watts
1	Rheostat, 200 ohms (for galvanometers of the order of 100-ohms resistance), or 500 ohms (for galvanometers of the order of 50-ohms resistance)
12	Rheostat, tubular, 25 ohms
1 pkg	Sandpaper, fine grit
12	Stop watch, 10-second sweep
12	Storage battery, 12 v, tapped for 6-v service
12	Switch, knife, DPDT
12	Switch, knife, DPST
24	Switch, knife, SPST
1 box	Tacks, iron (carpet)
12	Temperature coil, copper, approx. 3 ohms
1 pr	Test leads, 1000-v insulation
24	Test lead, with alligator clips
12 pr	Test lead, with pointed probes
12	Thermometer, Celsius, -1° to 101° in 0.2° subdivisions
1 spool	Thread, silk
12	Transformer, 6-v filament
12	Triode, type 6J5
2 ft	Tubing, rubber, 6 mm id
1 lb	Twine, cotton
12	Wheatstone bridge, slide-wire form
2 lb	Wire, annunciator, No. 18
1 spool	Wire, copper, bare, No. 30
2 lb	Wire, copper, insulated, No. 22
2 lb	Wire, copper, insulated, No. 28

Supplies

1 lb	Acetamide crystals
6 lb	Acid, hydrochloric, tech
7 lb	Acid, nitric, tech
18 lb	Acid, sulfuric, tech
4 gal	Alcohol, ethyl, denatured
1 qt	Alcohol, methyl
4 gal	Carbon tetrachloride, tech
3 lb	Copper sulfate, tech
2 pkg	Corks, student assortment of 100
5 gal	Distilled water
5 lb	Ether
8 oz	Gum camphor
	Ice cubes, as needed
1 oz	Lycopodium powder
16 lb	Mercury, tech
1 qt	Milk

1 lb	Naphthalene crystals	1 pt	Shellac
1 pt	Oil, crankcase, used	2 lb	Sodium chloride CP, fine cryst
1 oz	Oleic acid	1 lb	Sodium dichromate, tech, cryst
1 lb	Paraffin	9 lb	Sulfuric acid, conc
1 pt	Rubber cement	1 pt	Whiting suspended in alcohol

Appendix E
MATHEMATICS FOR PHYSICS

1. Symbols

In algebra the letter "x" is used to indicate the unknown quantity for which to solve. Physicists try to avoid "x" for unknowns, preferring to use letters that give some hint of the nature of the unknown quantity; thus, "v" for velocity, "t" for time, "p" for pressure, "f" for force, etc. While this practice is a useful one to follow, one should realize that any letter will do. Indeed, Greek letters are often used to stand for angles: for example, angle θ (theta).

It has been found beneficial to use *subscripts* to distinguish between several different quantities of the same sort. Thus, if we need to distinguish between the weight of a father and the weight of his son, use the letter "W" for weight for both, but indicate the two different weights by W_f and W_s, respectively.

Different forces might be indicated as F_1, F_2, F_3, and F_4. Subscripts are in common use throughout physics books.

2. Elementary Operations

Multiplication is indicated in the following ways. Numbers to be multiplied are separated by $\times$. Thus 20 times 4 is written 20×4. If a sum of numbers is to be multiplied, such as $4 + 7$ times 20, then parentheses are used and written as $20(4 + 7)$, without the use of the times sign ($\times$).

Of course it makes no difference which number is written first. Thus 20×4 is the same as 4×20, and $20(4 + 7)$ is the same as $(4 + 7)20$.

When letters are used to represent quantities the rules are similar. When pressure, "P," is to be multiplied by volume, "V," this is written "PV" without the multiplication sign. Similarly we write "abc" for "a" times "b" times "c."

If a quantity being multiplied (called a *factor*) is a sum such as $P + 15$, the product of, say, $P + 15$ and V is written $(P + 15)V$. This means that *each* quantity inside the parentheses is to be multiplied by the quantity outside. $(P + 15)V$ can therefore be written $PV + 15V$, and $ab(c + d)$ can be written $abc + abd$.

Division is commonly indicated by a horizontal line between *numerator* (upper number) and *denominator* (lower number).

2 divided by 3 is $\frac{2}{3}$ (or, to save space, 2/3)

V divided by T is $\frac{V}{T}$ or V/T

$3(a + b)$ divided by $c + d$ is $\frac{3(a + b)}{c + d}$

or $3(a + b) \div (c + d)$

Fractions written in this way can be simplified if both numerator and denominator have the same factor, for such common factor may be canceled. Thus "8" is a common factor in $\frac{24a}{16c} = \frac{8 \times 3a}{8 \times 2c}$

Dividing numerator and denominator by 8:

$$\frac{\cancel{8} \times 3a}{\cancel{8} \times 2c} = \frac{3a}{2c}$$

Similarly $\frac{9ab(c + d)}{3\,b(c + e)}$ can be simplified to $\frac{3a(c + d)}{c + e}$ since "3b" is a factor common to both numerator and denominator. Although "c" appears in both numerator and denominator, note that it is *not a factor* and hence cannot be canceled.

If either numerator or denominator is a fraction, it can usually be simplified by inverting the denominator and multiplying. In this way $\frac{7}{8}$ divided by $\frac{3}{4}$ is written $\frac{\frac{7}{8}}{\frac{3}{4}}$ and simplified to $\frac{7}{8} \times \frac{4}{3}$. It can be further simplified by dividing numerator and denominator by "4" (i.e., by canceling 4's).

$$\frac{7}{2 \times \cancel{4}} \times \frac{\cancel{4}}{3} \text{ thus becomes } \frac{7}{6}.$$

$\frac{9}{11}$ divided by 3 can be written $\frac{\frac{9}{11}}{\frac{3}{1}}$ or $\frac{9}{11} \times \frac{1}{3}$

which is $\frac{3}{11}$.

Similarly

$\frac{6ab}{5d}$ divided by $\frac{3ac}{20(c + d)}$ is $\frac{6ab}{5d} \times \frac{20(c + d)}{3ac}$,

and canceling reduces this to $\frac{8b(c + d)}{cd}$.

3. Exponents

When a number, "p," is to be multiplied by itself, the process is written as "pp" or "p^2," called "p squared." Similarly, if it is multiplied by itself again, "ppp" is written "p^3," called "p cubed"; and "pppp" is written "p^4" and called "p to the fourth," and so on. The number "p" is called the *base*, and the number which tells how many times it is multiplied by itself is the *exponent*.

Thus if one side of a cube has a length of 4 inches, the area of one side is $4^2 = 16$ square inches (in^2) and the volume is $4^3 = 64$ cubic inches (in^3).

Of course, p^1 is p; likewise $4^1 = 4$.

Negative exponents are very convenient in physics. They are a shorthand way of indicating division by a number whose exponent is positive. Thus, 1/10 can be written 10^{-1}; $1/10^2$ is also written 10^{-2}, and $1/5^8$ can be written 5^{-8}, etc. If a volume is to be divided into cubes whose sides are "p" long and whose volumes are therefore, "p^3," the number of cubes that would fit in the Volume V might be written V/p^3. Such an expression is often written Vp^{-3}. In the same way $\frac{a^2b}{cd^3}$ can be written as $a^2bc^{-1}d^{-3}$, and $\frac{a+b}{c+d}$ can be written as $(a + b)\ (c + d)^{-1}$.

Multiplication. When numbers with the same base are multiplied together, their exponents are added. For example, "ppp" is written "p^3" and "pp" is written "p^2." If "p^3" is now to be multiplied by "p^2," we are multiplying "p" by itself five times. Thus

$$p^3 \times p^2 = p^{3+2} = p^5$$

If $p = 3$, then $p^5 = 3^5$, which is 243.

$$y \times y^4 = y^{1+4} \text{ or } y^5$$

Division of exponential numbers with the same base is done by subtracting the exponents. When "a^5" is divided by "a^3" we can write $\frac{a^5}{a^3} = a^{5-3} = a^2$

Again, $\frac{2^6}{2^4} = 2^{6-4} = 2^2$.

The use of negative exponents does not require a new rule: $p^3 \times p^{-2} = p^{3-2}$ or p. You can see this will be so if you write the quotient completely and then cancel.

$$\frac{p \times \cancel{p} \times \cancel{p}}{\cancel{p} \times \cancel{p}} = p$$

$$3^3 \times 3^{-2} = 3^{3-2} \text{ or } 3^1 \text{ or } 3$$

which you can check by writing it as $\frac{3^3}{3^2} = \frac{27}{9} = 3$.

Consider the example "p^n/p^n" when "n" is any number (any exponent). When dividing one thing, "p^n," by itself, we know the answer is "1." But using the rule for exponents, we have $\frac{p^n}{p^n} = p^{n-n} = p^0$. Thus we conclude that any quantity, "p," to the zero power is equal to 1.

Similar letters with different subscripts are, of course, different numbers. Hence you cannot simplify a_1a_2 any further, and $a_1{}^2a_2 \times a_1a_2{}^3 = a_1{}^3\, a_2{}^4$.

If an exponential number, "a^5," is to be cubed, the operation is written $(a^5)^3$. This means $a^5 \times a^5 \times a^5$, which is "a" multiplied by itself 15 times, or a^{15}. Apparently this exponent could be found by multiplying 5 by 3

$$(a^5)^3 = a^{5\times 3} = a^{15}.$$

Again, another example, $(a^3)^x = a^{3x}$. (Caution: Do not confuse this operation with "a^3a^x," which equals "a^{3+x}.") As a final example, $(a^{-2})^3 = a^{-6}$.

Exponents can only be added and subtracted if the base of each is the same. For example, $2^4/3^3$ cannot be simplified by any operation we have described. Nor can anything be done with a^4b^3/c^2. But a^4b^3/c^2 divided by ab^2/c can be simplified by the rules learned earlier, as follows. First invert the denominator and then multiply.

$$\frac{a^4b^3}{c^2} \div \frac{ab^2}{c} = \frac{a^4b^3}{c^2} \times \frac{c}{ab^2}$$

Now divide the quantities that have the same base, which leads to the simplified form, a^3b/c. That is, both numerator and denominator are divided by ab^2c. Again, $\frac{(a+b)^4(a-b)^2}{ab(a+b)^3}$ can only be $\frac{(a+b)\ (a-b)^2}{ab}$, since the only base in *both* numerator and denominator is "a + b."

Some simplification is possible if different bases have the same exponent. Thus, $(2)^2 \times (3)^2$ can be written as $(2 \times 3)^2$. The result will be 36 (which you can check by noticing that $2^2 \times 3^2 = 4 \times 9 = 36$).

Again, $a^4b^4c^4$ is $(abc)^4$, and $\frac{p^3q^3}{r}$ is $\frac{(pq)^3}{r}$.

Fractional exponents are often used to indicate roots: $\sqrt{p}$ can be written as $p^{1/2}$. This is reasonable enough when you remember that $p^{1/2} \times p^{1/2} = p^1$, which is also obtained by addition of exponents. The cube root of "p" can similarly be written as $p^{1/3}$. The cube of this expression, which is certainly just "p," is found from $(p^{1/3})^3$ by the usual procedure of multiplying exponents.

If a cube has a volume, V, one side of the cube has a length $\sqrt[3]{V}$, which can also be written $V^{1/3}$. Likewise the area of one face of the cube will be $(V^{1/3})^2$, which can be written simply as $V^{2/3}$.

Powers-of-Ten Notation. Very large numbers and very small numbers are much easier to handle if they are written as powers of ten. *Any* number may be written as a power-of-ten multiplied by a second number between 1 and 10. Thus, 150, which is 1.5×100, may be written as 1.5×10^2. And 4,530,000 may be written as 453×10^4 or as 45.3×10^5 or, best of all, as 4.53×10^6. Notice how moving the decimal point one digit to the left is balanced by increasing the exponent by one. It is helpful in writing numbers in powers-of-ten notation to remember that 1000 is 10^3 and 1,000,000 is 10^6.

Numbers far smaller than one can be written in this way using negative powers of ten. A decimal fraction like 0.00371 is the same as 371/100,000 or $371/10^5$. This may be written as 371×10^{-5} or better as 3.71×10^{-3}. Notice that 1/100 is 10^{-2}, 1/1000 is 10^{-3}, and 1/1,000,000 is 10^{-6}.

The powers-of-ten notation is particularly useful in physics because enormously large and exceedingly small quantities are dealt with constantly. Thus, in a glassful of air there are about 7×10^{21} molecules, each about 10^{-8} cm in diameter, traveling about 5×10^4 cm/sec, and weighing about 5×10^{-23} gm. Numbers like these are easy to multiply and divide by one another and easy to compare with each other by using the powers-of-ten notation.

Multiplying 4,530,000 by 0.00371 may seem formidable. But it becomes easier if, as before, we write these numbers as $4.53 \times 10^6 \times 3.71 \times 10^{-3}$. Notice that $4.53 \times 3.71 = 16.8$ (to three significant figures) and $10^6 \times 10^{-3} = 10^{6-3} = 10^3$. Hence, $4.53 \times 10^6 \times 3.71 \times 10^{-3} = 16.8 \times 10^3$.

To divide 4,530,000 by 0.00371 write

$$\frac{4.53 \times 10^6}{3.71 \times 10^{-3}} = 1.22 \times 10^{6-(-3)} = 1.22 \times 10^9.$$

Here is a slightly harder example:

$$\frac{8 \times 5280 \times 0.870}{453 \times 2{,}080{,}000 \times 0.0140}$$

is first written

$$\frac{8 \times 10^0 \times 5.28 \times 10^3 \times 8.7 \times 10^{-1}}{4.53 \times 10^2 \times 2.08 \times 10^6 \times 1.40 \times 10^{-2}}.$$

Now we combine the powers-of-ten by applying the rules of exponents, and also combine the "ordinary" numbers by the usual laws of multiplication and division.

$$\frac{8 \times 5.28 \times 8.70}{4.53 \times 2.08 \times 1.40} \times \frac{10^0 \times 10^3 \times 10^{-1}}{10^2 \times 10^6 \times 10^{-2}}$$

$$= \frac{368}{13.2} \times \frac{10^2}{10^6} = 27.8 \times 10^{-4} = 2.78 \times 10^{-3}$$

(or 0.00278)

It is sometimes helpful to rewrite the last step to simplify the final division. Thus, in another problem, if we had $\frac{1.38 \times 10^8}{2.30 \times 10^{-2} \times 6.92 \times 10^5}$, we would get $\frac{1.38 \times 10^8}{15.9 \times 10^3}$.

If division is to give us a number between 1 and 10 times a power-of-ten, we must rewrite the denominator. Then $\frac{1.38 \times 10^8}{0.16 \times 10^1} = 8.67 \times 10^7$.

Similarly

$$\frac{1.28 \times 10^{-4}}{8.60 \times 10^3} = \frac{12.8 \times 10^{-5}}{8.60 \times 10^3} = 1.49 \times 10^{-8}.$$

or, equally correct,

$$\frac{1.28 \times 10^{-4}}{8.60 \times 10^3} = \frac{1.28 \times 10^{-4}}{0.860 \times 10^4} = 1.49 \times 10^{-8}.$$

If necessary to take the square root of a number written in the powers-of-ten notation, divide the exponent of 10 by 2. For this to be possible without producing a fractional exponent, the power-of-ten must be an even number. This is easily managed as shown by the following examples:

$$6.4 \times 10^9 = 64 \times 10^8 = 8 \times 10^4$$

$$0.0016 = 16 \times 10^4 = 4 \times 10^{-2}$$

Likewise when extracting cube roots, the exponent must first be made divisible by 3. Hence

$$\sqrt[3]{27{,}000} = \sqrt[3]{27 \times 10^3} = 30 \text{ and}$$

$$\sqrt[3]{64 \times 10^{-6}} = 4 \times 10^{-2}.$$

Sample Assignment—Arithmetic

1. Add: (Place line over last significant figure in answer.)
   a. $762 + 891 =$
   b. $8.721 + 7.915 =$
   c. $8.0125 + 0.012 =$
   d. $1.082 + 7.691 + 85.1 + 7.9254 =$
2. Subtract:
   a. $72.7 - 8.615 =$
   b. $1.07 - 0.291 =$
   c. $10.7954 - 2.7 =$
3. Multiply:
   a. $17 \times 23 =$
   b. $18.7 \times 19.2 =$
   c. $107.0 \times 92.1 =$
   d. $271.3 \times 24.9 \times 75.3 =$
4. Express as powers-of-ten:
   a. $4{,}000{,}000{,}000 =$
   b. $0.000000000007 =$
   c. $4{,}000 \times 7{,}000{,}000 =$
   d. $2{,}000{,}000 \times 155{,}000{,}000 =$
   e. $0.0021 \times .0000001 =$
   f. $2{,}000{,}000 \times .00004 =$
   g. $2{,}000{,}000 \div 4{,}000{,}000{,}000 =$
   h. $2{,}790{,}000 \times 8{,}473{,}796{,}821 =$
   i. $2{,}750{,}297 \times 8{,}610{,}325 \div 9{,}007{,}871 =$
   j. $.00479 \times 8{,}007{,}692 =$
5. Extract roots by powers-of-ten:
   a. $\sqrt{900}$ b. $\sqrt{16{,}000{,}000}$
   c. $\sqrt{0.0016}$ d. $\sqrt{.0000004}$
   e. $\sqrt{16000}$ f. $\sqrt[3]{27000}$

Sample Assignment—Arithmetic

1. Add:

a.	b.	c.	d.
-9	-54	0.0025	0.296
-2	33	-0.1024	-38.802

e. 5x, 6x, $-18x$, 40x

f. $4x - 3a - 3c - 11$, $2a - 3x + 4c$

g. $-3(x-y) + 6$, $10a - 5 + 4(x-y)$, $a - 3(x-y) + t$

2. Subtract:

a.	b.	c.	d.
16	-34	-78	106.25
66	23	-47	-6.07

3. How many degrees must the temperature rise (R) or fall (F) to change from:

a. $+3°$ to $+14°$ b. $-6°$ to $18°$
c. $0°$ to $-21°$ d. $+13°$ to $+40°$

4. Express the following numbers between 1 and 10 times the proper power-of-ten:

a. 643,000,000 e. 4536
b. 0.000250 f. 1890×10^3
c. 0.0000000000125 g. 8420×10^{-12}
d. 0.367×10^{-6} h. 0.000399×10^8

5. Extract roots by powers-of-ten:

a. $\sqrt{900}$ d. $\sqrt{0.0000004}$
b. $\sqrt{16{,}000{,}000}$ e. $\sqrt{16000}$
c. $\sqrt{0.0016}$ f. $\sqrt[3]{27000}$

Sample Assignment—Algebra and Trigonometry

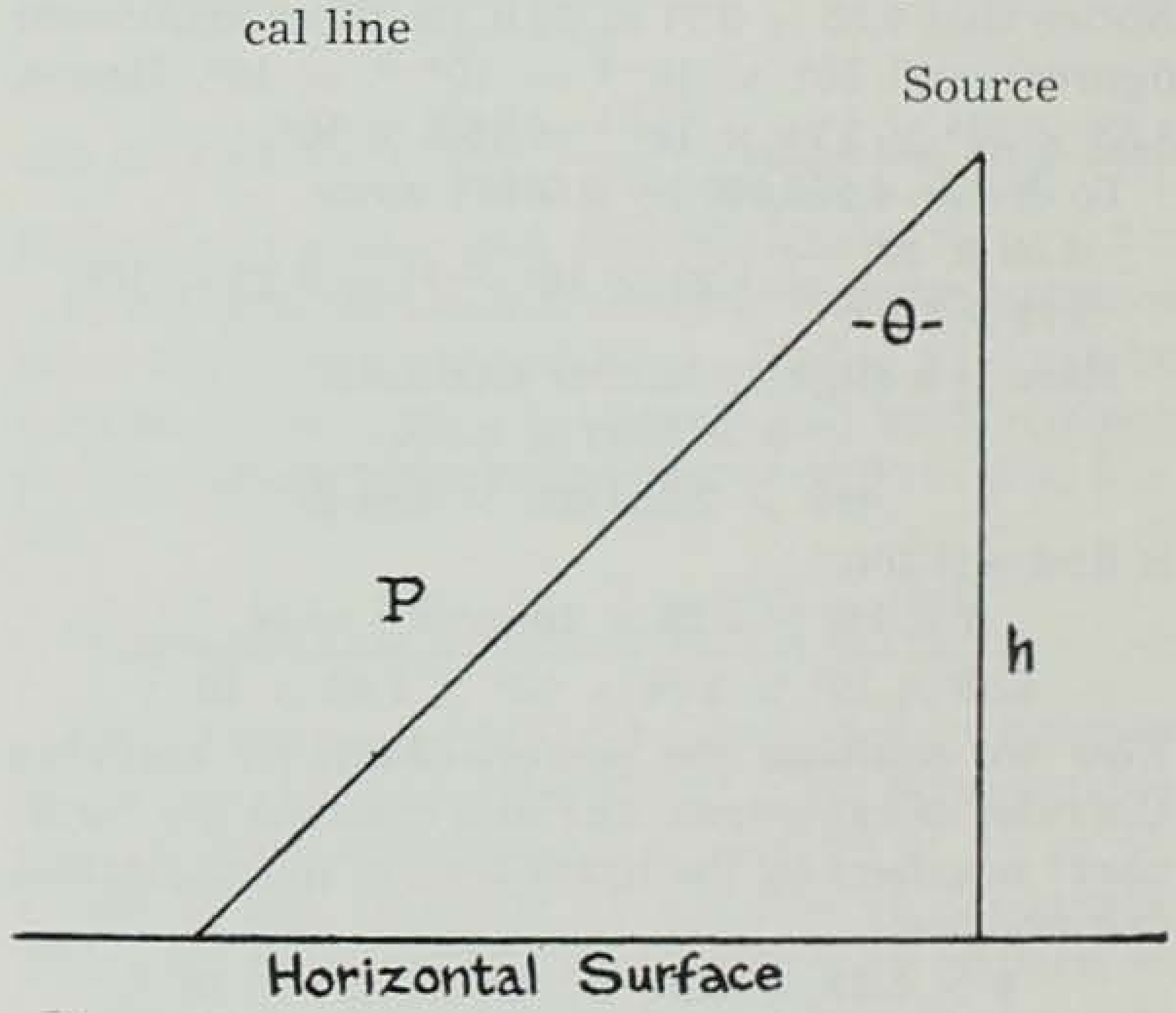
1. Solve for unknown:
   a. $x + 2 = 12$
   b. $a - 7 = 14$
   c. $2x - 7 = 19$
   d. $7y = 4.2$
2. Express the following rotation in angular measurement:
   a. 1/4 revolution
   b. 3/5 revolution
   c. 9/10 revolution
   d. 10/9 revolution
   e. 40/10 revolution
3. Express as radians:
   a. ½ revolution
   b. ⅞ revolution
   c. 2 revolutions
   d. 2½ revolutions
4. Determine:
   a. sin 0°
   b. cos 90°
   c. tan 90°
   d. tan 270°
   e. cos 360°
   f. sin 360°
   g. sin 720°

Sample Assignment—Algebra and Trigonometry

1. A room is twice as long as it is wide, and its perimeter is 144 feet. Find (a) length and (b) width.
2. A rectangular lot is 75 feet longer than it is wide. The perimeter is 600 feet. Find (a) length and (b) width.
3. Write in symbols that x exceeds y as much as a is less than b.
4. If x years ago a man was a boy 6 years old, express his age 13 years hence.
5. Write in symbols one-half the square of x plus twice the square of y.
6. A certain number increased by four times its reciprocal equals 8½. Find the number.
7. The sum of two numbers is 26. Their product is 153. What are the numbers?
8. The illumination on a horizontal surface from a source of light at a given vertical distance from the surface is given by the formula

$$E_n = \frac{I}{h^2} \quad \cos^3 \text{-}\theta\text{-}$$

E_n—illumination in foot candles
I—luminous intensity of source in foot candles
h—vertical distance in feet from horizontal surface
-θ-—angle between incident ray and vertical line



Solve for h, I, and -θ-

Sample Assignment—Graphs

1. Plot the following on separate graph sheets. Use 10 squares-to-the-inch graph paper.
   a. Equation $2x + y = 4$ (from $x = 1$ to $x = 8$ integral numbers)
   b.

x	y	
0	0	
10	1	Draw curve:
20	2	

(Continued on next page)

30	3
40	4

c.

x	y
0	0
95	1.8
201	3.9
290	6.1
400	8.0
502	10.1

Draw curve:

d.

Distance	*Time*
1 mile	2 sec
2 mile	4 sec
3 mile	6 sec
3½ mile	8 sec
3¾ mile	10 sec
3⅞ mile	12 sec
4 mile	14 sec

e. Plot following curves on same graph:

1.

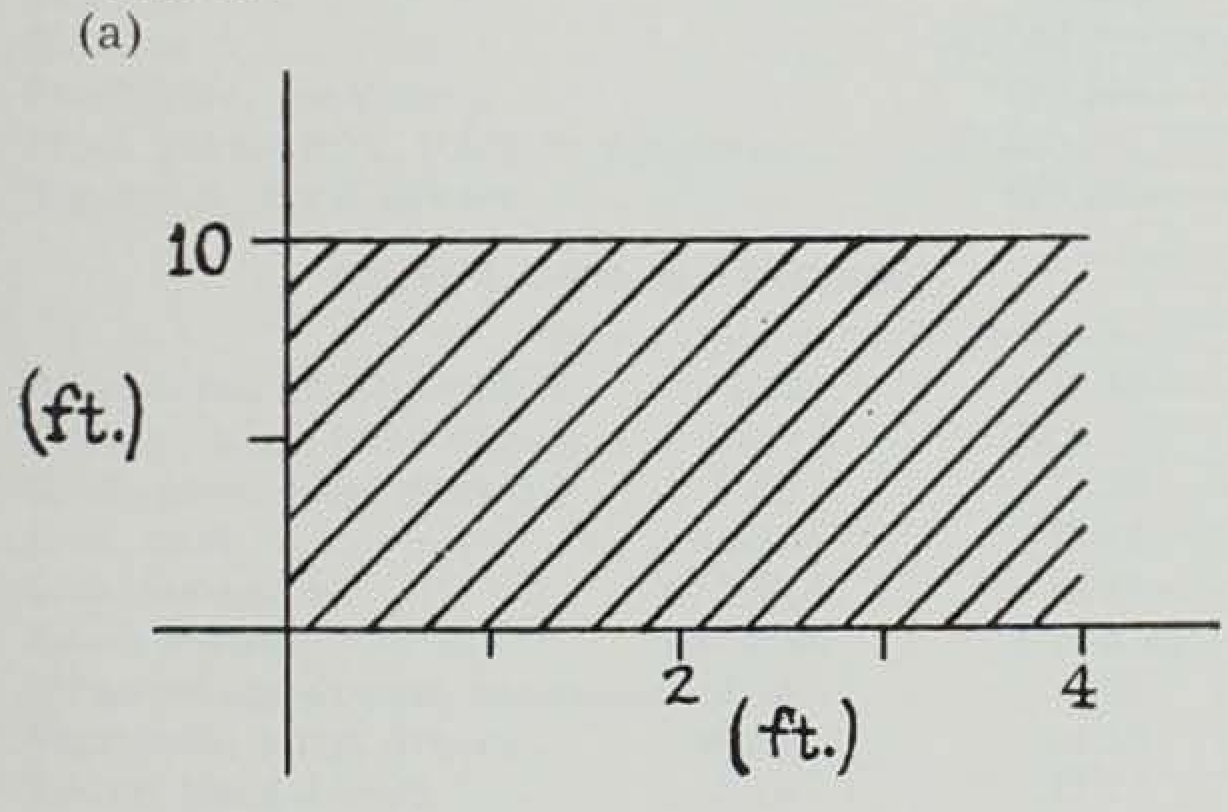
Time	*Distance*
0 sec	0 mile
1 sec	1 mile
2 sec	2 miles
3 sec	3.1 miles
4 sec	3.9 miles
5 sec	5.0 miles

2.

Time	*Distance*
0 sec	0 mile
1 sec	4 miles
2 sec	8 miles
3 sec	12 miles
4 sec	15.9 miles
5 sec	20.2 miles

2. Determine the tangent and slope of the curves plotted in number 1. If slope changes, compute at center position of curve.
3. Determine the area under the following curves:

(a)



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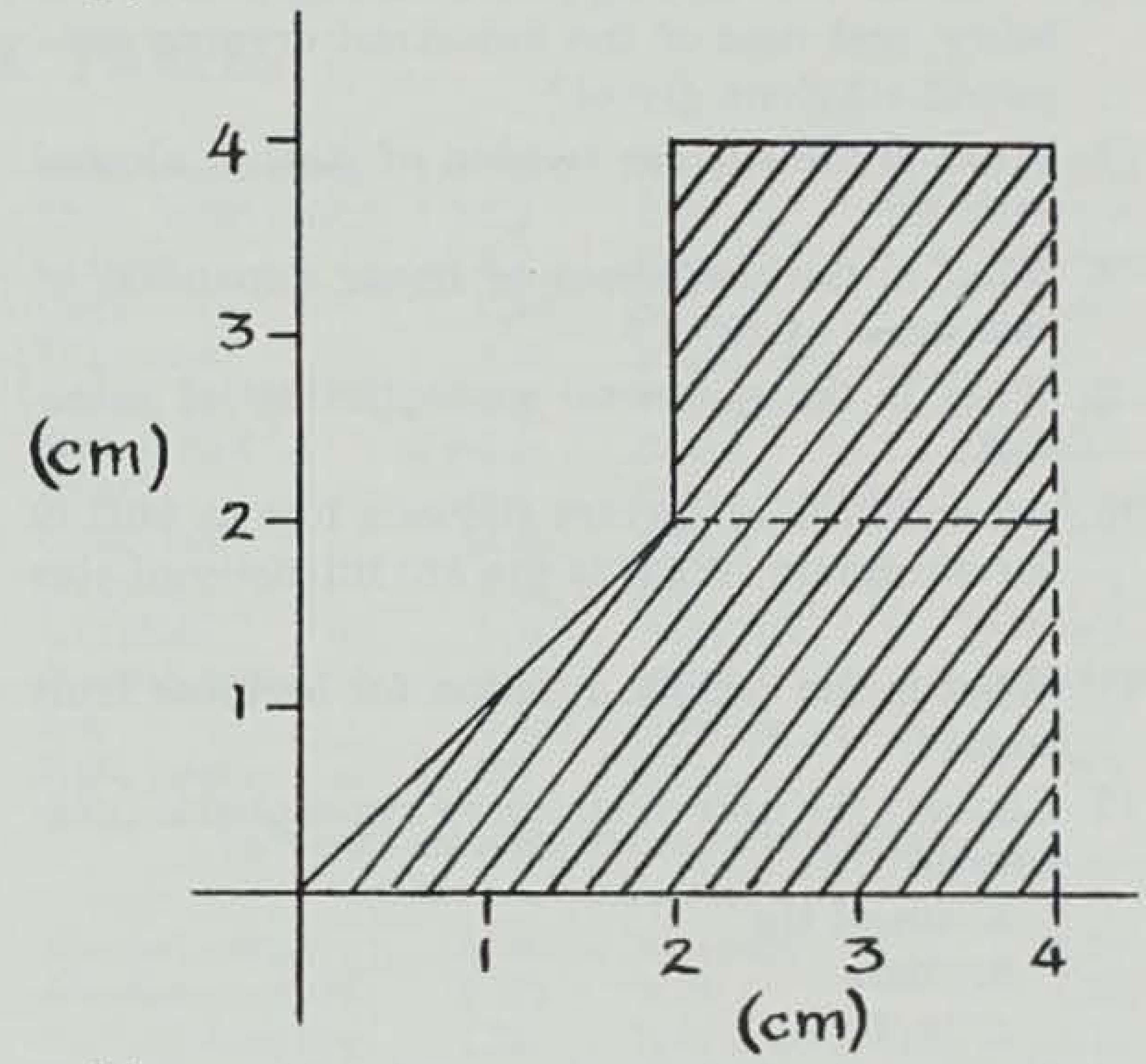

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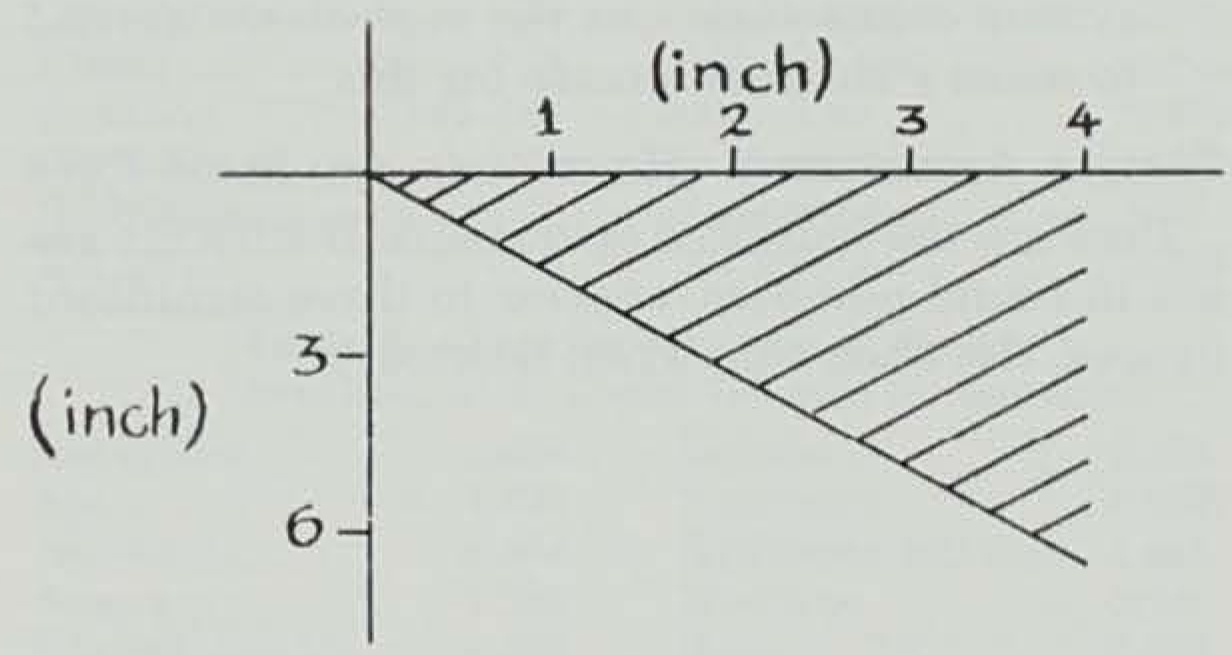

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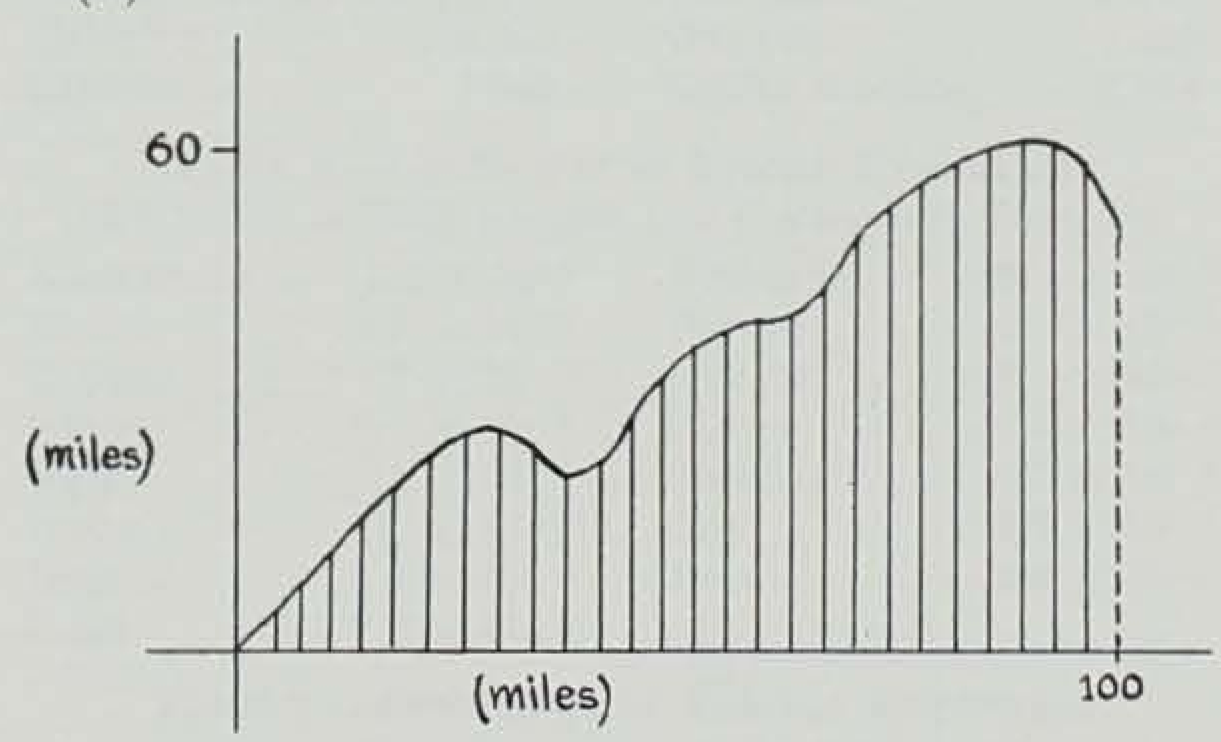


SAMPLE ASSIGNMENT—HANDBOOKS
(Questions from *Handbook of Physics and Chemistry—40th Edition*)

1. How many cubic inches are there in a gallon?
2. Find the following, using the appropriate table:
   a. $(554)^3$
   b. $(554)^{1/3}$
   c. $(5540)^{1/3}$
   d. $(55400)^{1/3}$
3. What is the atomic weight of iridium? What are its major uses? What is the most important salt of this substance?
4. What is the half-life of strontium^{90} (Sr^{90})? of Sr^{91}? of Y^{94}?
5. What is the molecular weight, crystalline form, formula, specific gravity, melting point, and boiling point of the inorganic compound cesium nitrite?

6. What are the melting point, boiling point, solubility, and uses of the industrial organic compound ethylene glycol?
7. What is the surface tension of methyl alcohol at 0° C?
8. What is the coefficient of linear expansion of cast brass at 20° C?
9. What is the magnetic susceptibility of celluloid?
10. An emission of spectra shows a line at 5402.79 for europium. What is the arc intensity of this line?
11. What is the specific rotation for levulose fruit sugar?
12. Convert the unit of standard atmospheric pressure to
    a. cm of Hg
    b. bars
    c. lb/ft^2
13. You want a tight seal around a high vacuum system connection. List the ingredients needed to make a stopcock grease for this.

Sample Assignment—Handbooks and Slide Rule

Perform the indicated operations. If answers are not in round numbers, express to three significant figures. Use slide rule when necessary.

1. $(10^4)^3$
2. $(10^2 \times 10^3)^3$
3. $(10^{-3})^4$
4. $(3 \times 10^{-3})^2$
5. $(5 \times 10^4)^2$
6. $(8 \times 10^4 \times 2 \times 10^5)2$
7. $(7 \times 10^{-3})^2$
8. $\dfrac{(8 \times 10^4)^2}{(2 \times 10^3)}$
9. 0.00081×0.009
10. $64 \times 10^{-5} \times 25 \times 109$
11. $6.28 \quad 4 \times 10^3 \times 7 \times 10^{-6}$
12. $8.6 \div .61$
13. $(751)^{1/2}$
14. $(892)^{1/3}$
15. $\log 1.72$
16. $\log 107.9$
17. $\log_{10} 7418$
18. $\log_{10} 1.79$
19. $\tan 31°$
20. $\sin 0.8°$
21. $\sin 72.3° \times \cos 21.2°$
22. $8.69 \sin 21.3°$
23. $(8.17)^{1/3}$
24. $1/(211)^{1/2}$
25. $\dfrac{159 \times 10^3}{\sqrt{0.000169 \times 0.000350 \times 10^{-6}}}$

Appendix F
HANDBOOK TABLES

Table 1.—Useful Numbers—English System

12 in = 1 ft	27 ft^3 = 1 yd^3
3 ft = 1 yd	231 in^3 = 1 gal
5280 ft = 1 mi	60 mi/hr = 88 ft/sec
1760 yd = 1 mi	7000 grains = 1 lb avoirdupois
144 in^2 = 1 ft^2	16 oz = 1 lb
9 ft^2 = 1 yd^2	2000 lb = 1 short ton
1728 in^3 = 1 ft^3	1 ft^3 of water weighs 62.4 lb

Table 2.—Metric-English Equivalents

1 in = 2.5400 cm	1 cm^2 = 0.1550 in^2
1 ft = 30.480 cm	1 in^3 = 16.3872 cm^3
1 yd = 91.440 cm	1 cm^3 = 0.0610 in^3
1 mi = 1609.4 m	1 grain = 0.06480 g
1 mi = 1.6094 km	1 oz = 28.3495 g
1 mm = 0.03937 in	1 lb = 453.592 g
1 cm = 0.3937 in	1 lb = 0.4536 kg
1 m = 39.37 in	1 g = 15.4324 grains
1 m = 3.2808 ft	1 g = 0.03527 oz
1 m = 1.0936 yd	1 g = 0.002205 lb
1 in^2 = 6.4516 cm^2	1 kg = 2.2046 lb

Table 3.—Tensile Strength of Metals
(In lb/in^2)

Aluminum wire	30,000-40,000
Brass wire	50,000-150,000
Bronze wire, phosphor, hard drawn	110,000-140,000
Copper wire, hard drawn	60,000-70,000
Iron wire, annealed	50,000-60,000
Iron wire, hard drawn	80,000-120,000
Lead, cast or drawn	2,600-3,300
Magnesium, hard drawn	33,000
Platinum wire	50,000
Silver wire	42,000
Steel	40,000-330,000
Steel wire, maximum	460,000
Steel, piano wire, 0.033 in diameter	357,000-390,000
Tungsten, hard drawn	590,000

Table 4.—Elastic Modulus

	$dynes/cm^2 \times 10^{11}$	$lb/in^2 \times 10^{4}$
Aluminum, 99.3%, rolled	6.96	10.10
Copper, wire, hard drawn	10.19-12.0	14.5-17
Gold, pure, hard drawn	7.85	11.38
Iron, cast	8.4-9.8	12-14
Iron, wrought	18.3-20.4	26-29
Lead, rolled	1.47-1.67	2.13-2.42
Magnesium, drawn, annealed	4.18	6.06
Platinum, pure, drawn	16.67	24.18
Silver, hard drawn	7.75	11.24
Steel, 0.38% C, annealed	20.01	29.01
Tungsten, drawn	35.5	51.49

Table 5.—Specific Gravity of Solids

Aluminum	2.7	Iron, steel	7.6-7.8
Bakelite	1.25-2.09	Iron, wrought	7.8-7.9
Brass	8.2-8.7	Lead	11.34
Brick	1.4-2.2	Limestone	2.7
Bronze	8.8	Lucite	1.16-1.20
Butter	0.87	Magnesium	1.74
Carbon	1.9-3.5	Maple	0.51-0.75
Chestnut	0.45	Marble	2.6-2.8
Coal, anthracite	1.4-1.8	Nylon	1.09-1.14
Coal, bituminous	1.2-1.5	Oak	0.60-0.98
Copper	8.9	Paraffin	0.87-0.91
Cork	0.24	Pine	0.37-0.64
Diamond	3.53	Platinum	21.37
Glass, crown	2.5	Porcelain	2.38
Glass, flint	2.9-5.9	Silver	10.5
Gold	19.3	Silver, sterling	10.38
Gold, 18k	14.88	Sulfur	2.0
Granite	2.65	Tin	7.3
Graphite	2.25	Tungsten	19.3
Human body	1.07	Velon	1.68-1.75
Ice	0.917	Vinylite	1.2-1.7
Iron, cast	7.1-7.7	Zinc	7.1

Table 6.—Specific Gravity of Liquids
(Room Temperature)

Alcohol, ethyl	0.789	Mercury	13.56
Alcohol, methyl	0.793	Milk	1.029
Carbon disulfide	1.29	Nitric acid, 68%	1.42
Carbon tetrachloride	1.60	Oil, castor	0.969
Chloroform	1.50	Oil, cottonseed	0.926
Ether	0.74	Oil, linseed	0.942
Gasoline	0.66-0.69	Oil, olive	0.918
Glycerin	1.26	Sulfuric acid	1.84
Hydrochloric acid	1.20	Turpentine	0.87
Kerosene	0.82	Water, sea	1.085

Table 7.—Specific Gravity of Gases
(Air Standard, at 0° C and 760 mm of mercury)

Acetylene	0.907	Helium	0.138
Air	1.000	Hydrogen	0.0695
Ammonia	0.596	Hydrogen chloride	1.268
Argon	1.380	Methane	0.554
Carbon dioxide	1.529	Neon	0.696
Carbon monoxide	0.967	Nitrogen	0.967
Chlorine	2.486	Oxygen	1.105
Ethane	1.049	Sulfur dioxide	2.264

Table 8.—Coefficient of Linear Expansion
(Increase in Unit Length per Centigrade Degree)

Aluminum	2.3×10^{-5}	Platinum	$9. \times 10^{-6}$
Brass	1.9×10^{-5}	Pyrex	$4. \times 10^{-6}$
Copper	1.7×10^{-5}	Quartz	$5. \times 10^{-7}$
Glass	$9. \times 10^{-6}$	Silver	1.9×10^{-5}
Gold	1.4×10^{-5}	Steel	1.3×10^{-5}
Invar	$9. \times 10^{-7}$	Tin	2.7×10^{-5}
Iron	1.1×10^{-5}	Zinc	2.6×10^{-5}
Lead	2.9×10^{-5}		

Table 9.—Coefficient of Volume Expansion
(Increase in Unit Volume per Centigrade Degree)

Acetone	1.49×10^{-3}
Alcohol, ethyl	1.12×10^{-3}
Benzene	1.24×10^{-3}
Carbon disulfide	1.22×10^{-3}
Carbon tetrachloride	1.24×10^{-3}
Chloroform	1.27×10^{-3}
Ether	1.66×10^{-3}
Glycerin	5.1×10^{-4}
Mercury	1.8×10^{-4}
Petroleum	9.6×10^{-4}

Turpentine	9.7×10^{-4}
Water	2.1×10^{-4}

Table 10.—Density of Water

°C	g/cm³	°C	g/cm³	°C	g/cm³
0	0.99987	15	0.99913	60	0.98324
1	0.99993	20	0.99823	65	0.98059
2	0.99997	25	0.99707	70	0.97781
3	0.99999	30	0.99567	75	0.97489
4	1.00000	35	0.99406	80	0.97183
5	0.99999	40	0.99224	85	0.96865
6	0.99997	45	0.99025	90	0.96534
8	0.99988	50	0.98807	95	0.96192
10	0.99973	55	0.98573	100	0.95838

Table 11.—Heat Constants

	Specific Heat	Melting Point	Boiling Point	Heat of Fusion	Heat of Vapori-zation
Alcohol, ethyl	0.581	—115°C	78.5°C	24.9	204
Aluminum	0.214	659.7	2450	76.8	
Ammonia	1.125 (liq.)	—77.7	—33.35	83.9	327.1
Brass	0.09	940			
Copper	0.0921	1083	2336	42	
Glass	0.1988				
Ice	0.5	0		79.71	
Iron	0.107	1535	3000	7.89	
Lead	0.0306	327.4	1620	5.86	
Mercury	0.0333	—38.87	356.58	2.82	70.6
Platinum	0.0324	1773.5	4300	27.2	
Silver	0.0558	960.8	1950	21.07	
Steam	0.48				
Tungsten	0.0336	3370	5900		
Water	1.00		100		539.55
Zinc	0.0925	419.47	907	28.13	

Table 12.—Equilibrium Vapor Pressure of Water

Temp. °C	Pressure mm of Hg	Temp. °C	Pressure mm of Hg	Temp. °C	Pressure mm of Hg
0	4.6	25	23.8	90	525.8
5	6.5	26	25.2	95	633.9
10	9.2	27	26.7	96	657.6
15	12.8	28	28.3	97	682.1
16	13.6	29	30.0	98	707.3
17	14.5	30	31.8	99	733.2
18	15.5	35	42.2	100	760.0
19	16.5	40	55.3	101	787.5
20	17.5	50	92.5	103	845.1
21	18.7	60	149.4	105	906.1
22	19.8	70	233.7	110	1074.6
23	21.1	80	355.1	120	1489.1
24	22.4	85	433.6	150	3570.5

Table 13.—Speed of Sound

(Approximate)

	m/sec	ft/sec
Air	331.5	1,087
Alcohol	1,213	3,890
Aluminum	5,104	16,740
Brass	3,500	11,480
Copper	3,560	11,670
Glass	5,030	16,500
Hydrogen	1,270	4,165
Iron	5,030	16,500
Maple, along grain	4,110	13,470
Pine, along grain	3,320	10,900
Steel	5,030	16,500
Water	1,461	4,794

Table 14.—Index of Refraction

(5900 A: Temperature 20°C except as noted)

Air, dry, 0°C	1.00029	Diamond	2.42
Alcohol, ethyl	1.16	Glass, crown	1.52
Benzene	1.32	Glass, flint	1.61
Carbon dioxide	1.00045	Quartz	1.48
Carbon disulfide	1.63	Water	1.33
Carbon tetrachloride	1.46	Water vapor	1.00025

Table 15.—Resistivity

(Temperature, 20°C)

	Ω-cm	Ω-circ mil/ft	Temperature Coefficient of Resistivity
Aluminum	2.828×10^{-2}	17.01	0.00445
Constantan	49	294	0.000002
Copper	1.724	10.37	0.00393
German silver	33	198	0.0004
Iron	10	60.2	0.0050
Manganin	44	265	0.000000
Mercury	96	576	0.00009
Michrome	100	602	0.0004
Platinum	10	60.2	0.003
Silver	1.629	9.80	0.0038

Table 16.—Electrochemical Equivalents

	Valence	g/coul		Valence	g/coul
Aluminum	3	0.0000932	Lead	4	0.0005368
Cadmium	2	0.0005824		2	0.0006150
Calcium	2	0.0002077	Magnesium	2	0.0001260
Chlorine	1	0.0003674	Nickel	2	0.0003041
Chromium	6	0.0000898	Oxygen	2	0.0000829
	3	0.0001797	Potassium	1	0.0004051
Copper	2	0.0003294	Silver	1	0.0011179
	1	0.0006558	Sodium	1	0.0002383
Gold	3	0.0006812	Tin	4	0.0003075
	1	0.0020435		2	0.0006150
Hydrogen	1	0.0000104	Zinc	2	0.0003388

Appendix G
SIGNIFICANT FIGURES

(Directions to be reprinted and distributed to students.)

Significant figures are the integers in a numerical result that are trustworthy in that they are believed to be closer to the actual value than any other integer. For example, an ordinary meter stick is used to measure a certain length. The measured length is found to lie between 20.5 and 20.6 cm. The length is recorded as 20.52 cm. which means that the length in question was estimated as two-tenths of the distance between 20.5 and 20.6 cm. The four integers in the number 20.5$\underline{2}$ are called significant figures. The first three are read directly off the meter stick, the fourth (underlined) is estimated. *It is a general rule always to estimate one place more than the instrument reads directly, the estimated place being underlined.*

Significant figures are extremely important since they indicate the limit to which any quantity may be measured. The following rules will assist in understanding significant figures:

1. *All non-zero digits are significant:* 159.7$\underline{5}$ g contains five significant figures.
2. *All zeros between two non-zero digits are significant:* 108.00$\underline{5}$ m contains six significant figures.
3. *Unless otherwise indicated, all zeros to the left of an* understood *decimal point but to the right of a non-zero digit are* not *significant:* 20$\underline{2}$,000 mi contains three significant figures.
4. *All zeros to the left of an* expressed *decimal point and to the right of a non-zero digit are significant:* 202,00$\underline{0}$ mi contains six significant figures.
5. *All zeros to the right of a decimal point but to the left of a non-zero digit are* not *significant:* 0.00064$\underline{7}$ kg contains three significant figures. (The single zero conventionally placed to the left of the decimal point in such an expression is never significant.)
6. *All zeros to the right of a decimal point and to the right of a non-zero digit are significant:* 0.0708$\underline{0}$ cm and 20.4$\underline{0}$ cm each contains four significant figures.

In performing operations with significant figures, the following rules are useful:

1. In "rounding off":

   When the figure next beyond the last figure to be retained is less than 5, the figure in the last retained place is to remain unchanged. Example: 2.342 rounded off to three figures is 2.3$\underline{4}$.

   When the figure next beyond the last figure to be retained is greater than 5, the figure in the last retained place is to be increased by 1. Example: 6.787 rounded off to three figures is 6.7$\underline{9}$.

   When the figure next beyond the last figure to be retained is 5, the figure in the last retained place is to remain unchanged if it is even, and is to be increased by one if it is odd. Examples: 4.785 rounded to three figures is 4.7$\underline{8}$. 4.775 rounded to three figures is 4.7$\underline{8}$.

2. In addition and subtraction, the result should not be carried beyond the first column which contains a doubtful figure.

   Example:
   $$\begin{array}{r} 12.1\underline{6}\text{ cm} \\ 3.\underline{2}\ \ \text{ cm} \\ \hline 15.\underline{36}\text{ cm or } 15.\underline{4} \end{array}$$

3. In multiplication and division, the result should contain one more place than the factor having the fewest number of significant figures.

   Example:
   $$\begin{array}{r} 762 \\ 6.3 \\ \hline 2286 \\ 4572 \\ \hline 48\underline{0}0.6 \end{array} \quad \text{or } ^{1}\ 4.8\underline{0} \times 10^{3}$$

4. In applying the rules for significant figures to angle measurements, 2, 3, or 4 significant figures require angle readings to 30 minutes, 5 minutes, or 1 minute respectively.

In completing computations in the laboratory, a table of logarithms or a slide rule should be used for all but the simplest operations. Use of a table of logarithms or a slide rule, causing an automatic elimination of unnecessary places, amounts practically to an application of the above rules for significant figures.

Appendix H
PROBLEM SOLVING

(Directions to be reprinted and distributed to students.)

Directions for Pupils

1. Read the problem carefully at least twice, trying to form *a picture of the situation* as clearly as you can, but making no attempt to solve it.
2. Draw and label a neat diagram if one applies to the problem situation.
3. After you understand the situation, ask yourself what principle or law applies. Not until you have the principle clearly in mind should you write it down, preferably in the form of a formula.
4. Usually you will be able to find the answer by substituting numbers in the formula you have written. (More difficult problems may require two or three formulas.)
5. Solve for the unknown quantity in your formula. A 10-inch slide rule is an excellent short-cut to problem solving and gives answers as accurate as data provided throughout physics books.
6. Go over your substitution, check your arithmetic, and be sure you have written units such as feet, grams, or seconds after your answer. Be sure your answer is reasonable.
7. Drawing a box around the answer will help it to show more clearly.
8. Outside assignments should be written on 8½″ × 11″ notebook paper. The assignment is due at the beginning of the next scheduled class period.
9. Sheets will include name, course, date, problem assignment, and page of assignment in upper right-hand corner.
10. You are encouraged to obtain assistance and guidance in doing outside assignments. Often a group of two or three students completing problems on a blackboard can assist each other to understand basic principles of the problems. Advice from scientists or engineers is often helpful. *Do not copy* the work. Your lack of knowledge of the material will be noted on tests and examinations.

Handling of Units

In performing computations involving lengths or other physical quantities, *the units should be included throughout;* they may be canceled, multiplied, or divided as though they were numbers. For example, transfer to centimeters a reading of ⅛ inch on a measuring scale, by using the fact that 1 inch = 2.54 centimeters. The specified reading can be multiplied by the factor $\frac{2.54 \text{ centimeters}}{1 \text{ inch}}$ without altering its value; thus,

$$\tfrac{1}{8} \text{ inch} = \frac{1 \cancel{\text{inch}}}{8} \times \frac{2.54 \text{ centimeters}}{1 \cancel{\text{inch}}} = \frac{2.54 \text{ cm.}}{8} = 0.318 \text{ cm.}$$

Again, find the number of kilometers in a mile, by using the fact that 1 meter = 39.37 inches. Since 5280 feet = 1 mile, the fraction $\frac{5280 \text{ feet}}{1 \text{ mile}}$ will have a value of unity, and the distance of 1 mile can be converted to feet by using appropriate fractions, each having a value of unity.

The entire solution is given by:

$$1 \text{ mile} = 1 \cancel{\text{mile}} \times \frac{5280 \cancel{\text{feet}}}{1 \cancel{\text{mile}}} \times \frac{12 \cancel{\text{inches}}}{1 \cancel{\text{foot}}} \times \frac{1 \cancel{\text{meter}}}{39.37 \cancel{\text{inches}}} \times \frac{1 \text{ kilometer}}{1000 \cancel{\text{meters}}} = \frac{5280 \times 12}{39.37 \times 1000} \text{ kilometers} = 1.609 \text{ km.}$$

This procedure may seem laborious for such a simple computation, but in the more involved calculations which will be met further on, there is a distinct advantage in carrying all unity through to avoid ambiguity and error.

Appendix I

CONCEPTS, TERMS, AND PROCESSES USED IN PHYSICAL SCIENCE

(Students should be familiar with most of these by the tenth class period.)

1. English units
2. Metric units
3. Centrigrade scale
4. Large numbers
5. Chemical reactions (mathematical identities)
6. Percentage
7. Circular functions
8. Comparison of two quantities by division
9. Ratio
10. Small numbers
11. Direction of a line
12. Volume
13. Negative number
14. Surface of a solid
15. Speed
16. Wave length
17. Equal
18. Wave frequency
19. Length
20. Velocity
21. Diameter
22. Computation by division, integers, fractions, and decimals
23. Average
24. Direct proportion
25. Structural formulas of chemistry
26. Rate
27. Constant
28. Fahrenheit scale
29. Reflection
30. Formulas and literal equations
31. Sphere
32. Multiplication of integers, fractions, and decimals
33. Positive numbers
34. Maximum
35. Rotation
36. Range
37. Horizontal
38. Vertical
39. Measurement of angles in degrees
40. Mathematical principle stated in words
41. Negative exponents
42. Area
43. Positive exponents
44. Parallel lines
45. Perpendicular lines
46. Curve
47. Acceleration
48. Latitude
49. Logarithm
50. Power
51. Slope
52. Variable
53. Straight line
54. Circle
55. Cone
56. Refraction
57. Minimum unit
58. Momentum
59. Spiral
60. Use of algebraic axioms
61. Focus
62. Reading and interpretation of tables
63. Cylinder
64. Radius
65. Inverse proportion
66. Subtraction of integers, fractions, and decimals
67. Ellipse
68. Factor
69. Line graph
70. Drawing to scale
71. Cube
72. Face of a solid
73. Symmetry
74. Planes of cleavage of a solid
75. Coefficient
76. Tetrahedron
77. Root
78. Curvature
79. Analogy
80. Hexagon
81. Concave
82. Convex
83. Parallax
84. Three dimensional
85. Dimensional units

Appendix J
SAMPLE TEST AND EXAMINATION QUESTIONS

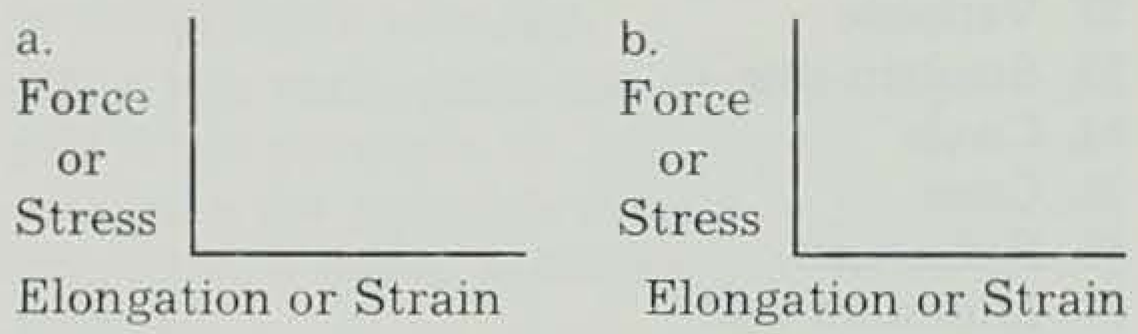
Mechanics

1. Explain the difference between mass and weight.

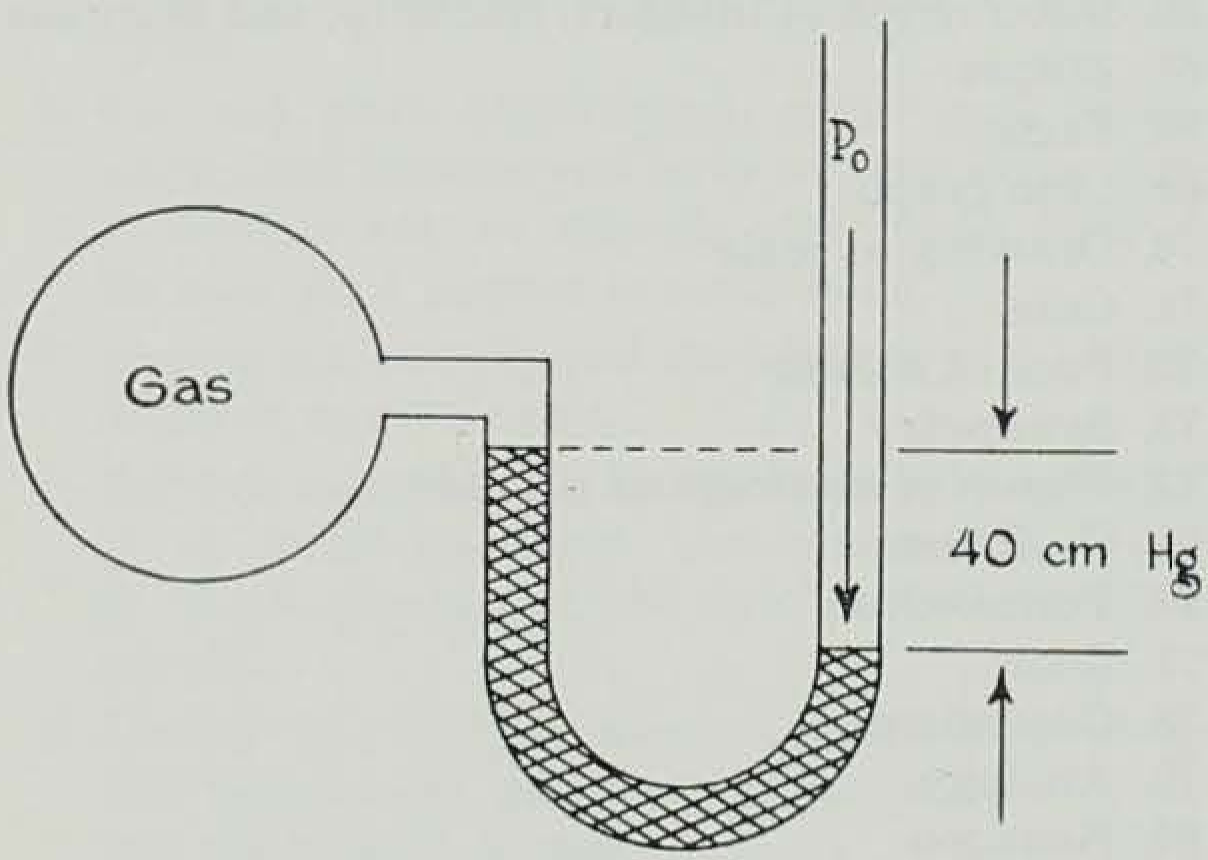
2. List the unit used to measure the quantity noted in system indicated.

	Length	*Time*
cgs	________	________
mks	________	________
fps	________	________

3. a. Sketch a force-strain (elongation) curve on (a) below if the material used for data follows Hooke's Law.
   b. Sketch a force-strain (elongation) curve on (b) below if the force exerted on the material used exceeds the elastic limit.



4. An open tube mercury manometer is connected to a vessel containing a gas, as shown in the diagram. Assume a standard atmospheric pressure for P_0.
   a. Is the pressure inside the vessel greater or less than atmospheric?
   b. What is the pressure (in cm of mercury) inside the vessel?



a) ________
b) ________

5. a. Define coefficient of friction.
   b. State Archimedes' principle.

6. Young's modulus for steel $= 20 \times 10^{11}$ dynes/cm^2.
   Young's modulus for copper $= 10 \times 110^{11}$ dynes/cm^2.
   a. Which will stretch more, a wire of steel or a wire of copper (all other factors: length, cross sectional area, etc., being the same)?
   a) ________
   b. Which will stretch more, a piece of copper wire of 0.2 mm^2 cross section or of 0.4 mm^2 (all other factors remaining the same)?
   b) ________
   c. Which will stretch more, a 1-meter piece of copper wire or a 2-meter piece of steel wire (all other factors remaining the same)?
   c) ________

7. A boy weighing 50 lbs sits 6 feet from the fulcrum of a 12-foot seesaw with the fulcrum at the center. At what distance from the other end should a 60 lb boy sit to balance the seesaw? ________

8. If the velocity of a body is constant, the acceleration is ________.

9. When the velocity of a body increases or decreases the same amount in successive units of time, the acceleration is ________.

10. An object which moves 3.0 meters during 1.0 seconds, 6.0 meters during 2.0 seconds, and 9.0 meters during 3.0 seconds, has a velocity of ________.

11. Graph distance (meters) vs. time (sec). (Obtain data from question 10.)

12. Graph velocity (m/sec) v. time (sec). (Obtain data from question 10.)

13. An object which moves 2.0 meters during the first second, 6.0 meters during the next second and 10.0 during the third second has an acceleration of ________.

14. Graph distance (meters) v. time (seconds). (Obtain data from question 13.)

15. Graph velocity (m/sec) vs. time (sec). (Obtain data from question 13.)

Radioactivity

1. Briefly discuss the following terms:
   a. Isotope
   b. Radioactivity
   c. Current

2. Which of the following statements are true?
   a. An electron is a negatively-charged particle. ________
   b. A neutron has approximately the same mass as the electron. ________

c. Isotopes having more neutrons than protons are generally more stable. ______

d. Most alpha particles are able to pass through several centimeters of lead. ______

e. A beta ray is a negative electron. ______

3. Discuss the operation of the Wilson cloud chamber.

Heat

1. Is the clinical thermometer based on the Fahrenheit or Centigrade scale? ______
2. What type of thermometer would be used in determining the temperature of molten steel? ______
3. What is a comfortable room temperature, 68°C, 68°F, 68°K? ______
4. If two frictionless surfaces were rubbed together, would heat be produced? ______
5. Is one Fahrenheit degree or one Centigrade degree the larger unit? ______
6. What type of heat transfer is based on a moving fluid? ______
7. What type of heat transfer is based on a solid medium? ______
8. What does the word "latent" mean? ______
9. Define the term "heat of sublimation."

______

______

10. What is the distinction between 72° Fahrenheit and 72 Fahrenheit degrees? ______
______ is a temperature on the Fahrenheit scale; ______ is a difference in temperature.
11. What common appliance radiates heat? ______
12. Why does it take more heat to solder a wire to a 100 gm copper block than a 50 gm block? ______

______

13. Why does a piece of steel seem colder than a piece of wood when left outside in the winter?

______

14. Why does one use oil instead of water to quench a hot poker? ______

______

15. How does your body cool on extremely warm days? ______

Light and Heat

1. Define three of the eight terms below:
   a. Calorie
   b. B.t.u.
   c. Specific heat of a substance
   d. Latent heat of fusion
   e. Latent heat of vaporization
   f. Parallax
   g. Dispersion
   h. Polarization of light

______

______

______

______

______

______

2. Indicate the most appropriate field in Column B which is directly concerned with each general problem in Column A.

(A)		(B)
a. Design of optical systems	____	Cryogenics
b. Measurement of heat	____	Heat transfer
c. Measurement of temperature	____	Calorimetry
d. Luminous efficiency and illumination	____	Spectral analysis
e. Atomic origin of light	____	Wave optics
f. Attainment of low temperatures	____	Quantum optics
g. Energy relations involving heat	____	Thermodynamics
h. Dissipation of heat	____	Thermometry
i. Identification of unknowns by light	____	Physiological optics
j. Optical phenomenon and sense organs	____	Geometrical optics
k. Study of interference and diffraction	____	Photometry

3. The melting and boiling points of some less common elements are given below. Indicate whether they are solids (S), liquids (L), or gases (G) at room temperatures (68°F = 20°C).

	MP	*BP*	
Bromine	7.2°C	58.8°C	______
Radon	—110 °C	—61.8°C	______
Iodine	113.7°C	184.4°C	______
Osmium	2700 °C	5300 °C	______

Light

...... dispersion	...... multiple images
...... interference	...... spectrum analysis
...... polarization	...... absorption
...... atmospheric refraction	...... diffraction
...... internal reflection	...... refraction of divergent rays
...... photo-emission	...... scattering

1. Match the following examples with the explanations above by placing the proper letter in each blank:
   a. Stars twinkle.
   b. A searchlight may be seen from a distance.
   c. Water appears more shallow than it really is.
   d. A spectrum is formed by a wedge of glass.
   e. An electric-eye is used to count samples.
   f. A line of 500 chorus girls appears perfectionist.
   g. A dark filter is used to observe the sun.
   h. Rings of colors are seen in a film of oil.
   i. A sample is tested for composition.
   j. A special filter is used to photograph a portrait in a glass frame.
   k. Two sources of light are almost indistinguishable.
   l. A glass prism seems to be coated with silver.
2. Identify the field of optics (*G*eometrical, *W*ave, *Q*uantum, or *P*hysiological) to which the following problems apply by placing the proper letter (*G*, *W*, *Q*, or *P*) in each space below:

Design of a refracting telescope	......
Eye fatigue and color illusions	......
Interference of light waves	......
Illumination of a room	......
Single slit defraction	......
Stroboscopic effect or persistence of vision	......
The electromagnetic explanation for reflection	......
The photoelectric effect	......
The depth of field of a camera	......
The luminous intensity of fluorescent lights	......

Appendix K
CRYOGENICS

George Heenan

(Enrichment material for teachers to use in discussion preparations.)

With the advent of the space age, many new terms have grown familiar. One of these is the term "Cryogenics." By no means a new word, "cryo" from the Greek means icy-cold, while "genics" means to generate. Thus, cryogenics is the generation of icy-cold. Several famous physicists have done great research in this area of the very low temperatures. The Joule-Thompson effect is a basic principle of cryogenics. When a compressed gas is permitted to expand, it uses heat in the process, thus lowering its temperature. If the gas were an ideal gas, no temperature change would result from the expanding process. However, since we do not have an ideal gas, there is a noticeable drop in temperature. When this process is repeated and then repeated, the temperature is lowered successively. The boiling point of the gas is then reached, and then upon further cooling, the gas will become a liquid.

Compared to the 212°F at which water becomes steam and at —40°F at which "Feron," the universal synthetic refrigerant makes this transition, atmospheric gases liquefy at exceedingly cold temperatures. Oxygen, the most abundant, undergoes the change at —279°F. It is here that an arbitrary line is drawn which indicates the realm of cryogenic gases. At these extreme low temperatures many other cryogenic fluids are found. At —302°F cryon is found; at about —320°F nitrogen, second most abundant, becomes a liquid. Some others are fluorine (—306°F), neon (—410°F), deuterium (—417°F), hydrogen (—423°F), and helium (—452°F). Thus at —452°F helium is only 7° above absolute zero.

It has been with the use of helium that scientists have been able to reach temperatures within a few hundredths of a degree of absolute zero. With the aid of magnetism, even lower temperatures have been reached.

When temperatures of this very low magnitude are reached, fundamental changes in mass and energy and electrical and magnetic properties occur. These changes have been put to full use in our space program.

A unique property of metals is that at these low temperatures they become superconducting, that is, they lose most of their resistance. A microwave amplifier 200 times as sensitive as a conventional radar receiver has been constructed using the maser. Consisting of a solid state material such as ruby, the maser picks up weak sound which otherwise would be undetectable and amplifies it enormously. The maser cannot do this unless it is operated at very low temperatures in the liquid helium range. Under the leadership of Bell Labs, G.E., and RCA, scientists are working on cryogenic control of magnetic fields. By immersing a magnet in a cryogenic fluid, the lines of force emanating from it can be collected and bent (or reflected) into stipulated confines.

A cryogenic gyroscope has been developed. The principle could replace mechanical gyroscopes. Involving the suspension of two rotating and opposite masses in space, also a magnetized "gyro" does not drift as the present mechanical types.

Recently much research has been done concerning "Cryo-pumping." This has been used to create high vacuums. By using cryogenic pumping to create the vacuum, the gases are minimized and eliminated instantly.

One of the areas of current research has been insulations. While the Dewar, designed by Sir James Dewar, has been one of the most efficient means of storing liquid, more work is being done to find new superinsulators.

One of the largest uses of cryogenic fluids is the missile industry. Using liquid oxygen (LOX) and others, they provide a good market.

Cryogenics is a growing field. Many new companies have built cryogenic laboratories to conduct research in this field. A newly established laboratory at Pioneer-Central Division of the Bendix Corporation is a good example of this trend. Dr. Thomas Flynn, one of the nation's top experts in the cryogenic field, has done much research at these low temperatures.

Cryogenics has proved itself a valuable tool for industry and scientists.

Appendix L
ULTRASONICS

W. R. Brooks

(Enrichment material for teachers to use in discussion preparations.)

Sound waves that are of such frequency as to be inaudible to the human ear are called ultrasonic or supersonic waves. The range of frequencies called ultrasonic extends from 20 kilocycles upwards to the megacycle region. For the higher frequencies, 200 to 300 kilocycles, a quartz crystal oscillator is employed as a sound-wave generator. Various acoustic phenomena may be demonstrated in these high ranges, and the waves are useful in illustrating principles of optics. For example, it is possible to construct a coarse, concave diffraction grating to form the spectrum of such sounds, or an ultrasonic inferometer to measure their wave length.

Some curious effects are observed when the oscillator is immersed in a vessel of oil. The surface of the liquid bulges into an agitated heap and emits a spray. If the oscillator is placed at the bottom of the vessel and a horizontal metal plate is lowered into the oil, the plate experiences a distinct upward thrust which has a pronounced maxima and minima as the plate is pushed downward, corresponding to interference modes and antinodes of stationary waves. A glass rod held between the fingers and dipped into the oil is so violently (though silently) agitated that its friction may burn the fingers.

The science of ultrasonics began in 1933 when Dr. Egon Heidemann started experiments at the University of Cologne, Germany. While attempting to photograph ultrasonic waves in air Dr. Heidemann used a smoke-filled chamber. When an ultrasonic beam was passed through the smoke, he found that smoke particles were precipitated, with the air being cleaned of dust and soot particles. Thus by accident, one of the first useful effects of ultrasonics was discovered.

Since 1933 ultrasonics has found widespread use in industrial applications. High-powered ultrasonic equipment is used for cleaning, drilling, welding, and soldering. Low-power ultrasonic equipment is employed in flaw detection, thickness gauges, depth and fish finding, level sensing, signaling, controlling, TV receiver control, alarms, flow metering, medical therapy, dental drilling, and dental prophylaxis.

One of the most widespread uses of ultrasonics is in the area of industrial cleaning. When a high frequency beam is introduced into a water bath, the sound waves alternately compress and decompress the solution. This causes a swarm of vacuum bubbles to form (cavitation). When the bubbles collapse they cause high impulse pressures which blast loose any impurities on an object in the solution. A great factor in ultrasonic cleaning is that small hidden areas in a part can be cleaned as easily as the outside surfaces. Wherever the water solution can penetrate, the cleaning process occurs.

A leader in the field of ultrasonic applications is the Sonic Application Laboratory of the Pioneer-Central Division, Bendix Corporation. In their modern laboratories, constant research is under way probing the unknowns of this new and fascinating science.

Appendix M
THE PELTIER EFFECT

(Enrichment material for teachers to use in discussion preparations.)

When there is a current through the junction of two dissimilar metals, the temperature changes. An emf is developed at the junction as electrons from one metal diffuse into the other to fill vacant energy levels in the other metal. When the current is in the direction of the emf, the temperature of the junction rises. This effect is superimposed upon the usual Joule heating of a conductor, and, in spite of Joule heating, it is possible to cool a suitably designed junction to a temperature lower than that of the surroundings. The Peltier effect in an arrangement of wires of two dissimilar metals similar to a thermocouple may be thought of as an electrically-operated heat pump, though to the present time, a very inefficient one. Greater efficiency may be developed in the future.

Appendix N

THE HUMAN FACTOR IN SPACE ENVIRONMENT

E. M. Vaughn

(Enrichment material for teachers to use in discussion preparations.)

"There is a curiosity to some men, their ever-pressing need to go where imagination impels them despite restrictions upon their movement, or even present comforts. Nowhere is this need more poignantly shown than in attempts to unravel the mysteries of space, to make the perceived *there* of space identifiable and familiar as the *here*. A few short months ago, there were many who scoffed at the idea of space travel, but who now take for granted the launching of space satellites. To those of us who have long buried our noses in science fiction, this tremendous accomplishment falls pitifully short of our own vicarious travels across galaxies via time warps and teletransportation. But we are no longer alone in believing that before long men will have journeyed to the moon and beyond."[1]

Dr. Pepinsky, author of the above statement, notes that mental patients have kept up to date by phantasmal rides to other planets; off social groups have gone modern with flying saucer cults; architects are designing "space age" buildings; and clothing manufacturers are designing "space age" clothes.

A scientist today is even recognized to some extent as a human being. In 1955 a very well-known scientist came to the Quad-City area and gave a talk on satellites and rockets. His audience consisted of three or four college science students. Today he commands an adult audience of several hundred when he speaks on the same subject.

Problems in space flight are man-created and, therefore, must be solved by man. Space problems in this report will fall into two general areas, physiological and psychological.

Physiology deals with living organisms.

Psychology deals with mental states or processes, the science of the mind.

A TV program had an interesting space problem one night. The plot of the program concerned a space ship captain's authority to perform the marriage of the lady astronomer and a space geologist on an extended flight through the ether. Is this a physiological problem or a psychological problem?

It will be impossible to present all of the space problems here, since the solution of one seems to generate others. The pages that follow deal with some of the more challenging ones.

[1] Harold B. Pepinsky, "The Conquest of Space," *The American Psychologist*, XIII (June, 1958).

SPACE ENVIRONMENT

Human engineering considers the man-machine system in space flights. In a manned space system the man-machine interaction can be diagramed as shown in Figure 1. It is a "closed loop" system.

Man's perception and reaction then control this system. Careful examination of the system will indicate the following:[2]

1. There always seems to be a general tendency to overestimate man's ability to adjust and make for things which are not quite optimum.

2. Human limits or tolerances are usually defined in terms of only one variable at a time. Interaction effects as would occur in space are rarely investigated.

3. Inferences regarding human reactions are often made from studies where the subject knows he is not facing danger; yet tests under these conditions are hardly optimistic in regard to human reactions to space conditions.

4. Statements regarding manned space vehicles refer to vehicles of relatively short flight. Problems will be different for crews involved in long uneventful space flights or residing in space stations. There may be a different environment. It is accepted that the immediate environment can markedly influence the behavior and thoughts of even the most normal individuals as was evidenced in Korean War brainwashings.

In the space environment, several factors are listed that would induce unusual or extreme human reactions. Since the space vehicle must remain a compromise between the psycho-physiological needs of the passengers and the structural engineering requirements, there will necessarily be non-optimal environmental conditions imposed by a man-machine system. These conditions can be interpreted as "stresses." Noise, weightlessness, ionizing radiation, fear, close confinement, recycled atmosphere, and odors will occur separately and together, over short periods of time and long periods of time. They will tend to wear down a person's resistance and resiliency. In addition, there will be social stresses that are present between a small group of people together for a long period of time.

Human reactions involving these and other stresses have been observed in the following areas:

[2] George A. Peters, "Psycho-Social Problems of Manned Space Flight," *Astronautics* (March, 1960).

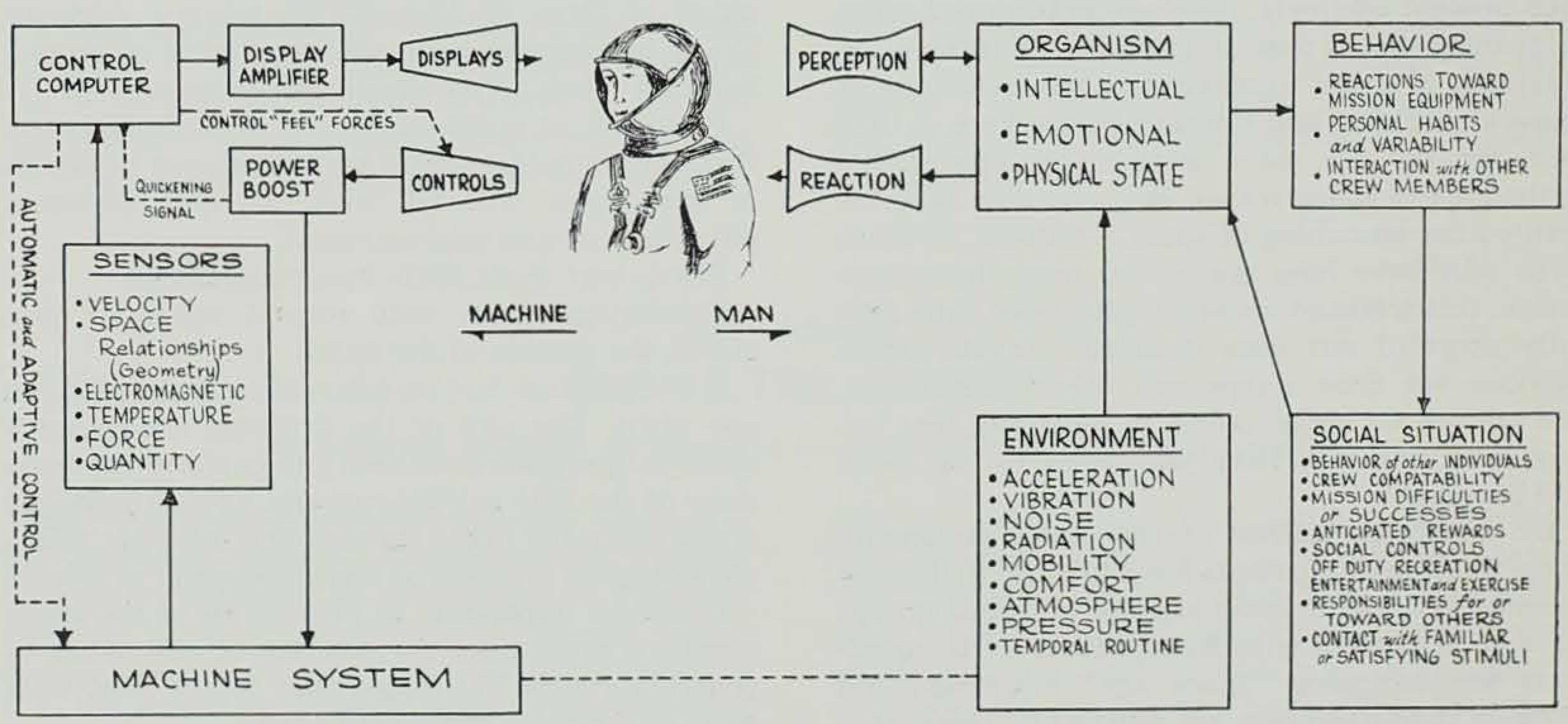


Figure 1

Man-Machine Interaction in Manned Space Flight

physical, social, behavioral, intellectual, and emotional. The observations were not necessarily made with simulated space vehicles but from a variety of sources such as prolonged underseas or aircraft flights, shipwreck, penal and prisoner of war experiences, laboratory simulation, and others.

Figure 2[3] is a curve of any limiting stress or departure from a preferred environment against time. The area below the curve represents conditions under which man can operate more or less normally or efficiently. The area above the curve represents conditions which man cannot tolerate and under which he cannot possibly operate. Because of the severity of the stress in this region, he is either incapable of performing, is unconscious, or dead. Separating these two regions is a broad transition band representing a gradual loss of efficiency and loss of ability to recover promptly when the stress is removed.

[3] Select Committee on Astronautics and Space Exploration, "Environment of Manned Systems," *Space Handbook* (Washington: U. S. Government Printing Office, 1959).

In general:

a. Individuals differ greatly in their ability to withstand stress. For some individuals the critical region would be down and to the left. For others, it would be up and to the right.

b. A given individual will not always react the same at different times. In addition, he can improve his performance by gradual acclimatization or conditioning.

c. The curves can be modified by all other factors in the man's environment.

d. The milder the stress, the longer he can tolerate it.

Two environmental stress-producing conditions,

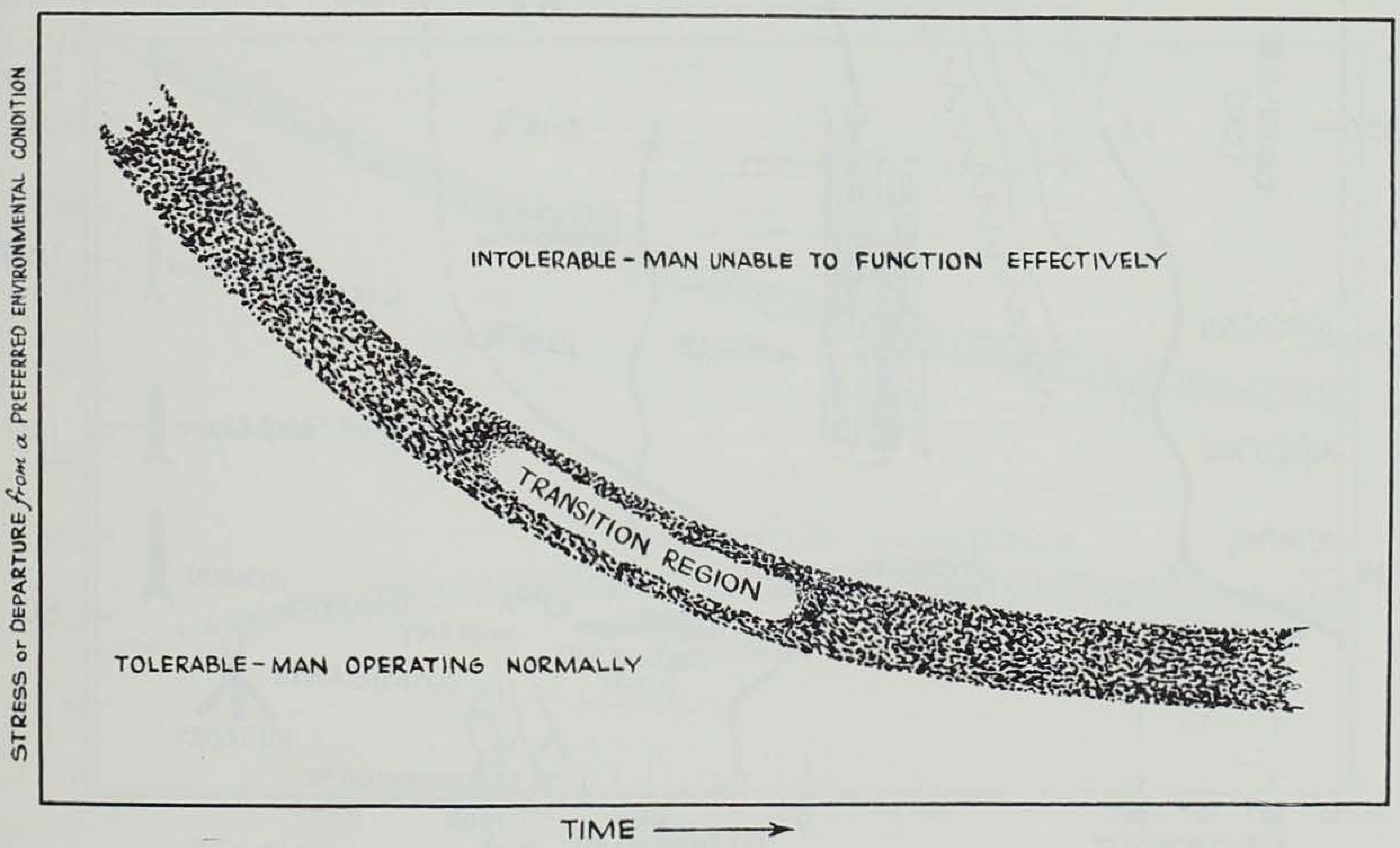


Figure 2
Stress-time Effects on Humans

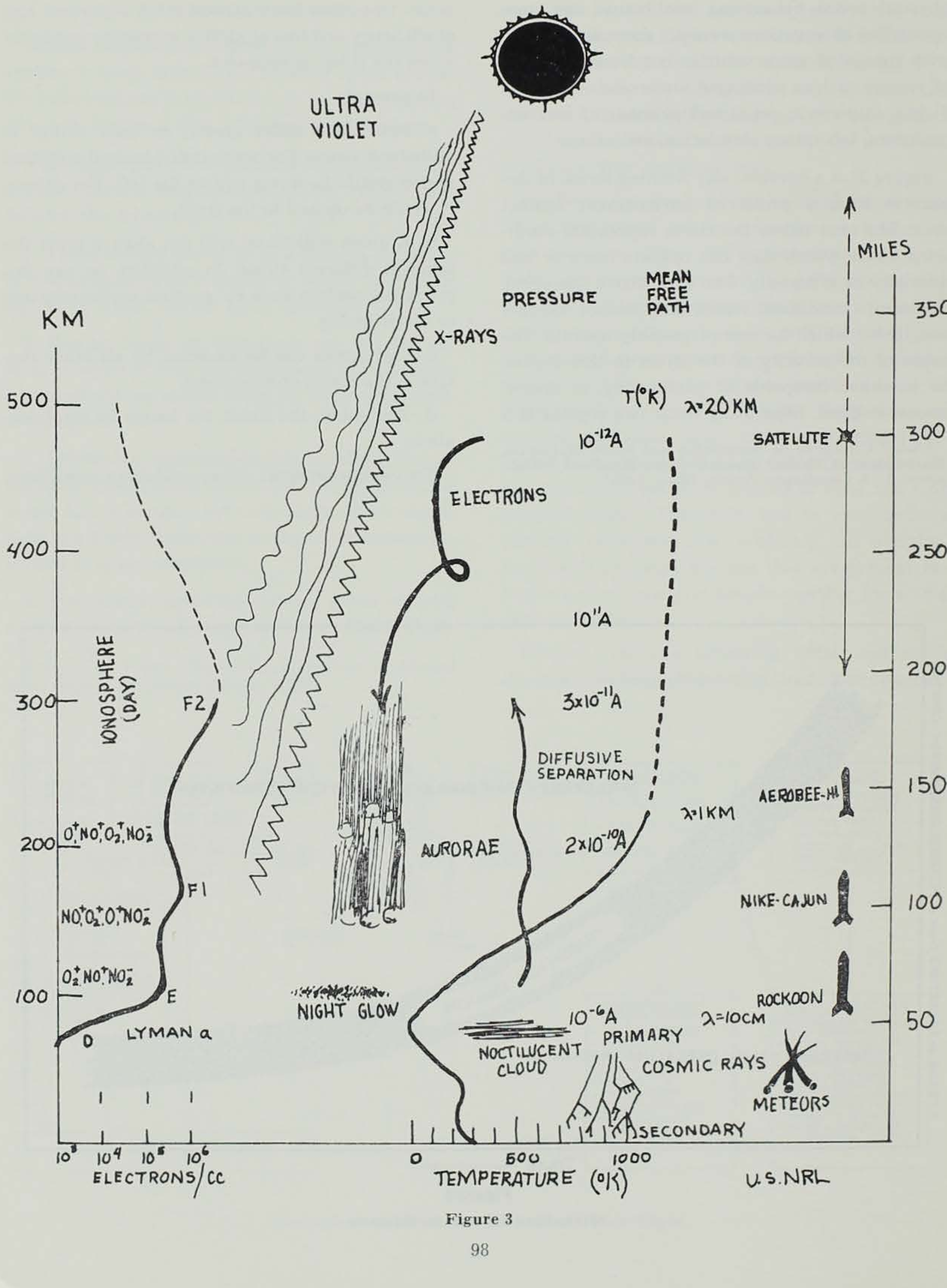

ULTRA VIOLET
X-RAYS
KM
500
400
300
200
100
IONOSPHERE (DAY)
F2
F1
E
D
LYMAN a
O^+, NO^+, O_2^+, NO_2^-
NO^+, O_2^+, O^+, NO_2^-
O_2^+, NO^+, NO_2^-
10^3 10^4 10^5 10^6
ELECTRONS/CC
ELECTRONS
AURORAE
NIGHT GLOW
NOCTILUCENT CLOUD
PRESSURE
MEAN FREE PATH
T(°K)
λ=20 KM
10^{-12}A
10^{-11}A
3×10^{-11}A
DIFFUSIVE SEPARATION
λ=1 KM
2×10^{-10}A
10^{-6}A
λ=10 CM
PRIMARY
COSMIC RAYS
SECONDARY
0 500 1000
TEMPERATURE (°K)
MILES
350
300
250
200
150
100
50
SATELLITE
AEROBEE-HI
NIKE-CAJUN
ROCKOON
METEORS
U.S.NRL

Figure 3

their effects and problems, will be explored in this report.

First, the problems in supplying (or not supplying) breathing gas to a space vehicle for a space passenger will be discussed.

Following this, the problems encountered in going through radiation fields existing or created in the regions away from the earth's surface will be considered.

BREATHING GAS

Table 1.—Composition of Normal Air, Typical Extremes, and Harmful Limits. (In per cents)

Element	Normal Air	Typical Extremes	Harmful Limit
Oxygen	21	19 (min)	13-14 (min)
Nitrogen	79		
Carbon Dioxide	0.03	1.3 (max)	2.4 (max)

The major elements in normal air are shown in Table 1.[4] There is a minimum harmful limit for oxygen and maximum limit for carbon dioxide. (There is some question on the 2.4 per cent for CO_2.) It should be noted, however, that these data refer to per cent of normal air at the earth's surface. In other words, a certain number of molecules of oxygen are needed per second to survive. A person leaving the earth encounters a lesser number of total molecules of air as he moves into space and thus a lesser number of molecules of oxygen (Fig. 3).

[4] Ernest J. McCormick, "Atmospheric Composition and Pressure," *Human Engineering* (McGraw-Hill Book Co., 1957).

Man's reaction depends on the number of oxygen molecules taken into his system, i.e., the level of oxygen pressure and the rate of penetration into the intolerable regions. The stress-time effects curve for this is shown in Figure 4. Anoxia results from too little oxygen. The direct effects of anoxia are physiological, but there is a psychological impact on the person and his performance—sleeplessness, headaches, lassitude, altered respiration, psychological impairment, inability to perform even simple tasks, and eventual unconsciousness. For a sudden transition a person loses consciousness, going into spasms or convulsions.

"Anoxia not only stops the machine; it wrecks the machinery."

Too much oxygen can also be lethal as shown in Fig. 5.[5] Prolonged exposure to pure oxygen results in inflammation of the lungs, respiratory disturbances (coughing, gasping, and pulmonary congestion), various heart symptoms, numbness in the

[5] Select Committee, *loc. cit.*

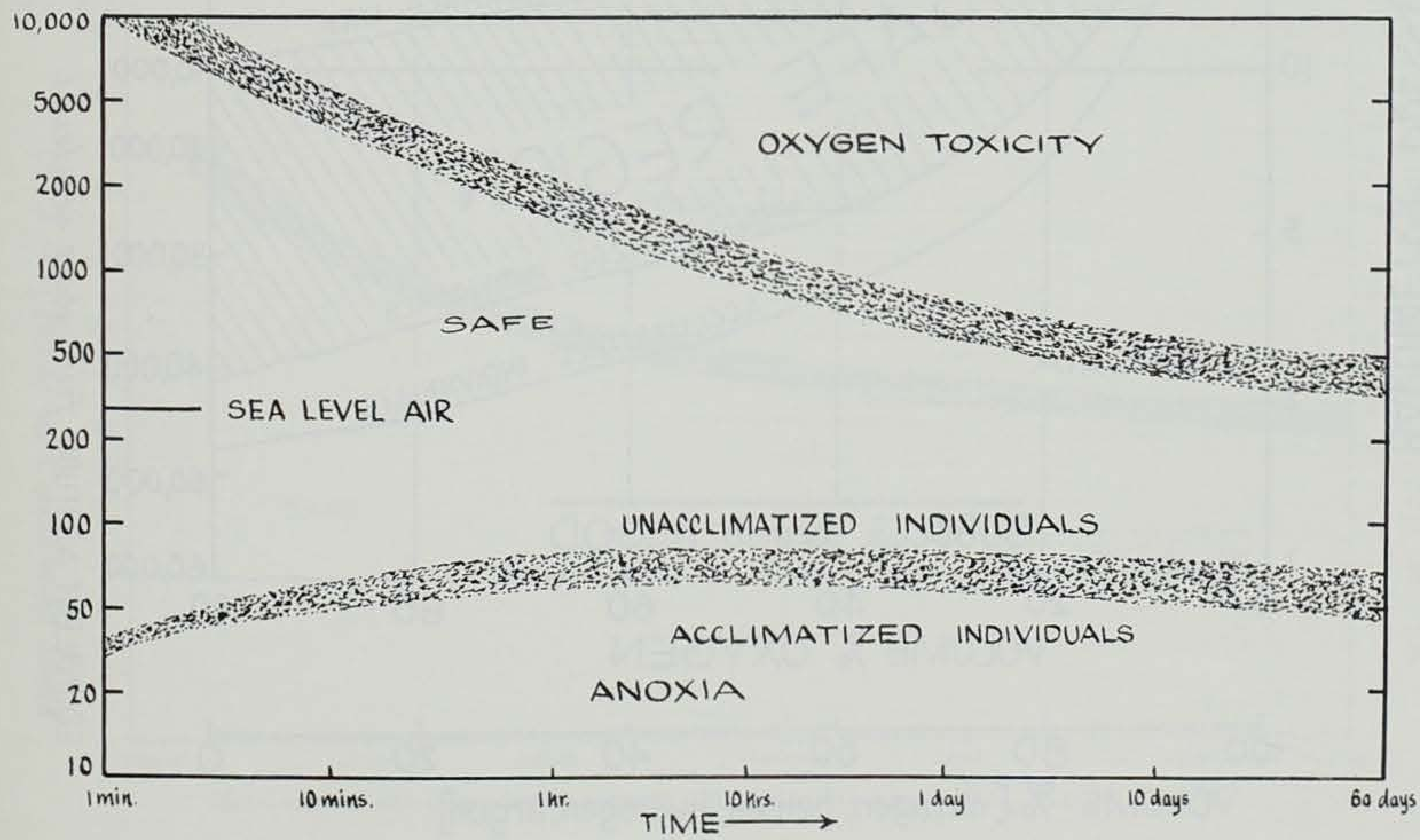


Figure 4
Human Time Tolerances—Oxygen Partial Pressure

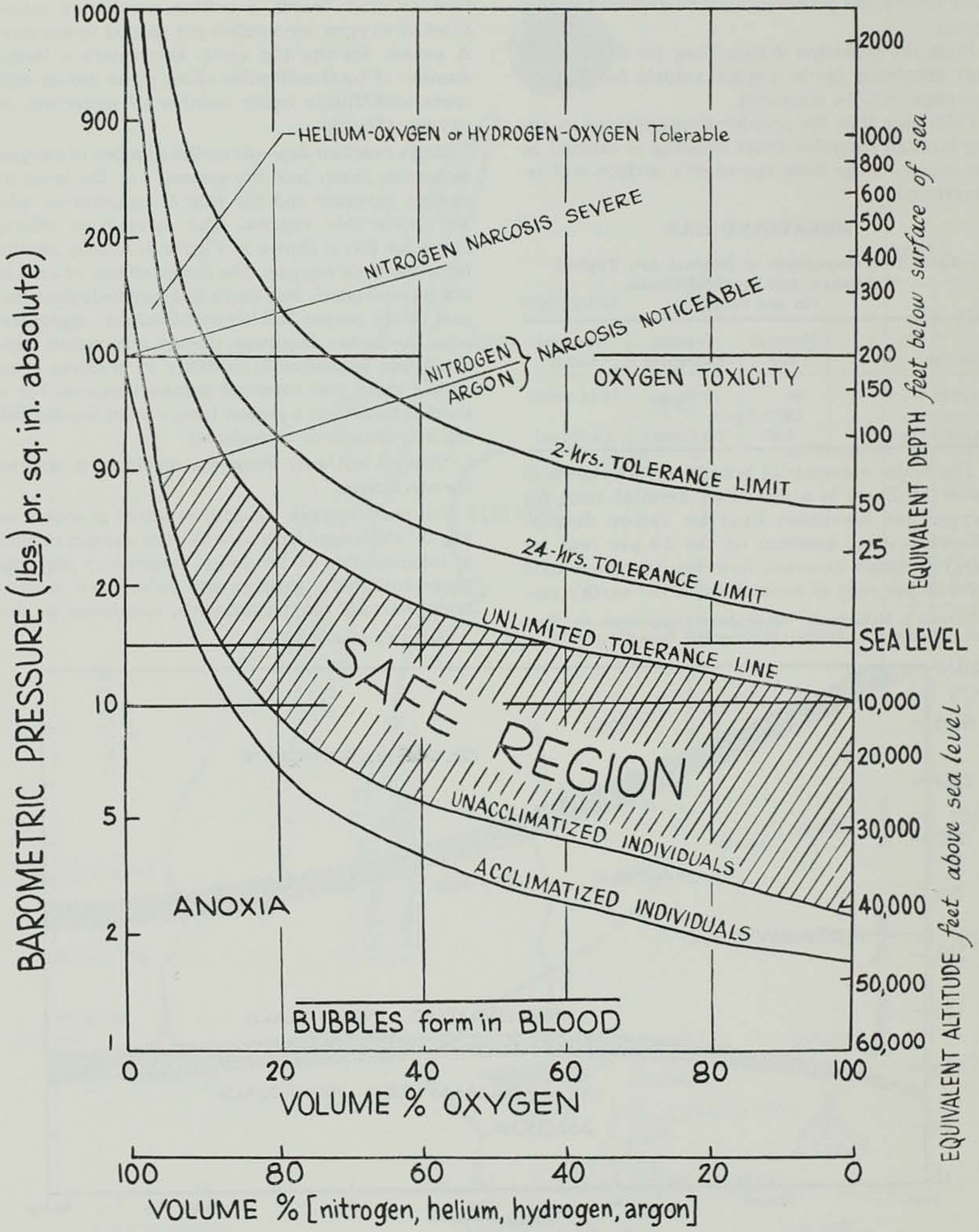


Figure 5
Human Tolerances—Atmospheric Composition and Pressure

fingers and toes, and nausea. One's tolerance to other stresses is impaired by low oxygen pressure.

Man normally produces CO_2 at nearly the same rate he consumes O_2, as shown in Figure 6. Acute symptoms due to excess CO_2 are heavy panting, marked respiratory distress, fatigue, stupefaction, narcotic effect, unconsciousness, and eventual death.

Table 2[6] indicates that the body needs approximately 250 cc of oxygen per minute. The brain comprises only 2 per cent of the body weight but requires 23 per cent of the body oxygen at rest and 40 per cent when convulsing. In other organs the reason for oxygen consumption is energy exchange, e.g., in the heart and skeleton muscles. The kidneys and other glands utilize energy to elaborate a secretion against osmotic gradients. The brain cells, however, seemingly have no need for free energy as they do not contract, divide, or move. Yet the brain cells are the most sensitive to the lack of oxygen and will consequently suffer irreparable injury from anoxia. The rest of the body may, in contrast, tolerate the same degree of anoxia.

Notice the increase in oxygen required by the brain when there is brain convulsion. This could result in a stress, creating unusual demands on the brain. Muscle exercise causes a large increase in oxygen consumption; thus the normal 5.4 liter/min of blood flow is not sufficient. Under these conditions, the blood flow must be bolstered to approximately 20 liters/min or the muscle demands will be met at the expense of the brain tissue requirements.

For a short space trip (several days) stored oxygen can be supplied for breathing purposes. This can be in the form of stored gas containers, LOX, or solid Super-Oxide. A five-man crew requiring approximately 100 pounds of oxygen for a 10-day trip could possibly be supplied by stored oxygen. The CO_2 can be discarded.

[6] Carl F. Schmidt, "The Adjustment of Oxygen Supply to Oxygen Demand in Organs," Symposium on Stress, Army Medical Service Graduate School (March, 1953).

Table 2.—Relationship of Activity to Oxygen Demand.

	Weight		O_2 Uptake	
REGION	Kg	Per cent of total	cc per minute	Per cent of total
Entire Body	63.0	100.0	250	100
Liver and Intestines	2.6	4.0	50	20
Kidneys	.3	.5	18	6
Brain at Rest	1.4	2.0	57	23
Brain Convulsion			100	40
Heart at Rest	.3	.5	22	9
Heart Anoxia			32	12
Total of Above at Rest	4.6	7.0	154	58
Muscles at Rest	31.0	50.0	50	20
Muscle Exercise			3,000	?

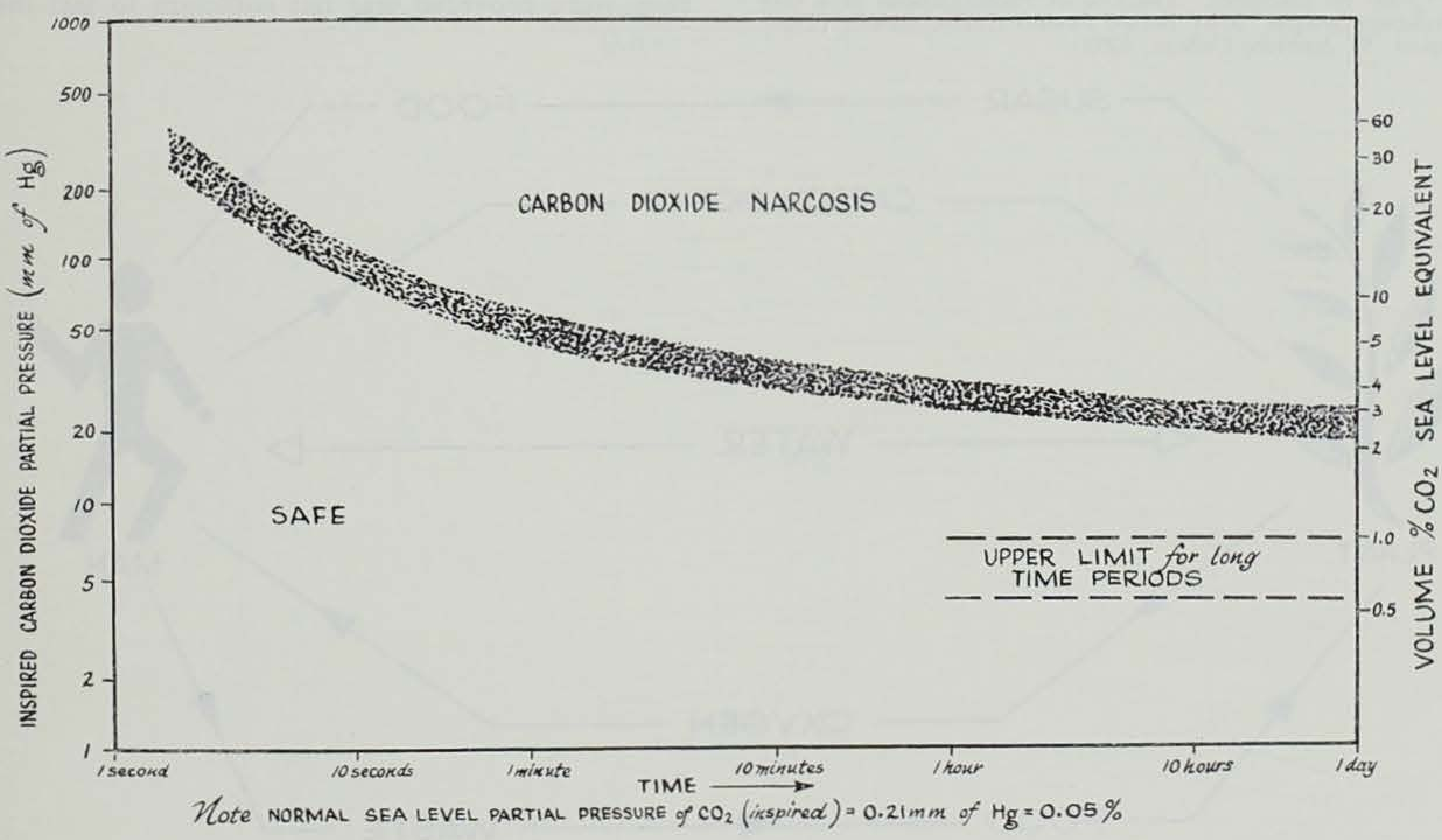


Figure 6
Human Time Tolerance—Carbon Dioxide Partial Pressure

Investigations are also underway to decompose this CO_2 and recover the oxygen. One possible way is to do this photochemically, using ultraviolet radiation present in space and a catalyst.

CLOSED REGENERATIVE CYCLE PRINCIPLES

Another method is to use a closed regenerative cycle similar to that which exists in nature. This system is the familiar animal plant cycle (Figure 7),[7] which has been providing breathable atmosphere to a manned space system for millions of years. In this case the space system is the earth.

Note the similarity of this to the human engineering cycle. Animals consume food composed primarily of carbohydrates and proteins. Water is consumed as the water present in fresh vegetables and other foods and in familiar pure form. Oxygen is taken into the body and combined with carbon present in digested food to produce CO_2 and energy.

Plants act in a manner which might be termed the biological opposite to animals. An essential part of the green plants, which include all those which manufacture their own sugars, is the compound chlorophyll, which has the ability to change water and CO_2 into organic compounds and free oxygen. This process is called photosynthesis, and it requires the input of energy in the form of light. Algae appear attractive as the plant media because they have a high photosynthesis efficiency and have no waste stalks.

A rather peculiar situation arises when considering the use of plant material such as algae in this closed breathing system. Algae will not merely grow and expel oxygen at will. The necessary physiological conditions must be present if this substance is to stay alive and not get psychotic. Algae need oxygen, light, and chlorophyll to be successfully raised. There also are other necessary elements such as an Mg ion.

An experiment has been performed using a gas exchanger photosynthetic process with mice and the algae, *Anicystis Nidulaus*. The container is shown in Figure 8. (An interesting psychological factor observed that had little to do with the primary experiment was that fighting was eliminated by using mice of only one sex in any experiment attempted.) After approximately a year of preliminary work, two mice were sealed in the capsule with food thought to be sufficient for one month. The mice were kept alive for 500 hours.

Mr. Lindorfer[8] describes the conclusion of the experiment as follows: "The only reason that the test was terminated was that the mice died after 500 hours due to the fact that the food with which they were provided was not sufficient to last the

[7] John H. Lindorfer, "The Use of Photosynthesis in a Gas Exchange System," *SIRP Report Pioneer Central-Bendix* (Davenport: St. Ambrose College, 1959).

[8] *Ibid.*

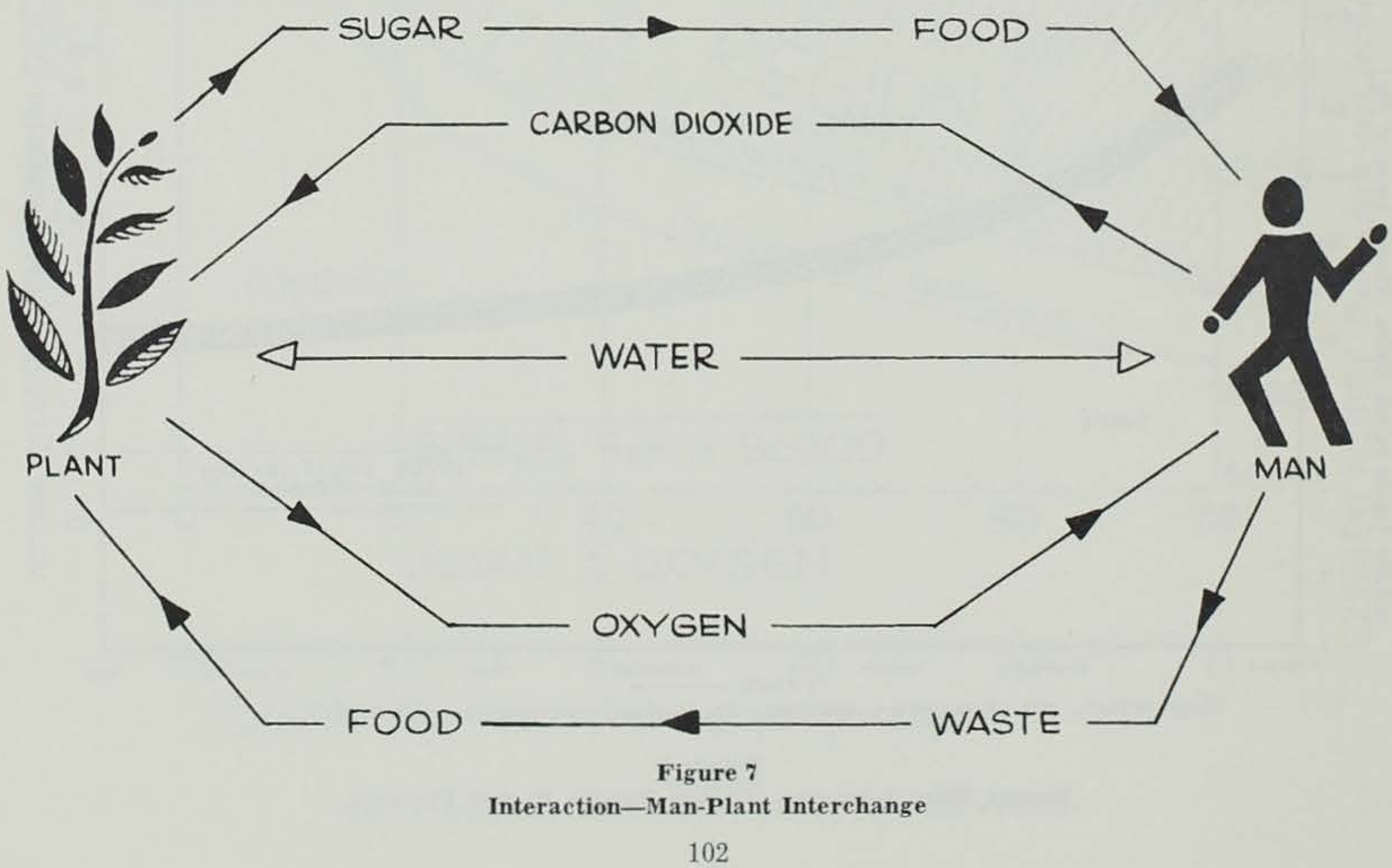


Figure 7
Interaction—Man-Plant Interchange

full time of the test, and the cause of death was diagnosed as malnutrition. When the case was examined after the dead mice were removed, no traces of food were found, indicating that the mice had eaten all of the food available. Observations during the test indicated that the mice were healthy until the food supply ran out and that they declined rapidly after that point, finally dying from lack of food. The mice would have been removed earlier, but it was thought that the mice might have hidden a quantity of food in some part of the cage which could not be seen, and they might, therefore, use it as a last resort, but this hope proved without basis.

"From this test it was decided that the cause of death had indeed been malnutrition and that the photosynthetic gas exchange system had functioned as planned. It is interesting to note that even with the inefficient lighting system, the initial weight of algae used was only one-eleventh the weight of the mice. The algae had grown rapidly during the test, more than doubling in concentration during the test period."

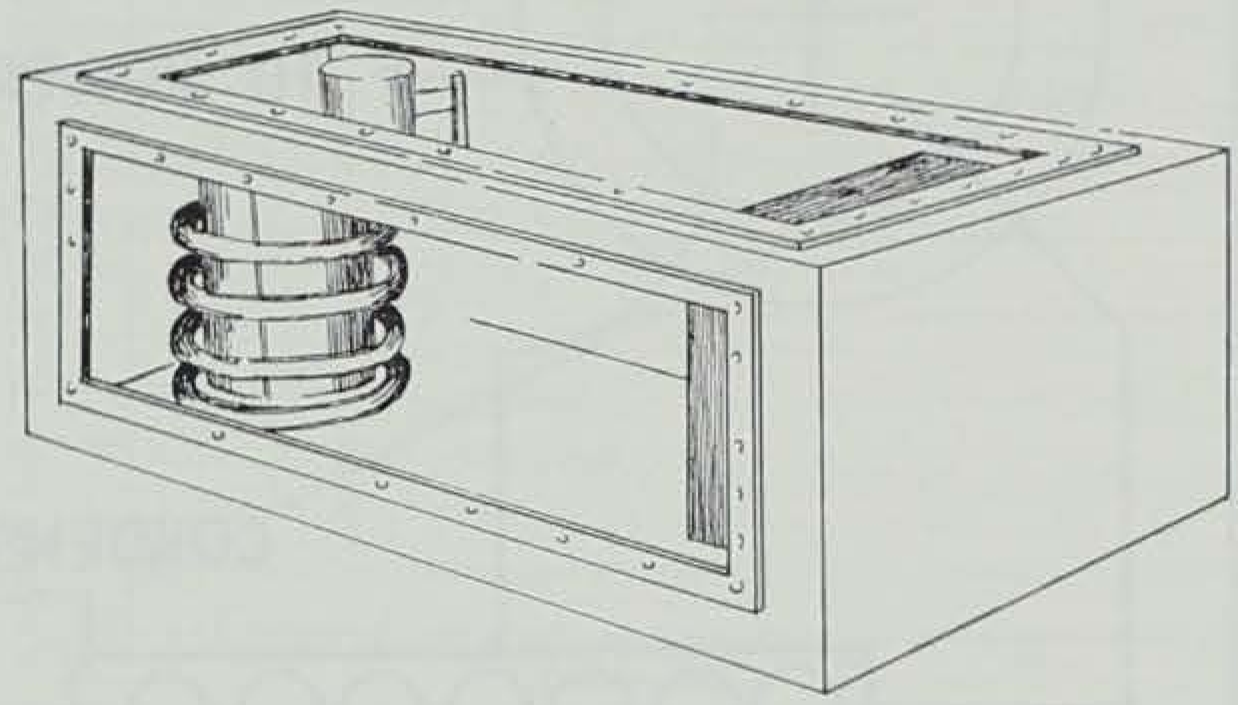


Figure 8

Necessarily, the next photosynthesis gas exchanger system test should be to see if it will act as efficiently for a manned system.

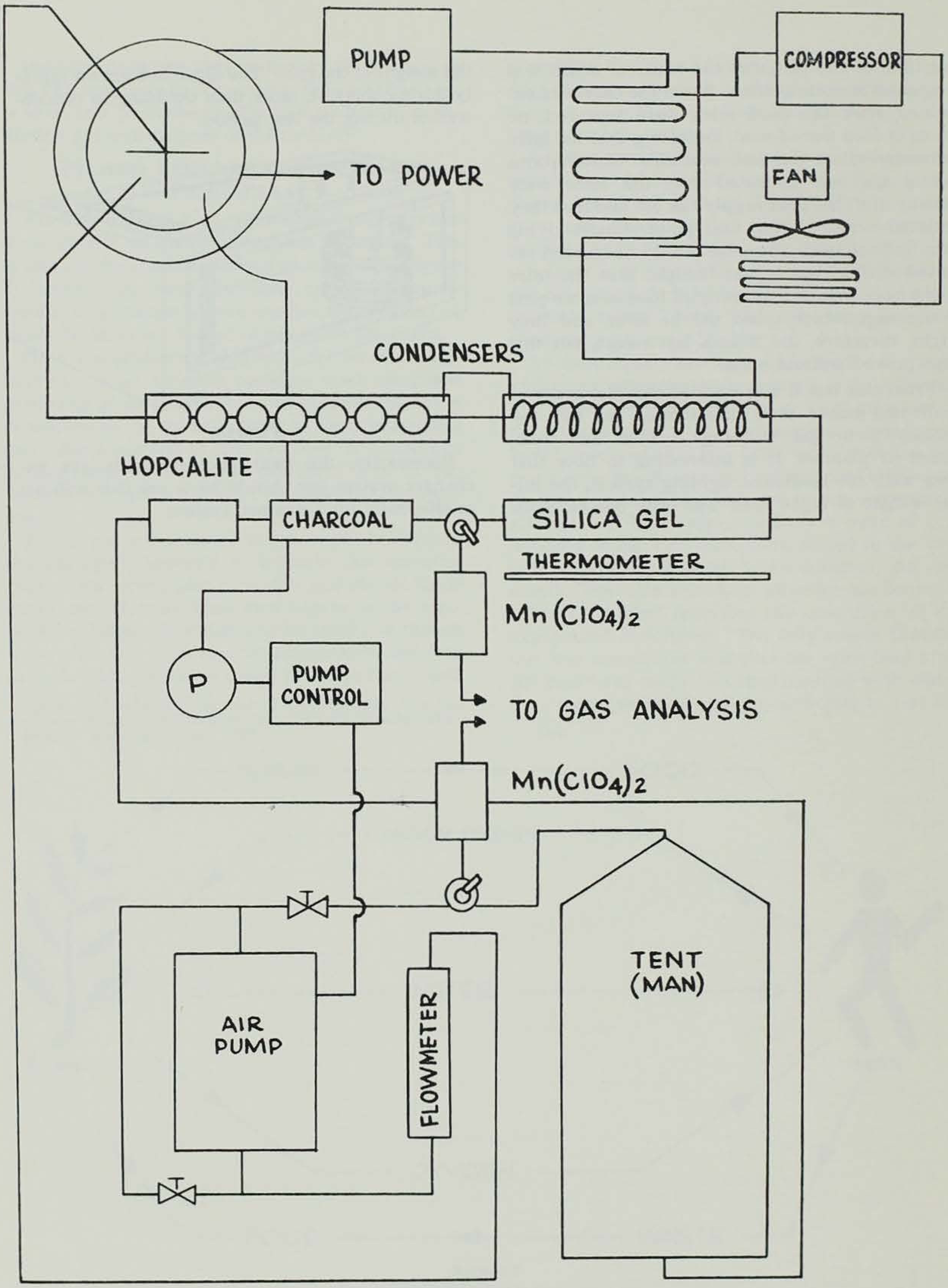

PUMP
COMPRESSOR
TO POWER
FAN
CONDENSERS
HOPCALITE
CHARCOAL
SILICA GEL
THERMOMETER
$Mn(ClO_4)_2$
P
PUMP CONTROL
TO GAS ANALYSIS
$Mn(ClO_4)_2$
TENT (MAN)
AIR PUMP
FLOWMETER

Figure 9

REVENGER IV

Figure 9[9] shows a block diagram of the equipment needed for a system of this type. A system was developed to determine the optimum operating conditions for a man-gas exchanger.

The algal suspension is contained in a 30-gallon barrel that has been painted with a silicon base paint and lined with a double thickness polyethylene bag. The liner prevents the algae from coming in direct contact with the metal barrel and is used to seal the culture solution within the closed system.

Eighty-one daylight fluorescent lamps are directly immersed in the algae culture. Direct contact of the lamps to the algae provides greater illuminance of the algal suspension. The purpose of using 81 lamps is to have more than the required amount of candlepower. This will allow for removal of lamps to obtain those necessary for maximum photosynthesis. All tubes are spaced 1.7 inches apart on centers leaving 0.7 inch to be illuminated.

Gas enters the algae tank through a manifold and passes through four glass tubes to the bottom of the barrel, where it enters four diffusion tubes. These tubes are perforated with small holes at one-inch intervals and sealed at the open end. The gas diffuses through the algae and is collected in the space above the suspension. From there it will be pumped back to the capsule.

Because of the large number of lights in the algae culture, cooling is necessary. This is achieved by placing the tank inside a larger barrel and circulating cooled water between the two containers.

[9] D. Michael Williams, "Revenger IV, Photosynthesis Gas Exchanger System for Man Support," *SIRP Report Pioneer Central-Bendix* (Davenport: St. Ambrose College, May, 1960).

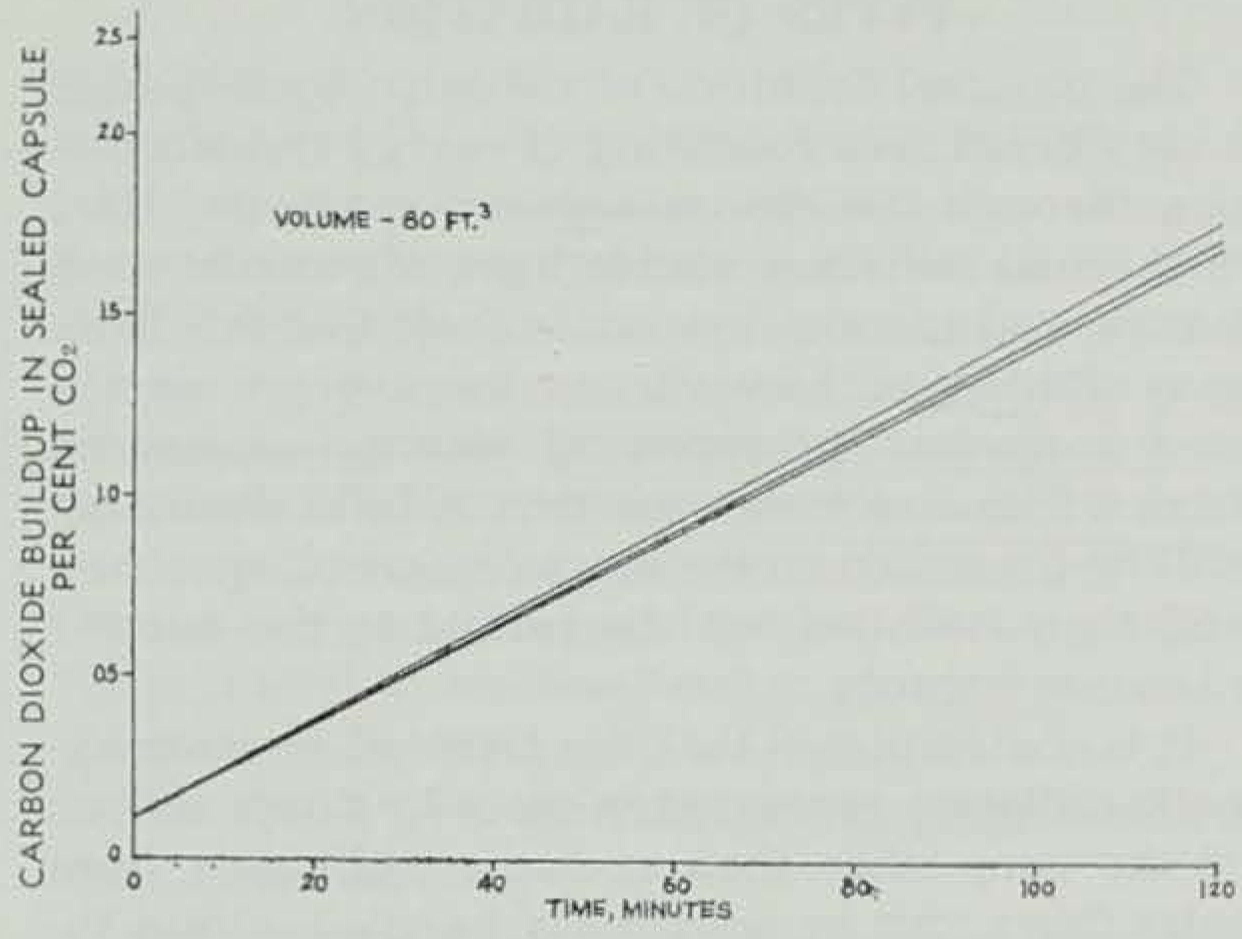


Figure 10

Experiments were performed to determine how much carbon dioxide a man will expel per unit of time at a given volume. A man was sealed in an 80 cubic foot polyethylene bag for two hours. Gas samples were removed every 15 minutes.

Figure 10 shows results of this experiment for three men with an average carbon dioxide build-up of 1.1 per cent each hour. This build-up rate will be used in all subsequent gas exchanger tests where the breathing of a man is to be simulated.

These are only preliminary tests to be made with the Revenger IV photosynthesis gas exchanger. Further tests will be performed to determine the exact flow rate to yield maximum photosynthesis. The number of lamps required will have to be found, and a method must be developed to harvest the algae and keep the algae concentration constant. When these problems are solved, the system will be used to support a man.

TYPES OF RADIATION

The physical definition of radiation encompasses a very broad area consisting of energy transformation through the electromagnetic spectrum. Heat or thermal radiation, visible light, ultraviolet rays, x-rays, and cosmic rays are included in this category. Radiation, however, to the average person means nuclear processes of energy emanating from a fission or fusion reaction. A brief discussion will be presented on the electromagnetic spectrum and then attention will be turned to the nuclear radiation hazards.

It is contemplated that the forms of electromagnetic radiation generated in space by direct actions of the sun, other than sporadic radiations from solar flares, can be adequately handled within today's technology.[10]

The effects of thermal radiation can be controlled by adjusting the absortivity and emissivity of the outer skin of the vehicle and almost any desired skin temperature can be obtained. As for solar radiations in the visible, ultraviolet, and soft x-ray region, present data indicate that they do not constitute a direct hazard to crews of space vehicles, as they can be easily attenuated by thin layers of almost any structural material.

[10] Select Committee, *loc. cit.*

Radiation Belts

The newly discovered "radiation belts" of the earth present a problem.

Preliminary examination of data from Explorer I (and later from Explorer Satellites III and IV, as well as from the Air Force Pioneer I and Army Pioneer III space probes) reveals the existence of a pair of bands of charged particles, protons or electrons, or both.[11]

Apparently the first radiation belt extends to 34,000 miles above the surface of the earth. The second belt, about 4,000 miles thick, extends outward some 8,000 to 12,000 miles. The particles composing the pair of belts reach the first peak intensity at an altitude of approximately 24,000 miles and peak again at 10,000 miles.

When these particles, streaming from the sun or other sources deep in space, reach the earth's mag-

[11] President of the United States, *U. S. Aeronautics and Space Activities Jan. 1 to Dec. 31, 1958.*

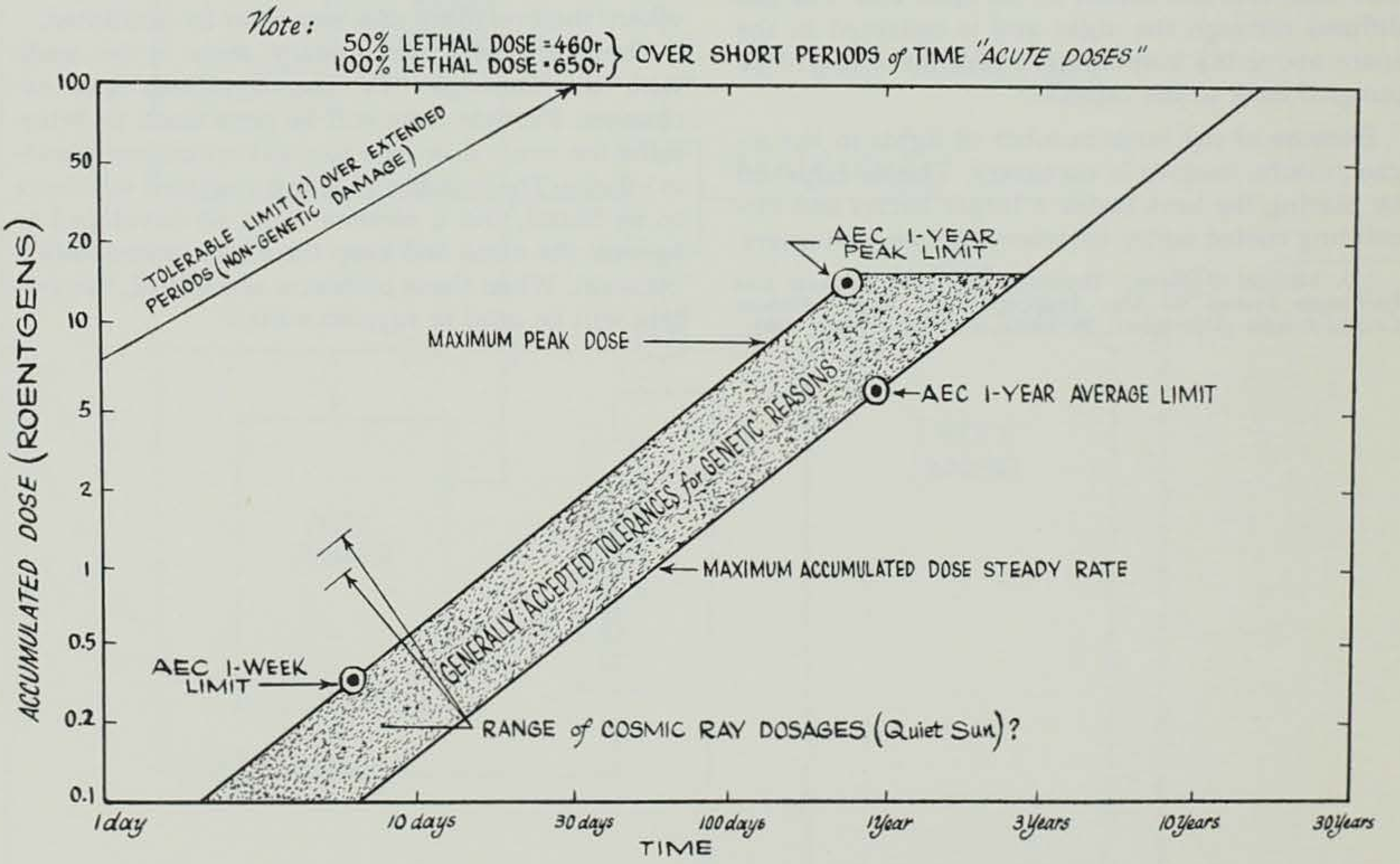


Figure 11
Human Tolerance to Radiation

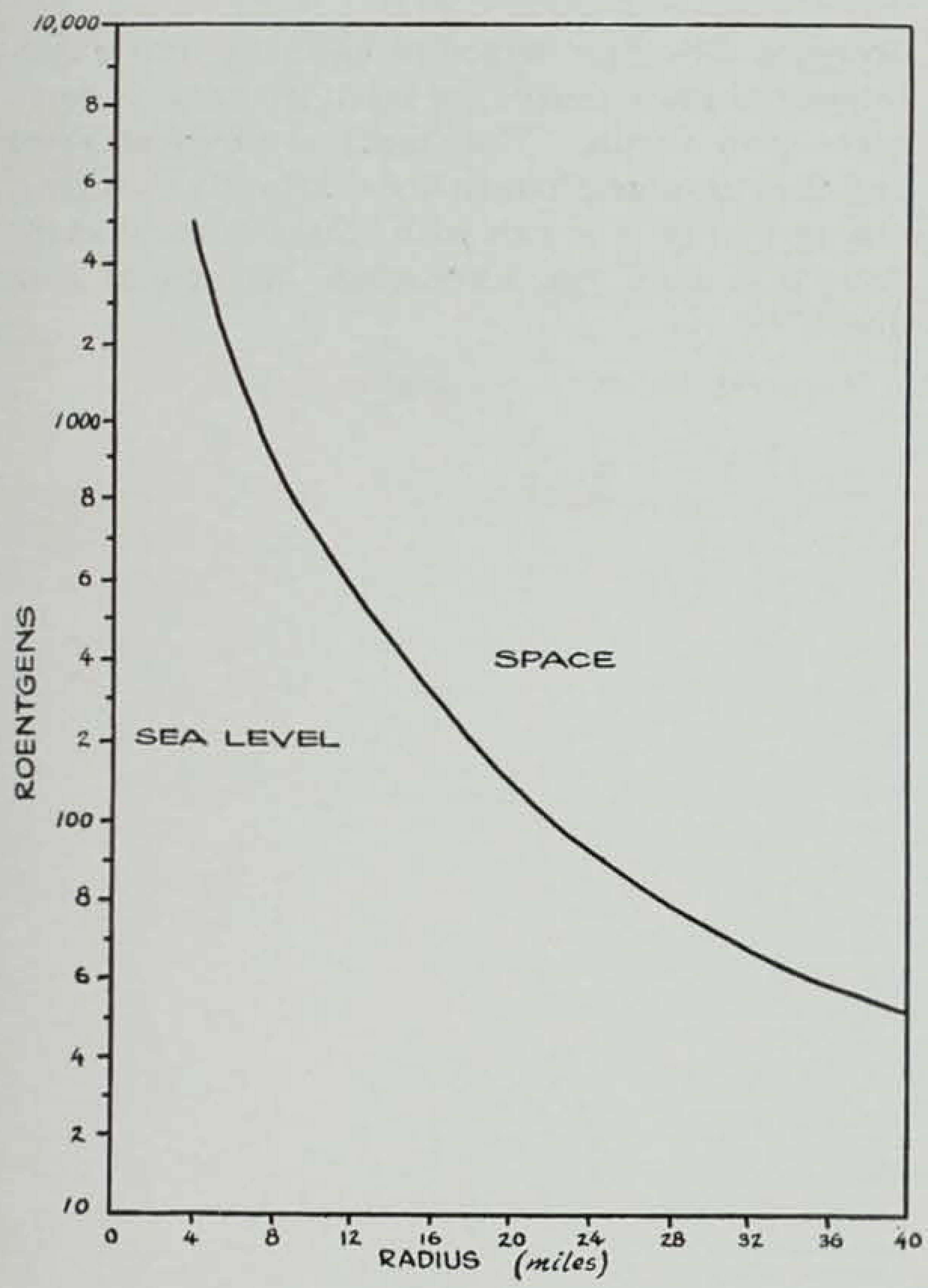


Figure 12
Nuclear Radiation Intensities (20KT)

netic field—some are deflected, a few filter through and are absorbed in the atmosphere, but a great many oscillate in spiral paths along the magnetic field's lines of force.

X-rays can be produced when high velocity particles from these belts infringe upon the material from which the space vehicle is constructed.

The problem of these belts can be met by either avoidance or shielding to reduce the dosage to human beings to an acceptable level.

Fairly dense material such as lead can be used as shielding. Space above the earth's polar region is almost void of particles and can be used as an escape route.

The hazard of cosmic radiation, however, remains an open question, since there is no satisfactory way to shield against it.

Figure 11[12] displays the generally accepted human tolerances with respect to genetic damage and non-genetic damage by gamma radiation.

Man-Made Radiation Perils

Man-made perils must also be considered when exploring the problems of space environment. In particular the use of nuclear weapons to create a nuclear radiation hazard must be considered.

"When a nuclear weapon is detonated close to the earth's surface, the density of the air is sufficient to alternate nuclear radiations (neutrons and gamma rays) to such a degree that the effects of these radiations are generally less important than the effects of blast and thermal radiation. The relative magnitudes of the nuclear radiation effects are shown in Figure 12[12] for a nominal fission weapon (20 kilotons) at sea level and in space.

"If a nuclear weapon is exploded in a vacuum, i.e., in space, the complexion of weapon effects changes drastically.

"First, in the absence of atmosphere, blast disappears completely.

"Second, thermal radiation, as usually defined, also disappears. There is no longer any air for the blast wave to heat and much higher frequency radiations are emitted from the weapon itself.

"Third, in the absence of the atmosphere, nuclear radiation will suffer no physical alteration, and the only degradation in intensity will arise from dispersion with distance. As a result, the range of significance will be many times greater than is the case at sea level.

"It can be seen that in the range 500 to 5,000 roentgens the space radii are of the order of 8 to 17 times as large as the sea level radii. At lower dosages the difference between the two cases becomes even larger.

"A yield of 20 kilotons has been used here as an example to show the dominance of nuclear radiation effects in space; however, it may well be that multimegaton warheads, rather than 20 kiloton warheads, will be far more representative of space defense applications. With such weapons, the lethal radii (from nuclear radiation) in space may be in order of hundreds of miles . . ."

The physiological and psychological effects of radiation are still being investigated. The entire question of these effects is being studied intensively, and undoubtedly much will be learned in the next few years.

CONCLUSION

The problems encountered as man attempts to step into space have created a challenge that he must accept and conquer. These problems, though seemingly tremendous, are not insurmountable. They can be solved by application and experimentation. Man has the desire and the ability to explore and learn.

[12] Select Committee, *loc. cit.*

The human engineering problems are many and varied. In closing, we again quote Dr. Pepinsky: "Not only for us, but for all pupils of behavior, there is an urgency upon us to consider and to work with the problems of physical space in relation to the adjustments of mankind. On our globe, the spaces between individuals are becoming smaller, as birth rates increase and death rates decrease. The imminence of entering into extraterrestrial space makes the room we have on earth seem even smaller. The limits of physical space and their meaning to man are constantly changing. Our challenge is to join with others in considering how man may yet accomplish his spatial conquest."[13]

[13] Pepinsky, *loc. cit.*